The Rapid Loading of Packs

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ABSTRACT

Traditionally timber packs were viewed as unsuitable for underground stope support in highly seismic areas. The design of packs has improved significantly and we can now design timber based packs which can be used safely in most applications, including highly seismic areas. The design of the "new generation" timber packs are based on understanding and controlling the following performance characteristics:

- *Slow loading and rapid loading characteristics and behaviour. This includes the determination of the change in load per order change in loading rate (the "x" factor)*
- *The quantification and relevance of resilience in support design.*

In order for a pack to perform well under rapid loading or seismic conditions, it is proposed that it must be:

- *Initially stiff. For a small pack 500 to 700 kN load must be reached in 30 to 50 mm deformation*
- *The load must be limited under slow loading. In the past it was postulated that the loads in timber mat packs were too high prior to seismic events occurring. During the seismic event this load is further increased due to closure resulting in damage to the footwall and hangingwall.*
- *The percentage increase of the load during the seismic event must be limited. This is quantified in terms of the "x" factor.*
- *The pack must remain stable.*

During the design, extensive laboratory testing was done on various packs, The interpretation of these results is further backed up by underground observations.

It will be proposed that timber can be used safely in seismically active areas. The latest end-grain and split slab technology allows us to design support systems, from timber, which can be both stiff and yielding, with minimal increase in load generated during rockburst activity..

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1 INTRODUCTION

Cementitious pack products have proven to be the bench-mark in mine support in areas where seismicity results in ground control problems. Historically, timber based mine support products, although more cost effective, have been tagged as being unsuitable because of unacceptably high '*x*' factors.

2 THE '*x*' FACTOR

Organic materials such as timber, and some other materials such as concrete, demonstrate a rate of loading effect. Essentially, the faster the material is loaded, the higher the resistive force that the material generates. This is quantifiable under laboratory conditions, the change in load being referred to as the '*x*' factor, where '*x*' refers to the percentage change in load per order of magnitude change in loading rate.

2.1 Laboratory slow loading pack performance

The press test results of packs are traditionally presented in a load (kN) vs. deformation (mm) graphical format. Deformation rates may vary press to press, but are normally about 20 to 30 mm per minute of closure. Figure 1 shows the required performance curve for seismically active conditions.

