

Safety in Mines Research Advisory Committee

Final Project Report

**Performance Specifications for Pack
Support Types to Cater for the Variety
of Geotechnical Areas Encountered in
the Mining Industry**

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Executive summary

The primary outputs of SIMRAC Project GAP 508 are:

1. The establishment of a standard pack testing methodology that can be applied to all pack types used in the gold and platinum mines, and
2. The provision of new standard performance curves for a variety of packs.

In order to complete this work, it was first deemed necessary to establish what types of packs are currently used in the mining industry, variations of these types and their prominence. Previous attempts at collecting this information had not been as successful as expected. Following several meetings with support suppliers, information on quantities was provided with details on pack types, sizes and configurations. Detailed user information was not requested, as suppliers were reluctant to provide this information in the past and have reiterated their concerns around market share details.

A review of previous pack performance and influencing factors resulted in the development of a standard pack testing methodology that could be applied to all pack types except for grout packs, for which further work is required. The end user has control over many of the factors affecting pack performance through contracts and visual inspection of timber condition, size and unit assembly upon delivery to the mine.

An area of contention that required further investigation as part of this project was the effect of loading rate on the performance of packs. Extensive testing in this area on a variety of pack types, together with information obtained from previous work has resulted in the establishment of factors governing the response of packs to variable loading rates. Packs have been broadly categorised in terms of their composition for which these new adjustment factors are applicable.

Original test results were collected from suppliers for inclusion into a new database of pack performance. In some cases, this has been supplemented with additional testing conducted as part of this project. New design curves have been established for a wider range of packs than was originally planned for in the project and these will replace dated results currently resident in the SDA database.

The existing Support Catalogue (from Project GAP 032) has been reviewed, and a more informative format has been proposed. The new performance data mentioned above has been presented in this proposed format at the end of this report. This information is available for inclusion in the database upon acceptance of this report.

Acknowledgements

The author would like to gratefully acknowledge that the work reported here has been the result of co-operation of representatives from many of the support suppliers and consultants for the mining industry, namely:

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1 Introduction

With the completion of the SIMRAC Project GAP 330 (Stope Face Support Systems), a formal, standardised testing procedure was proposed for the evaluation of elongate performance. Many of the new generation, yielding elongates were evaluated accordingly and this information is to be made available to the mining industry as a supplement to the database that currently exists within the Stope Design Analysis (SDA) program.

Since no standard testing programme had yet been established for packs, the need for its development soon became clear. The Support Catalogue compiled as part of SIMRAC Project GAP 032 (Stope and Gully Support) contained a lot of information on pack performance. This information was limited in extent due to its containing a series of one-off test results that could not be confirmed as representative of the product performance. Tests were conducted under a variety of conditions, the results of which were presented in an inconsistent manner.

This project was conceived with the intention of providing the mining industry with a standard pack testing methodology that could be applied to all pack types. The results of performance testing of packs would then be analysed in accordance with a standard technique from which standard performance curves would be established. These curves would be used by mine personnel to design support systems with some degree of confidence.

A survey of pack usage on gold and platinum mines was conducted through the support suppliers in order to establish the types and quantities of packs used by the industry. The performance of many of these packs could then be established through the proposed testing procedure in order to supply the industry with more reliable information on pack performance.

In order to achieve this, a literature review of previous work on timber and packs was conducted. One area in which there appears to be some discrepancy regarding the effect on pack performance is the influence of loading rate. A detailed investigation into this area was warranted and the results were found to be essential for the establishment of pack performance for support design purposes.

The relevant information for a wide variety of pack types has been collected and presented in a standard format. This format has been recommended as the standard for all support types. Upon approval of the findings of this project, the enclosed information (Appendix C) can be included in the existing database of support performance and for use in the SDA. Within a given time period, all old test results will be replaced with authenticated performance information.

2 Pack usage in the gold and platinum mines

Several attempts have been made recently at quantifying the usage of various support types in gold and platinum mines. Most of this work has been conducted through research projects, which required that information be supplied in as much detail as possible in terms of area of usage (by shaft, reef, stoping width, etc). On various occasions, information has been sought from both suppliers and the mines with the following problems reported:

Source from suppliers:

- Could not supply quantities by shaft or reef
- Not willing to supply information in detail
- Could not supply information on mining or rock mechanics aspects

Source from mines:

- Response was poor on occasion; other sources were required to estimate missing information
- Information from other sources did not always correlate with that obtained from mines
- Format and detail of information was inconsistent
- Staffing changes and shortages were reported as having resulted in significant delays in responding

Following preliminary discussions with the suppliers around the information required, it soon became clear to what level of detail they were willing to provide sales quantities. Although product details were provided for review and analysis, details were not to be published without acceptance from the suppliers of the final format of that information.

Bearing in mind the problems reported in the past, and the fact that certain details of pack usage were not required, it was considered that information from suppliers would result in a better response in the timeframe available. Details in terms of pack unit sizes and not distribution throughout the industry were of primary interest in terms of the requirements for this project.

All major support suppliers were willing to provide this information except Grinaker Duraset, who reversed an earlier decision to support this project. Other sources were approached in order to obtain the necessary information regarding quantities of pre-cast, cementitious pack units and hence, the information supplied herein should be considered as unreliable at this stage.

The smaller timber suppliers were not considered, as the majority of their supply to the mines is in poles and other non-pack timber. It has been estimated that their market share is about ten per cent of the total timber sold (primarily poles) and only one per cent of the pack market. This is certainly too small to warrant polling such a small market.

The suppliers were requested to provide the following detailed information:

- total units sold for the three month period to November 1998
- use of these units if not self evident
- detailed breakdown in terms of base area and unit rise

Certain assumptions had to be made regarding the use of the support elements supplied to the mines:

- configuration of packs for modular units
- proportion of units used at various configurations
- stoping width at which the packs are used

From the information that was supplied, the various pack types could be broadly grouped into six categories as defined previously by Daehnke et al (1998) in Table 2.1. Quantities of pack types that could not be ascertained, included cluster packs (although their classification as pack or elongate is not clear) and skeleton packs (as the source material for their construction can vary).

Table 2.1 Description of pack types referenced (after Daehnke et al, 1998)

Pack Type	Description
Mat Packs	Packs constructed from timber mats or slabs with horizontal grain timber only
End Grain Packs	Timber packs containing end grain members (including Brutus, Apollo, Lexus)
Brick Composite	Slabs with bricks attached
Timber Composite	Slabs with horizontal grain timber blocks attached
Pre-cast Packs	Cementitious based units (including Durapak, Herapak)
Grout Packs	Cementitious based packs cast <i>in situ</i>

The information from all major suppliers was collected, summarised and grouped into the categories listed in Table 2.1. Considering the assumptions on pack configuration and stoping widths, unit sales represent an estimated 121 000 packs constructed every month. The mat and end grain packs represent an estimated 69 per cent of the pack market (Table 2.2).

Table 2.2 Monthly pack usage in the gold and platinum mines as surveyed at the end of 1998

Pack Type	No. of Packs Installed	% of Total Packs
Mat Packs	47 000	38.8
End Grain Packs	36 500	30.2
Brick Composite	13 700	11.3
Timber Composite	900	0.7
Pre-cast Packs*	21 000	17.4
Grout Packs*	1 900	1.6
Total	121 000	

* estimated from various sources other than original supplier

These results can be compared to a survey conducted in 1995 (Hagan, 1997) where information was gathered from the mines (Table 2.3). The reduction in pack usage as a whole is clearly evident as well as a shift away from solid mat packs to end grain and pre-cast packs. The reduction in brick composite packs is also significant.

Table 2.3 Change in proportion of consumption of various types of packs from a survey conducted for 1995

Pack Type	1998 (%)	1995* (%)
Mat Packs	38.8	50.0
End Grain Packs	30.2	20.4
Brick Composite	11.3	20.0
Timber Composite	0.7	0
Pre-cast Packs	17.4	2.2
Grout Packs	1.6	7.4
Total No. of Packs	121 000	183 000

* from Hagan, 1997

It was noted that for a given pack size (Table 2.4), units were available in a range of rise heights, especially with mat packs. A detailed investigation of this range was conducted to assess the frequency of use of the various rise units. The results have been tabulated in Table 2.5. It must be noted that timber pack units are being supplied at a range of rise heights but the pre-cast units are currently only being supplied at 10 cm rise. This is a significant factor in the high proportion of 10 cm rise consumed.

Table 2.4 Range of unit sizes used by the mining industry

Pack Types	Nominal Sizes	Pack Types	Nominal Sizes
Mat Packs	55 square	Brick Composite	75, 2 brick
	75 half mat		110, 2 brick
	75 square		110, 3 brick
	110 half mat		150, 3 brick
Hard Gum Mat	55 square		55 cookie
End Grain Mat	55 square	Timber Composite	75, 2 block
	75 half mat		110, 2 block
	110 third mat		150, 3 block
Chocks / Slabs	75 – 225 mm	Pre-cast Pack	600 half mat

Table 2.5 *Proportion of pack consumption by unit rise*

Rise Heights	% of Use
9 cm	34
10 cm	44
11 cm	18
other	4

3 Factors influencing pack performance

There are many factors which influence the performance of timber-based packs. These factors may be divided into three different areas, namely: timber characteristics, pack construction and manufacturing quality.

3.1 Timber characteristics

Timber is a natural material which can only be partly managed by foresters and nurserymen to improve its most desirable characteristics. There are a number of natural characteristics that may affect the performance of a pack, the most important of which are detailed below.

3.1.1 Species

Most timber used in South African gold and platinum mines today comes from a number of Eucalyptus varieties. These vary in density from dry weights of less than 350 kg/m³ to over 900 kg/m³, with their strengths and variability of strength within an individual variety differing considerably. Figure 3.1, below, illustrates this point for six common varieties, showing the distribution in strength for tests on a number of random samples of each variety. Also shown is a general curve for a new clonal variety, showing the vast improvement in variability of strength that can be achieved.

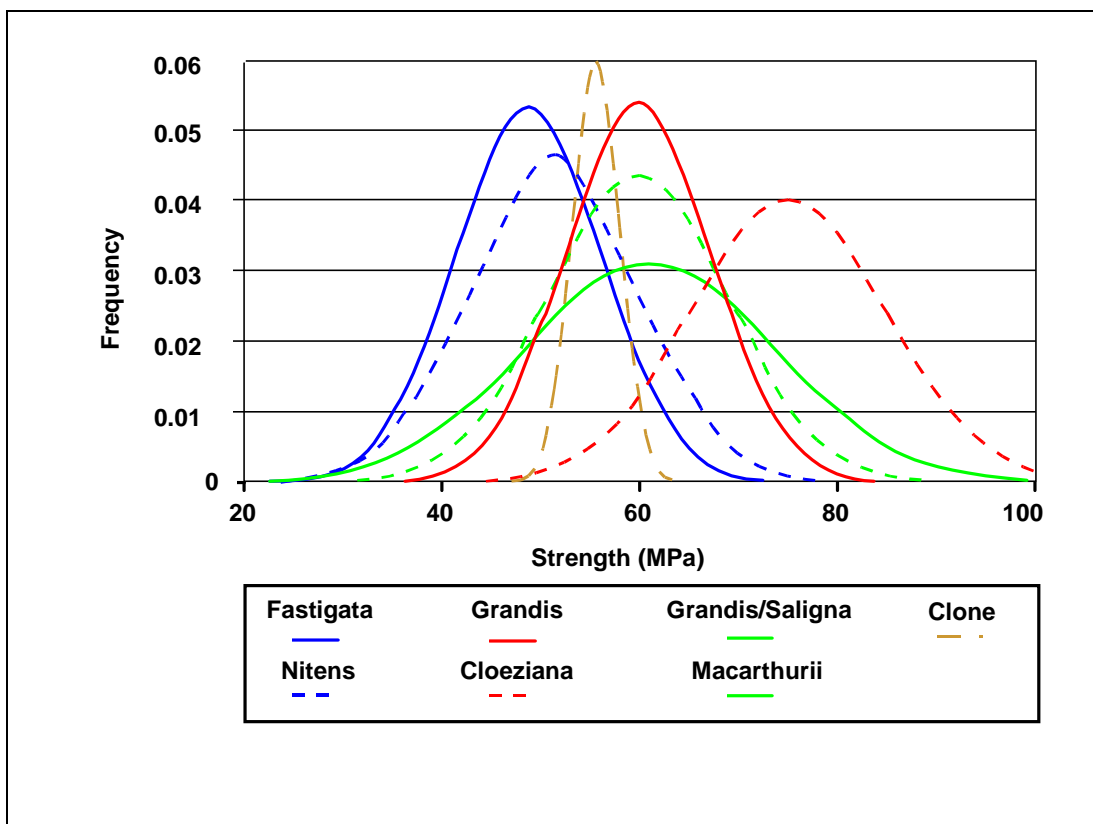


Figure 3.1 Strength distribution of Eucalyptus varieties

3.1.2 Density

In general, there is a direct relationship between density and strength of timber (Figure 3.2), the higher the density, the greater the strength. This is the main reason for the apparently stronger “highveld gum” variety. This is, in fact, just a normal Eucalyptus type which has been grown under conditions of either low water supply or cold weather or both for part of the year, which is typical weather for the highveld. These conditions cause the tree to grow more slowly than in the lowveld so the growth rings are closer together giving a more dense timber. For the same diameter of timber the highveld tree may be anything up to twice the age of its lowveld equivalent.

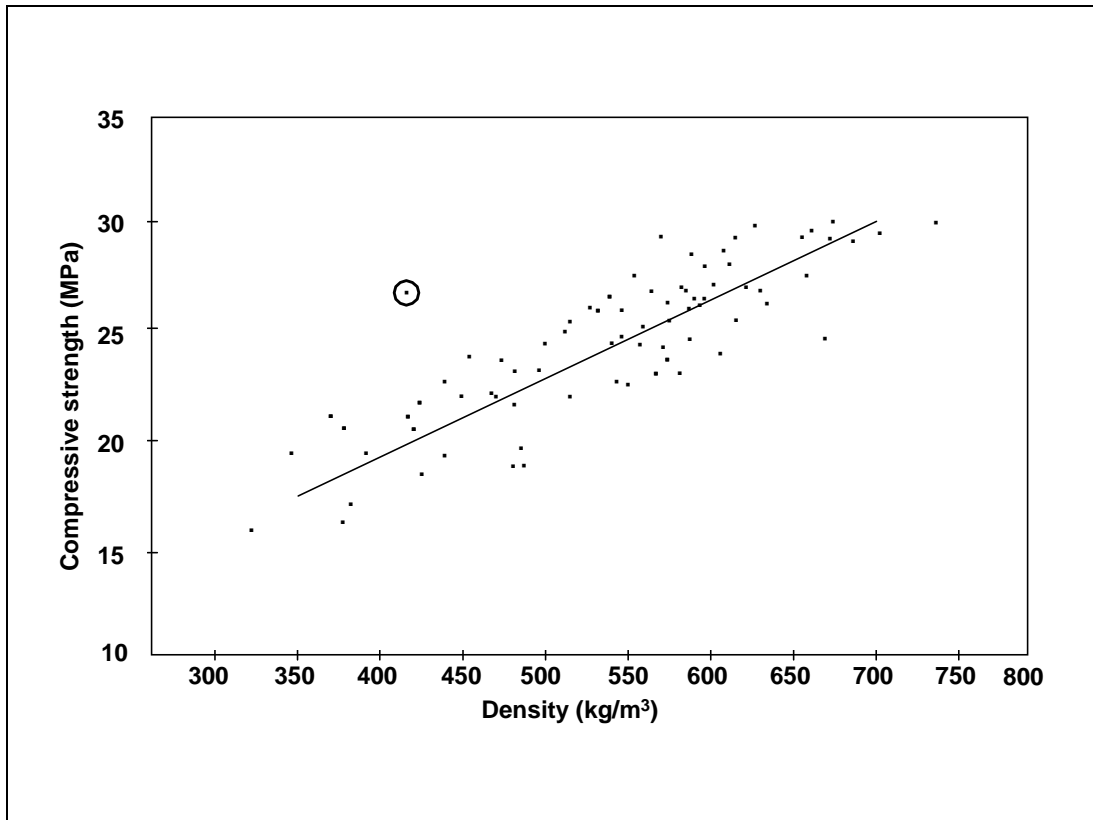


Figure 3.2 Relationship between density and strength. The circled specimen would be an ideal cloning candidate for use in the mining industry.

