A REVISED TIMBER ELONGATE DE-RATING FACTOR FOR PLATINUM MINES

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Abstract

This paper describes the development and implementation of a methodology and purposely-designed creep testing facility for the review through laboratory research of the current de-rating factor applied to timber elongate mining support. It is recognised that the current de-rating factor may underestimate the in-situ performance of timber elongates as it was developed from research work done on gold mines at a time when different elongates were being used without pre-stressing, conditions that differ markedly from those in platinum mines today. This paper describes the current support design methodology in lieu of the de-rating of timber elongates and the problem of its implementation in a low-closure environment. It further describes the methodologies that were designed to review this de-rating factor for low closure environments as well as the development of a creep testing frame and the outcomes and results from its application to timber creep testing.

1. Overview of Current Support De-rating Methodology and its Pitfalls

The current mining support design methodology requires three known quantities: the weight of the rockmass that is to be supported; the maximum deformation that an elongate is expected to achieve; the typical performance of the proposed elongate to meet the requirements of load and deformation. The performance of timber elongates has through the years been derived from compression testing in a laboratory, where the elongate would undergo an amount of compression deformation that it is expected to achieve in its intended application underground. This deformation would usually occur at a significantly higher rate compared to underground due to time and cost constraints of testing in a laboratory over long periods of time.

As it is recognised that timber undergoes creep, and subsequently load relaxation, when subjected to a low rate of deformation, the laboratory performance of timber elongates has to be adjusted for the lower deformation rate experienced underground. The formula below is used for this purpose (Ryder and Jager, 2002):

$$F_U = F_L \left[m \times log\left(\frac{V_U}{V_L}\right) + 1\right] \tag{1}$$

where F_U = underground load
F_L = laboratory load
m = correction factor (m = 0.123 for rockbursts and m = 0.084 for rock falls)
V_U = underground deformation rate (mm/day)
V_L = laboratory deformation rate (usually mm/min, but converted to mm/day)

Although differences between underground and laboratory deformation rates have the greatest effect on reducing elongate loads (Roberts et al 1987, Ryder and Jager 2002), the above formula is generally used to account for all the differences between laboratory and underground conditions. Differences between laboratory and underground conditions can also include (Malan, Piper et al, 2006):

- Roughness of rock surfaces
- Percentage of elongate in contact with hangingwall ("Point" loading)
- Angle of friction at the elongate or pre-stressing device and rock interface
- Condition of the elongate before installation
- Quality of installation
- Physical damage after installation
- Actual mode of deformation
- Ride between footwall and hangingwall
- Environmental conditions

The complication in using the formula in today's mining environment is that it was developed from research work done on gold mines in the 1980's (Roberts et al, 1987) when elongates used were very different to those currently in widespread use. Importantly, the research work was conducted before the introduction of pre-stressing devices which have improved the in-situ performance of timber elongates. As a further complication, the work was conducted in gold mines which typically have significantly higher closure rates compared to platinum mines.

Most notable is the tendency for the graph plotted from formula (1) to asymptote towards zero, i.e. residual strength is zero or 100% de-rating, with very low closure rates, as seen in Figure 1.