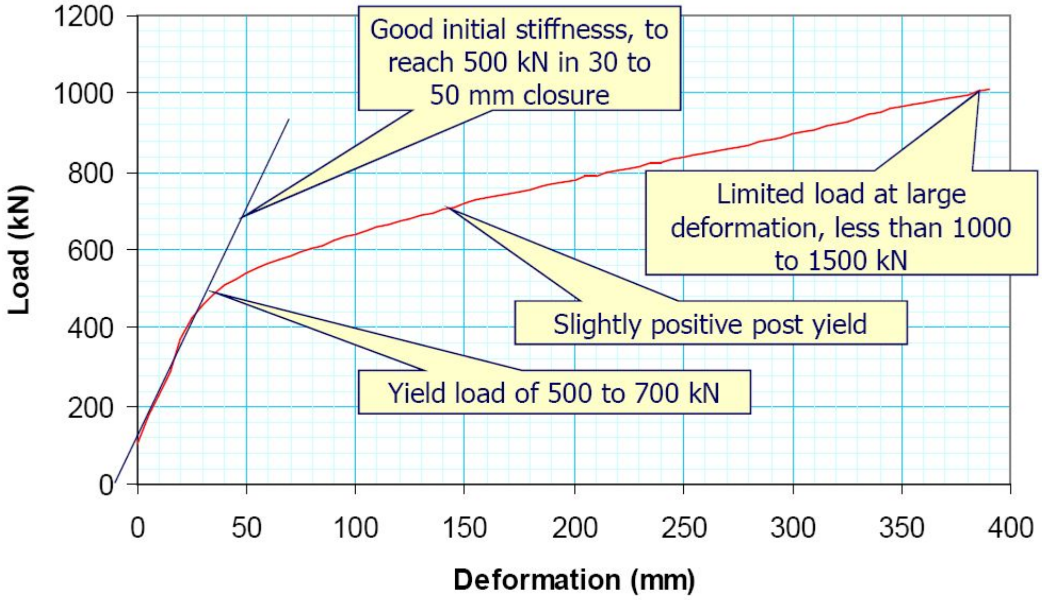

Figure 1: Required pack performance for slow loading

It is generally accepted that the required slow loading performance characteristic for seismically active areas, is one which is initially stiff with a high Young's Modulus, but has a yield load that is relatively low in the order of 500 to 700 kN. Ultimate stiffness should be low but positive through large deformations.

2.2 Laboratory rapid loading performance

Rapid loading assessment is normally done in the CSIR Terratek machine, and tests are done in accordance with Simrac guidelines (Kullman, 1999).

Packs are slow loaded in the Terratek machine for typically 50 mm of closure, and then subjected to rapid displacement of 3.0 m/s through a further deformation of typically 100 mm to 150 mm. Should the integrity of the pack remain acceptable, the pack may be subjected to a second or third cycle of rapid displacement.

Figure 2 shows a result achieved on a 60 cm Maximus pack. The rapid loading sections of the curve can be seen as jumps of increased load, the magnitude of which are proportional to the '*x*' factor.

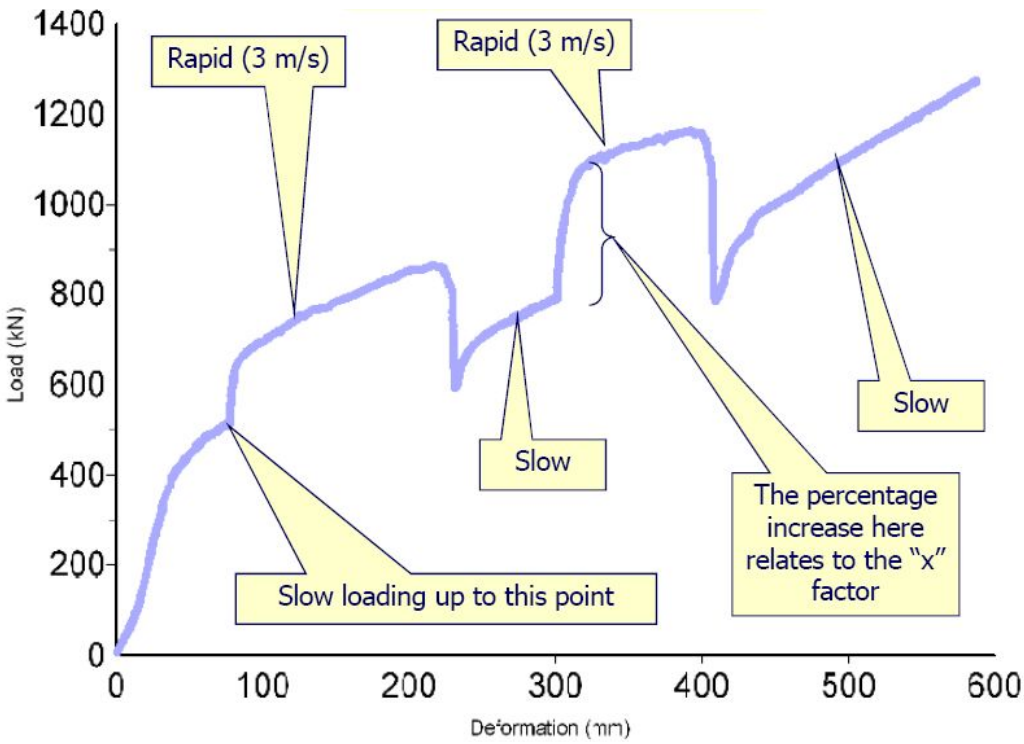

Figure 2: Load-deformation curve with rapid loading cycles.

