THE IN-SITU PERFORMANCE OF ELONGATE SUPPORT – MYTHS AND REALITIES

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Abstract

The Guideline for the Compilation of a Mandatory Codes of Practice to Combat Rockfall and Rockburst Accidents (2001) requires regular monitoring of the performance of support systems in important excavations. The guideline for complying with the Mine Support Quality Assurance regulation (14.1.6) (2003) provides recommendations for initial underground testing and underground trialling of elongates followed by evaluation on a regular basis. Although a number of years have lapsed since these documents were published, very few reliable underground load-deformation measurements are available and most support designs are based on generalised de-rating factors and other adjustments applied to laboratory test results. Recent developments with in-situ load measurement instrumentation have enabled considerably more in-situ performance graphs to be obtained for elongate support units. This paper presents some initial results from these in-situ measurements. The results suggest that commonly held beliefs regarding underground performance and the generalised adjustment factors may not be valid. This conclusion has significant implications for timber support requirements at a time where the supply of timber for mine support is becoming increasingly difficult.

1. Monitoring Requirements

The urgency for effective means to quantify in-situ elongate performance increased substantially with the introduction of the mine support quality assurance regulation, 14.1.(6) in 2003, and the associated mine support quality assurance guidelines produced by SIMRAC in 2006. The guidelines for complying with the regulation require regular in-situ monitoring of elongates. The Guideline for the Compilation of a Mandatory Codes of Practice to Combat Rockfall and Rockburst Accidents (2001) also requires "*regular monitoring of the performance of support systems in important excavations*".

The guideline for complying with the Mine Support Quality Assurance regulation (14.1.6) recommends four phases of elongate evaluation; initial and routine laboratory testing, underground testing, underground trialling and then routine underground assessments of the elongates used on a regular basis. The guidelines are summarised in Table 1. The requirements listed for new elongates would apply to existing elongates if these requirements have not been met previously.

The testing detailed in Table 1 is considered to be a minimum to obtain a basic understanding of the performance of elongates in the environment in which they will be used. Additional testing may be added at the customer or supplier's discretion. It is also important to document the relationship (through photographs) between the visual performance, in terms of modes of deformation, and the load-deformation characteristics. All relevant site conditions should be documented and any problems encountered with the use of the new elongate should be recorded.

Table 1. Summary of elongate evaluation requirements to meet Regulation 14.1.6

Product/testing type	Evaluation requirements
Laboratory testing of new elongates	Testing of at least 10 elongates of each type.
Laboratory testing of elongates in regular use	Quarterly quality control testing of at least 10 samples of each product type.
Underground testing of new elongates	10 new and 10 existing elongates to be monitored visually, of which 3 of each to be monitored for load-deformation performance.
Underground trialling of new elongates	At least one panel of new elongates to be monitored visually for abnormal modes of deformation, and 3 elongates to be monitored for load-deformation performance.
Routine underground assessments of elongates on standard stock	Abnormal modes of deformation to be monitored. Problem areas to be investigated.

In addition to meeting the requirements of the regulations and guidelines, in-situ monitoring of elongates is also required to quantify their performance characteristics for support system design purposes and for on-going improvements to elongate designs. It is estimated that well over 2 million elongates have been supplied and installed in South African gold and platinum mines since the mine support quality assurance guidelines were published in 2006. During the same period approximately 20 in-situ load-deformation measurements have been conducted, representing less than one measurement per 100,000 elongates installed.

In the absence of reliable in-situ performance data, elongate support systems are designed by de-rating the laboratory load-deformation performance to take into account the slower rates of deformation that occur underground (Roberts et al., 1987). The de-rating factor reduces the laboratory load bearing capabilities of the elongate by up to 40 per cent for situations such as shallow platinum mines where the underground closure rates are extremely low. However, the factor does not modify the deformation capabilities of the elongate or take into account other differences between laboratory and in-situ conditions such as :

- Non-continuous and variable rates of deformation
- Roughness of the rock surfaces
- Percentage of elongate in contact with the rock surfaces
- Angle of friction at the elongate (or pre-stressing device) and rock interface
- Condition of the elongate prior to installation
- Quality of installation
- Physical damage after installation (blasting, scraping)

- Actual mode of deformation
- Ride between the rock surfaces
- Climatic conditions.

2. Monitoring Methods

The standard instrument that has been used to quantify in-situ loads on elongates for many years is the 'stick load cell' (Figure 1). The cell consists of an oil or emulsion filled thin flat-jack surrounded by a heavy duty steel casing, acting as platens between the rock surface and the elongate. A pressure gauge is attached to the flat-jack and the pressure can either be read manually or by using a transducer and data logger instead of the pressure gauge. Although numerous results for mine poles have been obtained using this type of load cell, the design is inherently flawed for elongates that yield in a brushing manner. This mode of deformation imparts forces on the edge of the flat-jack which leads to fracturing of the welds and leakage of fluid at loads well below the maximum design load of 500 kN. Consequently, very few of the in-situ elongate performance graphs obtained using this monitoring device provide load measurements in excess of 50 millimetres deformation. Whilst this is adequate for mine poles, it is not sufficient for monitoring elongates which have the potential to yield up to 500 mm. Furthermore, the frequency of the manual readings is usually weekly but seldom more often than daily. As the in-situ load-deformation graphs presented in this paper will show, considerable important information is lost if intra-day readings are not obtained.

In view of the recent regulations, the growing need for regular in-situ monitoring and the widespread use of yielding elongates, a totally new load cell has been introduced to the market. This new yielding elongate load measurement device was designed to eliminate the fundamental design problem mentioned above, as well as other limitations. The new monitoring device is shown in Figure 2.

