

# The Real In-situ Performance of Pre-stressed Elongates

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## ABSTRACT

*Pre-stressed timber elongates have become an increasingly popular and important form of stope support in recent year and a knowledge of their in-situ performance is crucial for the design and selection of effective stope support. 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 pre-stressed timber elongates.*

*The purpose of this paper is to present some of the initial results from these in-situ measurements. Given the large number of variables which affect the underground performance, the size of the measurement database is insufficient to draw any firm conclusions at this stage. However, some interesting results and observations have emerged and a selection of the in-situ results is presented to illustrate these points. It is hoped that in-situ monitoring of the load-deformation behaviour of elongates will become much more widespread and thus enable more specific conclusions to be drawn and also enable the provision of more relevant design data.*

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## 1 INTRODUCTION

The determination of the performance requirements of an effective elongate-based stope support system is a relatively straight-forward exercise, in theory. It requires knowledge of the weight of the rock mass to be supported, the maximum deformation that the support units must accommodate and the performance characteristics of the proposed elongate support unit. The input data for the first two parameters are obtained from back-analyses of rock falls and the measurement of stope closure. The mean performance characteristics and the variability of elongates are determined from laboratory tests on batches of similar product. The results of these tests are then usually de-rated to take into account variables which are present underground but which are not included in the laboratory tests.

The reason for the ubiquitous application of a de-rating factor is that, despite regular installation of various monitoring devices to quantify the in-situ performance of elongates in the past 30 years, surprisingly few reliable results have been obtained. This is due to the cost and effort involved in obtaining measurements from the large number of different types of elongates in regular use, the lack of confidence in widely varying results, premature failure of the monitoring devices and the lack of transferability of the results to other mines with differing conditions. Almost every stope support design is based on an empirical equation, commonly referred to as the 'de-rating factor' or the 'load-adjustment formula'. The equation calculates that the reduction in the load can be as much as 40 per cent if the underground closure rate is as low as 1 millimetre per day. The equation for adjusting the load based on different rates of deformation is expressed in the following terms (Watson 2000):

$$F_U / F_L = [m \log(V_U / V_L)] + 1$$

Where :  $F_U$  = underground load

$F_L$  = laboratory test load

$V_U$  = underground rate of deformation  
deformation

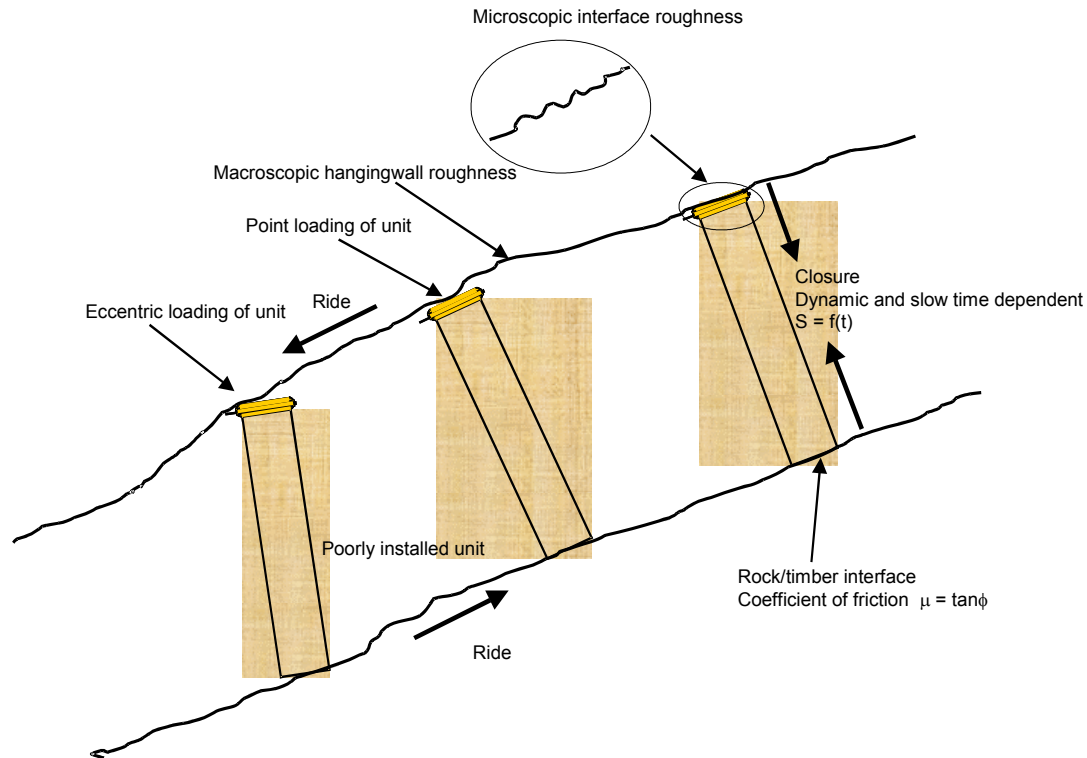
$V_L$  = original rate of

$m$  = an empirical factor (0.084 for rock fall conditions)

Although the equation is based on the differences between the rate of deformation underground (typically 1 to 10 mm per day) compared to the laboratory test (usually 30 mm per minute), it is generally used to adjust for all the differences between laboratory and underground conditions (Figure 1). The main differences between laboratory and in-situ conditions are listed below (Malan et al 2006).

- Absolute rate of deformation
- Non-continuous and variable rates of deformation
- Possible high rates of deformation during seismic activity
- 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.

The most important of these factors include the condition and extent of the contact between the rock and the elongate, ride movement between the hangingwall and footwall and the mode of deformation of the elongate (Piper et al 2000). Various studies have attempted to quantify these effects in the laboratory, the most comprehensive of which is documented by Daehnke et al (2000). However, the results demonstrate that the natural variability of timber is often too great to draw meaningful conclusions on the contribution of each variable which was evaluated. The need for actual underground measurements on elongate performance characteristics is the only means of taking into account all these variables.



**Figure 1. Diagram illustrating the various factors leading to the complex loading conditions experienced by elongates in underground stopes (Malan et. al. 2006)**

Furthermore, the current adjustment factors were derived prior to introduction of pre-stressing devices. These devices would be expected to significantly improve the in-situ performance of elongates by creating higher initial loads, increased indirect contact between the rock and the elongate and possibly less timber creep due to the energy stored in the pre-stressing device. The potential implication is that the current de-rating factors in widespread use may under-state the in-situ performance of elongates. If this proves to be the case, either elongate sizes could be reduced back to their levels 10 years ago or spacings could be increased. Either of these would be beneficial at a time when the regular supply of large diameter elongates is becoming increasingly difficult.