If the loading rate is varied while a pack is tested, the following procedure can be used to analyse the data. It has generally been accepted that loads can be predicted for various loading rates using the following relationship (Roberts et al, 1987, Kullman, 1999):

$$F_u = F_p\left(1 + \frac{x}{100}\right)^{log\frac{V_u}{V_p}}$$

Where $V_u =$ underground loading rate (either slow or rapid)

$V_p =$ experimental loading rate, i.e. in the press

$F_u =$ force generated at underground loading rate V_u

$F_p =$ force generated at press loading rate V_p

x = load adjustment factor expressed as a percentage per order of magnitude change of loading rate.

The platen velocity was calculated at small increments and the above relationship applied, using the most appropriated value for x.With the ease of computing within data spreadsheets, the 'x' factor is adjusted until the peaks of the rapid loading sections of the curve are flattened. Figure 3 shows a typical smoothed curve.

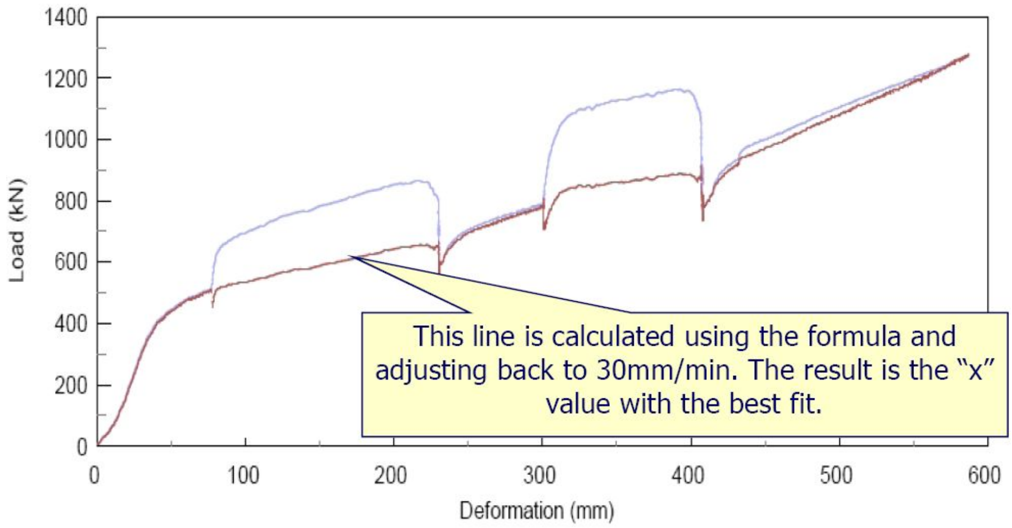

Figure 3: Data analysis of a rapid loading curve. The blue line gives the original data. The red line gives the adjusted data. In this case *x*=8.3 was used.

3 RESILIENCE

One contentious issue is that of resilience. The resilience of timber was quantified in different ways; by applying loading cycles during slow loading of a pack in a press and by measuring the rebound during a drop test. It is also argued that a degree of resilience from support is required for best performance during seismic events underground.

3.1 Loading cycles in a press

The energy absorbed by a pack is represented by area under the load-deformation curve. Further, the amount of energy released by the pack during unloading is also represented in the same manner. A 60 x 9 cm Timrite Lexus pack was subjected to loading cycles. The results are given in Figure 4.