This also accounts for the fact that a cross-section of a tree trunk has greater strength towards the outside, as the rings there tend to be closer together. This gives the tree some of the properties of a pipe structure which is very resistant to bending which, surprisingly enough, is the major loading regime a tree trunk has to resist.

Interestingly, there are some anomalies in the density / strength relationship which can result in a low density tree having a high strength (see ringed specimen in Figure 3.2). This specimen would be an ideal clone subject, as these are properties ideal for mining timber.

3.1.3 Moisture content

Probably the most critical factor that is within the control of the people who handle timber is the moisture content.

When the tree is felled, depending on the time of year, rainfall patterns, etc, the moisture content can be well in excess of 100 per cent (defined as the weight of water relative to the weight of dry wood).

The tree is left in the plantation for some period of time, to allow it to lose some of its excess water. It is then taken to the mill and processed, then delivered to the mine. From felling to delivery may take up to six weeks, again depending on the time of year, etc. In this time, the moisture content will have dropped to between 50 and 80 per cent.

The timber will then stand in the delivery or mine yard for another period of time during which the moisture content will drop still further, again depending on the conditions of storage. Dry, warm, windy conditions will obviously drop the moisture content more rapidly than cold wet weather.

When the timber is sent underground, the rate of moisture content reduction tends to be much lower than on surface as the ambient conditions will generally have high humidity and low air flow.

The lowering in moisture content, however, only becomes a problem when it drops below the fibre saturation point (around 28 per cent in Eucalyptus). In fact, the lowering of moisture content makes the timber lighter to handle.

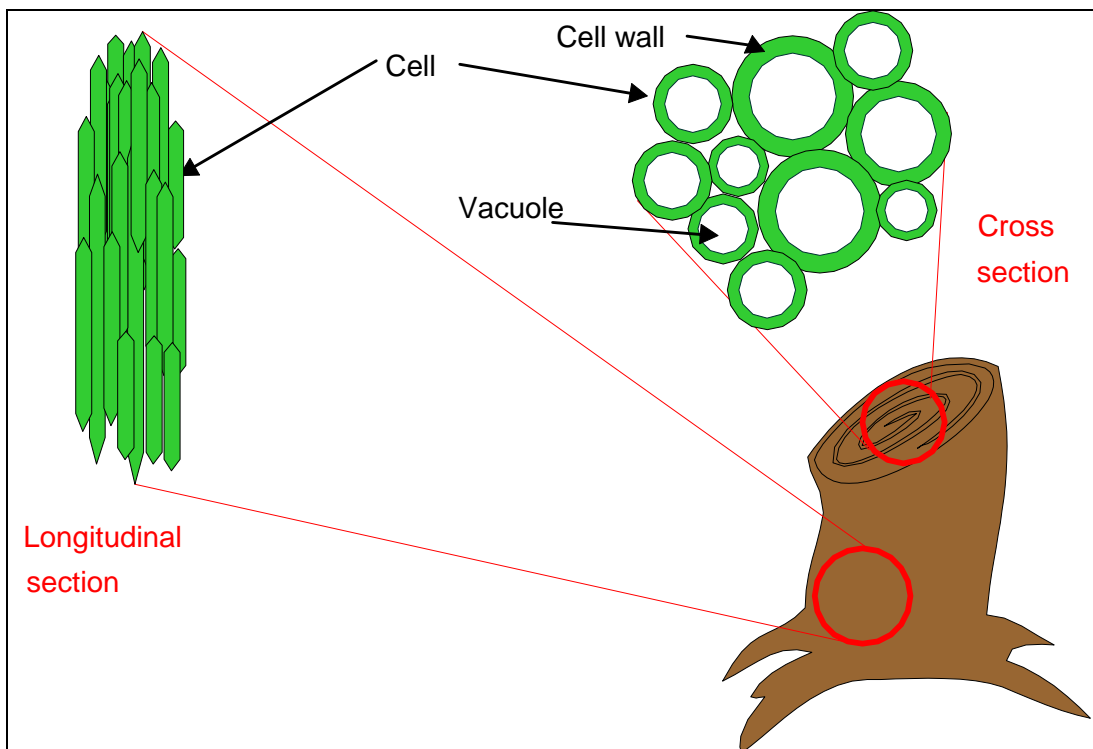


Figure 3.3 Sections showing the structure of timber

As the moisture content drops to the fibre saturation point, all that is removed is free water in the cell vacuoles (Figure 3.3). When the moisture content drops below this point,

however, the moisture is then removed from the structure of the cell wall itself, and the wood becomes stronger (Figure 3.4). This may sound like an advantage, but the wood also becomes more brittle.

For elongates, this is highly disadvantageous, as they will snap and collapse rather than yield. For packs which use mostly the compressive strength of timber, such as mat and end grain type packs, this is not such a serious problem, as it just makes them stronger, though less able to withstand very large deformations. For packs such as composites, however, which use the tensile and shear strength properties of timber to a much greater extent, it can also be a major problem. The pack members will tend to fail sooner in compression than the equivalent fresh timber.

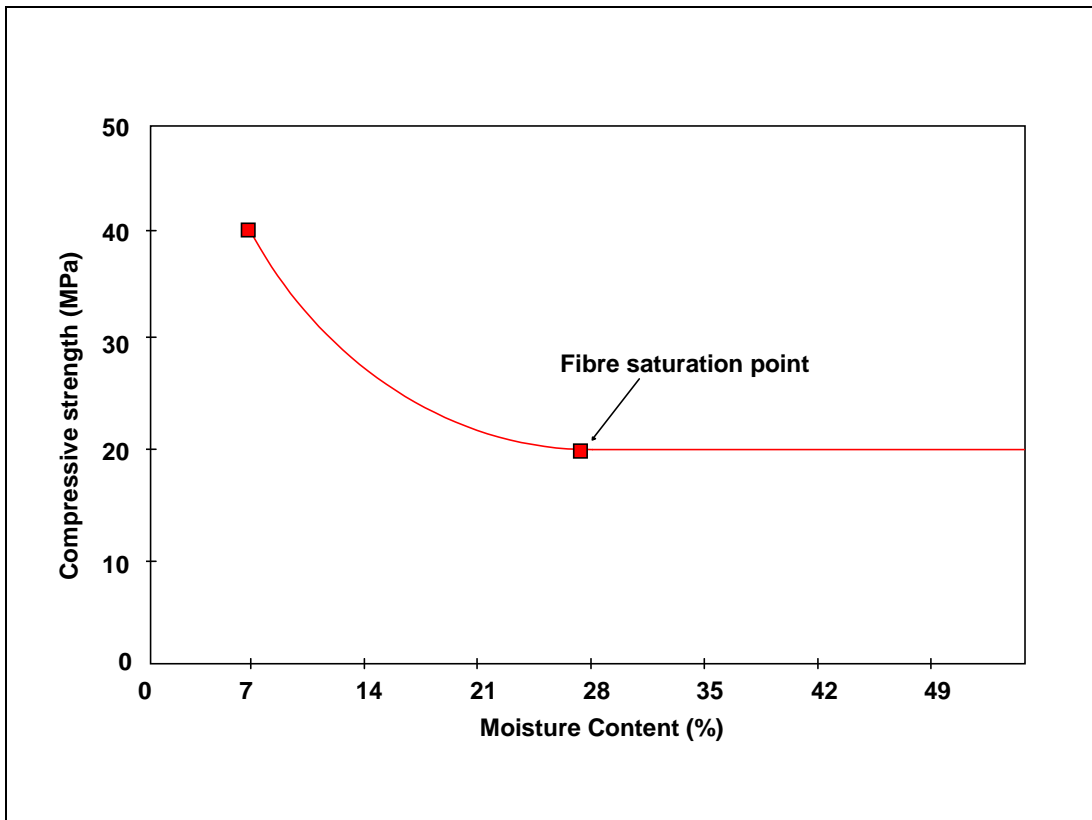


Figure 3.4 Relationship between moisture content and strength

3.1.4 Rate of loading

A consequence of the nature of timber is that it exhibits an attribute commonly known as creep. This means that if a piece of timber is loaded, the timber will deform when the load is applied, but will continue to deform at a decreasing rate over time, finally reaching some equilibrium point.

This means that if the load is applied slowly, the timber will attempt to “creep away” from the load, but if the load is applied quickly the timber will be unable to react fast enough.

This is a very simple explanation for the much lower loads measured underground in quasi-static loading regimes, and the much higher loads measured during rapid loading of timber support units, compared with the standard laboratory tests.

This factor is documented in more detail in Chapter 4.

3.1.5 Anisotropy

The structure of timber (Figure 3.3) makes it behave differently depending on the direction in which it is crushed relative to the grain (Figure 3.5).

The ratio of parallel to perpendicular compressive strength in Eucalyptus is in the order of ten to one. The bundles of tube like cells give the timber tremendous strength parallel to the grain but will only allow a small amount of deformation before it fails. Similarly, the tubes give rise to the timber's relatively low strength perpendicular to the grain, but also its acceptance of high deformation without failure.

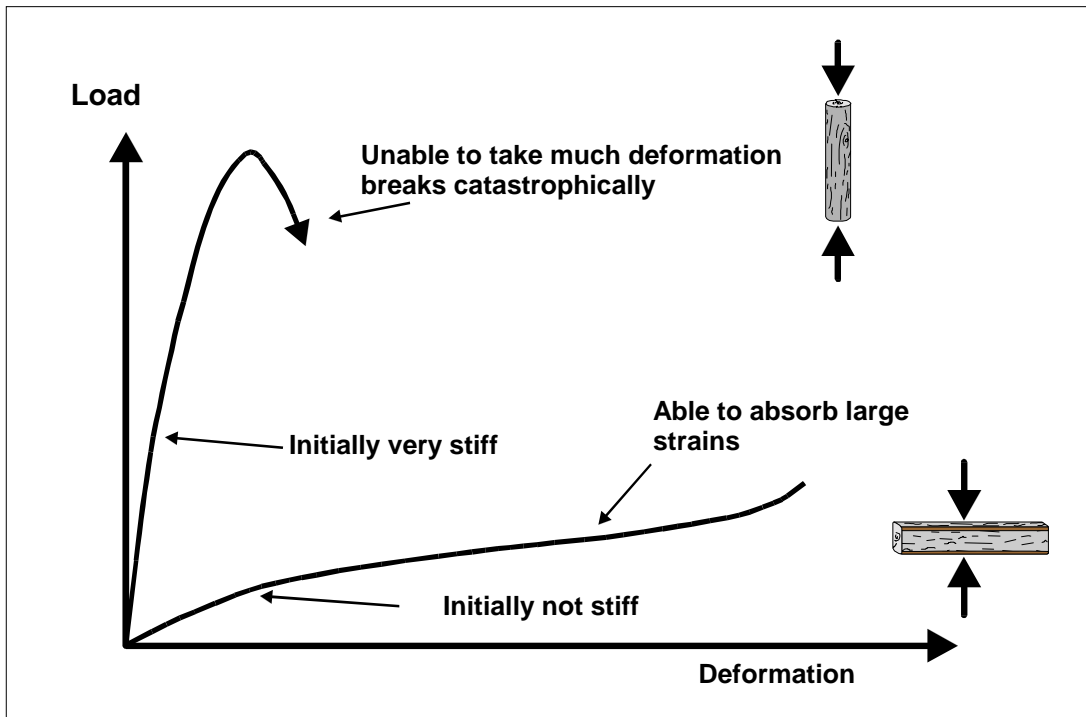


Figure 3.5 *Anisotropic performance of Eucalyptus timber*

It should be noted that northern hardwoods, such as oaks, do not exhibit such a marked difference in parallel and perpendicular compressive strength.

3.1.6 Other factors

There are a number of other factors which can affect the performance of timber-based support units. These are mainly due to growth factors and the nature of different tree species.

Wattle, for instance, rarely grows straight for any significant length, and pine poles have rings of knots which cause rapid failure when loaded parallel to the grain. Timber cut from very large, and therefore old, trees can have grain which is not parallel to the sides of the slab. This can lead to load shedding and premature splitting under load.

3.2 Pack construction

Within this factor there are also a number of different areas where apparently small changes can have large effects. These can be divided into general, internal and end effects.

3.2.1 General effects

When building packs, they must be installed as governed by the Code of Practice in effect at the time.

This means that the size of the pack must be correct for the stoping width at the point of installation:

- In general, a height to width ratio of 2:1 (using the narrowest width) is accepted practice where significant convergence is expected.
- It should be noted, however, that larger ratios may be acceptable in applications where little convergence is expected. The structural stability of such packs must however always be tested to the expected deformation before being introduced.

The type of pack must be correct for the area where it is installed:

- Where convergence is low, very stiff packs should be used.
- Where convergence is high, packs which are stable at large deformations are required.

The pack must be installed correctly with respect to dip and to hanging- and footwall features:

- Conventionally, packs are installed perpendicular to dip. If the footwall is not flat, however, this may be difficult to achieve (Figure 3.6).

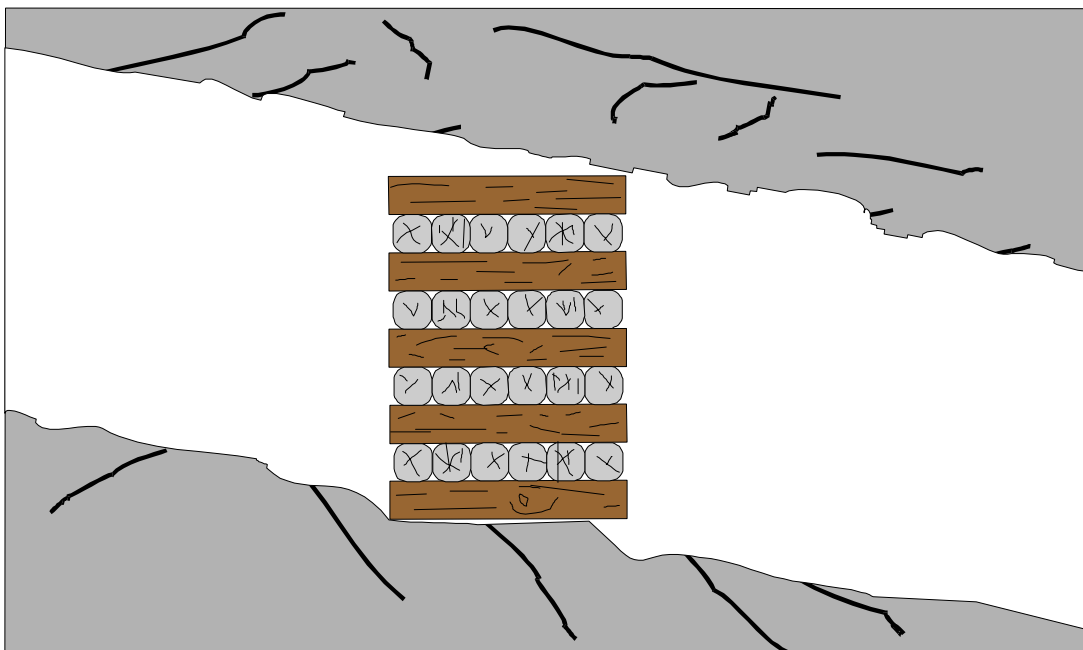


Figure 3.6 Pack installed incorrectly

3.2.2 Internal effects

There are many possible ways of building a pack badly, all of which will affect its performance.

If composite type units are not stacked properly in line, then shearing can take place, prematurely failing the pack (Figure 3.7a).

Similarly, if packs with end grain or other blocks in them are not aligned as specified by the supplier, the performance of the pack will not give the designed support resistance.