## 2 MONITORING REQUIREMENTS

In addition to the technical aspects of obtaining a better understanding of the in-situ behaviour of elongates, there are regulatory requirements to be fulfilled. The urgency for effective means of quantifying 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 Guidelines 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 for new elongates would apply to existing elongates if these requirements had not already been met.

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

| <b>Product/testing type</b>                                    | <b>Evaluation requirements</b>                                                                                                                                    |
|----------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 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.                                                                                  |

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 obviously any problems encountered with the use of the new elongate should be recorded.

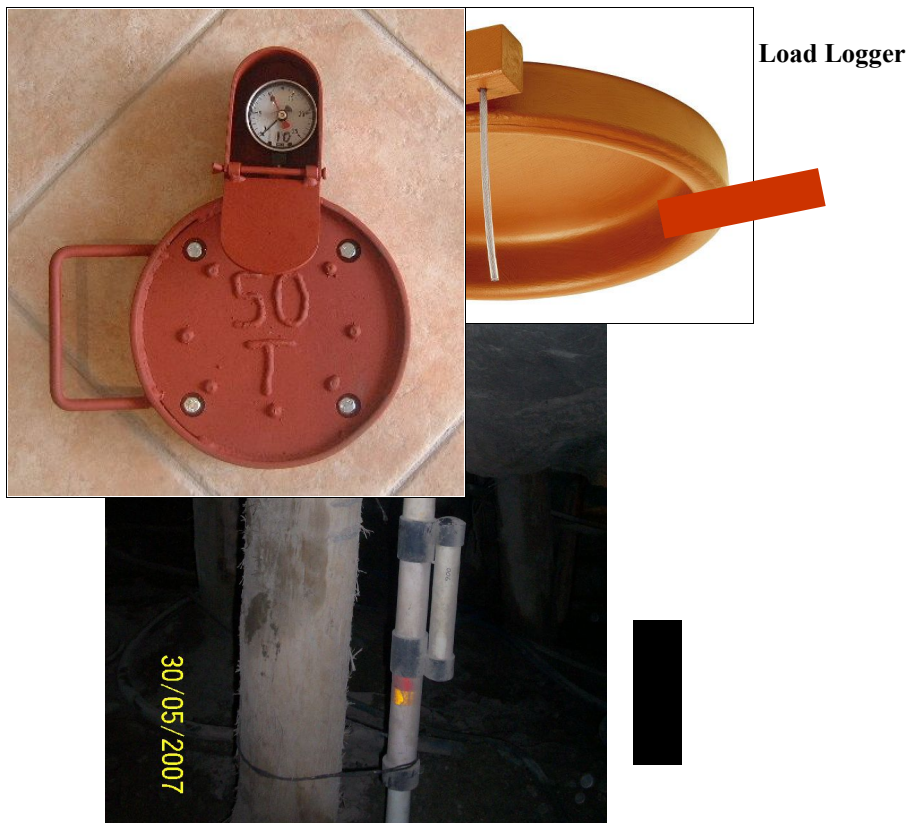
### 3 MONITORING METHODS

The standard instrument that has been used to quantify in-situ loads on elongates for many years is the 'stick load cell' (Figure 2). 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 provides 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 3.

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 4 and 5 show typical installations which include the device used for measuring stope closure and the wireless data transfer unit.





**Figure 5. Typical underground installation**

erous in-situ measurements obtained to date are  
been selected to cover a range of elongates and to  
itu results. The quantity of results is not sufficient  
The results given below include the following

e pole (Figure 6).

cm pod unturned pencil prop.

cm pod unturned pencil prop.

cm pod unturned pencil prop.

aturn prop.



**Figure 6. Load and Closure Logger installed on a mine pole**

#### **4.1 16 – 18 cm Mine Poles**

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. Figure 7 shows a typical installation.



**Figure 7. Closure and Load Loggers installed with a mine pole in a shallow platinum mine**

An example of the load versus time behaviour of the mine poles is shown in Figure 8. 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 9). Despite the very low closure rate the mine pole lost less than 10 per cent of its load during the following two weeks.

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 10 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 but this represented

over 50 per cent of the initial load. The later increase in load, with no closure, seen in Figure 10 was also noted by Daehnke et al (2000) and was ascribed to an increase in temperature and hence pressure in the pre-stressing device.