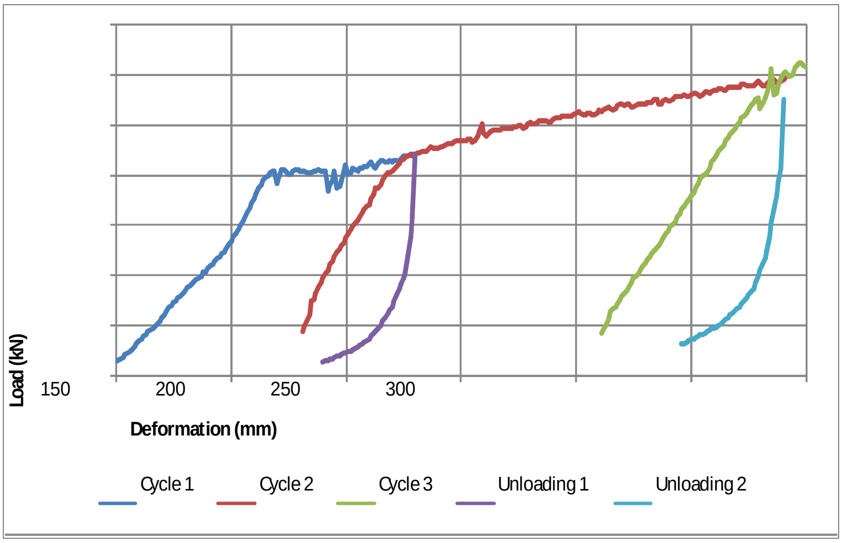

Figure 4: A Timrite Lexus pack was loaded to approximately 130 mm deformation (cycle 1), unloaded, loaded to 280 mm deformation (cycle 2), unloaded and loaded again.

It is concluded that for the specific test done, the amount of energy released by the pack during unloading is approximately 5.4 per cent of the energy absorbed by the pack up to 300 mm deformation. Further, the amount of energy released by the pack is similar during the two cycles.

3.2 Analysis of drop test data

Drop tests were done in the drop test facility at Reatile Timrite R&D in Westonaria. A free falling mass of 16 000 kg is dropped onto a pack. If the pack has resilience, any energy not absorbed by the pack will effectively be put back into the mass in the form of bounce. From the height of the bounce, the amount of energy not absorbed by the pack during the first oscillation can be calculated. Figure 5 shows results from drop tests being done on a 60 x 60 cm Timrite Lexus.

An Extended Lexus pack in the drop test facility of Reatile Timrite. The mass is 16 tons.

From the equation for potential energy

$$E=mgh$$

Where E=potential energy

m=mass

h=height

It follows that the total amount of energy available during a drop test is proportional to the drop height to the turning point of the weight. The amount of energy absorbed by the support is simply a ratio between the maximum energy available and the energy available at the apex of the rebound. Table 1 gives a summary of the drop test data.

Table 1: Summary of drop test data

	Distance travelled by the weight		
	Timrite Lexus		Extended Lexus
	Test 1	Test 2	Test 1
Start	0	0	0
At Impact	459	1781	1261
Maximum	582	2025	1424
Minimum during bounce	470	1943	1258
Settling	520	1970	1351
Energy absorbed	80.8%	96.0%	88.3%
Energy not absorbed	19.2%	4.0%	11.7%

From this it can be seen that the amount of energy released by the pack is similar at low and high deformations. This again is similar to the observation during the slow loading.

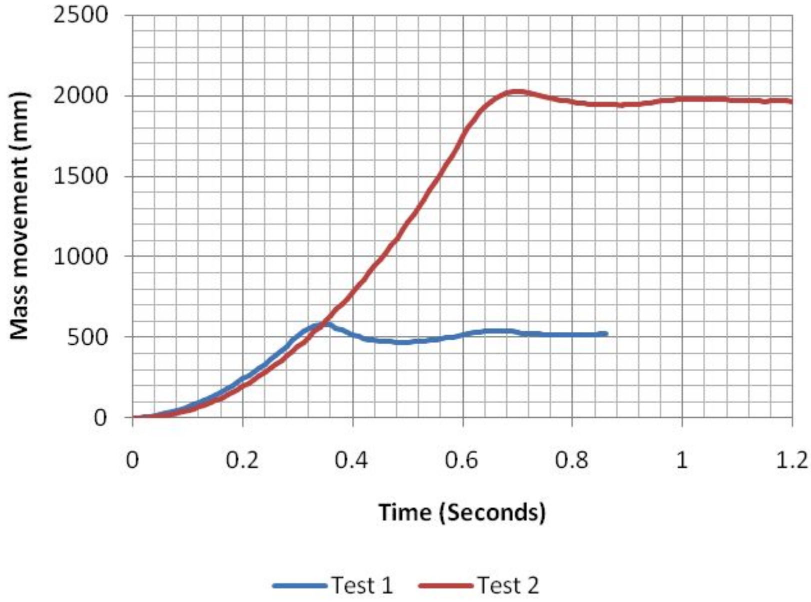

Figure 5: Data from two drop tests done on a 60 x 9 cm Timrite Lexus pack.

