The paper was published in the proceedings of the 11th International Symposium on Field Monitoring in Geomechanics and was edited by Dr. Andrew M. Ridley. The symposium was held in London, United Kingdom, 4-7 September 2022.

INTERNATIONAL SYMPOSIUM 11TH FIELD MONITORING IN GEOMECHANICS

Monitoring prop loads in deep excavations, measurements and analysis.

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Abstract

This paper describes a project where loads were calculated from measurements of strain on a specially manufactured section of prop using vibrating wire strain gauges. The measurements were recorded on wireless nodes and transmitted for near "real-time" viewing on an internet-based data analysis and interpretation system. The results showed that the strains (and therefore the inferred loads) varied diurnally due to ambient temperature changes and this caused the measurements to trigger frequent alarms that the monitoring thresholds had been exceeded. The paper illustrates how the system can be used to fit curves through the measurements and if the curves rather than the fluctuating data is compared to the thresholds significantly fewer alarms would be triggered and a better understanding of the loads due to excavation is achieved.

Keywords: Excavations, Load Monitoring, Strain Gauges, Real-time Analysis

1. Introduction

A supported excavation generally consists of a retaining wall, with the ground outside the excavation at a higher elevation than the ground inside the excavation. The part of the retaining wall that is above the formation level of the excavation is required to support the ground outside the excavation and to do so it might require temporary or sometimes permanent props (struts) to do so without potentially damaging bending moments developing within the retaining wall. It is equally important to ensure that the loads, which develop in the props during excavation do not over-stress the props.

Structural loads can be measured using load cells or calculated from measurements of the strains that develop in the props during loading. Batten et. al (1999) presented a comprehensive review of the use of vibrating wire strain gauges to calculate loads in tubular steel props and concluded that the stress distribution over the cross-section can be very non-uniform particularly close to where the prop is attached to the wall. Furthermore, the importance of temperature variations was highlighted. A project where strains are being used to calculate the loads in props must therefore consider these points carefully.

Figure 1: Site arrangement showing load monitoring section.

In the project presented in this paper the strains were measured on a specially manufactured square section that was inserted between the main prop and the retaining wall close to the point where the two were connected (see figure 1). To justify measuring the load in this way a full-scale test was first undertaken in the fabrication yard to compare the applied loads with the measured loads.

2. Positioning of the strain gauges

An important aspect of calculating load in props using strain gauges is selecting where to place the strain gauges. Strain in a prop is made up of that due to axial loads and that due to bending, which originates from the self-weight of the prop. If the requirement is to measure axial load it should ideally be measured close to the neutral axes of the prop to minimize the effect of bending. In a circular or square hollow section this is at the centre of the hollow part of the prop and it is not possible to place a gauge there, so the gauges are typically placed on the outside (or inside) surface of the section, diametrically opposite one another in pairs. The section used for the tests and measurements presented in this paper is shown in figure 2.

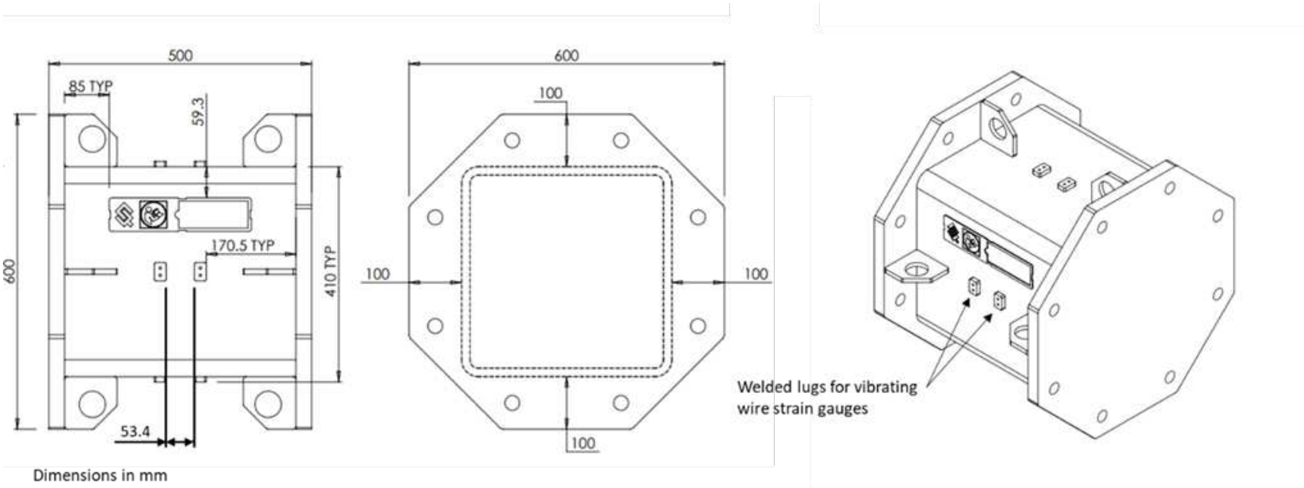


Figure 2: Load monitoring section.