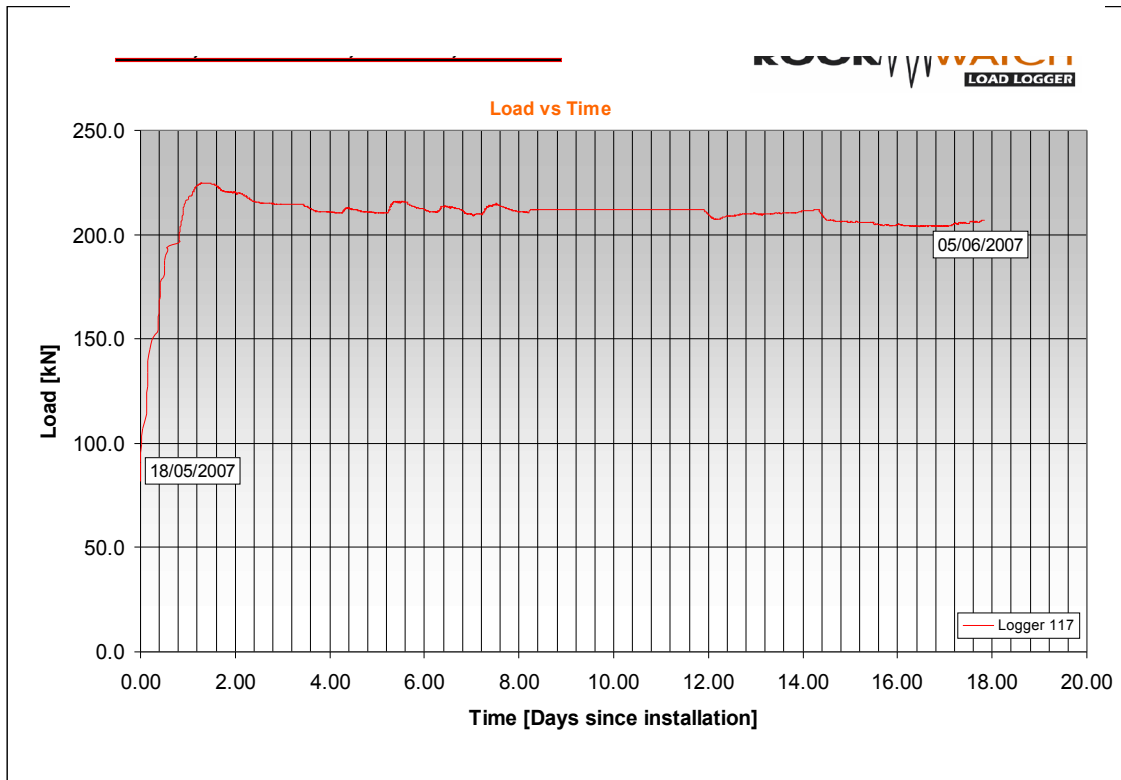
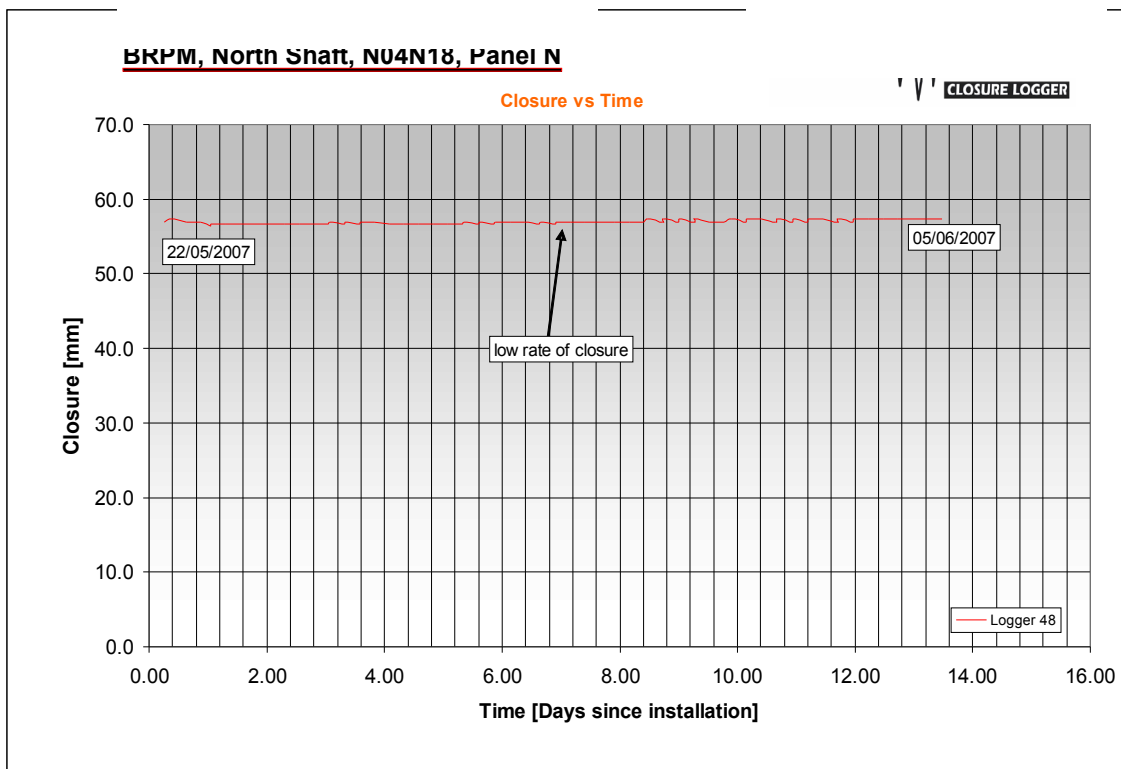
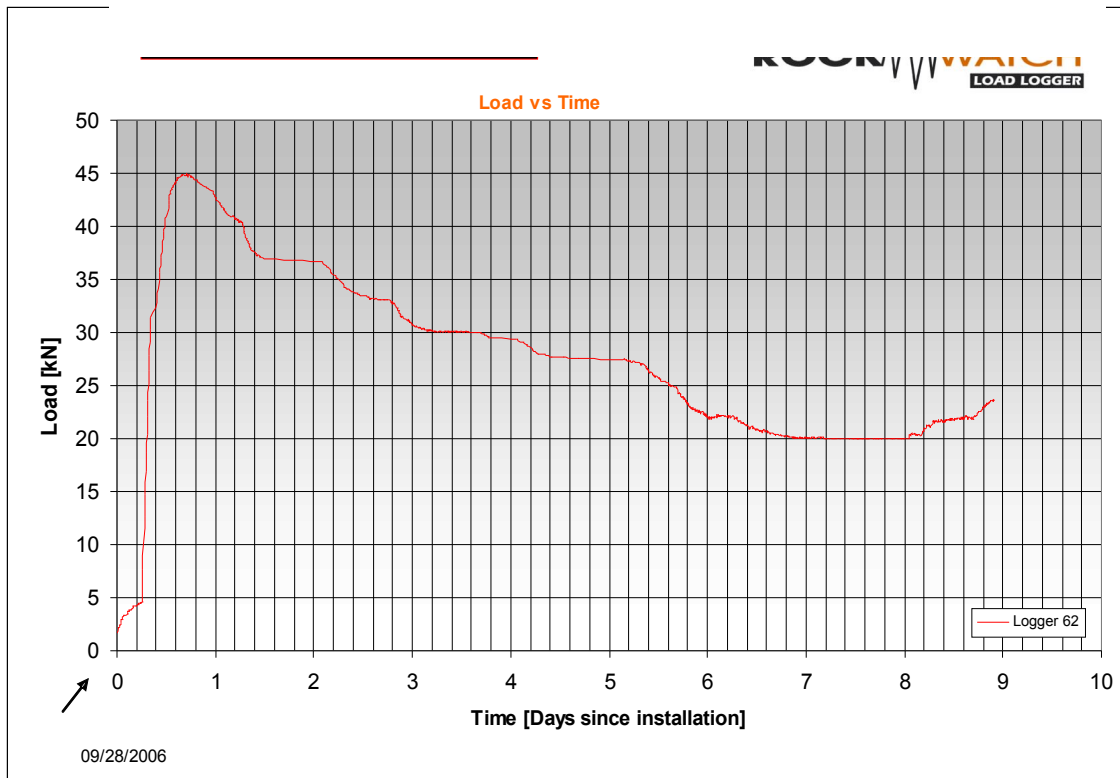


Figure 8. An example of the load versus time behaviour of a 16 – 18 cm diameter mine pole



**Figure 9. Rate of deformation adjacent to the elongate**



**Figure 10. An example of the load versus time behaviour of an 18 – 20 cm diameter mine pole at a site where no closure took place**

#### 4.2 16 - 18 cm Pencil Props

An example of a 16 – 18 cm diameter pencil props with a 10 cm pod diameter and its associated Load and Closure Loggers is shown in Figure 11. 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 12 and 13 show examples of in-situ load versus deformation graphs based on an average closure rate of 2.5 mm per day.