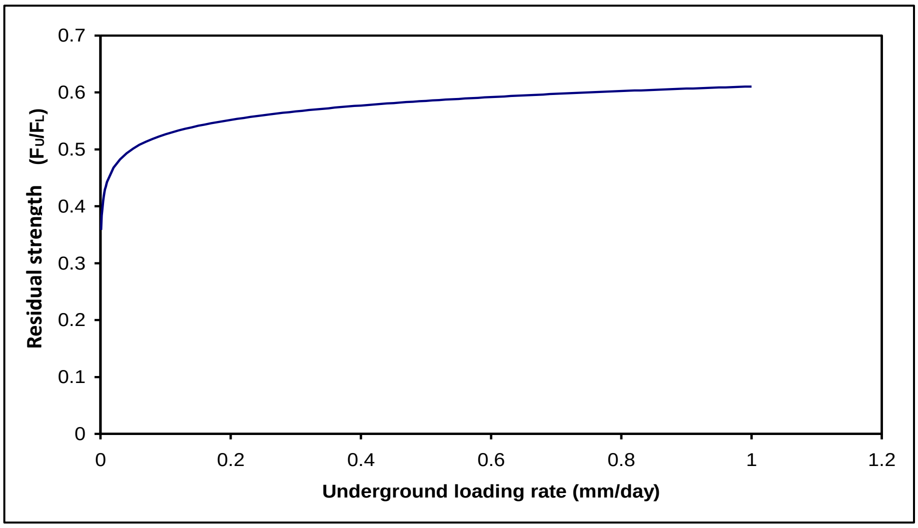

Figure 1. <u>Plotted graph of de-rating formula showing tendency to zero for very low closure rates</u>

As the current de-rating formula results in a 40% de-rating if a laboratory rate of 30mm/min and an underground rate of 1mm/day is used, given the reasons stipulated above, it is believed that the current de-rating formula may underestimate the in-situ performance of timber elongates. If it can be proven that the de-rating is too severe, elongate diameters may be reduced, or support spacings increased which could result in significant cost savings for platinum mines. As a further advantage, it provides an opportunity for a better understanding of safety factors used in stope support design.

2. Methodologies for Laboratory Testing to Review the De-rating Factor

The first phase of the methodology that is being used to review the current de-rating factor is based on laboratory testing at 30mm/min and 1mm/day. All underground variables were removed from the testing procedure in order to isolate deformation rate as the only variable that could affect performance. This included excluding pre-stressing of elongates. It was recognised that the inherent timber variability would be critical to the methodology. Figure 2 below shows the markedly different performance of two apparently identical Mine Poles to illustrate the inherent timber variability, with the same principle applying to Pencil Props.

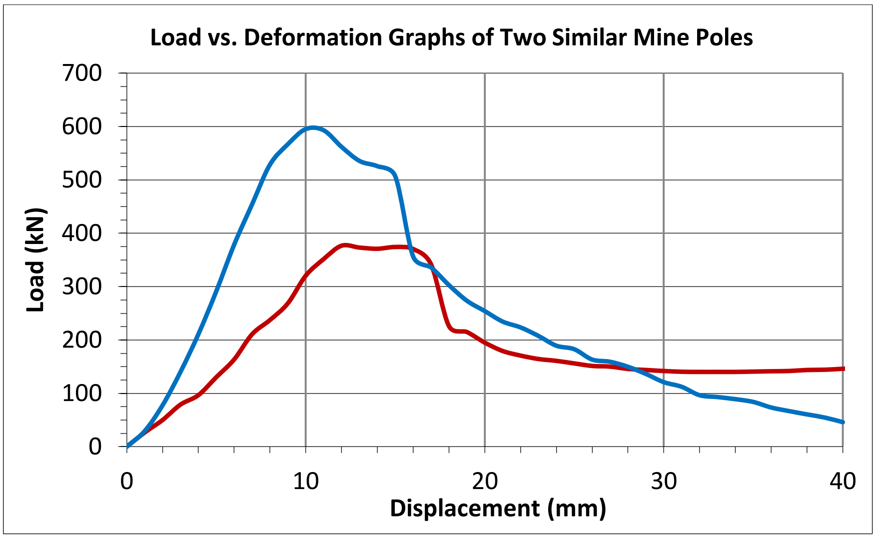

Figure 2. **<u>Graphs of two Mine Poles showing a large difference in performance</u>**

It was decided to approach the issue of timber variability in a novel manner. All testing would be conducted with Mine Pole and Pencil Prop pairs cut from a single length of timber sourced from the same tree. The assumption was that two abutting sections of the same length of timber would produce similar load deformation results with minimal variability thereby addressing the concern of inherent timber variability. In theory it would be possible to compare the load-deformation results of an elongate pair at deformation rates of 30mm/min and 1mm/day, which represent typical laboratory and underground deformation rates respectively. To verify this, each elongate in a pair was tested at 30mm/min and the actual variability was quantified. In addition, it was recognised that timber for mining support is grown in regions of different climatic conditions across the country and therefore timber from at least three regions was tested. Figure 3 below shows graphs of a 150cm length, 15-16cm diameter Mine Pole pair with very good similarity in performance up to 30mm which represents the usable deformation range of Mine Poles.