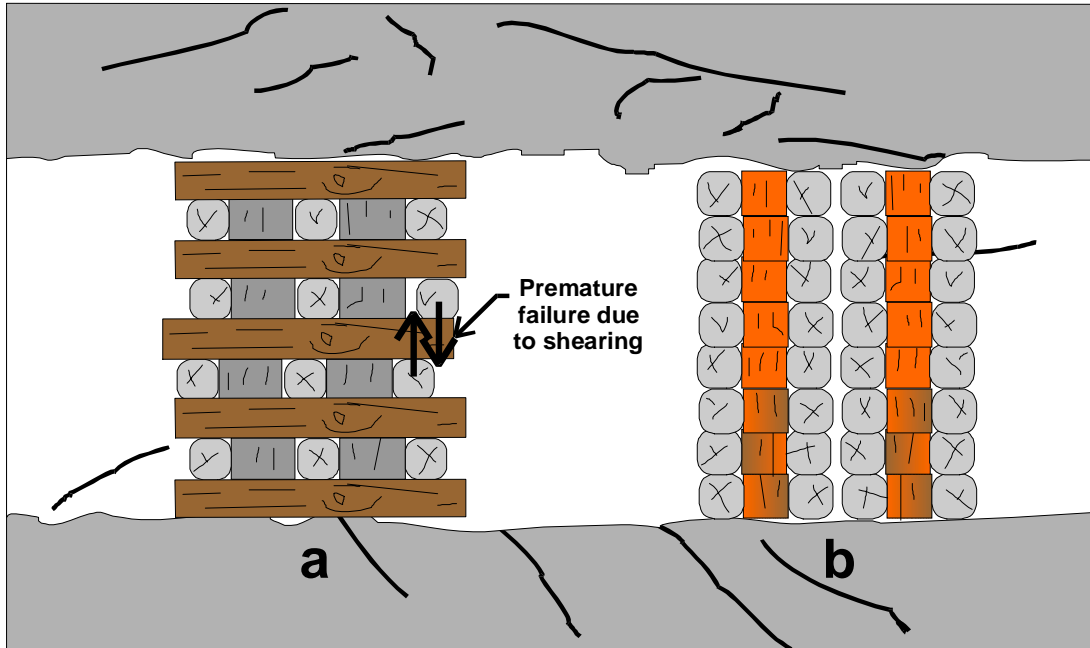


Figure 3.7 *Incorrect construction techniques*

If modular packs are built without rotating alternate layers relative to each other, then the pack will react as if it were separate packs with high aspect ratios (Figure 3.7b).

When wedging a pack, it is important to use a full wedge box which will adequately continue the support column through the whole pack. If only three pairs of wedges (as commonly seen underground) are used across a mat pack, for instance, the initial performance of the pack will be seriously softened during the most important part of its work - when it is supporting the hangingwall above the working area. Ideally, some other type of pre-stressing should be used in most instances; this improves the performance of the pack *in-situ*. This is discussed in more detail below.

3.2.3 End effects

The smoothness of the hanging- and footwall does not only impact on the orientation of the pack. If they are uneven, then the pack will be loaded unevenly, much to the detriment of its performance. This is especially important where packs tend to use either fewer tension members (composite packs) or high cement content (pre-cast packs). Bending a slab over a point of rock will quickly break it under loading.

It has been shown that the end effects on a pack can lead to as much as a 53 per cent reduction in load carrying ability compared to the de-rated press performance.

One way of overcoming these effects, at least partially, is to use a cementitious pre-stressing system of some sort. The introduction of a grout filled bag on top (or below) the pack will remove the unevenness and, of equal importance, will make the pack into an active support. The pre-stressing will prevent the pack from being blasted out, and also greatly improve its loading characteristics by removing point loading and taking out the initial softness in the pack due to uneven construction.

3.3 Pack pre-stressing

Although it was not intended to assess the effects of pre-stressing systems as part of this project, it was deemed prudent to at least bring attention to this topic. Appendix A contains a summary of preliminary pre-stressing test results conducted on one type of pack. The following testing was conducted:

- pack only, 3 tests
- pre-stressed packs with full wedge box, 2 tests
- pre-stressed packs with weeping grout system, 2 tests
- pre-stressed packs with non-weeping grout system, 2 tests
- non-weeping pre-stressing only, 1 test

The following procedure was followed:

- packs were constructed to the same size (height to width = 1)
- packs were tested at 25 mm/min
- all pre-stressing systems were installed with a gap in the pack of 25 to 30 mm
- pre-stressed systems were left for approximately 4 hours for curing and stress relaxation
- the pre-stress bags were all cut on one side just prior to testing to simulate potential damage from a blast

All pre-stressing systems did provide some effective pre-load on the packs evaluated. However, the wedges did compromise the initial stiffness of the pack that was achievable without a pre-stressing system. The weeping and non-weeping systems were both beneficial in terms of pack performance. The weeping system did maintain a much higher pre-load on the pack.

These tests were conducted on only one type of pack and the effects reported here are likely to vary from one pack type to another. Further work in this area is warranted, including investigations of how to integrate these results for support design purposes.

3.4 Manufacturing quality

The other major contributor to pack performance is how well the pack units have been manufactured.

Considering composite packs, the right size blocks have to be attached in the right place or it is extremely difficult to build the pack correctly.

For end grain packs, again, the right size block needs to be in the right place, and it needs to be the same rise as the slabs or the initial load will not be carried through the pack (in the case of short blocks) or the pack will quickly buckle (in the case of long blocks).

For both these types, the blocks must also be attached properly so they cannot easily be knocked off during transport or pack construction.

The units of pre-cast packs must all have the same, consistent dimensions, particularly the rise, otherwise the slabs will shear or crack across the step formed in the layer below. Figure 3.8.

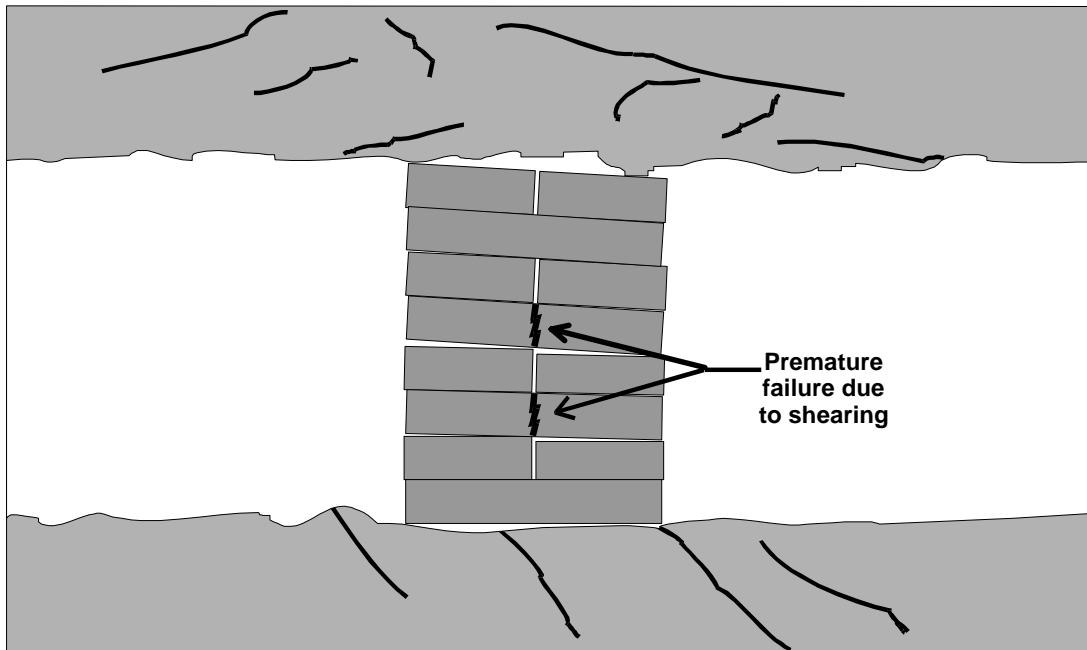


Figure 3.8 *The effect of poor manufacturing quality*

4 Proposed pack testing methodology

Several of the support suppliers do have testing procedures that they apply to their own products but there is currently no standard methodology applied to all variations of pack types. As with the investigation into elongates and the development of a methodology for testing and evaluating them (GAP 330), the same is now being proposed for packs.

As discussed in the previous chapter, several factors govern the performance of packs. A testing procedure could be developed that could account for all these influences, but this would be very costly and time consuming to the point that it would be so completely impractical that a testing programme may never be completed. Current available and published results on pack performance (Taggart, 1994; CSIR, 1995 and Coetzer, 1995) do provide an insight into the performance of quite an extensive range of packs where the testing conditions have been reasonably well documented. These are however, a collection of one-off tests with no evaluation in terms of the consistency of that performance.

An attempt to evaluate one of the critical factors affecting pack performance was reported by Taggart (1994) where the influence of dynamic loading conditions was investigated. Although these were a series of one-off tests, certain trends in pack behaviour were evident. Of significance is the effect observed when loading rates were varied during the testing of individual packs, eliminating the variations that can be expected from one pack to another.

These results however are not consistent with the findings reported by Spearman and Pienaar (1987) where the effect of compression rate on individual timber blocks was investigated. Here, tests were conducted at rates of 1 per cent strain per minute to 0.5 per cent strain per day (equivalent to 10 mm/min and 5 mm/day for a 1 m pack).

As part of this project, a testing programme was initiated that would further investigate this variation in loading rate effects. Several different types of small packs were tested at various rates ranging from the dynamic range (up to 2.5 m/sec) to very slow (0.2 mm/min), a difference of nearly six orders of magnitude in testing rate. It became clear that there was a difference in the effects of loading rate under dynamic and slow loading conditions. This is discussed in some detail later in this chapter.

Several attempts have been made regarding the prediction of pack performance based on its individual components, scale effects (pack size variations) and loading rates. Preliminary work indicates that the loading rate effects are reasonably consistent within certain pack types and assumptions can be made in applying these factors to other variations of these pack types. The only other area that needs investigation is the actual pack size (consisting of base area, unit rises and modular configurations).

Following many formal meetings with support suppliers, industry consultants and users, a simple testing methodology has been developed and is proposed below. The following considerations were made when developing this procedure:

- Packs to be constructed as per manufacturer's standard (including aspects such as base configuration and blocking as in composite packs).
- The pack is to be tested to within 15 per cent of the maximum aspect ratio (height:width) specified by the supplier.
- Much less testing should be required for packs than for elongates because of more consistent behaviour. Each pack already reflects the interactive behaviour of many units so that the variability of the individual elements has been smoothed.

Failure modes are consistently compressive provided the packs are constructed to within the specified height restrictions. Therefore, a minimum of three tests is required for audited / finalised inclusion in the database. If however, the variation in performance seems significant, it would be desirable to conduct additional tests.

- The standard loading rate to be set the same as for elongates and this has currently been proposed at 30 mm/min. Results are acceptable within a range of 20 to 30 mm/min as long as the rate is recorded and is reflected as such in the database.
- It is suggested that packs be tested to 600 mm or 50 per cent compression, whichever is less.
- Every variation in pack size and construction needs to be evaluated although generic types (such as mat packs) will not be specified by supplier.

However, this procedure may not be very relevant for grout packs and although some new information will be included in the new SDA database, it is presented as provisional results and must be used with caution. The most significant factor revolves around the curing conditions of these packs, as underground conditions cannot practically be duplicated due to compression during the curing period. Further work is required in this area.

Proposed Pack Testing Methodology

- The standard testing rate for all pack types is 30 mm/min; results will be accepted for rates of 20 to 30 mm/min and the actual rate will be specified.
- Each pack will be tested at an aspect (height:width) ratio equal to within 15 % of the maximum specified by the supplier.
- Each pack should be compressed to 600 mm or 50 %, whichever is less.
- Each pack variation must have at least three test results for analysis; more may be desired if the variability in performance is high.
- The average pack performance of at least three test results will be used for design purposes.
- The rate dependent factors set out in this document will be applied to the respective pack types unless additional tests have been conducted to determine these for a specific pack. The procedure must be similar to that discussed below.

4.1 Loading rate effects on pack performance

The effects of variations in loading rate on the performance of timber based support units have been investigated previously by Spearman and Pienaar (1987) and later by Taggart (1994). The former evaluated these effects with individual timber blocks under very slow loading rates, equivalent to those encountered quasi-statically underground. Taggart however, tested full size packs under rapid loading conditions, similar to what is expected during rockburst incidents. These results did not correlate and further investigation into this effect is warranted.

The equation governing the effects of the change in loading rate used by Taggart is however still applicable. The effect of loading rate on the performance of packs is expressed in terms of the following logarithmic function (Lightfoot, 1997):

$$F = F_o (1+x)^{\log (v/v_o)} \quad (1)$$

Where:

- F = adjusted force
- F_o = known force (usually from laboratory tests)
- v = adjusted loading rate
- v_o = original loading rate (used to obtain F_o)
- x = rate adjustment factor

For every order of magnitude change in the compression rate, there is a factor of (1 + x) change in load resistance generated by the pack. For example, if (x = 0.1) then if the compression rate increases from 1 to 10 mm/min, the load is increased by a factor of 1.1 or a 10 per cent increase over the full load / deformation curve.

The conclusion and recommendation made by Roberts (1995) based on the work completed for SIMRAC project GAP 032 was that a factor x = 0.16 would be applied as the rate adjustment factor for all packs under all conditions. This was applicable for the findings of the limited work conducted on rate effects within that project, but did not consider previous work.

To further investigate these variations, tests were conducted on a variety of packs ranging from solid mats to pre-cast cementitious packs. Some of this work was conducted in conjunction with other testing programmes such as consulting projects, product development work and testing specifically for this project. The following tests were conducted towards rate effects:

Pack Type	Minimum Loading Rate	Maximum Loading Rate	No. of Tests
Solid Mat	1.5 mm/min	15 mm/min	11
Cementitious 1	36 mm/min	3 m/sec	10
Cementitious 2	1.5 mm/min	15 mm/min	13
Brick Composite	1.0 mm/min	25 mm/min	8
Composite Timber	0.2 mm/min	2.5 m/sec	10

Initially, multiple tests were conducted at various loading rates in order to account for some of the variability that can be encountered from one pack to the next. In addition to this, other tests were conducted with variable rates during the same test. The latter was found to be of significant value for the evaluation of brick composite packs. Taggart (1994) in his testing of brick composite packs found that with one-off tests at various loading rates, there was little consistency in performance but while varying the rate during one test, the rate effect was obvious and consistent.

The results of some of the tests conducted to evaluate the loading rate effects on pack performance have been included in Appendix B. These findings have been summarised in Table 4.1 for the various categories of packs evaluated. The rapid loading effects for solid mat and brick composite packs were not evaluated in this exercise since the results obtained by Taggart (1994) already quantified these effects. One type of cementitious

pack had also been evaluated under dynamic conditions (Smit et al, 1998) the results of which have been considered here.

Table 4.1 Rate dependent factors governing the performance of packs.

Pack Type	Rapid Loading Rate Effect (%)	Slow Loading Rate Effect (-%)
Solid Mat	16	12
Composite Timbers *	12	12
Brick Composite	16	10
Cementitious	10-12	10-12

* including end grain and timber composite packs

4.2 Facilities available for commercial pack testing

Several facilities are available to the mining industry at which pack testing can be conducted but they all have differing capabilities and various problems. These facilities include the following:

CSIR, Division of Materials Sciences and Technology (MATTEK)
Mondi, Research and Development Centre
Western Holdings, AngloGold

CSIR, Mining Technology also operate a press that could be used for testing small or small-scale packs but would not be capable of testing according to the above proposed testing procedure. The largest pack that could be effectively tested would be a 900 mm cube sized unit, although it does have a load capacity exceeding any other press at 25 000 kN.

Mattek

Within the industry, this facility is most frequently used for product development and routine testing. This press is sufficiently large to test any pack and has a piston stroke in excess of 400 mm. The platens can also be reset during a test to conduct a second compression on the pack for another 350 mm or more. However, most of the load is removed during this process. As the hydraulic piston retracts and the bottom platen lowers, the top platen is brought down, maintaining a reasonably consistent pack height and load (although load fluctuations of as much as 1 000 kN have been noticed during this process). During the process of load relaxation and recompressing to regain the load from the end of the first compression, the pack is usually compressed by an additional 20 to 40 mm (depending on the resilience of the type of pack tested). Considering the loads that are being generated and the amount of compression that the units have already undergone, this off-setting is not considered significant.