Figure 11. Closure and Load Loggers installed with a pencil prop in a deeper platinum mine

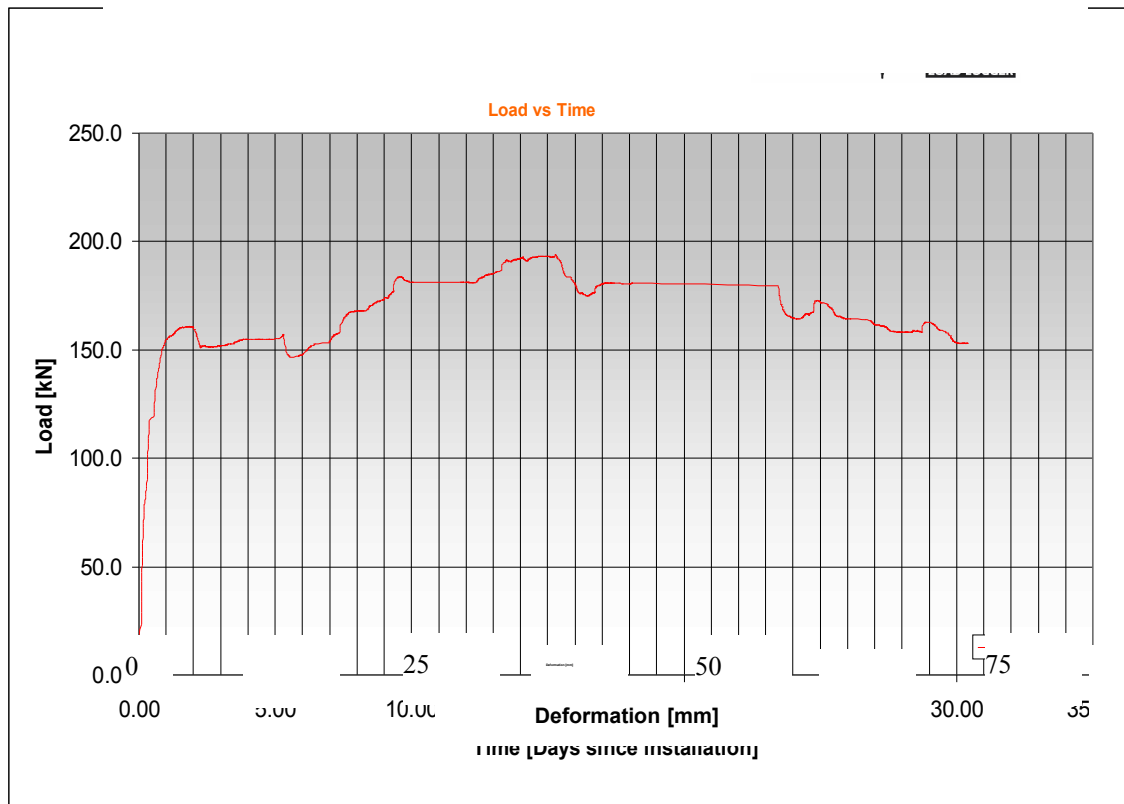
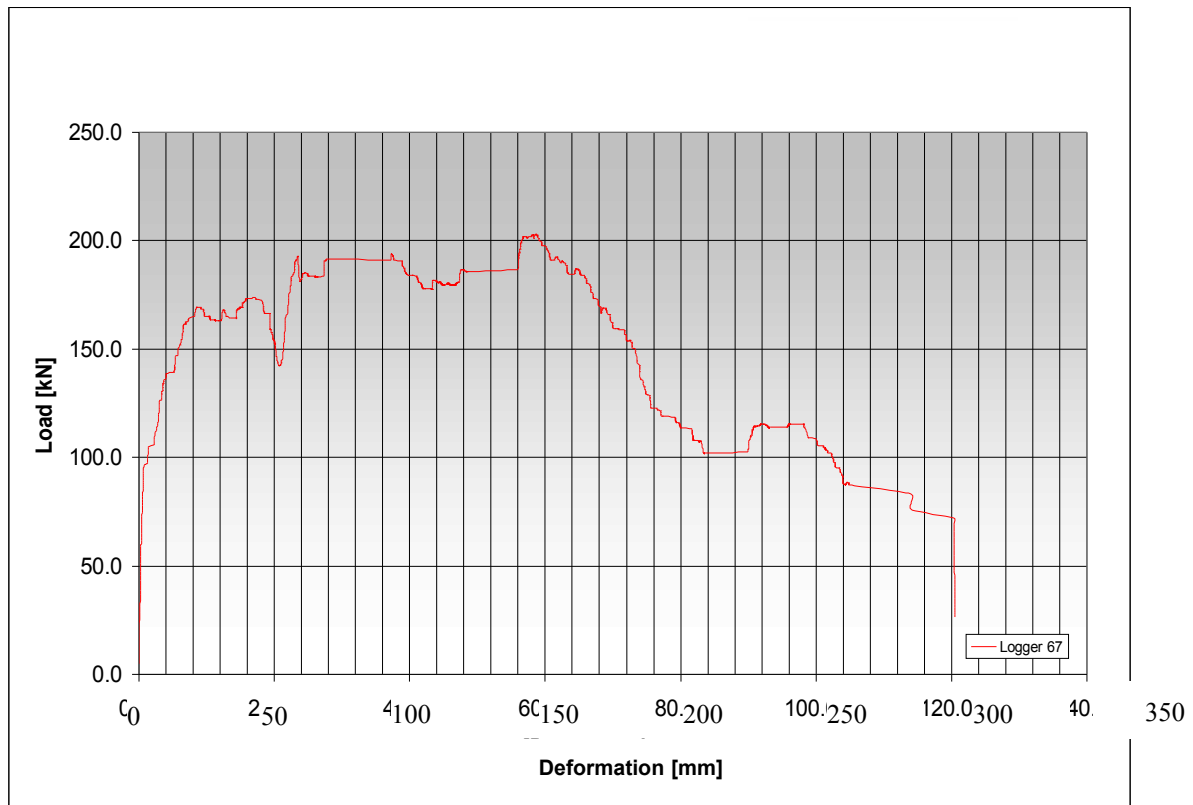


Figure 12. An example of the load versus deformation behaviour of a 16 – 18 cm pencil prop



**Figure 13. Another example of the load versus time behaviour of a 16 – 18 cm pencil prop**

Figure 12 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 suggest 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 13 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 maintain loads above 100 kN for another 100 mm of deformation.