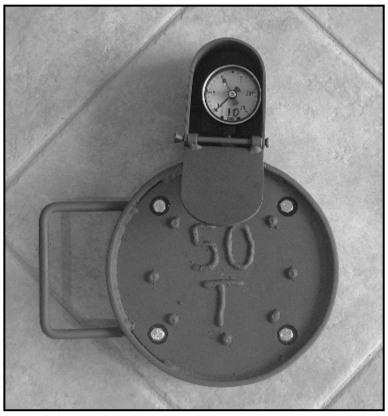

Figure 1. 50 ton Stick Load Cell

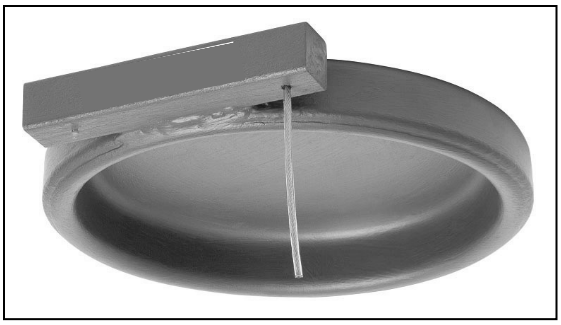

Figure 2. New Load Logger

Figure 3. The monitoring system

Figure 4. Typical underground installation

The pressure vessel is based on the commonly used pre-stressing device which is light, inexpensive and well proven. The vessel is inflated and filled with water to ensure a separation between the top and bottom steel surfaces of at least 30 millimetres. This separation enables monitoring to continue even if excessive tilting or brushing of the elongate takes place. Loads have been measured up to 800 kN and 400 millimetres of deformation in laboratory trials and 600 kN and 280 mm underground. Load is transmitted to a pressure transducer and the readings are stored in the logger assembly. Data can be extracted without the need for cable connections from a distance of up to 30 metres using a specially designed Download Unit. Load is recorded every 5 minutes and can be stored for up to 2 weeks. Strain gauges are situated around the pressure vessel to compensate for changes in the shape of the pressure vessel. Figures 3 and 4 show typical installations which include the device used for measuring stope closure and the wireless data transfer unit.

3. In-situ Results

Some examples of the results from the numerous in-situ measurements obtained to date are given in the sections below. The results have been selected to cover a range of elongates and to illustrate certain interesting aspects of the in-situ results. The quantity of results is not sufficient to draw any firm conclusions at this stage. The results given below include the following elongate types :

- 1.6 m long x 16 – 18 cm diameter mine pole.
- 1.1 m long x 15-18 cm diameter x 12 cm pod unturned pencil prop.
- 1.6 m long x 16-18 cm diameter x 10 cm pod unturned pencil prop.
- 1.2 m long x 18-20 cm diameter x 12 cm pod unturned pencil prop.

3.1 Timber Creep

A number of Closure and Load Loggers were installed on pre-stressed mine poles with thin end diameters ranging from 16 to 18 cm in a shallow platinum mine with very low rates of closure. Figures 5 and 6 show typical installations.

An example of the load versus time behaviour of the mine poles is shown in Figure 7. It can be seen that the pole was pre-stressed to about 80 kN before reaching a peak load of about 220 kN. Although some closure took place immediately after the mine pole was installed, very little additional closure took place (Figure 8). Despite the very low closure rate the mine pole lost less than 10 per cent of its load during the following two weeks.

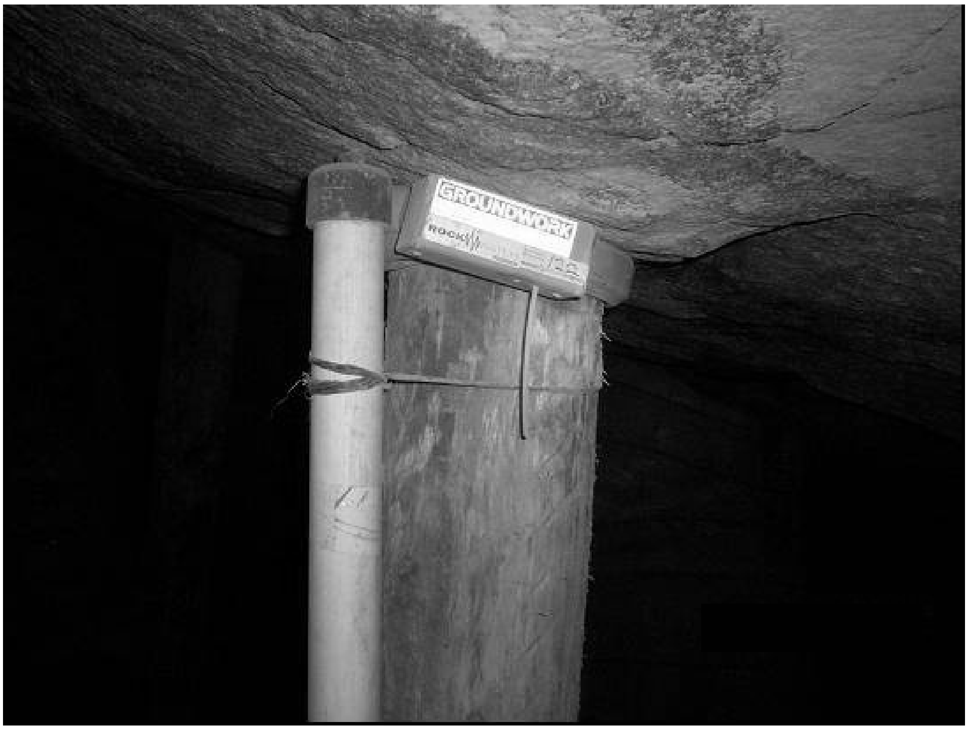

Figure 5. Load and Closure Loggers installed on a mine pole

Three aspects of the loading response of this particular mine pole are interesting. Firstly, the high initial stiffness which enabled the load to increase from 80 to 220 kN within a few millimetres of deformation. Secondly, the maximum load of 220 kN which indicated that the mine pole (with a laboratory peak load of between 300 and 400 kN, depending on diameter) had not been fully loaded. Thirdly, the relatively small reduction in load despite the very low closure rates is surprising. This result is similar to those obtained in the laboratory (Daehnke et al 2000) where a 10 per cent reduction in load occurred over the first 3 days with very little further load reduction during the subsequent 10 days.

Figure 6. Closure and Load Loggers installed with a mine pole in a platinum mine

Figure 9 shows the initial load vs time behaviour of an 18 – 20 cm diameter mine pole installed with limited pre-stressing load and in an area with absolutely no closure. After being pre-stressed to 45 kN the pre-stressed pole also lost about 25 kN in load. Although this is significant in percentage terms it is similar in absolute kN terms to the reduction in load for the mine pole shown in Figure 7. The later increase in load, with no closure, seen in Figure 9 was also noted by Daehnke et al (2000) and was ascribed to an increase in temperature and hence pressure in the pre-stressing device.