It is not clear however, if the load relaxation and cycling can in any way affect the integrity of the pack structure and therefore result in unreliable test results during the second compression. It does not appear that this is happening, but different types of pack may be more affected by this than others.

Of some concern however, is the approximately 20 mm displacement shift (on the x-axis) that occurs during the early stages of testing. This is clearly evident on the graphed result shown in Figure 4.1. This effect is machine related and care needs to be taken when interpreting these results, especially in terms of initial stiffness.

The computer output for the test results is not very user friendly. Although all the necessary information is contained on the printouts, the graph axes are non-standard and do not allow for easy comparison. In addition, ASCII files generated from the program are not easily imported into other applications, such as spreadsheets, for data manipulation.

The press operator also has to rely on using the pen plotter because the computer acquisition system has previously been unreliable. Various reasons have been given for this but the problem remains. Paper copies of the test results report the loads in short tons and not metric units, but this is stated on each graph with the conversion factor.

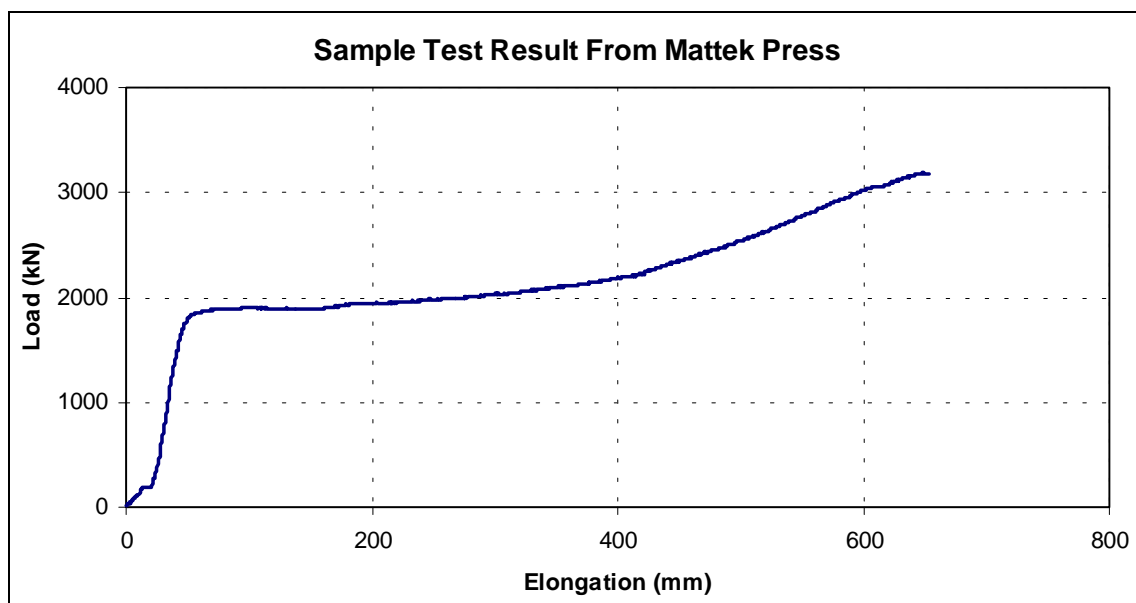


Figure 4.1 Typical test graph produced from the press at Mattek. Note the displacement shift that occurs during the initial stages of the test (here at about 200 kN or 20 mm compression). The second compression on this test began at about 420 mm.

Mondi

The Mondi press is very well run and maintained with upgrades being implemented as the need arises. A servo-controlled system is currently being introduced and should be operational shortly. The computer acquisition system has been designed with the user in mind and makes provision for easy data comparison.

The press has a large base area but does have a height restriction of only 1.6 m, limiting the size of pack that can be tested according to the proposed procedure. It does however, have the ability to conduct full compression of the units being tested to a maximum load of 10 000 kN.

Of concern, is the fact that this is not an independent facility with Mondi having interests in mine support. Some suppliers have expressed concern over the use of this press and it is therefore not widely used by suppliers other than Mondi themselves.

Western Holdings

This facility is no longer fully manned and is operated on a part-time basis as requested by the industry. There does not appear to be a permanent operator and its current level of maintenance is not clear. Mondi personnel have operated it at times.

This testing machine does have the base area and height required to test almost all variations of packs but has a load capacity of only 750 tons which may be a limitation with larger packs.

One concern with this press is the loading system. Compression of units is accomplished with pulses of compressed air driving the hydraulic system. In this way, the system is driven by two loading rates with several orders of magnitude variation in rate. The effects of this type of loading are not clear, but the effects of loading rate have been well documented.

5 Support catalogue / database

The Support Catalogue issued in GAP 032 is currently the only source of information generally available to the mining industry on laboratory tests conducted on a fairly wide range of packs. It consists of all easily collected test results (non-confidential) that were available to the industry at the time of compilation. Some additional testing was conducted to provide data for units where previous results were not available. Since this is basically a collection of one-off tests, it is likely that some anomalous (non-typical) results may have been included.

The results are not directly comparable however, as they were conducted under varying conditions. This includes the following ranges:

- pack height-to-width 1 to 2.5
- load rate 5 to 30 mm/min

Although all the information relevant to the test conditions was recorded, direct visual comparisons of the graphed test results may be misleading without considering these factors.

After several years now, some of the information has become outdated and new support types have become very popular, especially in the area of elongates. To update the current catalogue would be difficult, especially on an industry wide basis.

Although the style of presentation of data in the Support Catalogue is consistent, the method of description, especially in terms of unit dimension, does vary. The amount, order and completeness of the information supplied to describe the particular units is variable within the elongate and pack test results.

It is therefore recommended that a new database of support test results, carried out in accordance with approved standard procedures, be developed. Access to the database by all of the industry could be arranged in a number of ways convenient to various sectors of the industry.

5.1 Recommended data presentation

The description of the units must reflect the standard product that is supplied to the mine. If there are variations from the standard items (such as timber type, cement strength, configuration, etc.) it must be clearly stated for the attention of the user.

A consistent method of presentation in terms of the unit description and test results is important for ease of use. This should include dimensions, construction and test result graphs.

Since packs of various types are affected differently by the loading rate, it was felt that the presentation of only the laboratory test results would not be sufficient to allow for direct comparisons between different products. Since the loading rate is critical in terms of extrapolating the laboratory test results to the normal slow *in situ* convergence rates or to the dynamic situation, these values need to be reported and the implications also graphically presented to again allow for informed comparisons. The effect of the loading rate on the pack performance should therefore also be presented.

It was therefore considered essential that not only the original results, but also some standard design curves be presented as part of a catalogue. Since standard curves for elongates were based on a 90 % lower confidence limit (Daehnke, et al, 1998), an attempt was made to conduct similar evaluations for pack results. However, three test results is too few to conduct such evaluations and even a slight variation in performance can result in a significant de-rating in performance where it is not warranted (Figures 5.1 and 5.2). This is especially so in the case of brittle materials (cured bricks and grouts) where the onset of failure can vary, but be within design limits. For this reason, average performances are suggested and have been used in this report. At a later stage, when perhaps ten or more tests have been carried out on each pack type, the 90 % confidence method could be introduced. At this stage, the three test averaging method is considered satisfactory for a preliminary database that can be produced in a reasonable timeframe.

The standard curves generated from the actual test results should always be reported as 30 mm/min, irrespective of the rate of testing. This would require that if the original tests were conducted at a rate other than 30 mm/min, they would be converted to this standard, based on the stipulated adjustment factor. Support design requirements are generally based on the assumption that ground velocities of up to 3 m/sec can be expected during seismic events (and have actually been recorded at 2.1 m/sec). *In situ* convergence rates have been recorded from a fraction of a millimetre to several tens of millimetres (often associated with production blasts). It is suggested therefore, that a graph with three design curves based on the following loading conditions be presented in the catalogue along with the actual laboratory results. All graphs are also to be presented with standard scales for axes (discussed in Appendix C).

Dynamic loading	3 m/sec	180 000 mm/min
Standard laboratory		30 mm/min
<i>In-situ</i> equivalent	10 mm/day	0.0069 mm/min

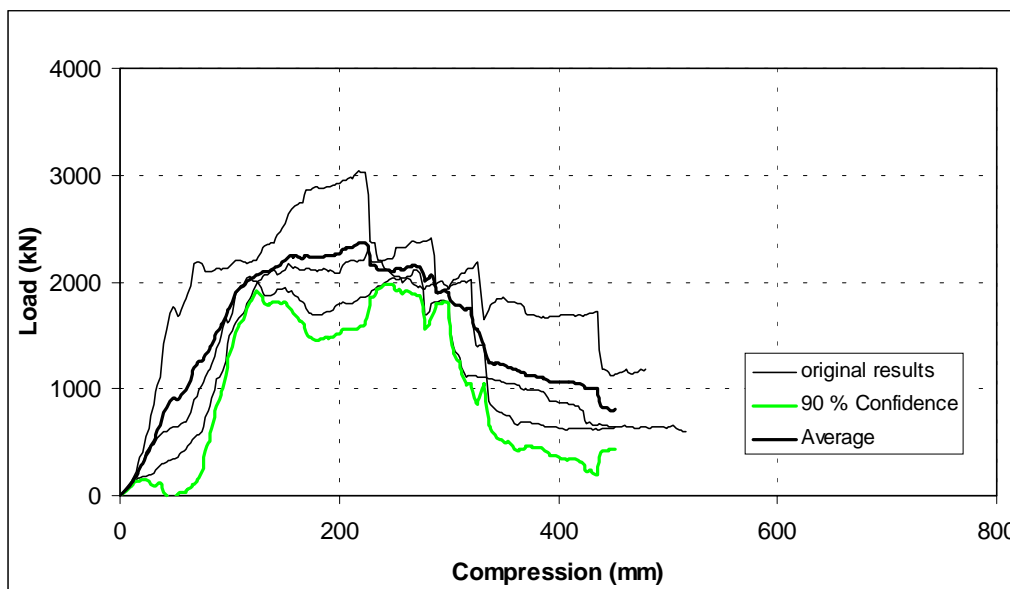


Figure 5.1 Effect of the analysis techniques reviewed to derive the standard design curve for a product with significant variability

Not everyone is familiar with all the products available on the market, especially if they are not standard items on mines where these people have experience. Also, as new products, or variations of existing products become available, it is much easier to make people

familiar with them if test results are accompanied by photographs or sketches of both the individual units and of packs under construction. An example of this is the album compiled from testing conducted at the testing facility in Welkom (Coetzer, 1995) although this only contains individual test results.

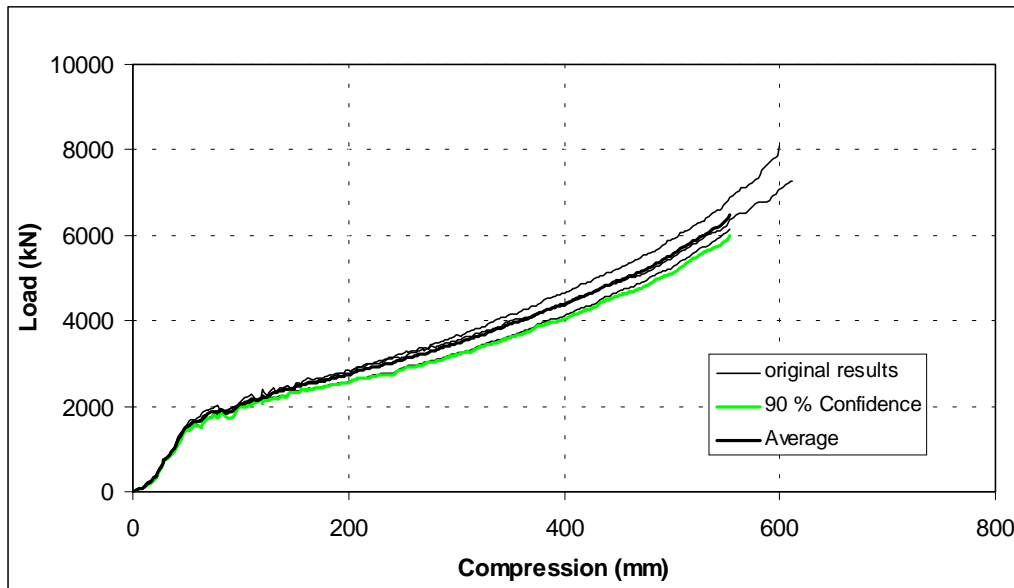


Figure 5.2 Effect of the analysis techniques reviewed to derive the standard design curve for a product with little variability

A catalogue of test results and design curves does not need to be issued in book form. This could be integrated as part of the SDA database as all the information contained in this format would be either required or generated by the SDA program anyway (except for the attached picture / illustration). Updates could be obtained as electronic, downloadable information from a Web site or on disc or CD from whichever organisation is responsible for maintaining the database (currently CSIR, Mining Technology through SIMRAC project GAP 630).

The format should be maintained through a proper database that can be added to at any time (utility program or SDA add-on module) at the request of either mine personnel or suppliers of products being tested. Support performance curves are currently hardwired into the program as a dynamic link library file that leaves little flexibility for the addition of new data without issuing completely new files. Under this format, illustrations cannot be easily linked to specific test results.

The need to establish the quality of the performance data, at least initially where a significant amount of legacy data still exists in the database, cannot be over emphasised. Unaudited results must be identified for mine personnel and must be stipulated as such on any outputs. These could include the data currently in the database or user input data. Provisional results could also be represented in this way. This would be for test results not yet completed or that need to be redone at the required test heights.

A complete set of the new information that is available to be included into the SDA has been attached in Appendix C. Note that the format described above has been used in all cases, even if most of the pictures are currently not available. An example is provided on the following page.

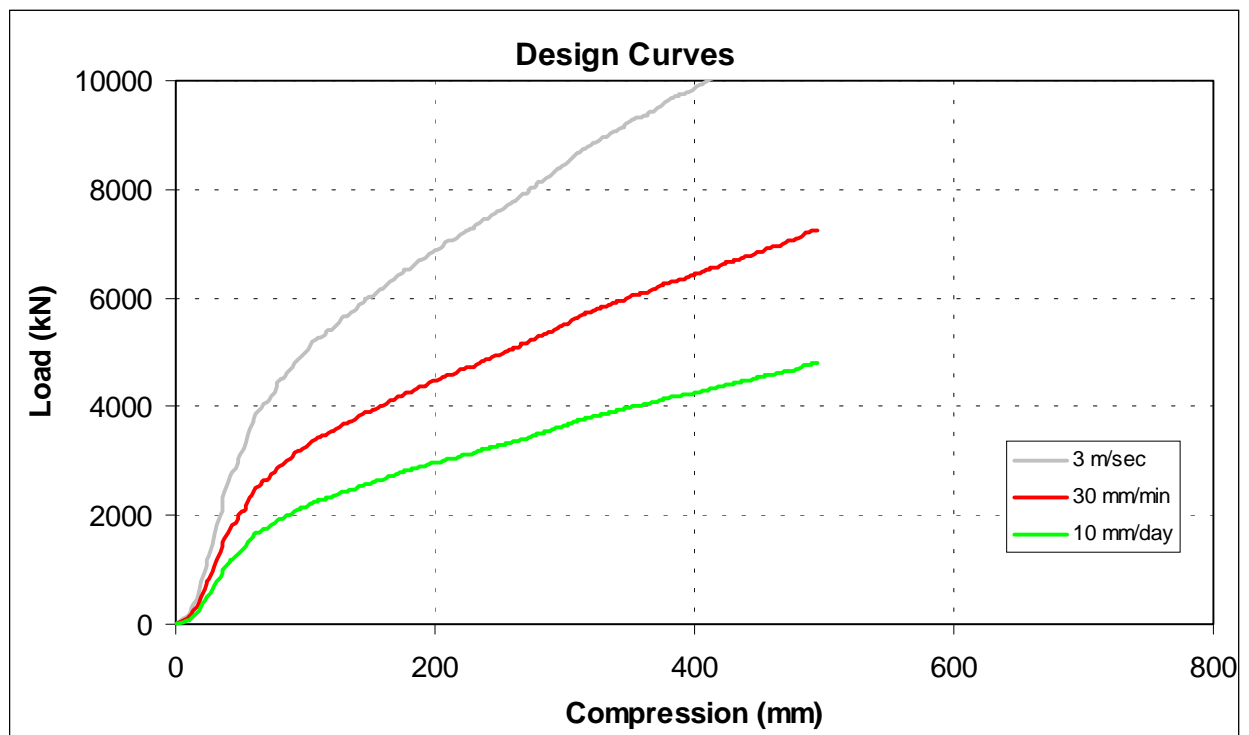
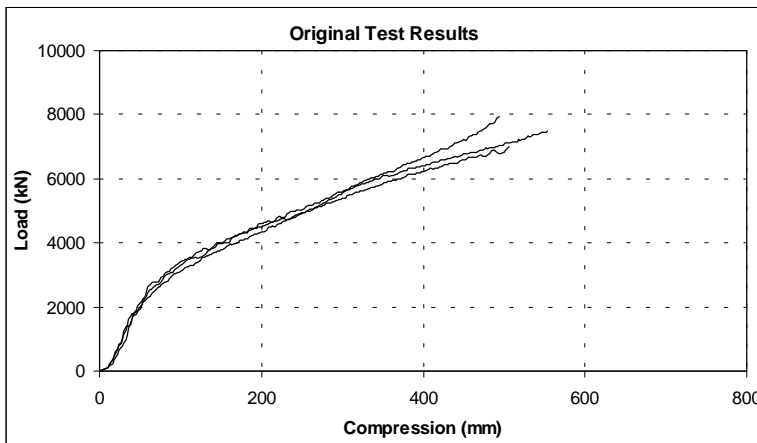
Lexus Pack 110 x 110, 11 rise