Figure 14 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 15 and the load vs deformation data is presented in Figure 16.

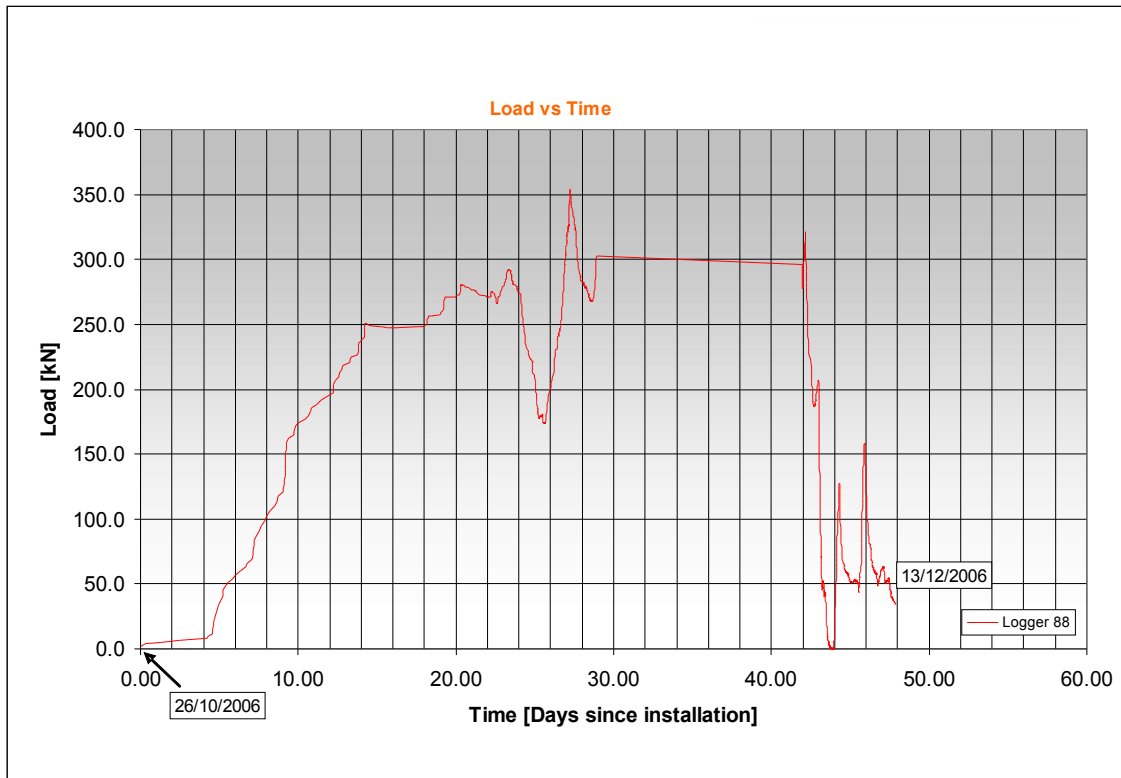


Figure 14. In-situ performance of a 16 – 18 cm (12 cm pod) pencil prop at a higher closure rate

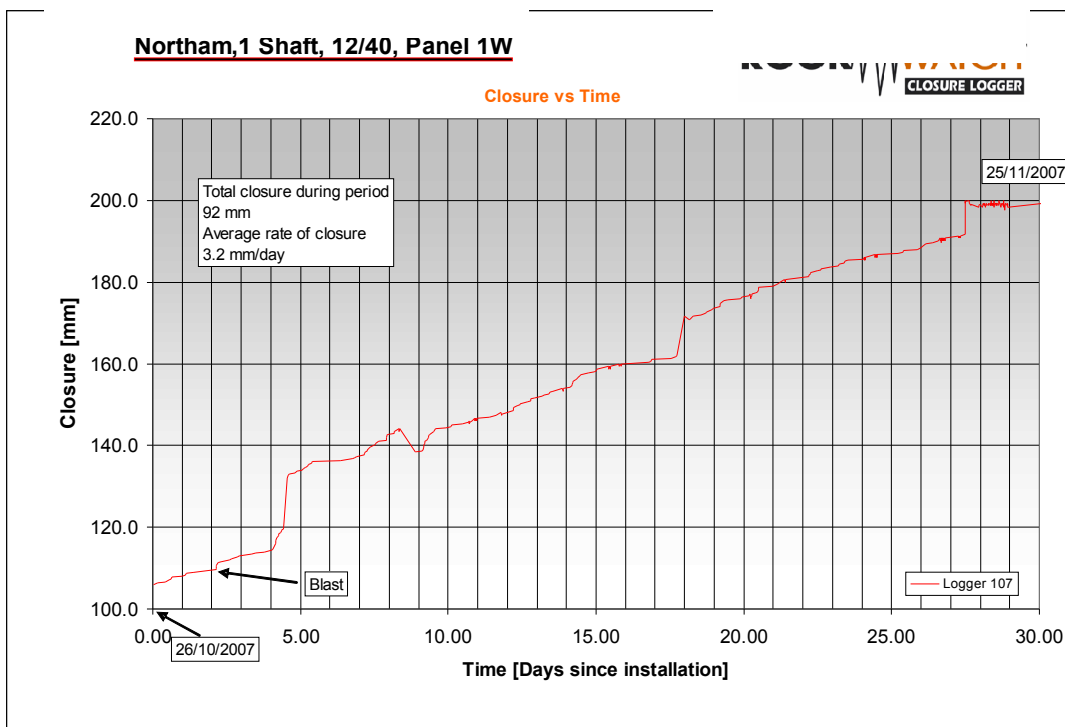
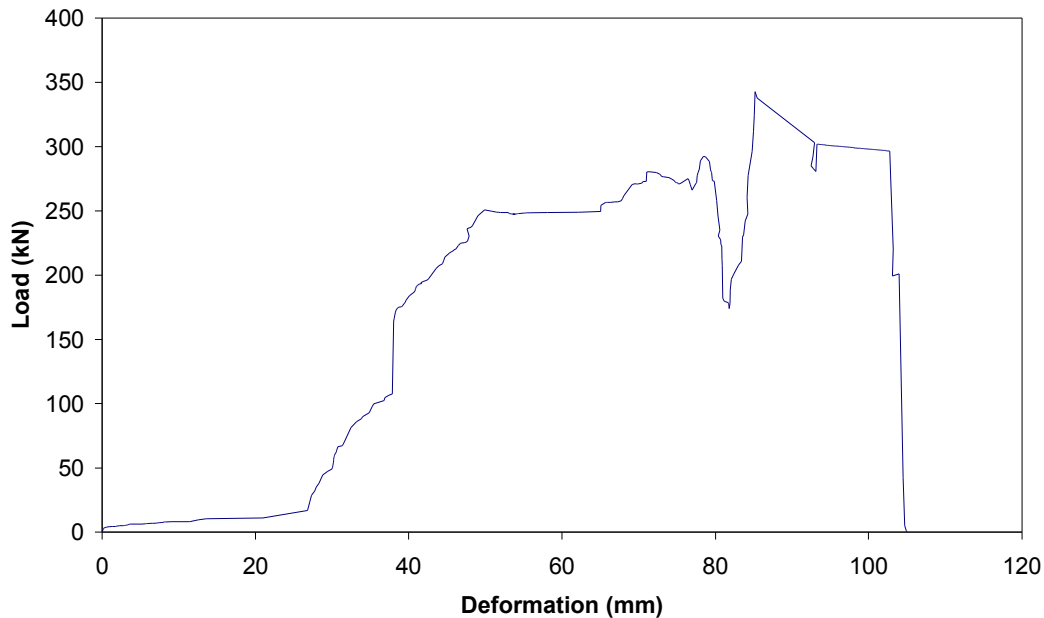