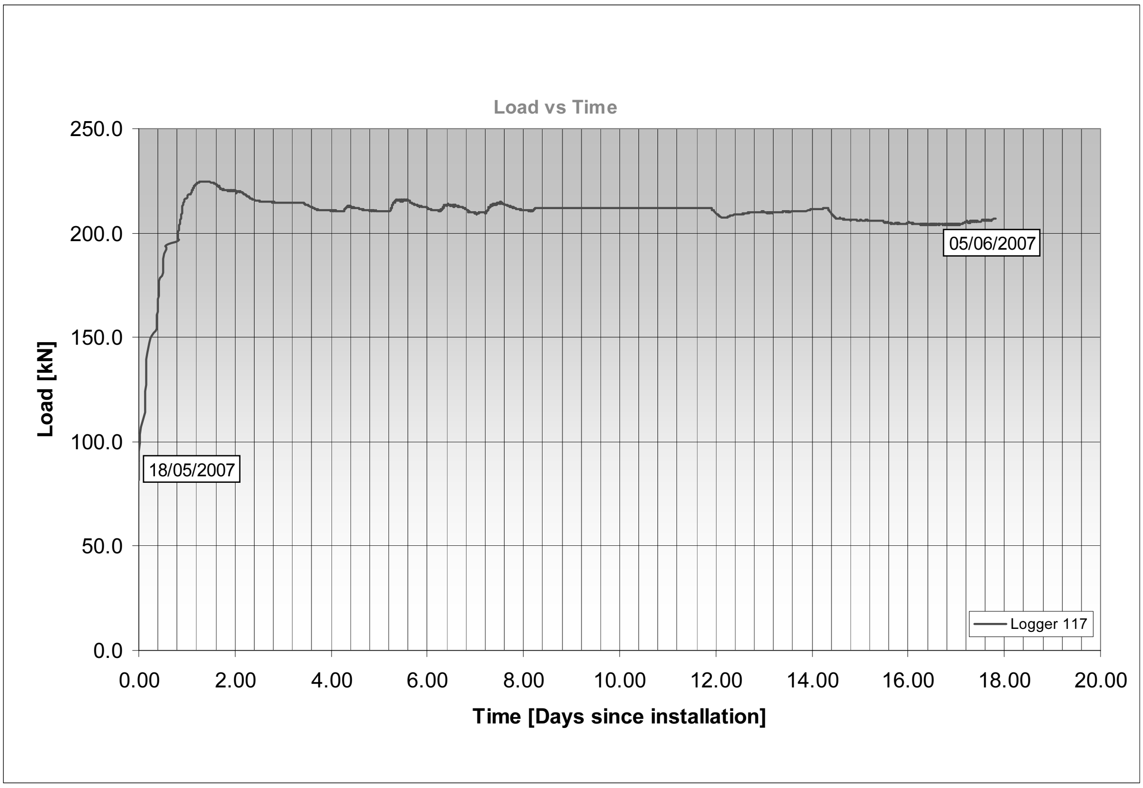

Figure 7. An example of the load versus time behaviour of a 16 – 18 cm diameter pole