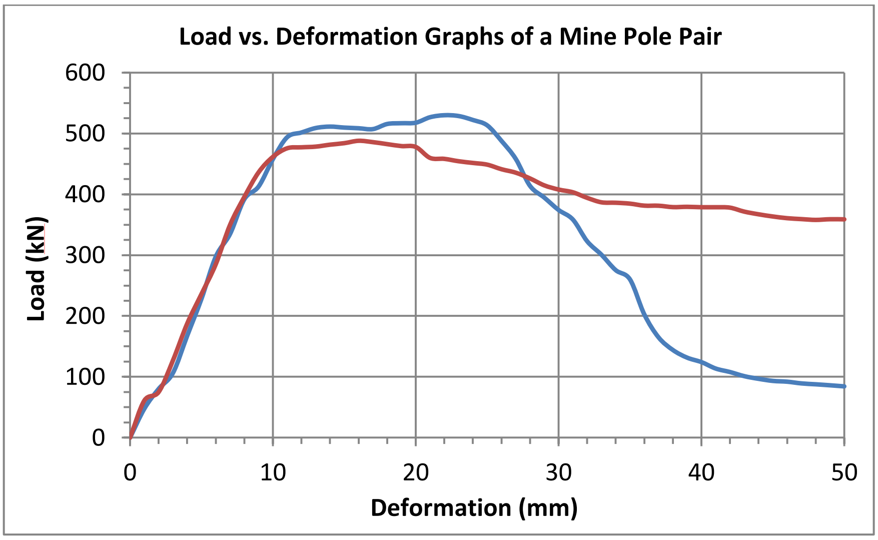

Figure 3. **<u>Graphs of two Mine Poles in a pair showing very good similarity</u>**

The loads from the Mine Poles in a pair are converted from a kN value to strength in MPa to account for the variation in diameter, due to taper in the original length pole, and the mean difference calculated from these strengths is taken as the variability. Mean difference is calculated as the difference in the strength of the poles in the pair divided by the mean of the strengths. Table 1 below presents the results of variability tests from three regions:

Table 1. **Results of variability testing from three growing regions**

Region	Typical variability (%)
A	2.7
B	6.9
C	4.0

From the results of variability testing, it was clear that, if timber from region A was utilised for further laboratory testing, the typical variability of 2.7% was minimal and it was deemed that timber variability may be successfully negated using elongates pairs.

As the intention is to progress to reviewing the de-rating in respect of yielding elongates, specifically Pencil Props, variability testing of Pencil Prop pairs was conducted. The preparation of the long length poles that would be used to manufacture the pairs was the same as for the Mine Poles pairs. However, the Pencil Props had to arrive at Groundwork for testing pre-cut in pairs as the yielding ends were manufactured at the mills. Figure 3 below shows the graphs of a Pencil Prop pair displaying very close similarity, supporting the methodology of addressing timber variability using yielding elongate pairs in respect of testing at 1mm/day and 30mm/min.