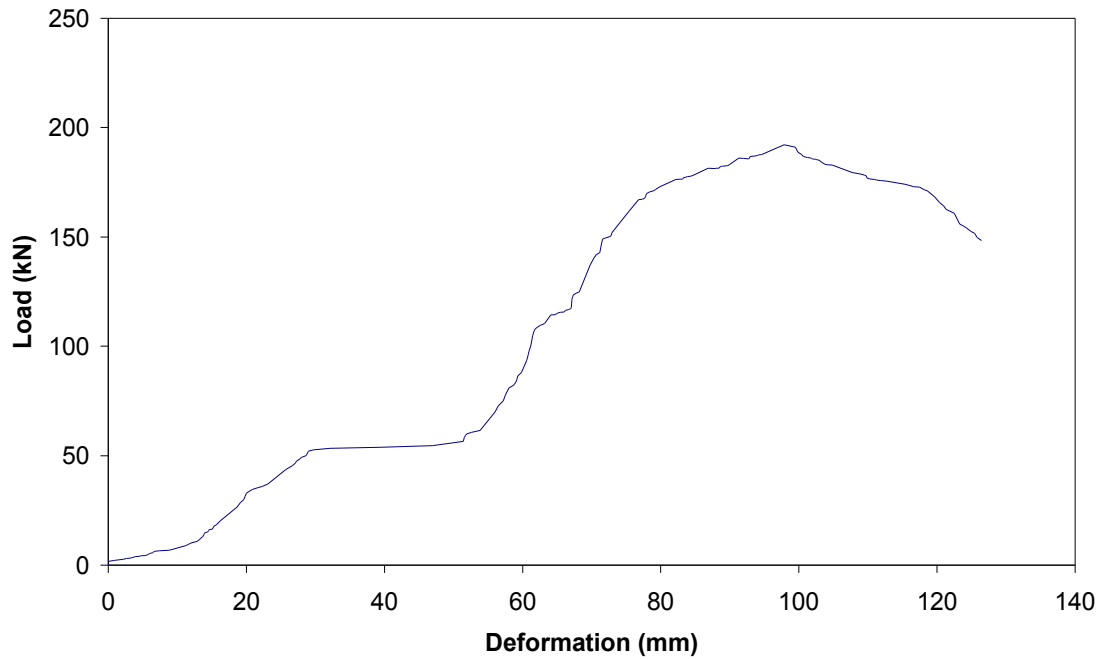
Figure 15. Closure recorded adjacent to Load Logger number 88

The graph in Figure 16 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).