Description:	75 x 33 x 11
Lab Test Height (mm):	1600
Lab Test Rate (mm/min):	30
Rapid Rate Adjust (%):	12
Slow Rate Adjust (%):	12

Comments

2BV (11 x 11) 1BH

Picture



6 Conclusions

1. The use of solid mat packs still dominates pack usage in gold and platinum mines. These account for more than one-third of all packs constructed although this is a decrease from the 50 per cent obtained from a survey on usage in 1995. The use of end grain and pre-cast packs has increased significantly and they now account for nearly half of all packs installed.
2. A simple pack testing methodology has been presented which requires that at least three tests be conducted on all pack variations. These tests are conducted at 30 mm/min at a pack height equal to within 15 per cent of the maximum specified aspect ratios. Average performance curves are derived on which loading rate adjustment factors are applied.
3. Unless there is something fundamentally different about a new type of pack (such as construction material or yield behaviour), the information presented here should be sufficient to categorise new packs in terms of loading rate effects. If it is believed that there is a significant difference in loading rate behaviour, it would then be the responsibility of the supplier to have the standard tests conducted and results interpreted for inclusion into the database. Under most conditions, that would be three tests for every configuration of the pack.
4. A standard format for data presentation has been proposed which includes basic pack construction information, graphed test results, design curves and a photo or sketch of pack units or construction / configuration.
5. New standard design curves have been established and attached, in the above-mentioned format, in Appendix C.
6. Pack performance will be influenced by construction and installation factors. Some of these include slab / block sizes, source stock, percentage contact area between layers, moisture content, condition of timber, loading rate and pack size. Contracts between mines and suppliers should stipulate the specifications of the support units supplied, therefore the user can control these variables.

7 Recommendations

Funding was made available through this project to supply the mining industry with some typical pack performance information on a limited number of packs or pack types. As a result of the simplified pack testing methodology that has been presented and recommended within this document, a considerable amount of information has been collated and is ready for inclusion into a database pending acceptance of this report. However, some of this information is to be considered provisional, as it does not strictly comply with the prescribed testing methodology. Additionally, much of the information from the old database will not be replaced since new, multiple test results have not been obtained. These should be carried out in the near future.

- Old information within the database should be replaced with new results or deleted entirely as from June 2000.
- Provisional, new performance results where the testing method does not comply with proposed standard procedure should be updated by June 2000.

This should provide manufacturers with ample time to conduct the necessary tests and to have the results processed for inclusion in the database before the old results are deleted from the database.

The pack performance information provided here is to be included in the SDA database following acceptance of the findings of this project. However, this only makes the information available to those persons with access to the SDA software. A catalogue format may still be desired for performance comparisons, especially in terms of loading rate effects. For this, a proper database would be desirable which would contain the basic information on the individual support units and the original test results on which the design curves were based and then generated. This could be made available on the Web site or on CD in response to specific requests.

Although a considerable amount of work has been carried out on the effects of loading rate, not every pack type has been put through this process. Packs of similar type and construction have been considered to exhibit similar behaviour in terms of their response to loading rates. If at any time, a supplier / manufacturer does not feel that this approach is appropriate for a particular product, it would be their responsibility (at their own expense) to have tests and evaluations conducted similar to those presented here, to then reflect that particular unit's performance.

7.1 Further work

- The issue of pack pre-stressing has been touched on but this has only been investigated with one type of pack for a specific curing period.
- Very little work has been conducted on underground monitoring of pack behaviour and this has been done under varying conditions making comparisons difficult. In some instances, the underground performance has been reported as almost mimicking laboratory test results in terms of yield loads although the initial stiffness is in almost all cases compromised by non-parallel, non-planar end effects. If sufficient *in situ* performance results could be obtained, some sort of laboratory equivalent test procedure could be developed to assess a pack's response to non-ideal loading and end effect conditions.

- As mentioned previously, the conventional procedure for pack construction requires that they must always be built normal to the strata. However, ride is a significant factor to be considered (especially in more steeply dipping stopes) and can affect the performance, and even stability, of certain packs such as composite or end grain types.
- An issue raised earlier is the evaluation of grout based packs. Because they are cast in place as they cure, they may be compressed at the same time. A completely different laboratory test procedure needs to be established. A fully cured pack must be much stronger than one compressed as it is curing. Reliance may however be made solely on *in situ* evaluations under varying conditions, requiring an extensive monitoring programme.

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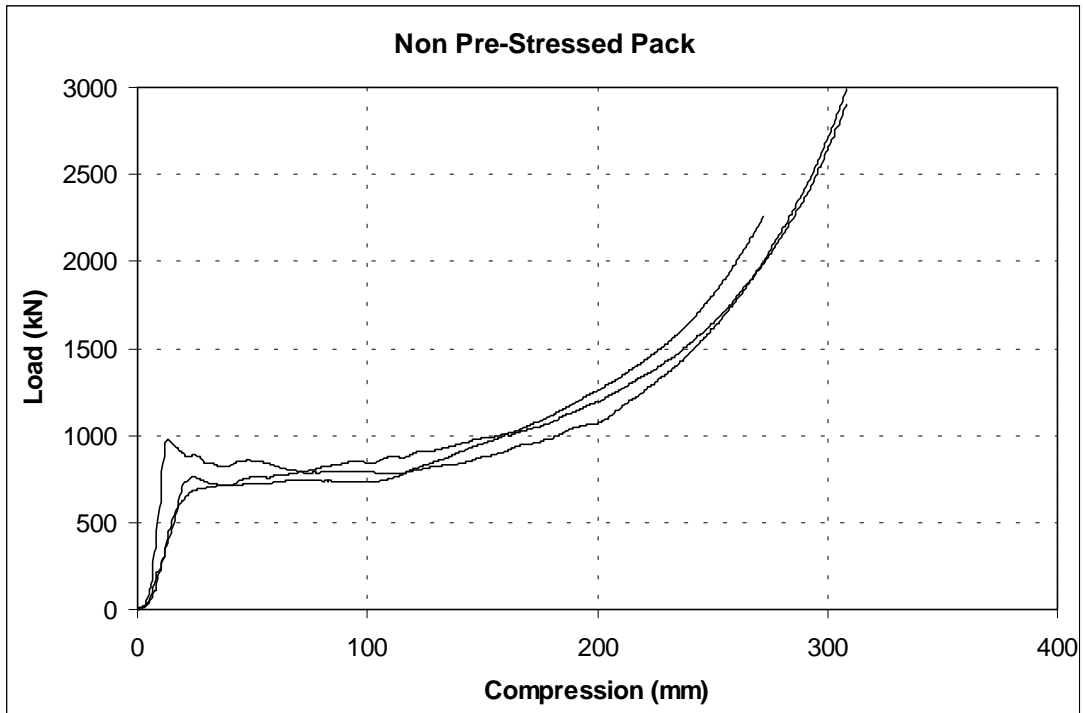
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Appendix A

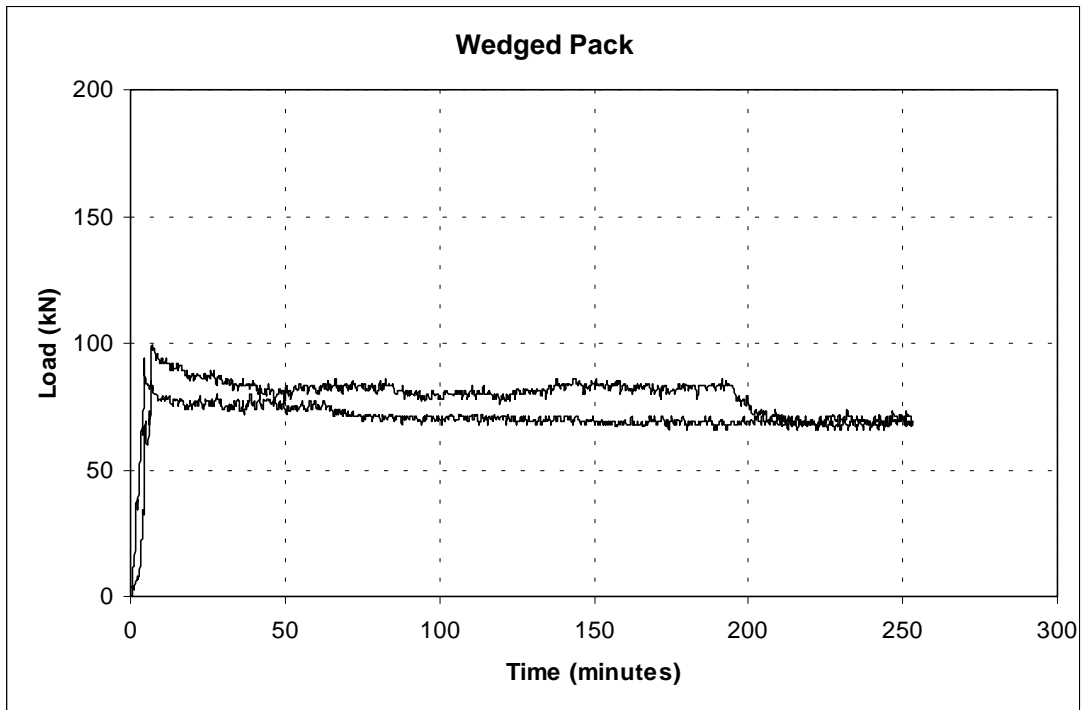
Pack pre-stressing, preliminary evaluation

Preliminary tests were conducted on a variety of pre-stressing systems in order to assess the effects on pack performance. All pre-stressing systems do provide some effective pre-load on the packs evaluated. However, the wedges did compromise the initial stiffness of the pack that was achievable without a pre-stressing system. The weeping and non-weeping systems were both beneficial in terms of pack performance. The weeping system did maintain a much higher pre-load on the pack.

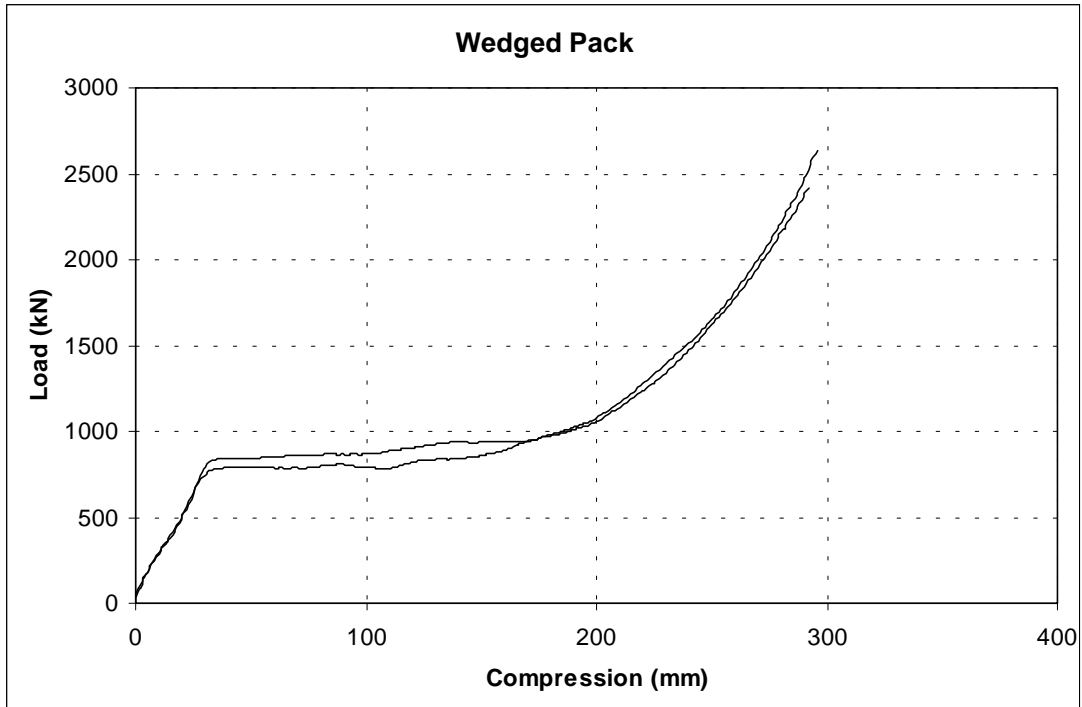


Three packs were tested throughout the pre-stressing evaluation to ensure consistent pack performance while assessing the effects of the various pre-stressing systems.

A full wedge box was inserted into the pack one-third of the down the pack. The wedges were hammered in with considerable effect to ensure a good, consistent pre-stressing effect.

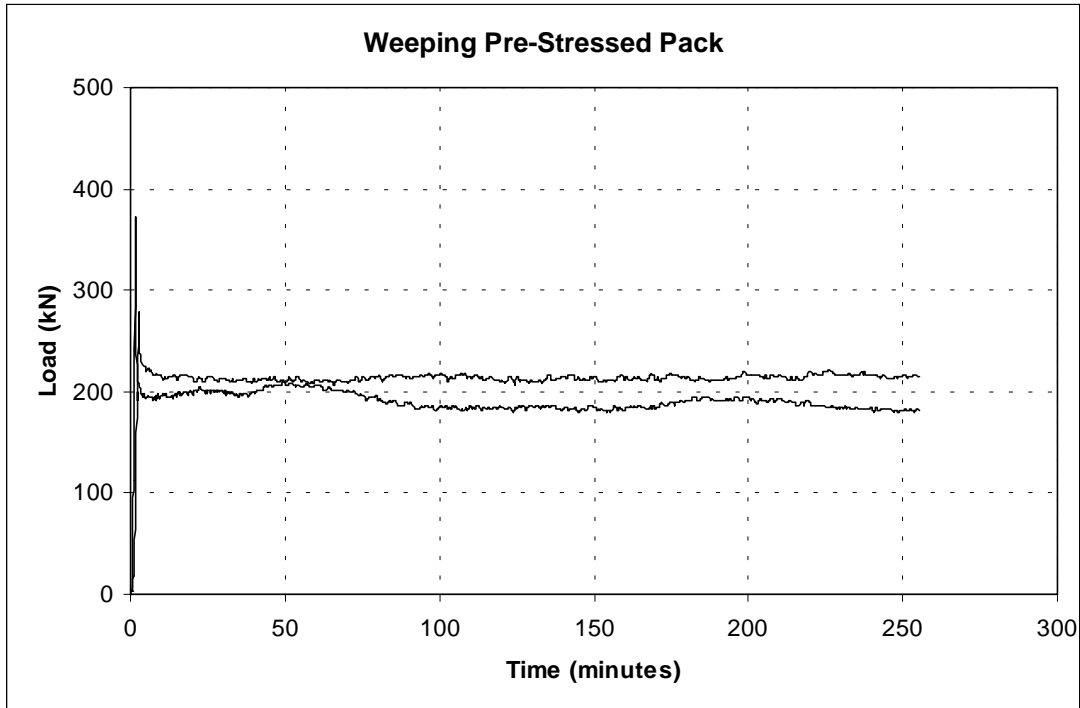


Response of the pack to the pre-stressing over a 4 hour period.