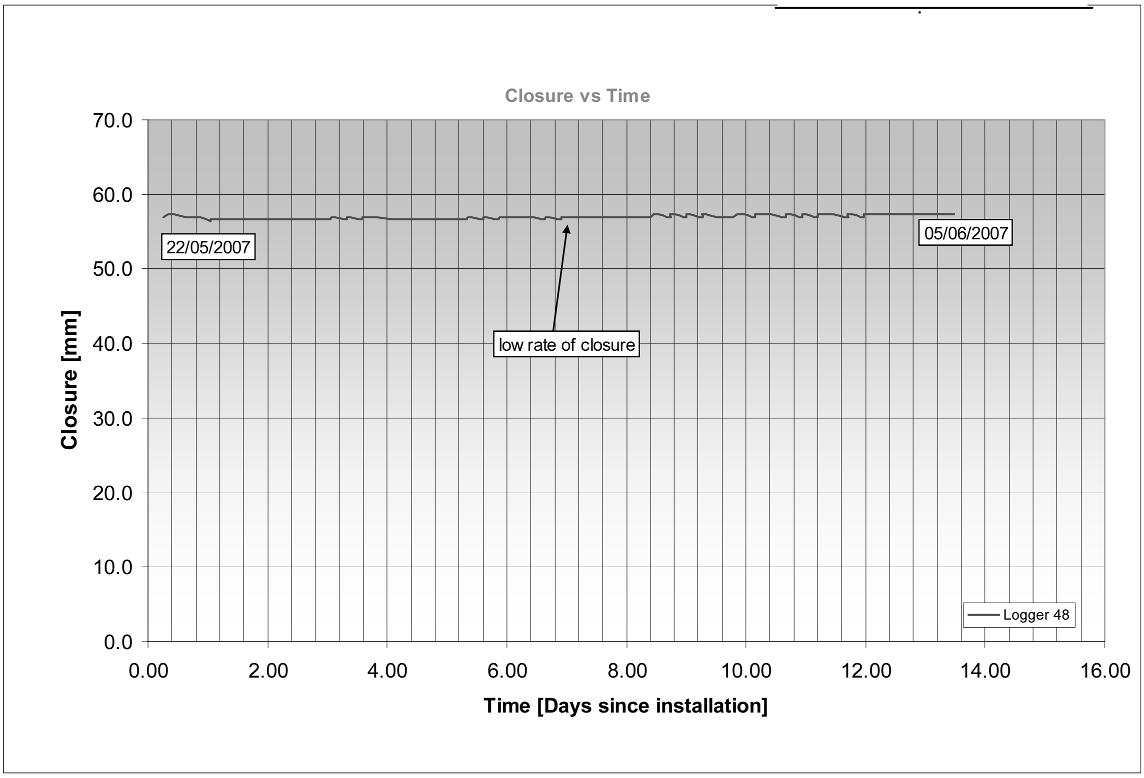

Figure 8. Rate of deformation adjacent to the elongate

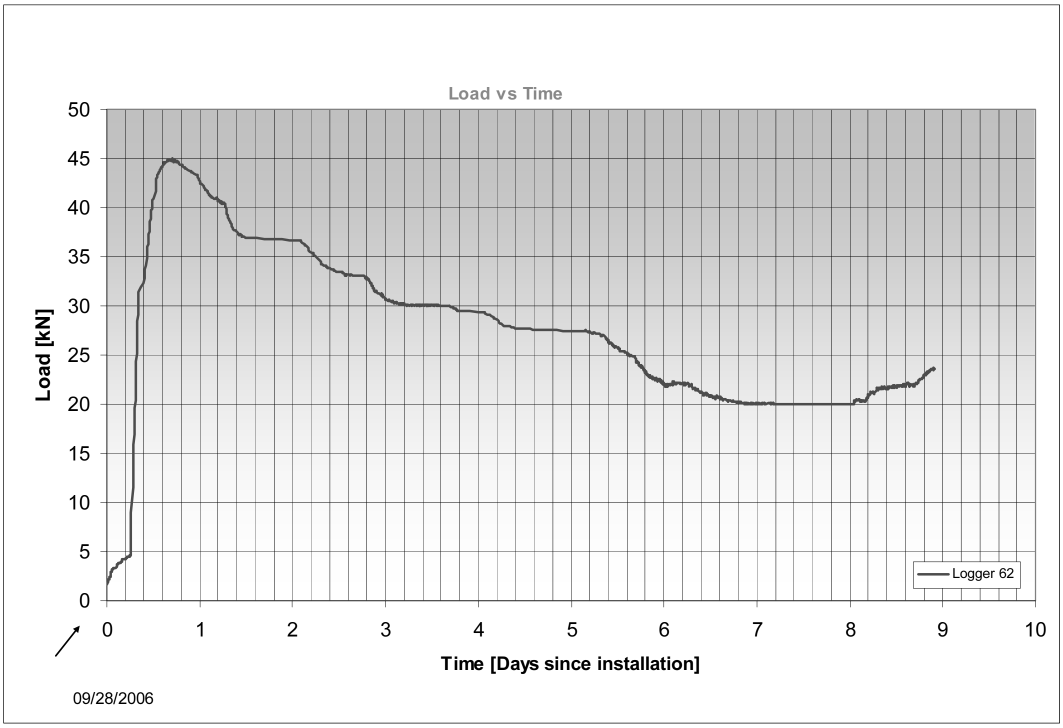

Figure 9. An example of the load versus time behaviour of an 18 – 20 cm diameter mine pole at a site where no closure took place

3.2 Effect of Pre-stressing

An example of a 16 – 18 cm diameter pencil prop with a 10 cm pod diameter and its associated Load and Closure Loggers is shown in Figure 10. Pencil props are used in this deeper platinum mine to enable the load-bearing capabilities of the elongate to be maintained while closure of up to 150 mm occurs. Figures 11 and 12 show examples of in-situ load versus deformation based on an average closure rate of 2.5 mm per day.

Figure 10. Closure and Load Loggers installed with a pencil prop in a platinum mine

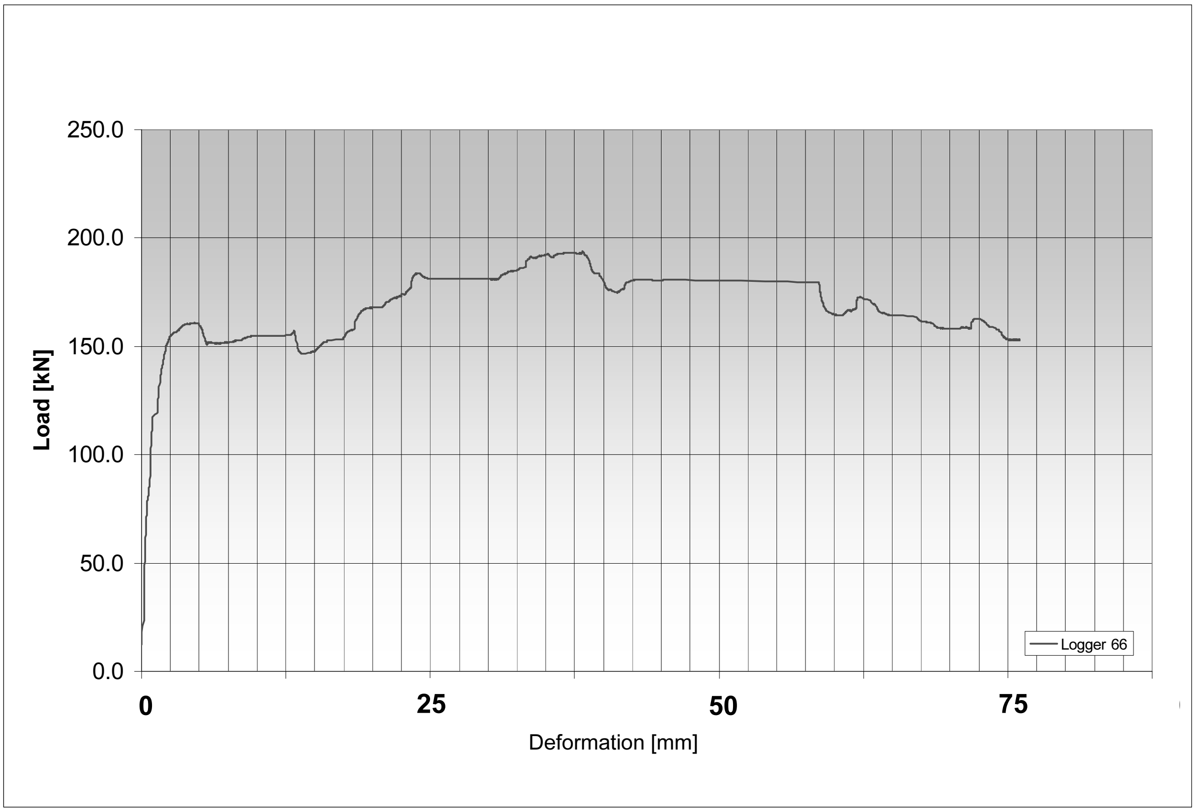

Figure 11. An example of the load versus deformation of a 16 – 18 cm pencil prop

Figure 11 shows that the elongate was pre-stressed to about 50 kN and it exhibited high initial stiffness to reach a yield load of 160 kN at 5 mm. A peak load of about 190 kN was achieved at about 40 mm of deformation. Due to the wide variability in the laboratory performance of elongates and the additional variables encountered underground, comparisons between the in-situ of individual elongates and laboratory performance is almost meaningless. However, for information the average laboratory yield load is about 220 kN and the average laboratory peak load is 260 kN. This suggests that the in-situ performance of this particular elongate was about 27 per cent less than the mean of numerous laboratory tests on similar elongates.

Figure 12 shows the results from a similar elongate in the same area of the mine. It is interesting to note that the yield load and peak loads are very similar to the first elongate. As expected from laboratory tests, this type of elongate yielded 150 mm before shedding load. However, the load shedding from its peak load was not as rapid as normally observed in the laboratory and the elongate maintains loads above 100 kN for another 100 mm of deformation.

Figure 13 shows the load versus time performance of a 16 – 18 cm diameter pencil prop with a 12 cm diameter pod at a platinum mine with a higher rate of closure of about 6 mm per day. It can be seen that little or no pre-stressing took place and a yield load of 250 kN was achieved after considerable time and hence deformation. The peak load was about 300 kN (excluding the spike load of 350 kN). The closure vs time graph is shown in Figure 14 and the load vs deformation data is presented in Figure 15.