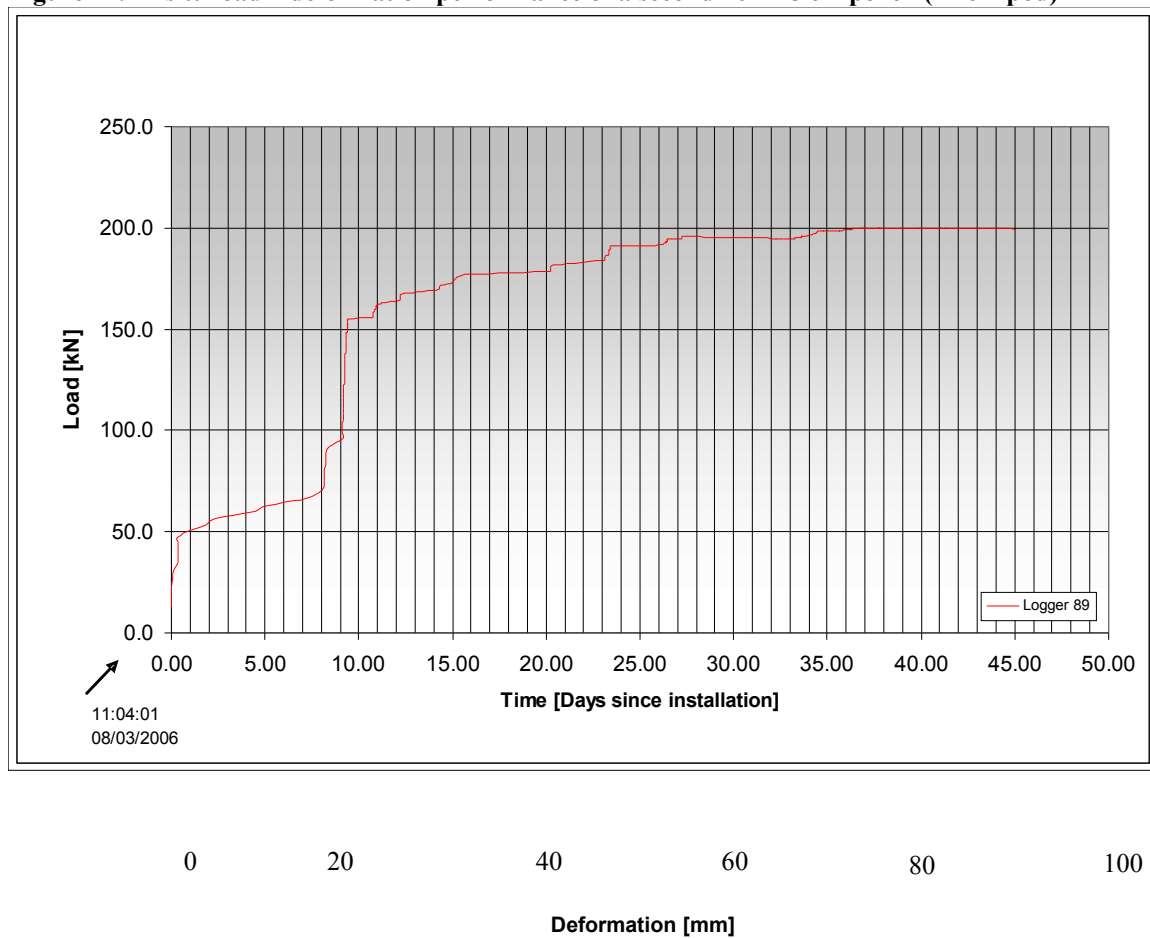


**Figure 16. In-situ load – deformation performance of a 16 – 18 cm pencil prop (12 cm pod)**

Figure 17 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 17. In-situ load – deformation performance of a second 16 – 18 cm pencil (12 cm pod)**



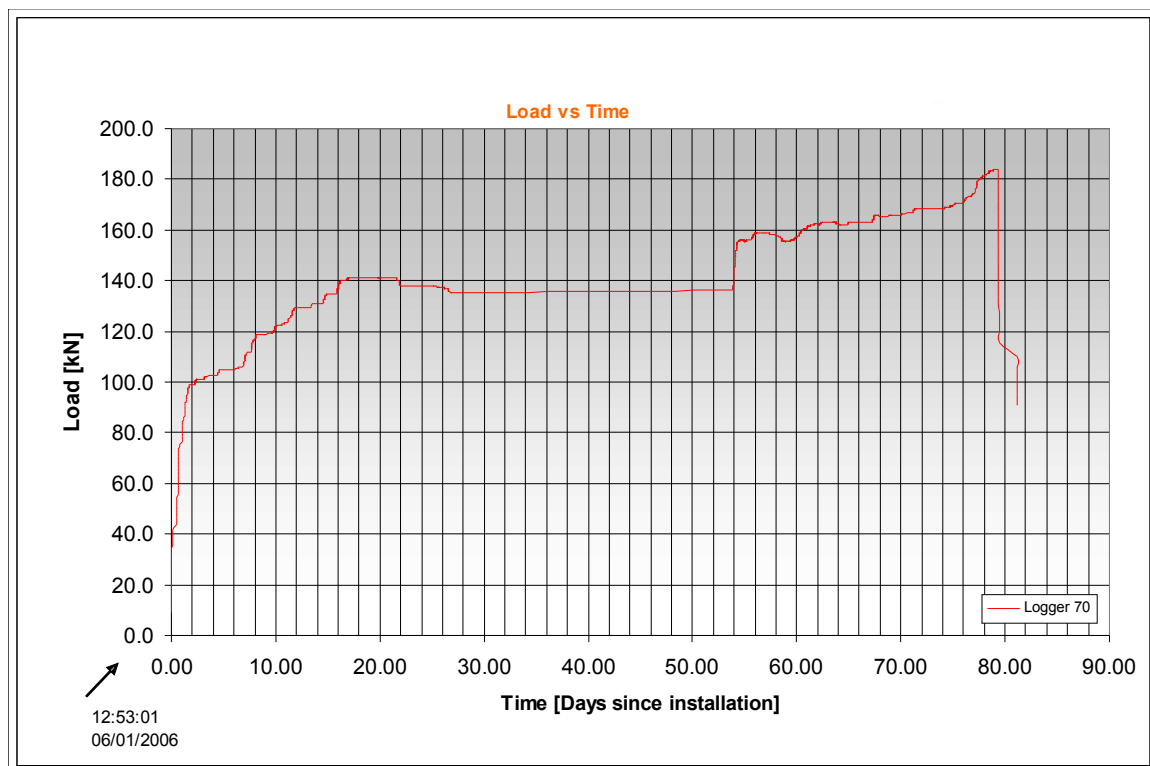
**Figure 18. In-situ load – deformation performance of a 15 – 18 cm pencil prop (12 cm pod)**

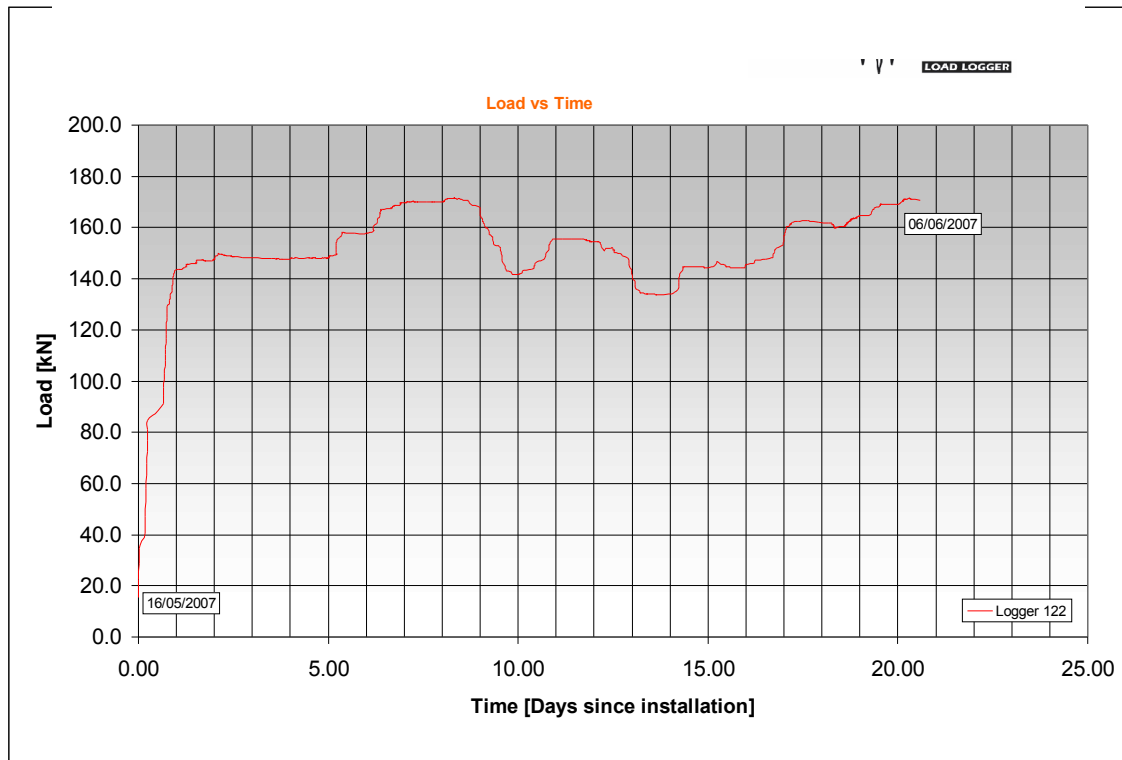
Figure 18 shows an example of a 15 – 18 cm diameter pencil prop with a 12 cm pod diameter from a third mine with a closure rate of about 2 mm per day. Despite some degree of pre-stressing (30 kN), low initial stiffness was experienced until the elongated made full contact with the rock surfaces after 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.