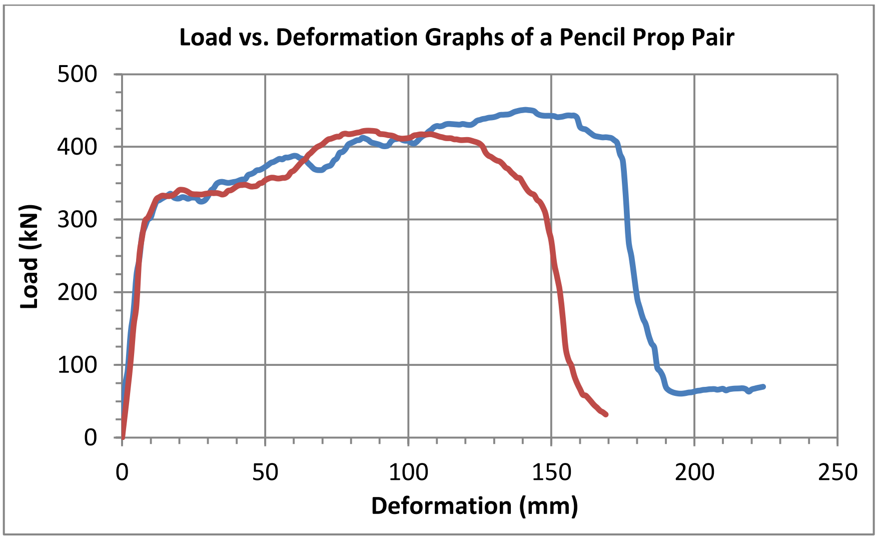

Figure 4. **Graphs of two Pencil Props in a pair showing good similarity**

Analysis of the variability between two Pencil Props in a pair was more complex than for Mine Poles due to the addition of yielding rather than a single peak. It was decided to determine the variability in Pencil Props pairs by calculating the Mean Difference in the load values of the elongate pair at each incremental millimetre of deformation. This incremental Mean Difference is then averaged over the range of deformation over which stable yielding of the pair occurs. Pencil Prop pairs were sourced from three regions as well: region A from Mine Pole pair testing, and two new regions, D and E. Table 2 below summarises the results of pair variability testing from the three regions.

Table 2. Results of variability testing from three growing regions

Region	Typical Variability (%)
A	11.5
D	21.2
E	10.8

The results from Pencil Prop pair variability testing indicate that region E would provide Pencil Props with the least variability between pairs. Although the typical variability is shown as 10.8%, the variability of the majority of the pairs tested was in a range of 4 – 7% with a only a few pairs with higher variability distorting the average.

Results from Mine Pole and Pencil Prop pair testing indicated that the variability of load-deformation results between two halves of the same length of timber are within acceptable limits and the proposed methodology for laboratory testing to review the de-rating factor would be acceptable.

3. Development and Application of a Frame for Timber Creep Testing

No commercial facilities are available to test timber at 1mm/day and hydraulics are not suited for creep testing. Groundwork went through a process of designing and fabricating a frame on which to do this type of testing. A photo of the frame is given below showing the ancillary equipment. For the purpose of this paper, the frame is known as the Slow Loading Frame (SLF).