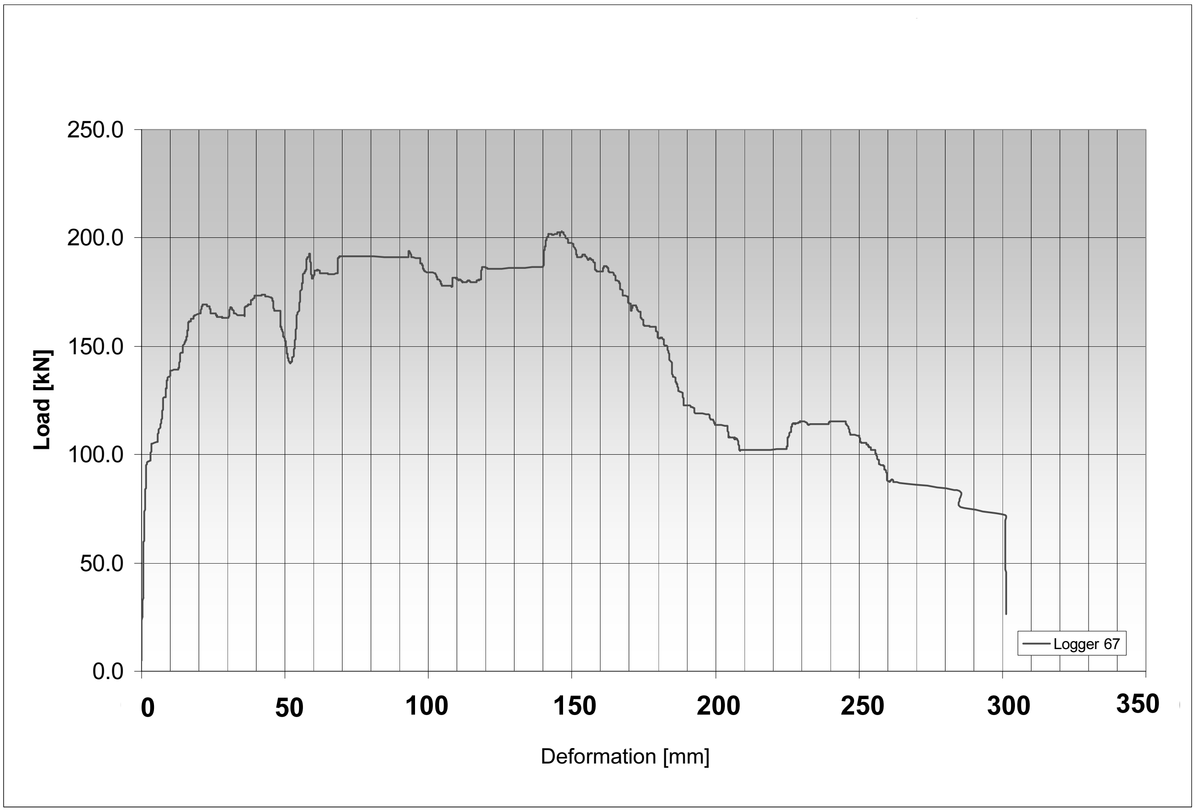

Figure 12. Another example of the load versus time of a 16 – 18 cm pencil prop

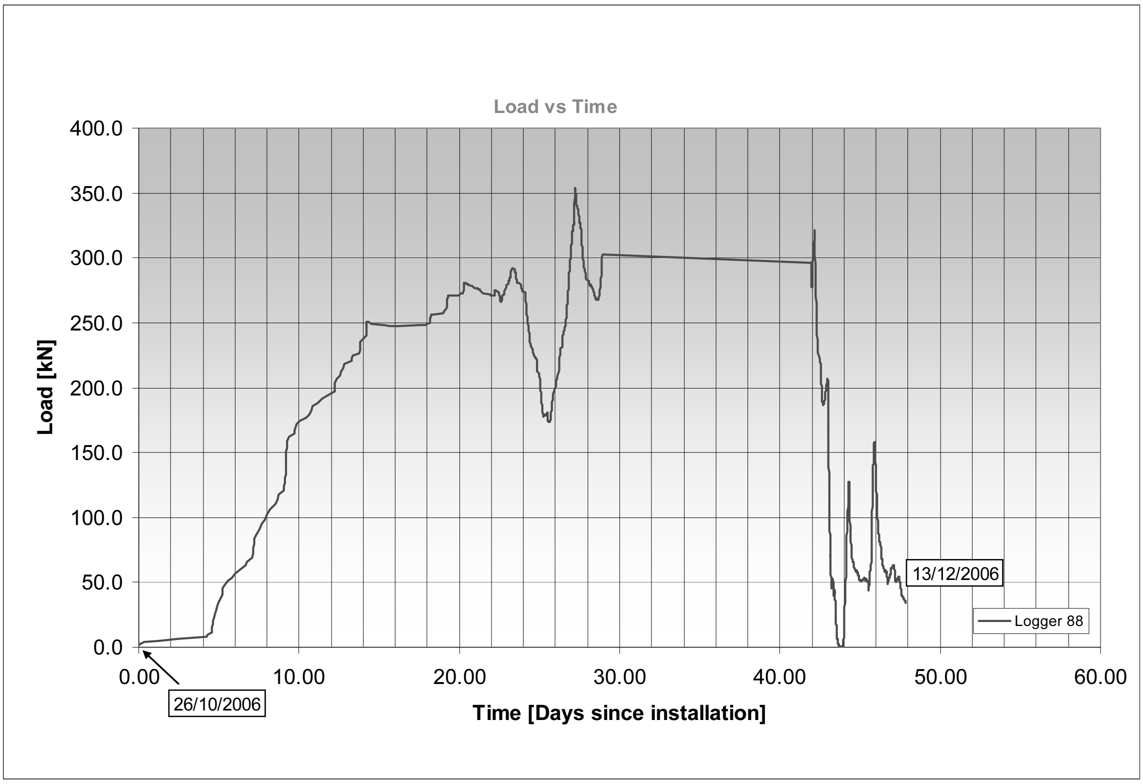

Figure 13. In-situ performance of a 16 – 18 cm (12 cm pod) pencil prop at a higher closure rate