#### 4.3 18 - 20 cm Pencil Props

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. Some results are shown in Figures 19 and 20.

In both examples pre-stressing appears to have been carried out and high initial stiffness has been achieved. However, the yield load in both cases is less than half of that obtained in laboratory tests. The peak load in Figure 19 is much lower than expected and the yieldability of about 150 mm is also below laboratory expectations. The maximum deformation of the second elongate has not been reached. The reasons for these results being considerably less than expected are not clear. The results emphasise the variability in the in-situ performance of elongates and the need for a large sample size before drawing any conclusions.

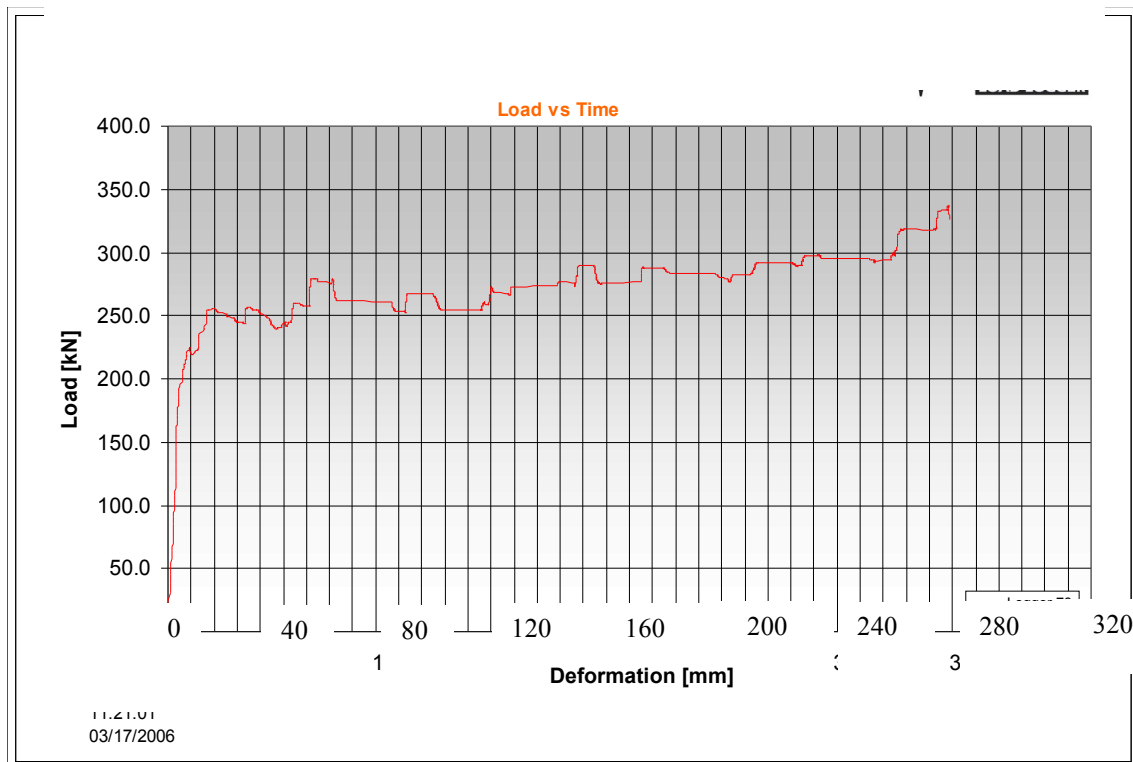


**Figure 19. In-situ load – deformation performance of an 18 – 20 cm pencil prop (12 cm pod)****Figure 20. In-situ load – deformation performance of an 18 – 20 cm pencil prop (12 cm pod)**

#### 4.4 20 cm Saturn Props

The Saturn Prop a 20 cm diameter high yield elongate, similar to a Wedge Prop, and these products are used widely in the deeper gold mines. Laboratory tests show that they have an average yield load of 400 kN and can maintain this load for up to 400 mm. Peak loads of up to 500 kN are usually obtained during testing.

Figure 21 shows the result of one particular in-situ monitoring of a Saturn Prop in a deep level gold mine with an average closure rate of about 8 mm per day. Although the pre-stressing load was relatively low (25 kN), high initial stiffness was achieved with a yield load of 250 kN being achieved at only 15 mm. Thereafter the load was maintained, reaching a maximum of 340 kN after nearly 280 mm of deformation.



**Figure 21. In-situ load – deformation performance of a 20 cm Saturn Prop**

## 5 SUMMARY OF RESULTS

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. The results can be summarised as follows :

- Using this new style load-deformation instrumentation, elongate loads of up to 600 kN (not shown in this paper) and deformations of up to 280 mm have been recorded. This particular instrumentation appears to be a well-suited to quantifying the in-situ performance characteristics of yielding elongates.
- 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.
- 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.

- 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.
- 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.

## **6 RECOMMENDATIONS**

Based on 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 has a very beneficial effect on their in-situ performance and systems should be put in place to ensure that 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 devices.
  - 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.

## 7 ACKNOWLEDGMENTS

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