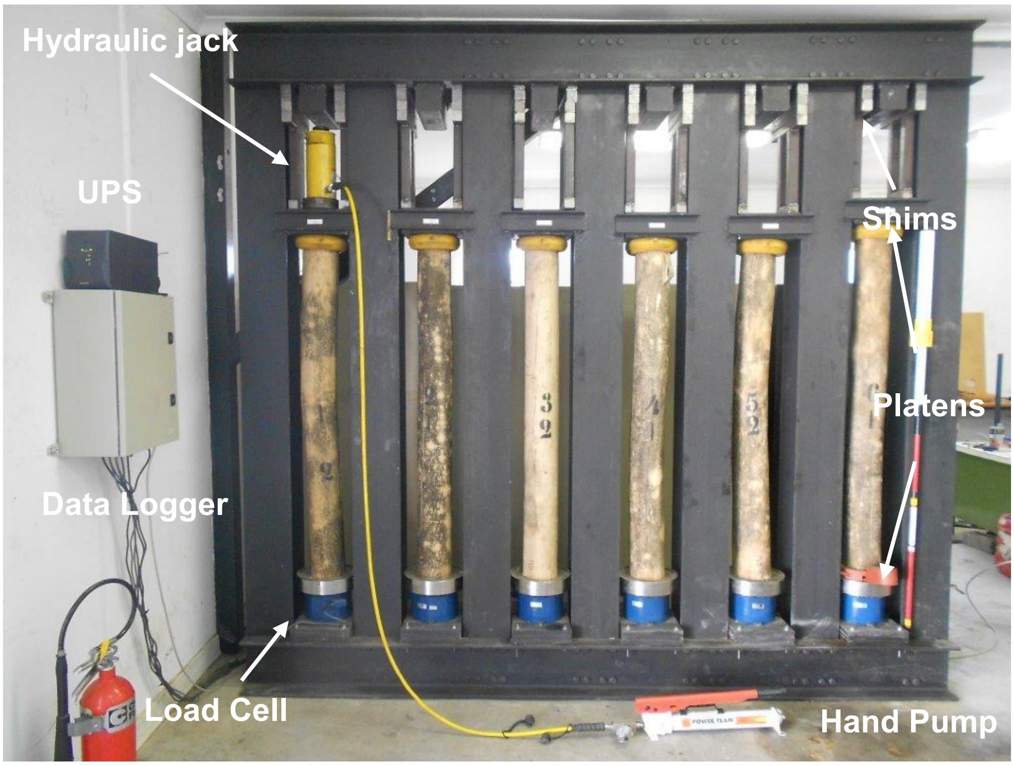

Figure 5. **Photograph of Slow Loading Frame and other equipment**

The hydraulic jack placed on top of the top platen provides the necessary downward force to create a millimetre of deformation, after which a millimetre thick steel shim is inserted above the vertical stands sitting on top of the upper platen. The jack is then released and the two shim and stand assemblies abut against the topmost horizontal beam to keep the deformation at the required level until the following day. The load cells installed in each bank of the SLF send signals to the data logger to be logged as kN values. The photograph below shows the assembly of vertical stands and shims butting against the horizontal beam. Once four millimetre shims have been inserted, on the next millimetre increment all are replaced by one five millimetre shim.

Figure 6. **Assembly of vertical stand and shims abutting the top horizontal beam**

Before the SLF could be applied to testing Mine Poles at 1mm/day, it was necessary to test the frame through an accelerated testing procedure at 5mm/day. This would ensure that peak loads of the installed test elongates would be obtained as soon as possible and any problems would be detected and addressed before testing at 1mm/day. The following issues were encountered during this initial test, with the last two from the proper 1mm/day test:

3.1 Loss of power to data acquisition system

It was found on one overnight period of data logging that all power to the data acquisition system was lost due to a power failure, resulting in a loss of data. A PSU was installed in series with the main power supply to provide power during possible periods of power loss in further testing.

3.2 Time-dependant crack formation

Although not strictly a problem derived from testing on the SLF, it was found during the initial test that minor pre-existing cracks in the test Mine Poles would open to a greater extent than seen during routine 30mm/min testing. It was apparent that this significant crack propagation may present an extra variable to the test methodology, although the extent of this effect is unclear. Therefore, to mitigate any effect of crack propagation it was decided to do further testing with elongates that have minimal pre-existing cracking.

Figure 7. Photographs of Mine Poles in SLF with significant crack propagation

3.3 "Overloading" caused by shimming system

To fix the displacement after a millimetre of deformation has been achieved, it is required to insert a millimetre thick shim on top of the stands sitting above the upper platen before releasing the jack. Naturally, it is required to create slightly more than one millimetre deformation to insert the shim, and this slight "overloading" causes a significant spike in the load on the elongate and then relaxes as the jack is released. It is recognised that this cumulative overloading and relaxing at each millimetre deformation increment would have an adverse effect on the performance of the elongate. The figure below shows the load vs. time data from a 1mm/day test with the load spikes clearly visible.

To mitigate the load spikes, a new system for fixing the displacement has been designed that will eliminate the need to overload the elongates in that the amount of deformation required can be accurately obtained and fixed. A prototype that will be manufactured and trialled so that it can be put in place for any further slow load testing.