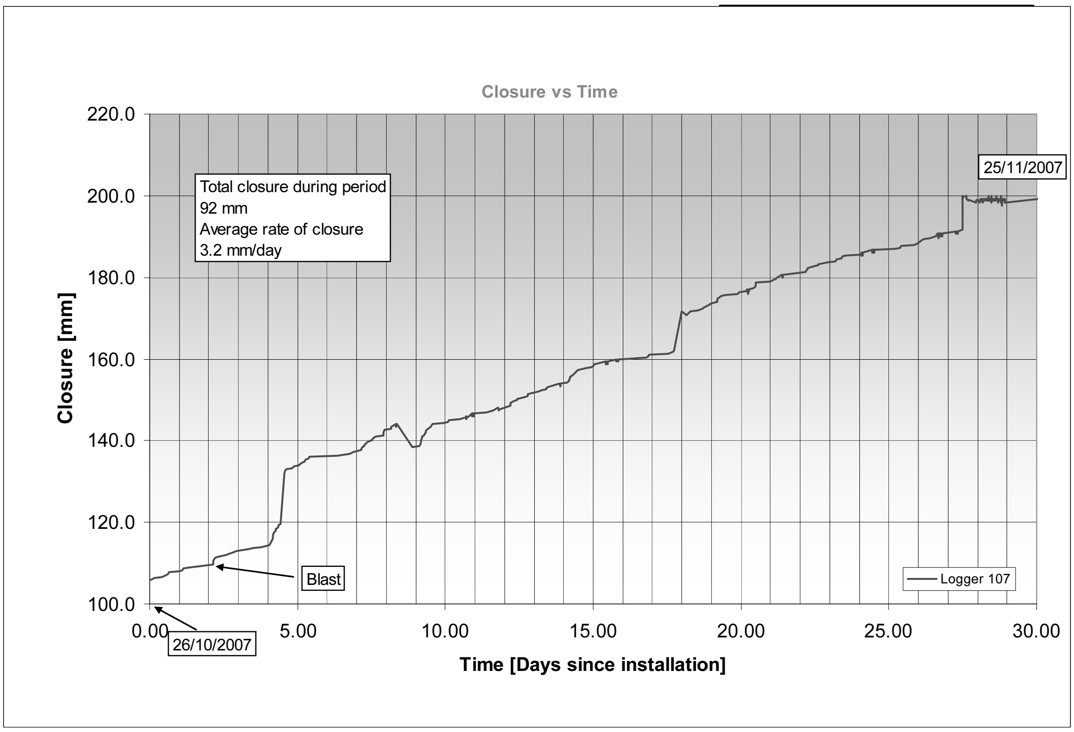

Figure 14. Closure recorded adjacent to Load Logger number 88

The graph in Figure 15 shows low initial stiffness of the elongate which was attributed to little or no pre-stressing. The yield load, peak load and maximum deformation are in line with the average laboratory test results for this size of pencil with a 12 cm pod (relative to the 10 cm pod in the earlier figures).

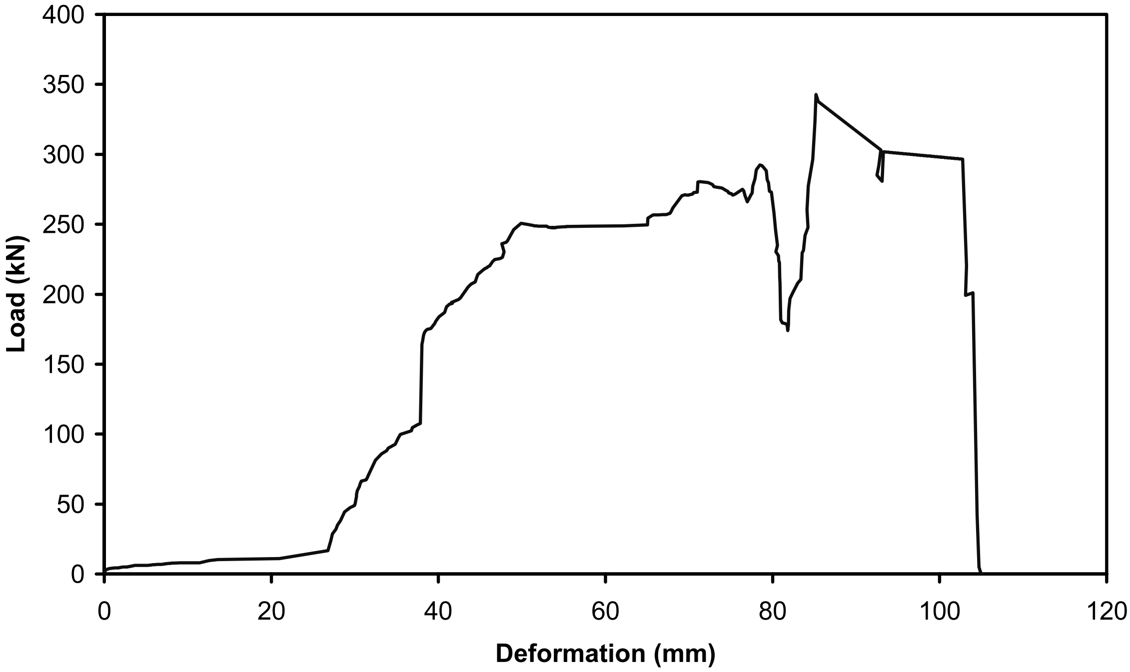

Figure 15. In-situ load – deformation of a 16 – 18 cm pencil prop (12 cm pod)

Figure 16 shows the load – deformation graph for another example of the same type of elongate (16 – 18 cm diameter, 12 cm pod pencil prop), in the same area. No pre-stressing appears to have taken place and the elongate exhibits low initial stiffness. The yield point is not well-defined and the peak load reached was only 190 kN compared to 300 kN in the earlier example.