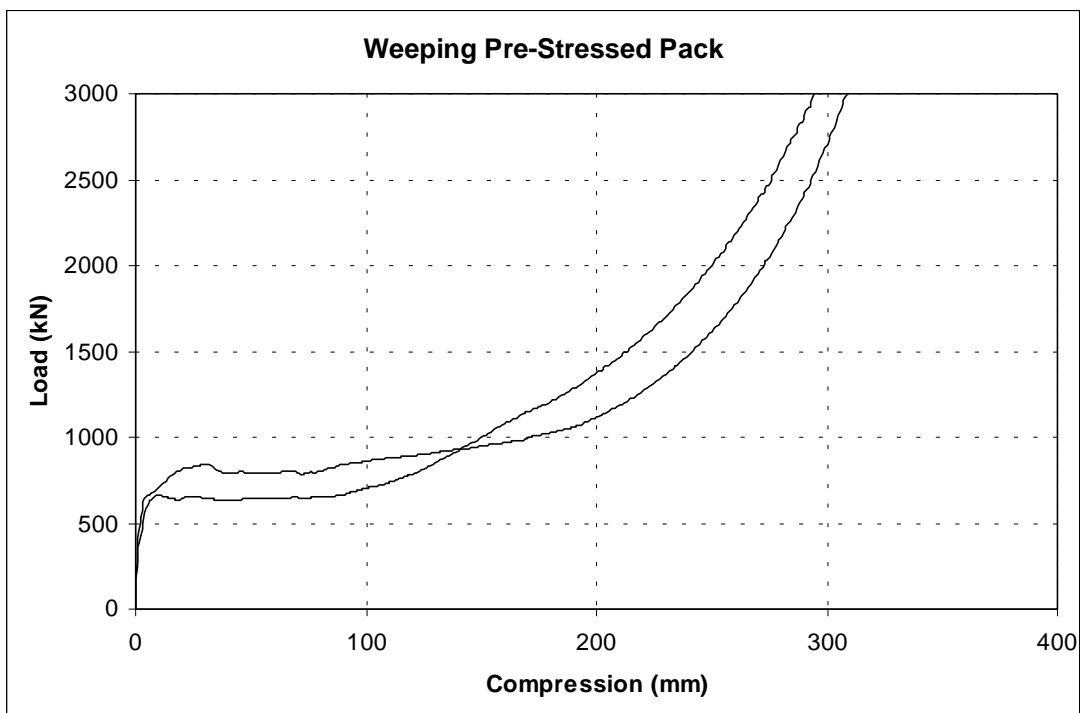


Although the pre-stressing effect is obvious, the presence of the wedges has resulted in a 'softer' initial pack performance.

The weeping system was installed at the top of the pack. Once the bag was filled and the lance removed, the load dropped quickly to a sustainable level. It is likely that any creep effect that the pack might have exhibited was removed during the pumping stage where much higher stress levels were reached (and maintained during pumping) prior to removal of the lance.

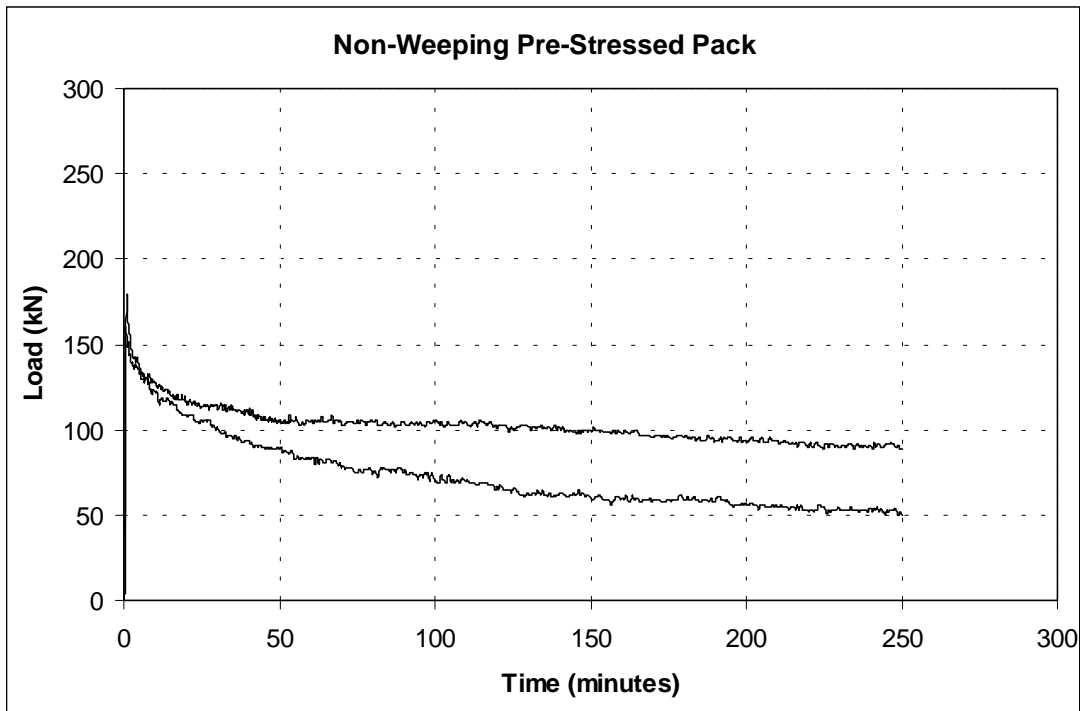


Response of the pack to the pre-stressing over a 4 hour period.

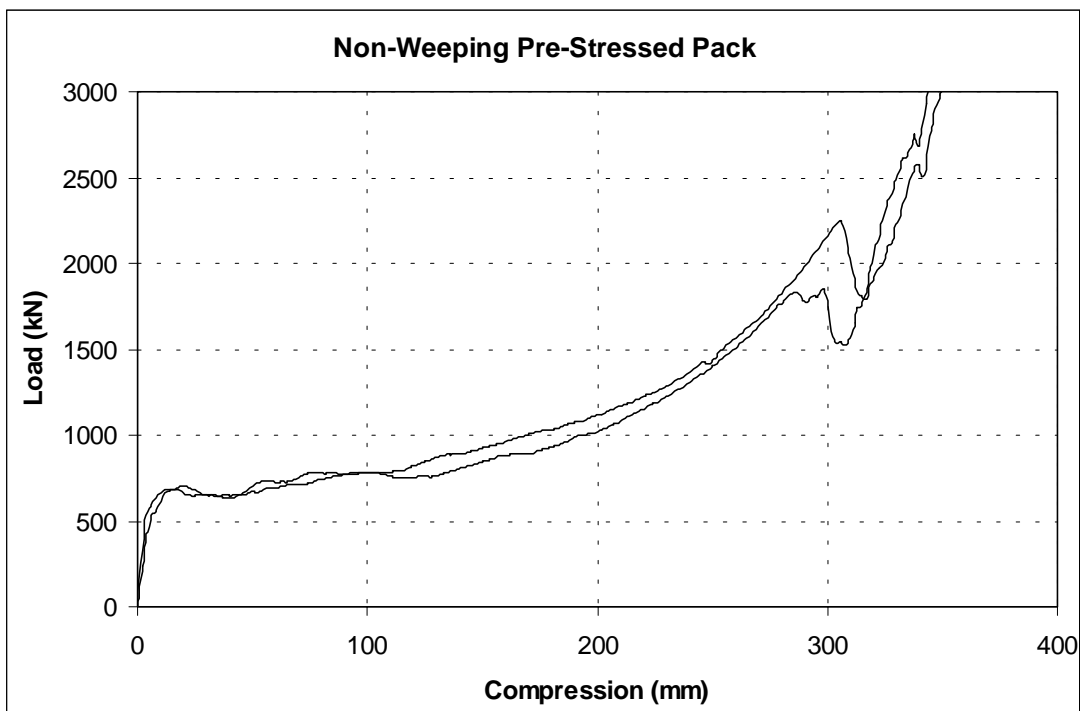


Very good initial pack stiffness is evident upon compression of the pack.

The non-weeping system was installed at the top of the pack. Once the bag was filled, a considerable amount of 'creep' occurred in the system. It is unclear whether this is due to the pack, pre-stressing system itself or both.

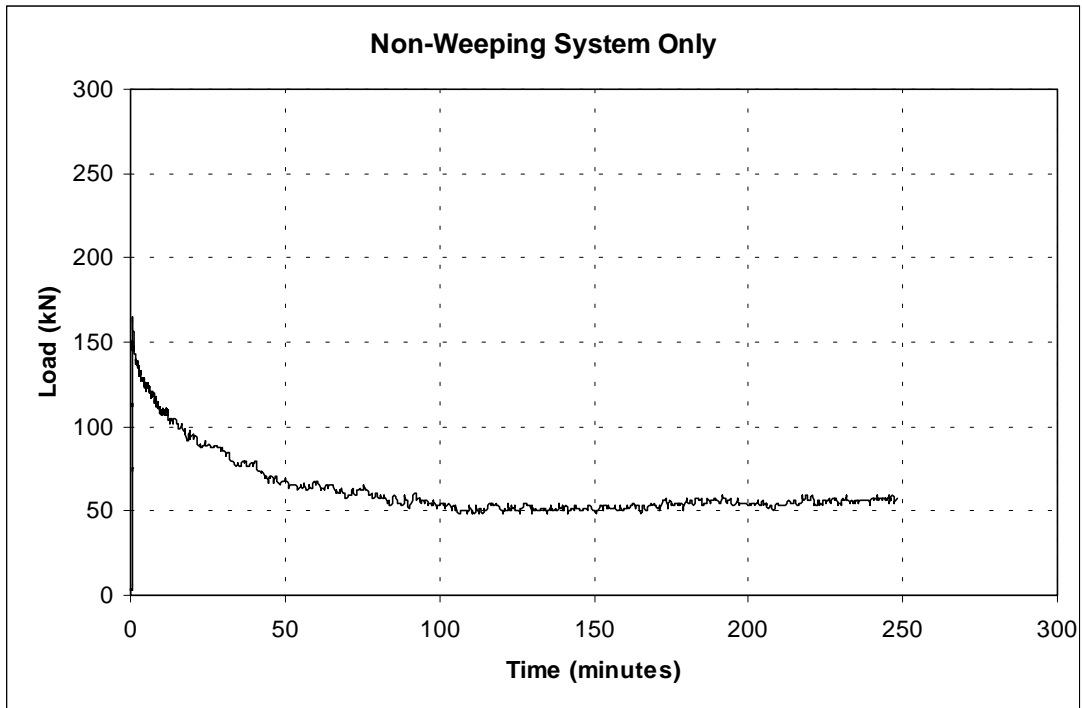


Response of the pack to the pre-stressing over a 4 hour period.

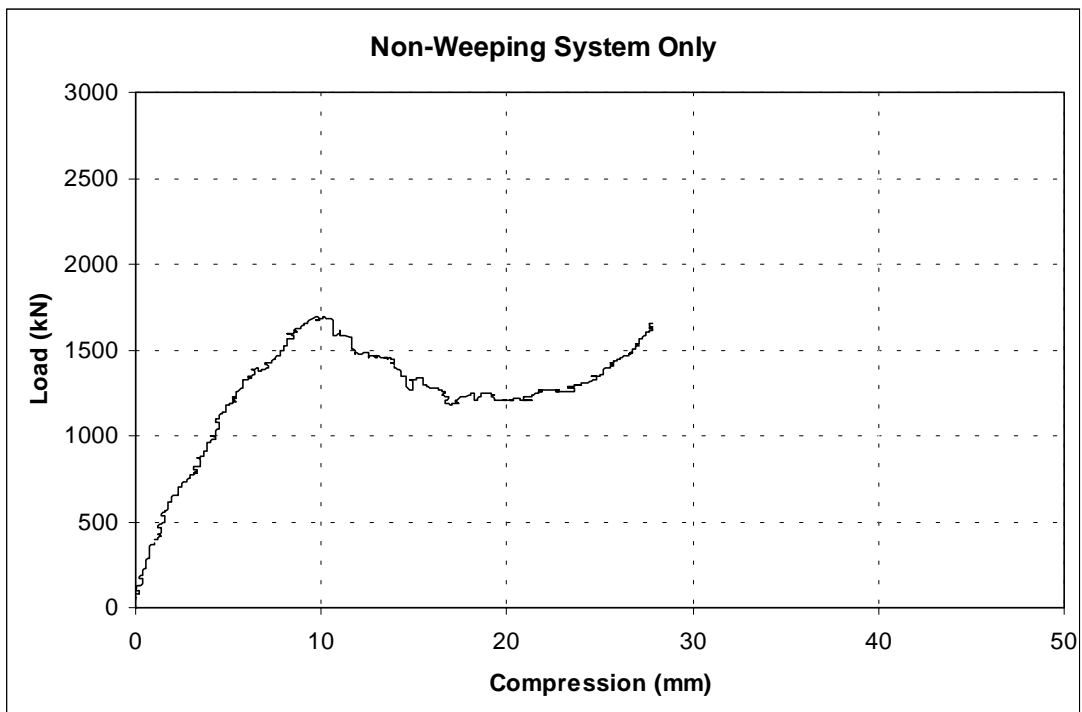


The initial stiffness of the pack during loading is not as good as that from the weeping system, but still a much improved performance from the pack alone. The loss of load at 1 800 kN is due to the failure of the grout. The bag began to fail and the grout was squeezed from the bag.

The effects of the non-weeping system alone was assessed to account for the results from the pre-stressed pack test results above.



The load loss over the 4 hour curing period was similar to that noted in the pack test. This may be the result of creep in the pre-stressing bag itself (which is known to occur based on bag testing) and / or the curing process of the grout mix.

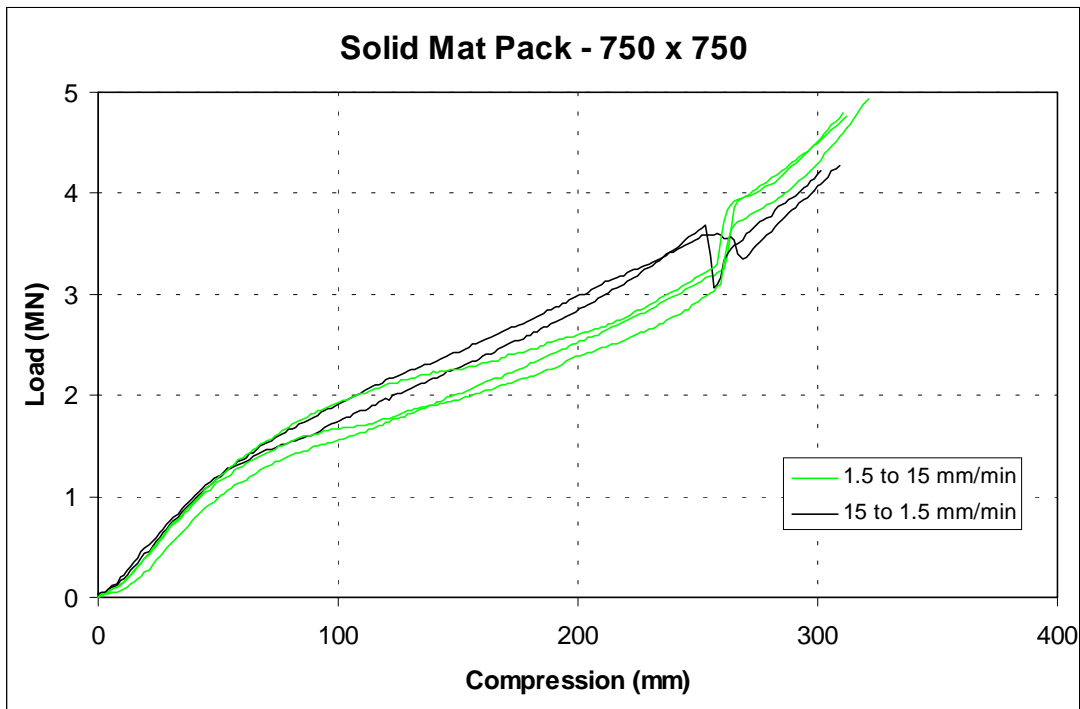


When the grout bag was slowly compressed, the grout began to fail at approximately the same level as that noted in the pack test.