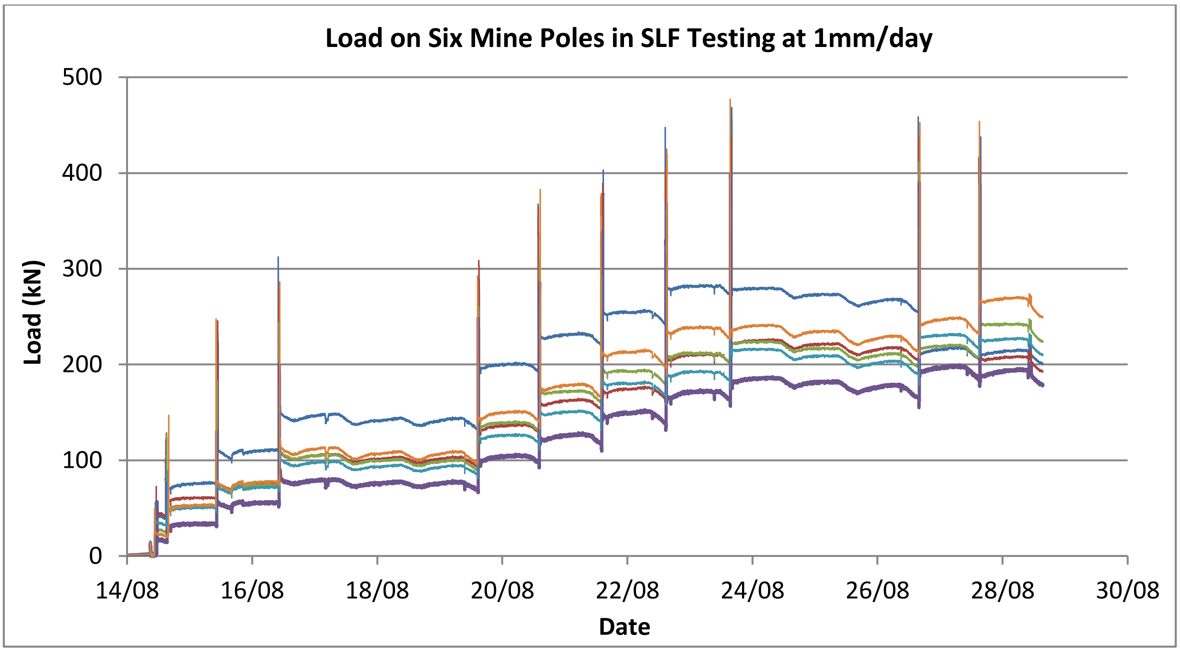

Figure 8. **Load vs. time data from a 1mm/day test showing load spikes due to overloading of elongates**

3.4 Effect of temperature on load

It was apparent that temperature was affecting the logged load data to an extent that it caused fluctuations that coincided with the daily temperature cycles with a negative correlation, i.e, a temperature decrease caused an increase in load and a temperature increase caused a decrease in load. In addition, it appeared that the cyclic temperature trend was increasing as the spring season was coming into effect. This increasing trend was having a coinciding downward trend on the load, exacerbating the actual load decrease due to creep. As the frame is a steel construction, and steel is known to expand or contract with an increase or decrease in temperature respectively, it was suspected that this expansion and contraction was the cause of the load fluctuations as the negative load to temperature correlation would suggest. Figure 7 below shows the fluctuation in load with temperature over a period of data logging over a weekend where no deformation was taking place.