3.3 Factors influencing resilience of timber packs

Timber packs with only horizontal grain units like mat packs, have a lot of resilience. Elements that break up during deformation, such as end grain blocks and split slabs, reduce resilience. We can therefore design timber packs to have target resilience, within limits.

3.4 The required amount of resilience

There are advantages and disadvantages of support having resilience. The major disadvantage is perceived as energy from the pack contributing to hanging wall failures. The major advantage is keeping contact between support and hangingwall. Without debating whether the hangingwall oscillates during a seismic event, consider both possibilities:

3.4.1 The hanging wall does not oscillate

Assuming the hangingwall moves downwards during a seismic event (or positive closure if movement in the footwall as well) with no oscillation: The hangingwall experiences a force by the support and resilience is totally irrelevant.

3.4.2 The hanging wall oscillates

Assuming the hangingwall oscillates during a seismic event: If the support has no resilience, contact will be lost between the hangingwall and the support, resulting in possible falls of ground. This is of overriding importance.

4 HISTORICAL VIEW

There is a belief in the industry that timber packs will damage gullies under rapid loading. This is probably for two main reasons:

- It is believed that the load generated by timber packs is always high, (and ever increasing) especially at high closures. This is based on the behaviour of old fashioned Mat Packs. Modern timber packs are rather different (see Figure 6)

- The "x" factor for solid timber packs and horizontal grain timber blocks is 16 % (Spearman et al, 1987). We can now design timber packs with "x" factors less than 10.

During rapid loading, the already high load generated by the 'old' timber pack is further seriously increased by the high '*x*' factor. The peak load produced within the structure of the pack is then sufficient to damage the fractured rock it is supposed to be supporting.