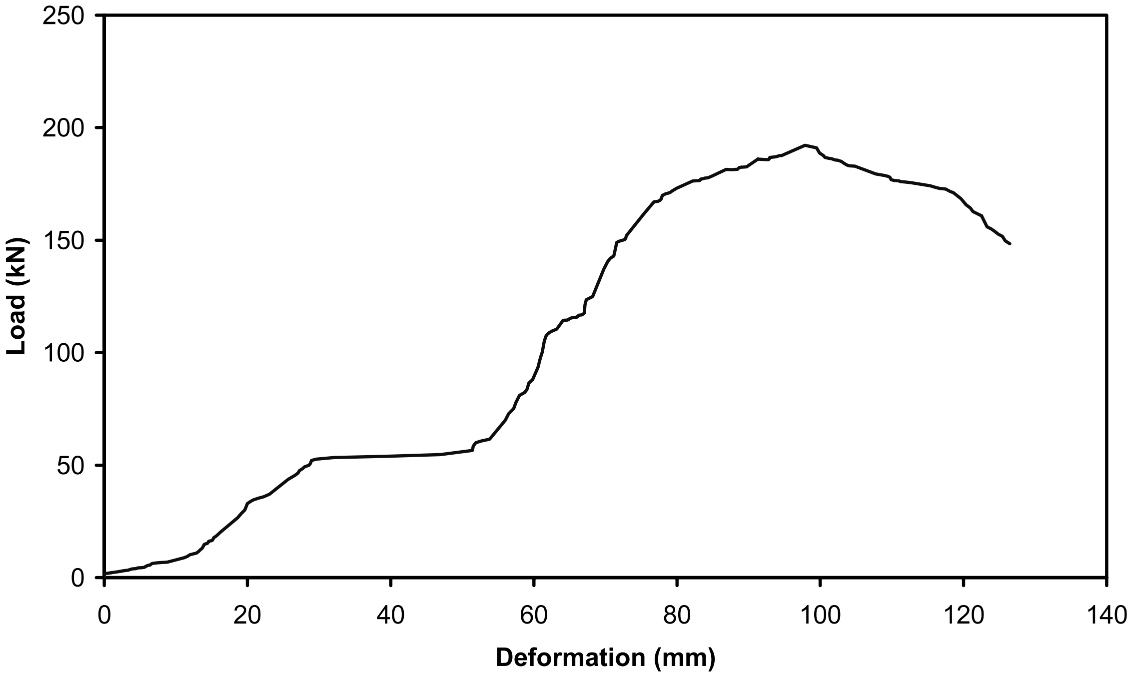

Figure 16. In-situ load – deformation of a second 16 – 18 cm pencil prop (12 cm pod)

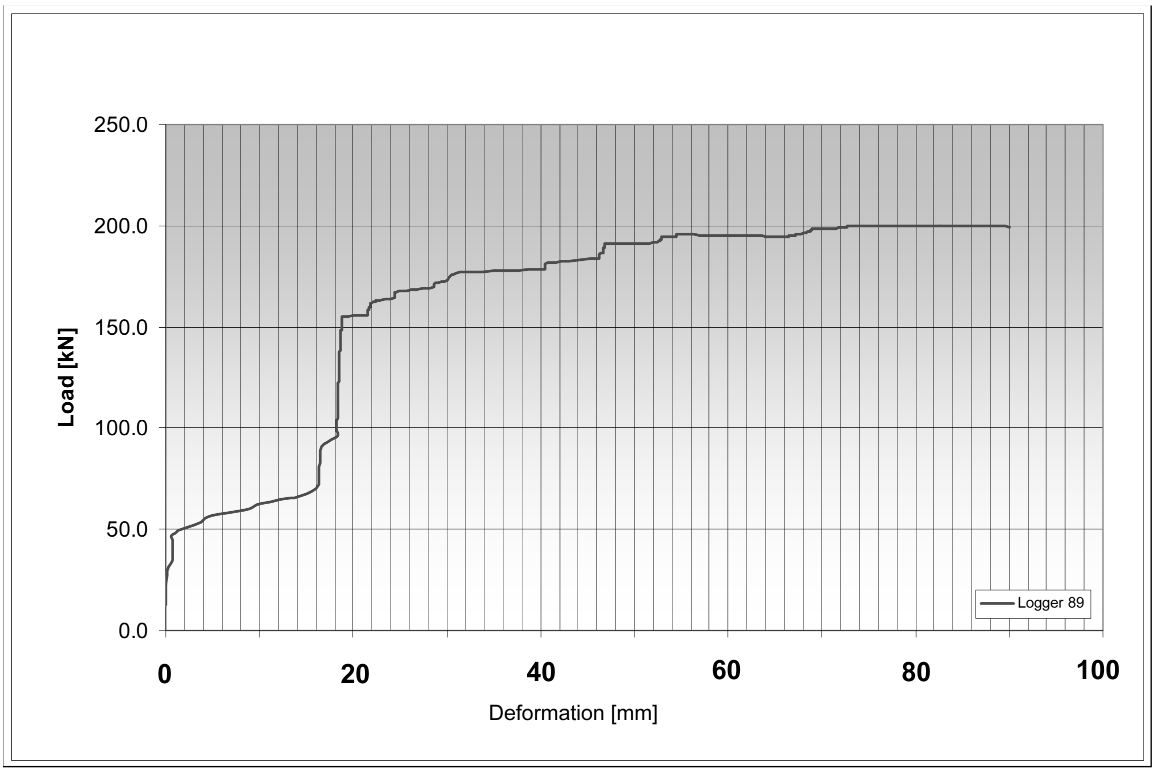

Figure 17. In-situ load – deformation of a 15 – 18 cm pencil prop (12 cm pod)

Figure 17 shows an example of a 15 – 18 cm diameter pencil prop with a 12 cm pod diameter from a third mine with a closure rate of about 2 mm per day. Despite some degree of pre-stressing (30 kN), low initial stiffness was experienced until the elongate made full contact with the rock surfaces after about 15 mm. The yield load also appeared to be about 160 kN at 20 mm and the load had reached 200 kN after about 80 mm of deformation.

Measurements have also been made on 18 – 20 cm diameter pencil props with 12 cm pod diameters at another platinum mine with an average closure rate of 1.5 to 2 mm per day. These props are used where higher yield loads and yieldability are required. Based on laboratory tests, they have a nominal 300 kN yield load and a minimum of 200 mm yieldability. An example of the results is shown in Figures 18.

Pre-stressing appears to have been carried out and high initial stiffness has been achieved. However, the yield load is less than half of that obtained in laboratory tests and the yieldability of about 150 mm is also below expectations from laboratory tests. Although the exact reasons for the result being considerably less than expected are not clear, they emphasise the variability in the in-situ performance of elongates and the need for a large sample size before drawing any conclusions.