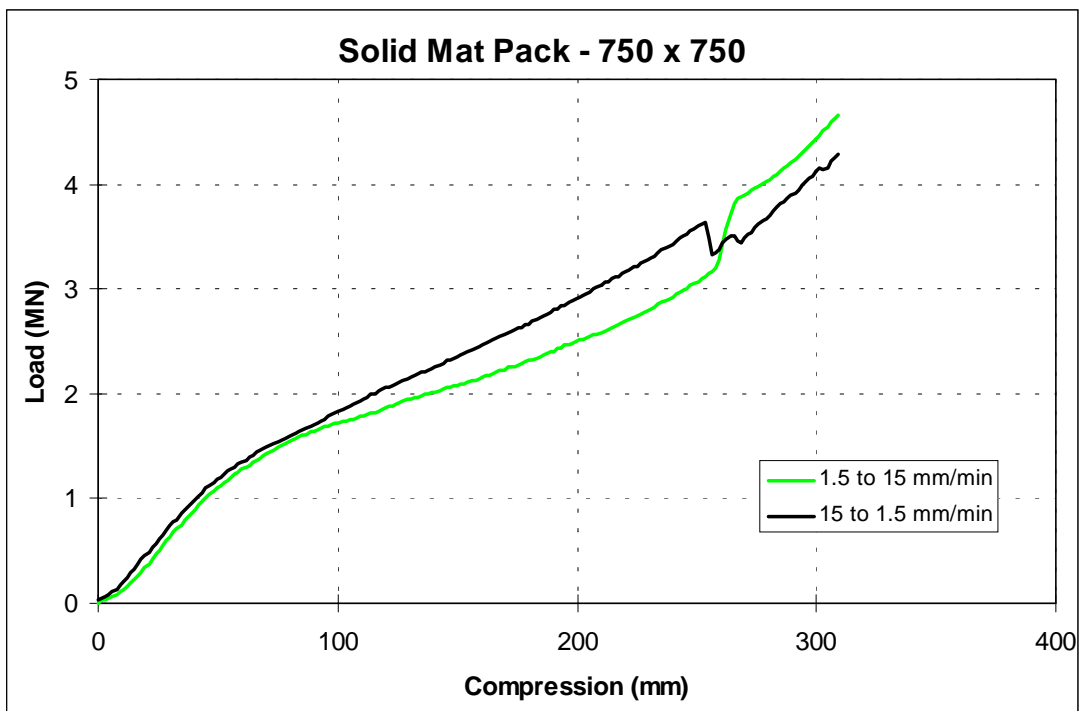
Appendix B

Loading rate effects on pack performance

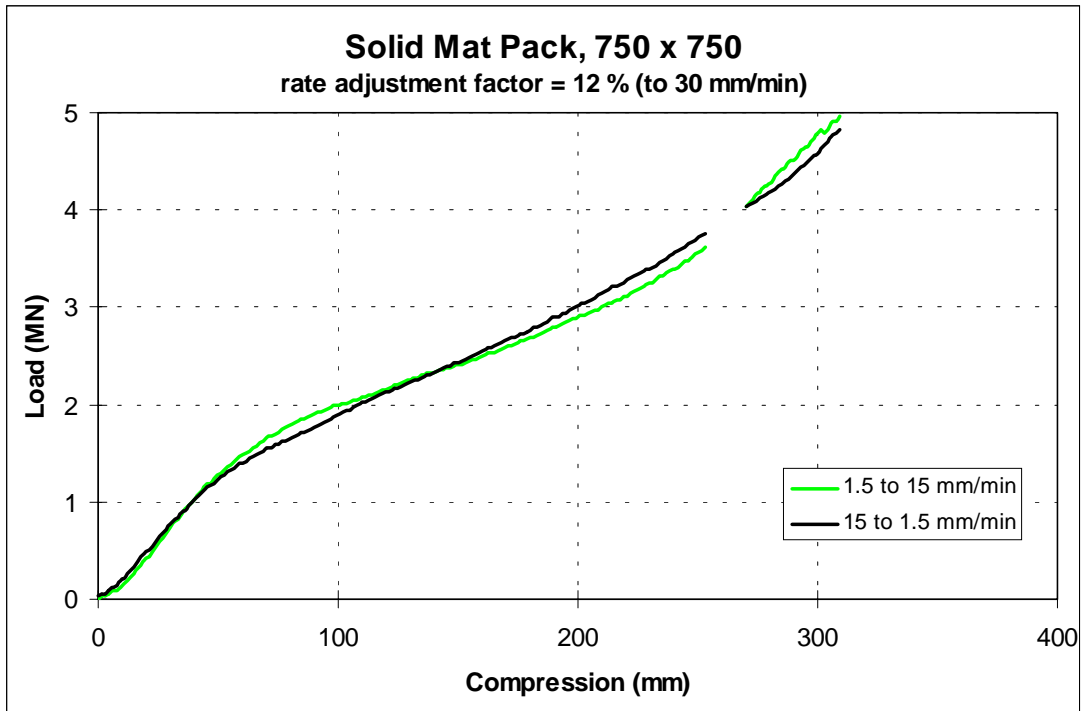
The variability in performance of the solid mat packs tested for this evaluation did not result in a clear effect of loading rate except when the rates were varied in the latter stages of each test. From the 11 tests conducted, five were done so with variable loading rates and these are evaluated below.



The variability in performance during the first 150 mm of these tests is likely the result of variations in mat contact surfaces. During the latter portions of the tests, the rate effects become more prominent. This more consistent performance allows for a comparison of the average performance of these two sets of curves.

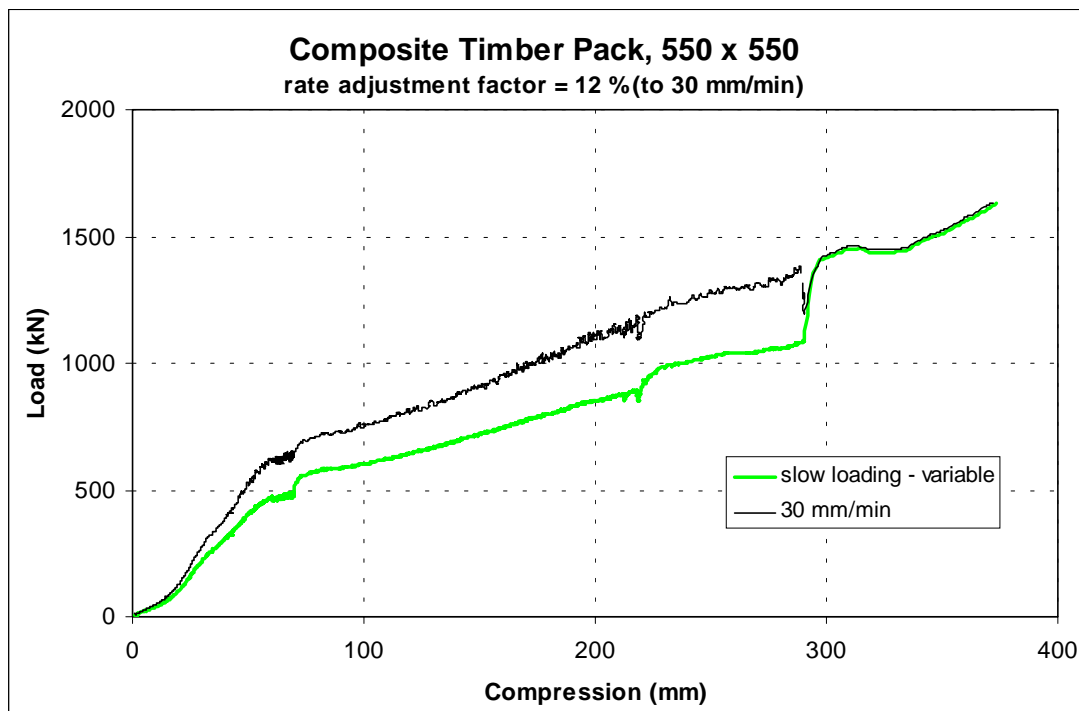


Average performance for the two sets of curves from the top graph.

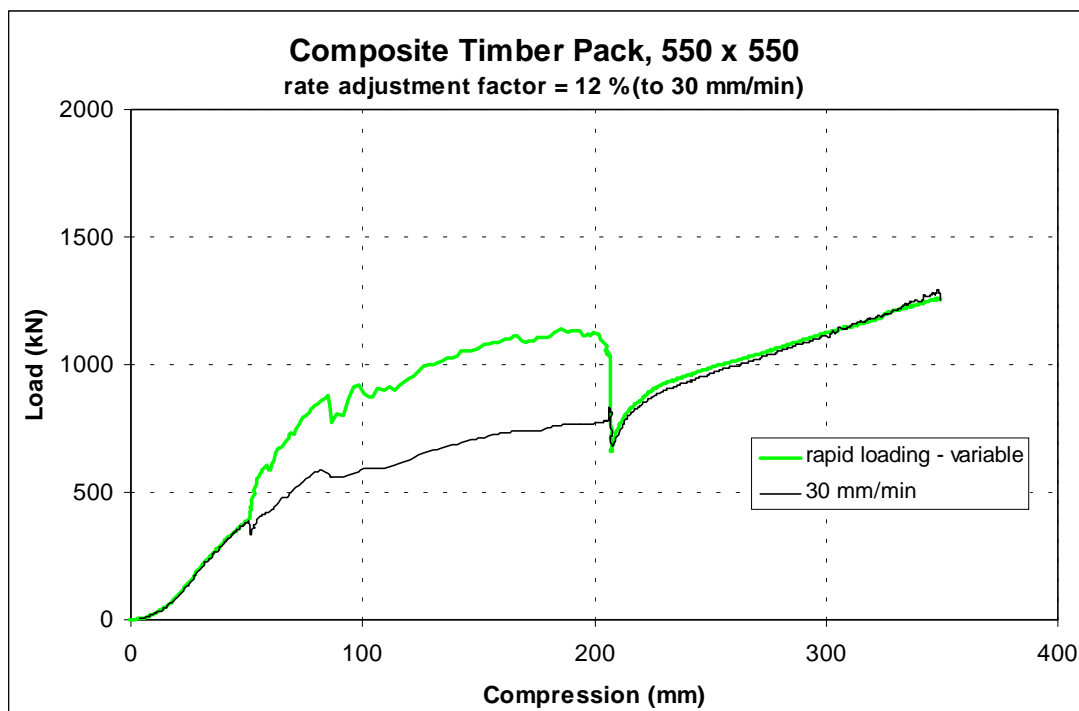


Applying a rate adjustment factor of 12 % on the above curves results in a consistent design performance curve even in the more variable, initial stages of the tests.

A type of timber pack containing composite timbers was evaluated at variable loading rates under dynamic and quasi-static conditions. Again, multiple tests were conducted at each of 3 loading rates. During these tests, the rates were varied to evaluate the effects.

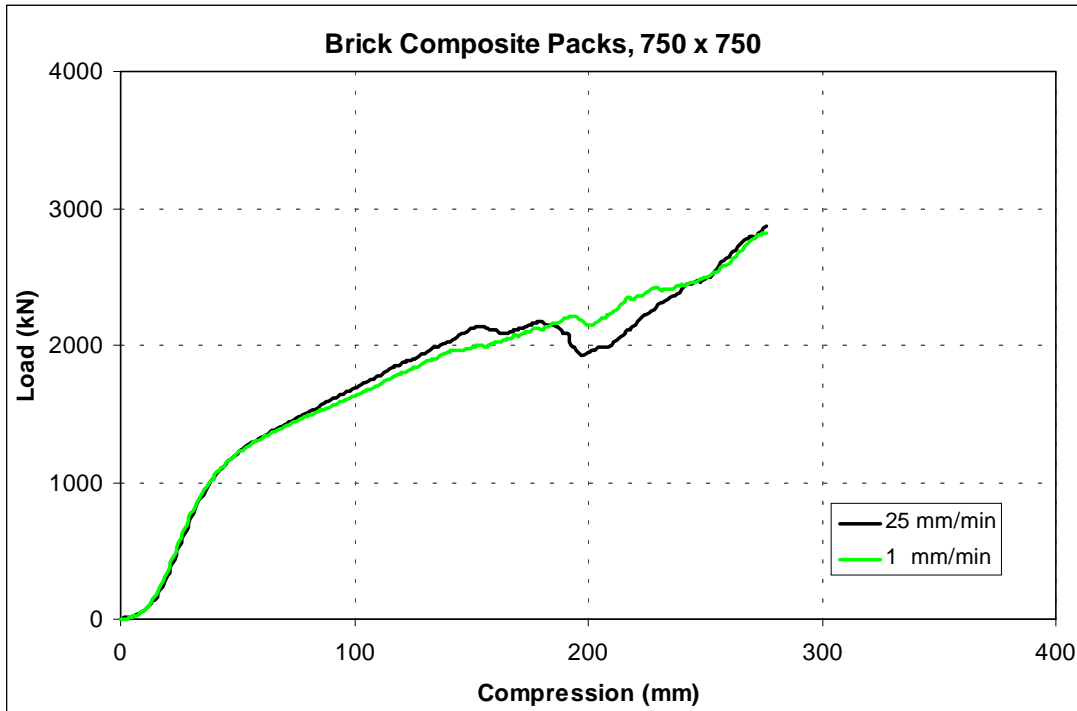


During this slow test, the loading rate was allowed to vary from about 0.2 to 25 mm/min. Applying an adjustment factor of 12 % results in the standard curve shown above. Results were consistent for all 3 slow tests.

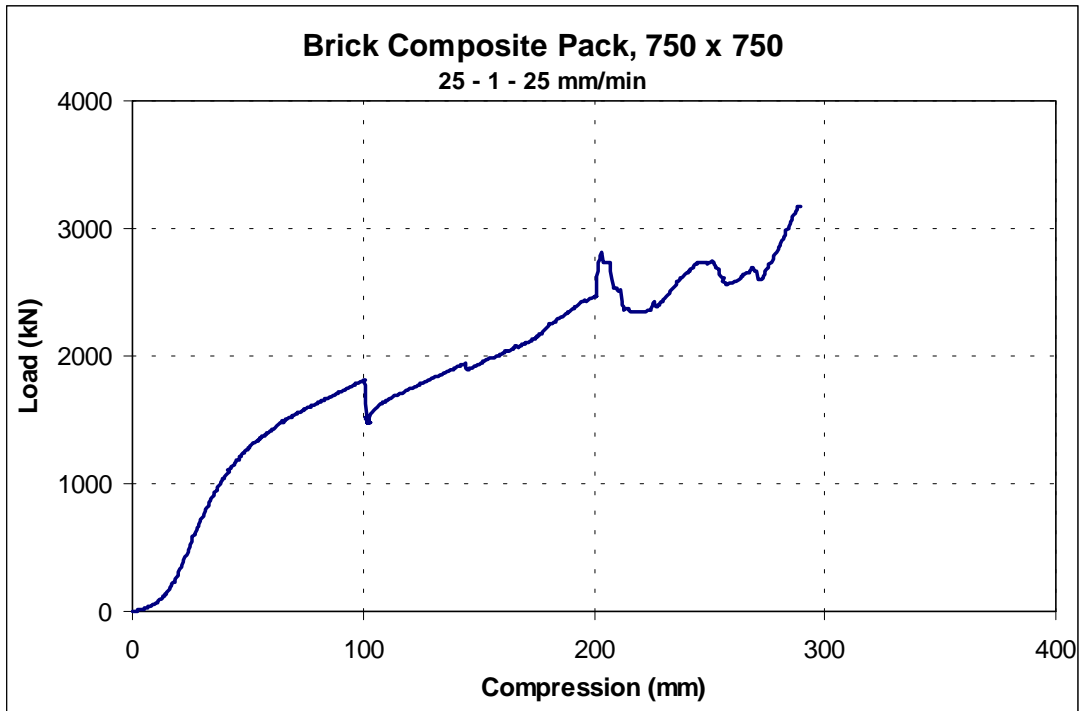


During dynamic testing, these packs were first slowly loaded to 50 mm compression before rapid compression to 2.5 m/sec. Again, a rate factor of 12 % could account for the rate effects and the standard curve is presented.