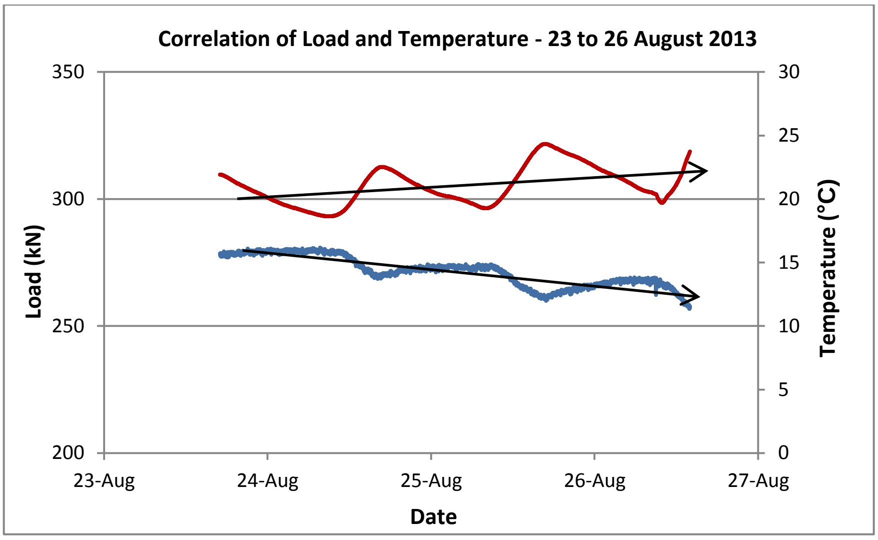

Figure 9. Effect of temperature on load: red line represents temperature and blue line represents load

It was decided to attach instrumentation to the frame at the top and bottom platen that would very accurately measure any movement of the frame between these parts due to temperature. This span was measured as it was the movement between these points that was of concern in respect of the effect of this movement on the load of the elongate. This data confirmed that the frame was moving up to 40µm from the lowest to highest temperature values and vice-versa. As the data logger is very sensitive to minor changes in the millivolt signals from the load cell Wheatstone Bridges, these very small movements were affecting the data as seen in figure 7 above. In addition, the effect of temperature changes on the data acquisition system was also determined. This was done by measuring load variations without an elongate in the SLF. It was observed that temperature would also have an effect on data logging with a positive correlation, although this effect was as little as 5kN from low to high temperature.

Statistical methods have been applied, with some success, to filter and analyse data fluctuations due to temperature changes. Instrumentation was also used to measure physical quantities related to this relationship. Despite this, it is recognised that more should be done to mitigate load fluctuation due to temperature cycles. This can include installing instrumentation in line with the data acquisition system that will transform the sensitive millivolt signal from the load cells to another, more stable signal or building an insulating room around the SLF in which the temperature can be controlled.

4. Results

At the time of writing this paper, only results for tests conducted on Mine Poles have been completed. Results indicate that the actual strength de-rating obtained from the 1mm/day deformation rate are on average roughly equal to the 40% strength de-rating from the current de-rating formula as can be seen in Table 3 below.

Table 3. Results of de-rating tests on six Mine Pole pairs without pre-stressing units

Pair	Actual Strength De-rating (%)
1	38.1
2	56.2
3	40.3
4	42.0
5	35.1
6	44.6
Average	42.8

It was decided to repeat the 1mm/day-30mm/min test on new elongates, but with the addition of pre-stressing units. The view of testing with pre-stressing, although it would include a variable that was initially sought to be removed from the methodology, was that the 1mm/day test would start at an initial higher load. This would enable loads on the elongates to reach a peak before the overloading effect became significant as was the case with testing without pre-stressing units. All elongates were pre-stressed to 200kN so that a common base existed between elongates. The results from these tests were encouraging and three 1mm/day-30mm/min pairs showed promising results when compared to a nominal 40% de-rating when using the current de-rating formula, as can be seen in Table 4 below:

Table 4. Results of de-rating tests on three Mine Pole pairs with pre-stressing units

Pair	Actual Strength De-rating (%)
1	24.5
3	33.6
6	25.4

Other findings include:

- Initial results show that there is a clear difference between tests with and without pre-stressing units.
- Intra-day creep is not as significant as expected
- The preliminary results show a de-rating of between 25 and 35 per cent due to a reduction in the deformation rate from 30mm/min to 1mm/day.
- There is more complexity to analysing the data than expected.

5. Further work

- Put new displacement-fixing system in place
- Repeat 30mm/min and 1mm/day testing on Mine Poles without the effect of overloading
- Testing with Pencil Props at 30mm/min and 1mm/day to establish a de-rating for the yielding elongate
- Testing at deformation rates between 1mm/day and 30mm/min to populate the continuum of loading rates
- Importantly, test underground to confirm or refute obtained results and further quantify contribution of underground effects

6. References

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