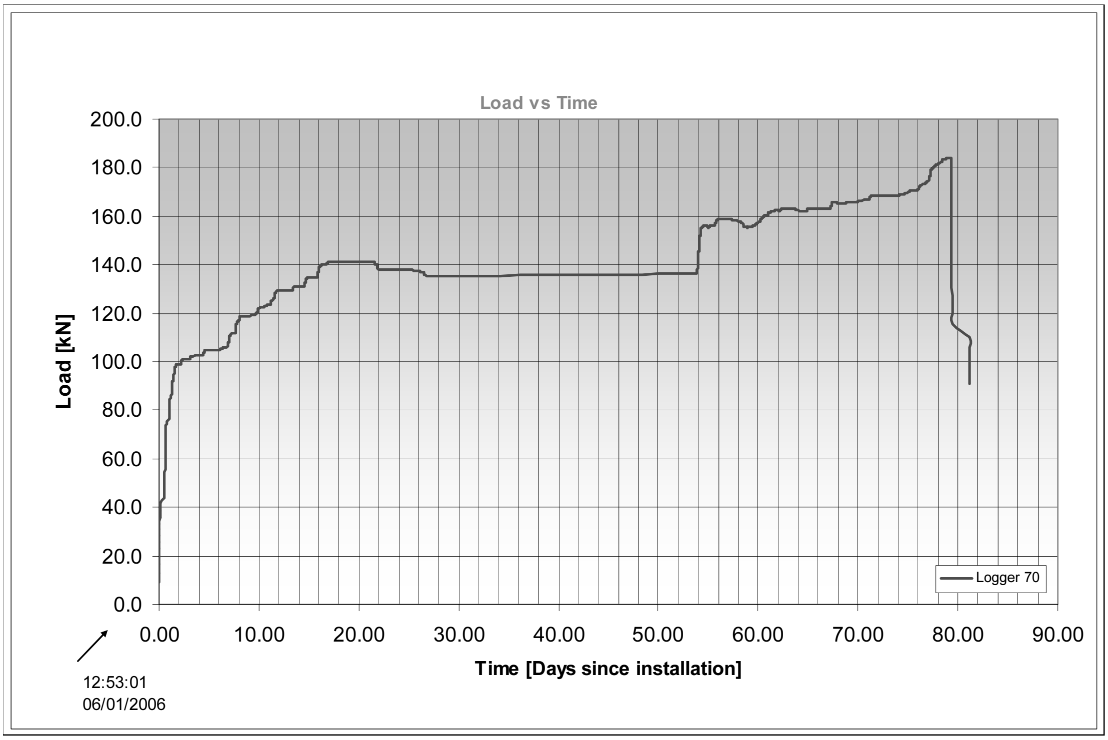

Figure 18. In-situ load – deformation of an 18 – 20 cm pencil prop (12 cm pod)

4. Myths and Realities

The newly designed instrumentation described in this paper appears to be well-suited to quantifying the in-situ performance characteristics of yielding elongates. Elongate loads of up to 350 kN and deformations of up to 300 mm have been recorded. The results presented in this paper represent a sample of the in-situ load versus time and load versus closure graphs obtained to date. They have been selected to illustrate various characteristics which have been observed from the monitoring programme to date. Although it is premature to draw any firm conclusions, these preliminary results suggest that some long-held beliefs regarding the in-situ performance of elongates may be more myth than reality :

- Timber creep has been observed in the in-situ test results but it does not appear to be as large as expected, especially considering the generally low rates of closure (less than 3 mm per day) under which many of the results were obtained. The pressure contained within the pre-stressing device is considered to contribute positively towards the lower timber creep effects.
- Pre-stressing of elongates, even by as little as 25 kN, appears to substantially increase their initial stiffness in the underground environment. With very little or no pre-stressing, considerable deformation can occur before load is generated in the elongate. The results show that pre-stressing in excess of 25 kN appears to generate a yield point in the timber at deformations as low as 10 to 15 mm which is similar to laboratory tests. High initial stiffness is ascribed to the good contact between the rock and the elongate created by the pre-stressing device.
- Although variability in the in-situ performance characteristics has been recorded, it is not as wide as expected, or indeed as large as determined from measurements using earlier instrumentation. This is quite remarkable given the wide variability under laboratory conditions and the fact that many more variables are present in the underground environment. The consistency may be partly explained by the greater care with which elongates to be monitored are installed.
- These preliminary results suggest that a de-rating factor of up to 40 per cent for low closure areas may be appropriate to take into consideration not just the much lower rate of deformation, but all differences between laboratory and underground conditions. However, de-rating the minus 1 standard deviation (84% confidence level) or the minus 1.645 standard deviation (95% confidence level) elongate performance graph appears to be too conservative.

The results from in-situ monitoring of elongates may have far-reaching implications. If it can be shown that the current de-rating factors are too conservative, either elongate sizes can be reduced back to their levels 10 years ago or spacings between elongates can be increased. Either of these would be beneficial at a time when the regular supply of large diameter elongates is becoming increasingly difficult.

5. Recommendations

Based on all the in-situ elongate load – deformation results obtained to date, and not just the examples presented in this paper, the following recommendations are made :

- Pre-stressing of elongates to at least 25 kN appears to have a beneficial effect on their in-situ performance. Systems should be put in place to ensure that at least these minimal levels of pre-stressing are achieved.
- The performance of elongates is very site specific and elongate support system design should be based on measurements at each site and not on de-rating factors or measurements from other sites.
- If measurements are conducted by mining personnel, it is critical that all variables are recorded. The list given in Section 1 should be considered as a starting point.
- Until such time as more in-situ measurements are available, it is not unreasonable to use the somewhat conservative de-rating factor as defined by Roberts et al (1987).
- Hundreds more measurements are required to fully understand the in-situ performance of elongates and a regular programme of in-situ measurements at all sites using elongates would assist in obtaining this understanding. In particular, further information is required on :
  - The effect of deformation rate on timber creep for elongates using pre-stressing.
  - The effect of elongate length on load bearing capabilities.
  - The determination of elongate performance under dead-weight, not closure-driven, load generation in the elongate.
  - The contribution of each underground variable to in-situ elongate performance.
- At present the de-rating equation applies a factor to adjust the entire load-deformation graph of the elongate laboratory test results based on differential rates of deformation. The rock engineer must decide whether to use the yield load or the peak/ultimate load for support design purposes, depending on their expected hangingwall loading conditions. It is the authors view that further measurements could result in the development of different factors for each of the parameters, yield load, peak or ultimate load and yieldability.

6. Acknowledgements

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7. References

Daehnke, A., Watson, B.P., Roberts, D., Acheampong E. and van Zyl, M. (2000) The impact of soft loading conditions on the performance of elongate support elements. SIMRAC Final Report GAP 613, Johannesburg, March 2000.

Guideline for the Compilation of a Mandatory Code of Practice to Combat Rock Fall and Rock Burst Accidents in Tabular Metalliferous Mines, Mine Health and Safety Inspectorate, Pretoria, July 2001.

Malan, D.F., Piper, P.S., Clements, T.N. and Hayes, S.J (2006) Development of a practical guideline for support quality assurance for different systems used in tunnels and stopes. SIMRAC Final Report SIM 04 02 05, Johannesburg, August 2006.

Piper, P.S., Akermann, K.A. and van Aswegen, L. (2000) The Underground Performance of Yielding Timber Elongates at RPM Amandelbult Section. SANIRE Symposium 2000 *(Keeping it up in the Bushveld),* Rustenburg, October 2000.

Roberts, M.K.C., Jager, A.J. and Riemann, K.P. (1987) The performance characteristics of timber props, COMRO Research Report, No. 35/87, Johannesburg, August 1987.