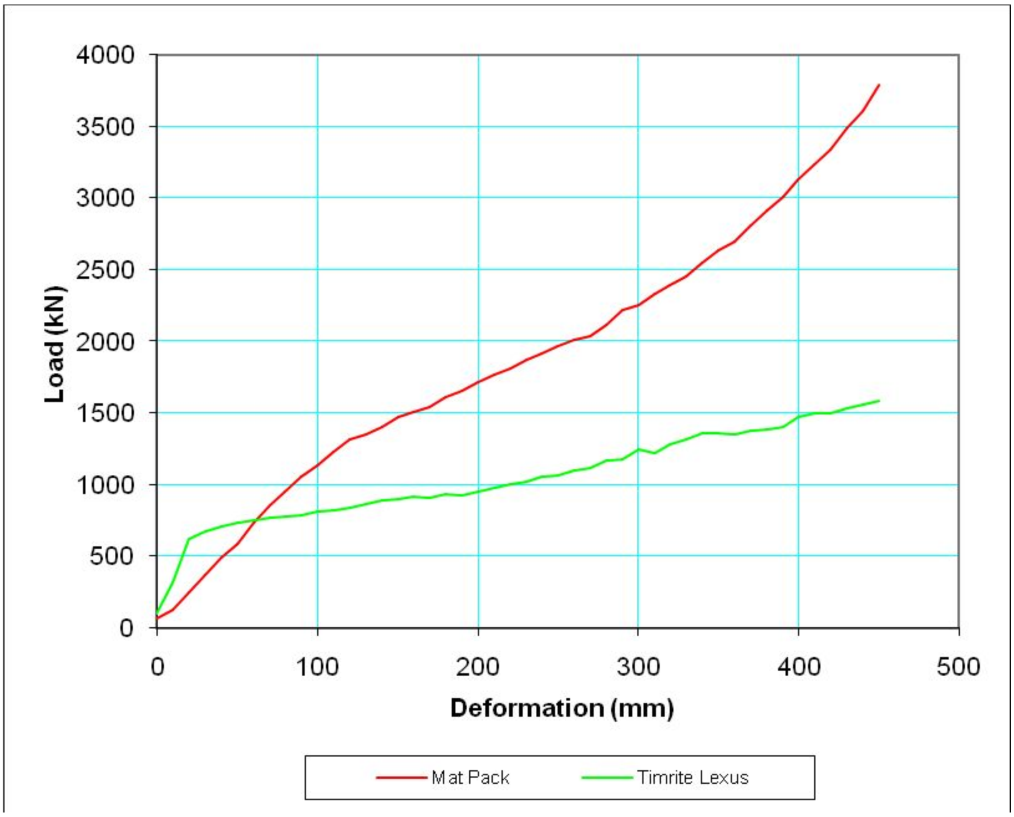

Figure 6: Load-deformation curve of an old fashioned Mat Pack and a new generation timber pack. It can be seen that the Timrite Lexus generates more than double the load of a Mat Pack at low deformations and less than half the load at high deformations. In addition to that, the percentage increase in load during a seismic event of the Timrite Lexus will be just more than half (9/16) of the percentage increase in load of a Mat Pack.

5 ENGINEERING OF TIMBER PACKS

The design of timber packs has changed over the years. Early mat type products were replaced some 15 years ago, under the perceived need for stiff strong products, such as Hercules type packs. Support requirements however, have changed with the proven track record of the cementitious units that have enjoyed a high market share for the last few years.

Based on the success of the cementitious packs, the required pack performance curve should be one that is stiff, i.e. generates load quickly, but that yields at relatively low loads. The ultimate stiffness of the pack should be positive, but the pack should not generate the large loads that result in gulley damage.

Lastly, but very importantly, the '*x*' factor must be reduced as far as possible, to reduce peak loads under rapid loading conditions.

Recent research and development efforts have demonstrated that timber packs can be engineered to required performances. Timber is a natural material with some natural variance in strength, dependant on a number of factors such as speed of growth, density, moisture content etc. A timber pack can be engineered by taking the timber of known strength and manipulating the dimensions and orientation of the composite pieces, to make up pack units of a whole range of performance characteristics.

The two main aspects that have combined to improve pack performance are:

- **The use of end-grain blocks.** It is commonly known that mining timber has a yield strength of approximately 2.5 MPa when loaded perpendicular to the grain, and 25 MPa when loaded parallel to the grain. The use of end-grain blocks in recent years has been common to improve the Young's Modulus of previously 'un-stiff' timber mats. The stiffness of the pack can be controlled by altering the block on block contact area layer on layer within the structure of the pack.

- **The use of split slabs**. It has been observed that by reducing the width, and therefore the timber content, of the horizontal grain components within a timber mat, the yieldability of the final pack product is improved. The reduced volume of the thinner slabs allows the fibers to yield in a manner that result in a reduction of the ultimate stiffness of the overall pack.

  It has been shown in the laboratory, that a beneficial off-shoot of the improved yieldability is the reduction in the '*x*' factor for that type of design.

Using the design considerations above, along with conventional timber pack designs, a variety of combinations can be used to fulfill various mine support requirements. The volume and placement of each component within the structure of a completed pack has resulted in Young's Modulus as high as 100 MPa and '*x*' factors for timber packs as low as 8.3%

6 SUMMARY

Timber packs were historically believed to be detrimental to ground conditions under rapid loading. With current technology available to us however, it is possible to design cost effective timber based pack products that have the following attributes:

- Initially stiff with a high Young's Modulus.

- Be able to yield at acceptably low loads.
- Have low ultimate stiffness and therefore do not generate huge loads at higher closures.
- Have low '*x*' factor values
- Have the ability to absorb, dissipate large amounts of energy, and
- Are stable

We firmly believe that the new generation Timber Packs can safely be used in seismically active areas.

ACKNOWLEDGEMENTS

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