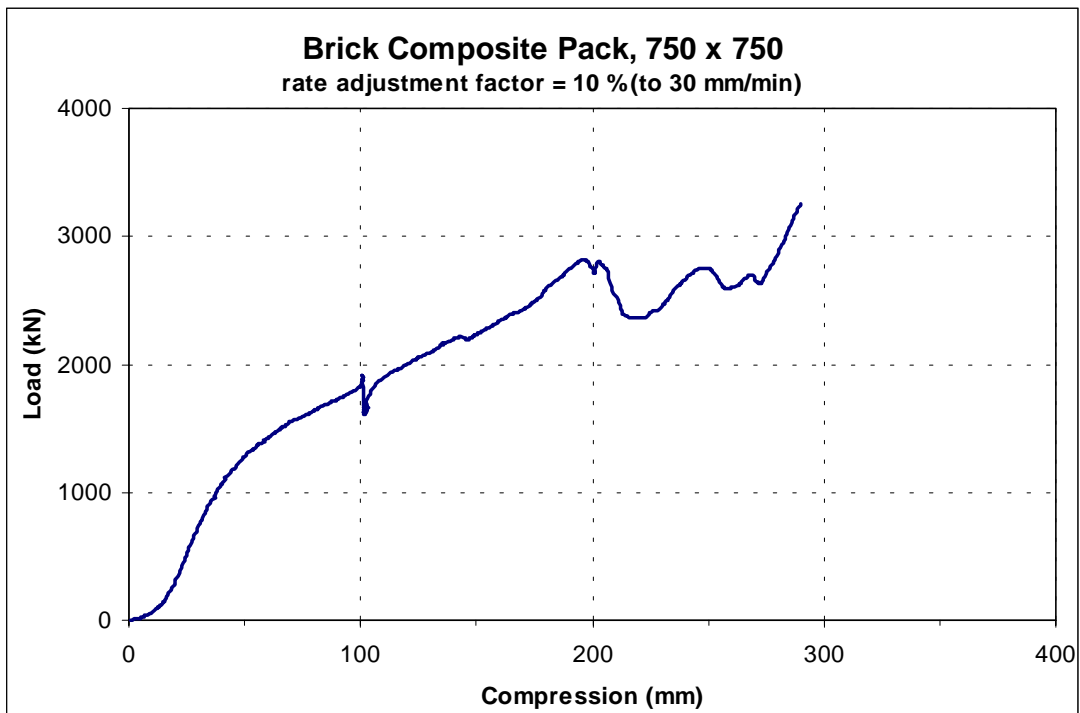
Just as Taggart (1998) had found during the dynamic testing of brick composite packs, the evaluation of rate effects at slower loading rates also did not indicate a significant rate effect. This is in spite of having tested three packs at each of two different loading rates. Reliance had to be made on tests where the loading rate was varied within tests in order to assess the effects of loading rate. Two additional tests were conducted where rates were varied and the effects assessed.



Three packs were tested at each of the loading rates noted in this graph and yet the average performance of these is almost identical.

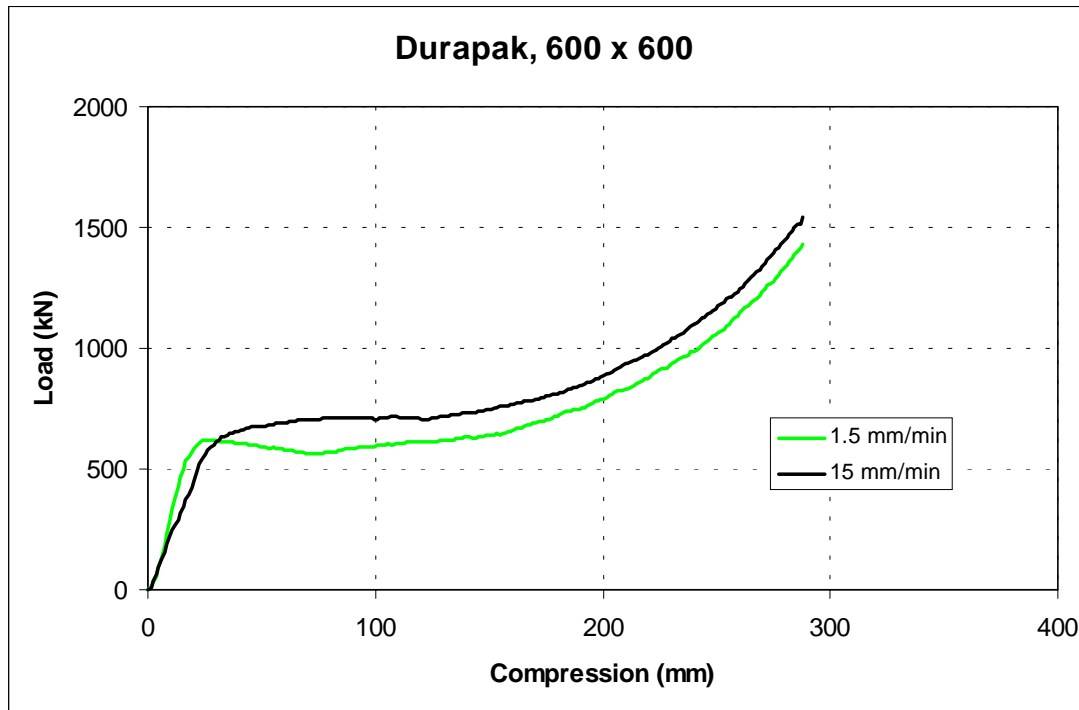


During the testing of this pack, the loading rate was varied from 25 to 1 and back to 25 mm/min at 100 and 200 mm compression respectively. The effects of these rate changes are clearly evident.

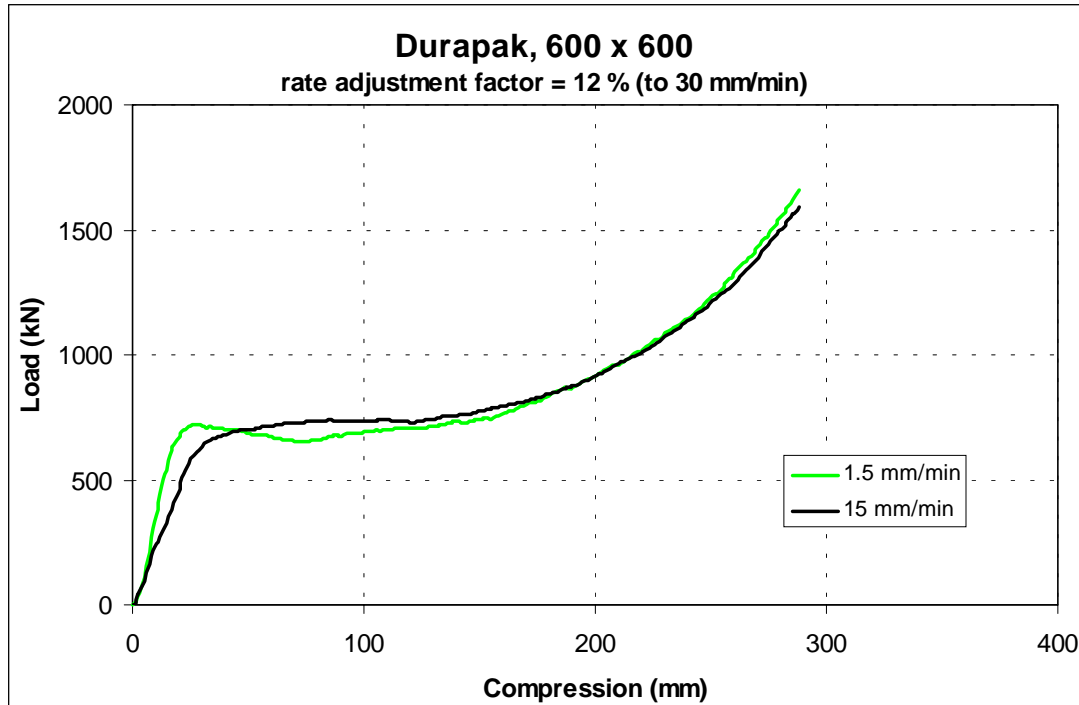


Using a loading rate adjustment factor of 10 %, the performance curve from the top graph was adjusted to the standard rate of 30 mm/min.

Several tests were conducted on Durapak at rates slower than the standard laboratory rate to complement the rapid test results reported by Smit et al (1998). Other than some variability in initial pack stiffness, the performance of these packs was consistent.

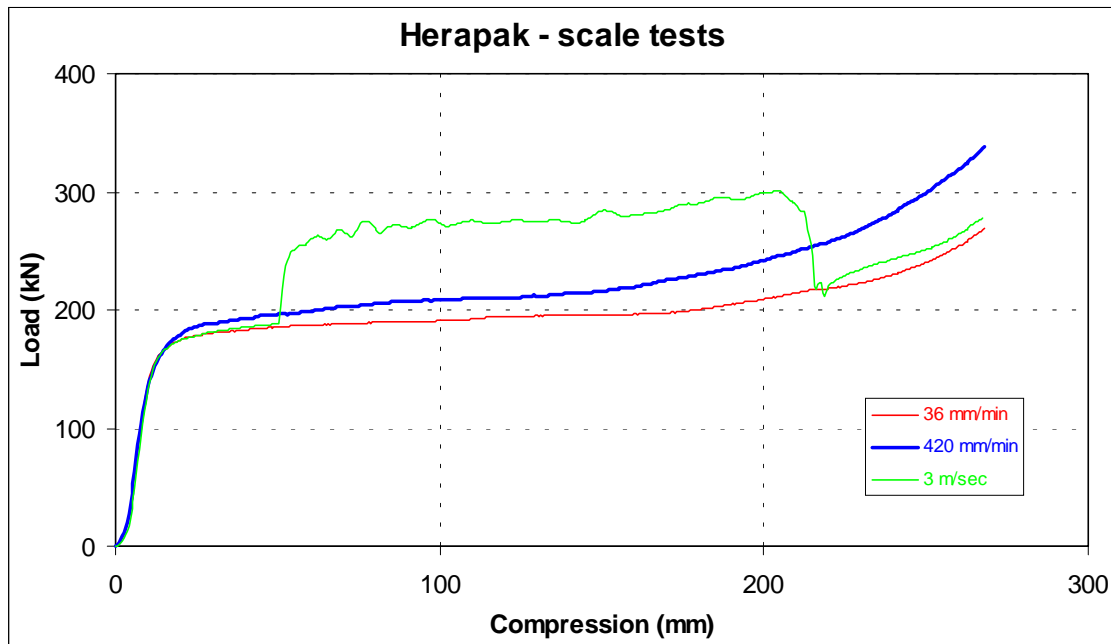


The two average curves presented above represent eight pack tests.

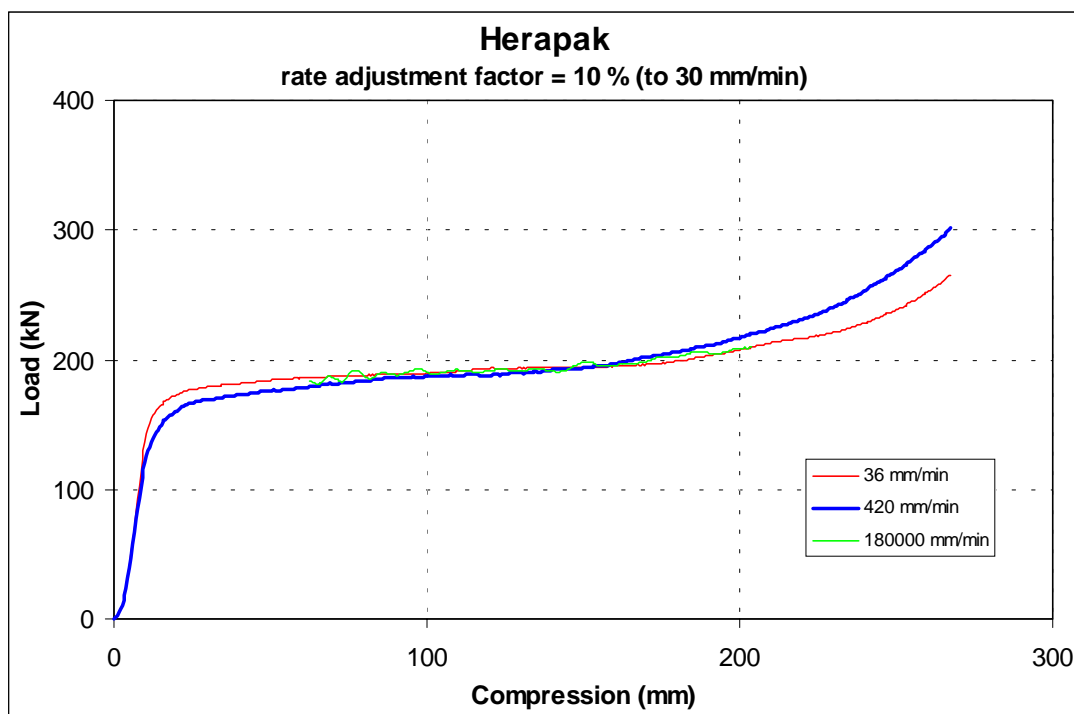


A rate adjustment of 12 % results in a consistent pack performance.

Laboratory testing of scaled down versions of the Herapak were evaluated to a height to width ratio of 2 (Kullmann, 1998). Tests were conducted at 3 rates from standard to dynamic. The consistency of the product allowed for a direct comparison of the average performances at these rates.



Average performance of multiple tests at 3 loading rates.



The application of a 10 % rate adjustment factor results in a consistent 30 mm/min design curve.

Appendix C

Performance tests and design curves

This section contains all the results of tests conducted and information collected on packs currently in use or available for use in the mining industry. The format used for the presentation of these results in this section is the same as that recommended for the catalogue or database. A full description of the units is provided to ensure no confusion regarding details in construction variations. A photo or sketch of the pack illustrating its construction should also ultimately be included. Other information of relevance for use in the design of support systems includes

- original pack test height
- laboratory test rate (eventually all tests should be at 30 mm/min)
- loading rate adjustment factor for dynamic conditions
- loading rate adjustment factor for an equivalent *in situ* condition

No information is included here unless there are at least three test results on each pack to indicate the consistency of the pack's performance. From these results, an average performance curve was established and this has then been used to generate the 30 mm/min standard laboratory design curve presented in the second graph. From this curve, the two loading rate factors described above are used to generate the dynamic (3 m/sec) and *in situ* (10 mm/day) design curves. These have been included solely for comparative purposes. The actual convergence rates are design parameters that are site specific and need to be determined or estimated by the responsible mine personnel.

If the SDA is to be used for the design of support systems, the enclosed standard 30 mm/min curves will be used by the program with adjustments made according to the information entered by the user.

Consistency in the presentation of the results is essential to minimise confusion when making quick comparisons. The test and design graphs are to be presented on the same scales, both for loads and displacements. All X-axes (displacements) are to be presented on a scale of 0 to 800 mm even though the test procedure requires only a minimum of 400 mm compression of the units. The Y-axes (loads) are presented on two possible scales due to the range of strengths that can be achieved through various types and sizes of packs. The standards for this are 4 000 kN and 10 000 kN.

Elongates

If this format is also to be adopted for elongates, similar standards can be applied in terms of presentation. Due to the varying yield and failure modes governing the behaviour of elongates, a separate set of laboratory curves would be presented for slow and dynamic test results and hence, different design curves. The rate adjustment factors would not be applicable in these cases.

Information would be required in terms of pre-stressing devices and headboards that are an integral part or optional with elongates.

Abbreviations

BV	Vertical block orientation
BH	Horizontal block orientation
Lab	Laboratory
S	Slab (horizontal grain orientation)