Four arc weldable strain gauges were attached to each load monitoring section as shown and connected to an 8-channel vibrating wire wireless node. Wireless nodes were selected to reduce the need for cables to be run around the site and the consequent risk of the cables being damaged by construction work. The strain gauges had a range of 3000 microstrain and an accuracy of ±0.1% of the full scale. The gauges were attached to the load monitoring section using welded lugs and set-up at a mid-range to have adequate movement to record compression and extension. After the gauges and the node had been connected and tested, they were covered to protect them from the construction activity.

Figure 3: Load monitoring section showing strain gauges and protection to prevent damage.

3. Pre-installation tests

Before moving the load monitoring sections to site a test was undertaken on one of the load monitoring sections to see if the measured strains could be used to calculate a representative load. A reaction frame was fabricated to allow a prop and load monitoring section to be jacked, thereby applying known loads to the assembly (see figure 4).

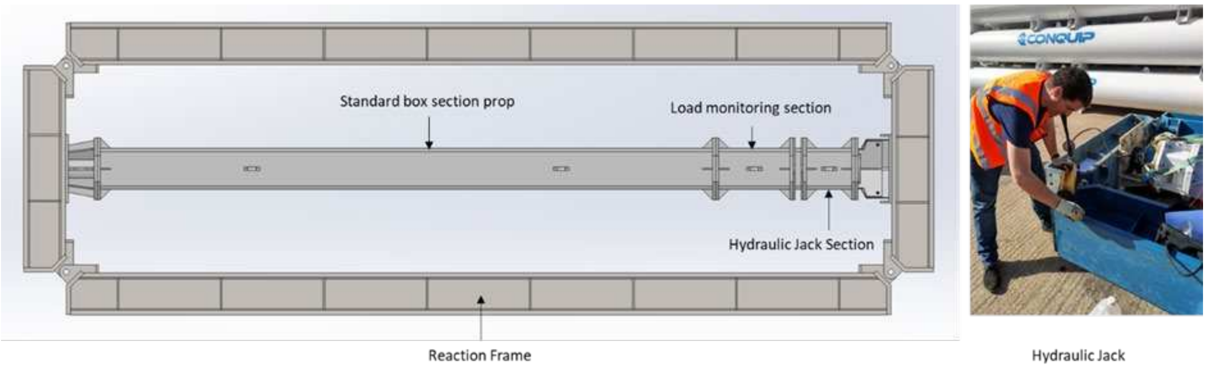


Figure 4: Test arrangement showing reaction frame and hydraulic jack.

The results of the test are shown in figure 5. Unfortunately, one of the strain gauges malfunctioned during the test and there was insufficient time to replace it. Of the three functioning strain gauges, gauge 1 (fitted to the top of the load monitoring section) recorded the highest strain, gauge 3 (fitted to the bottom of the load monitoring section) recorded the lowest strain and gauge 4 (fitted to one of the sides of the load monitoring section) recorded a strain that was almost exactly mid-way between the strains measured on the top and bottom faces and therefore the average of the three working gauges.

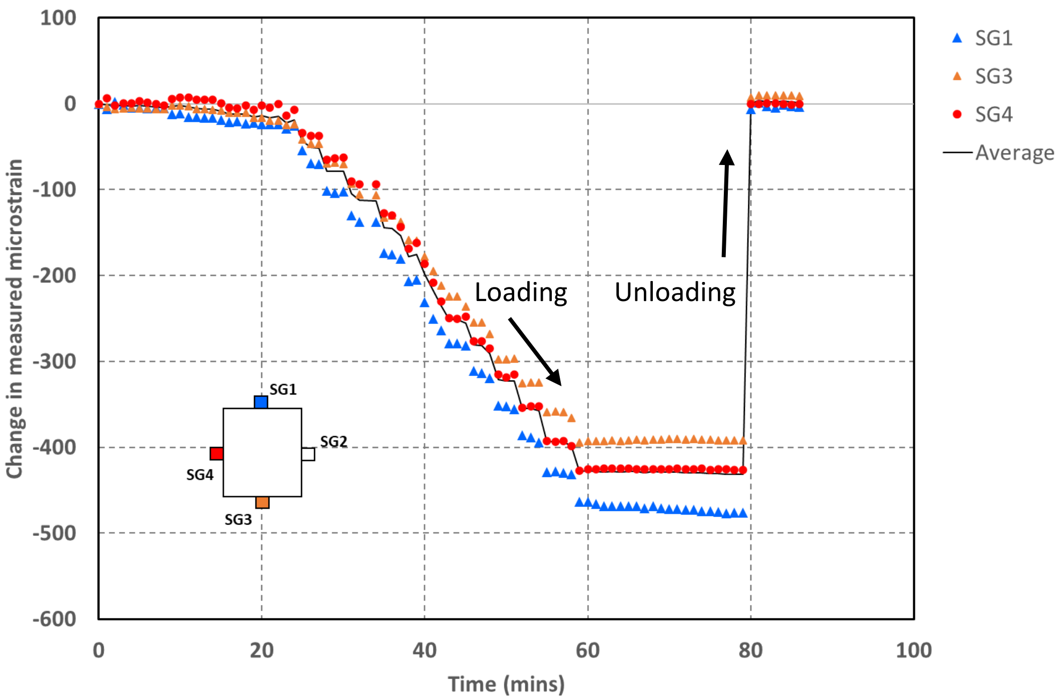
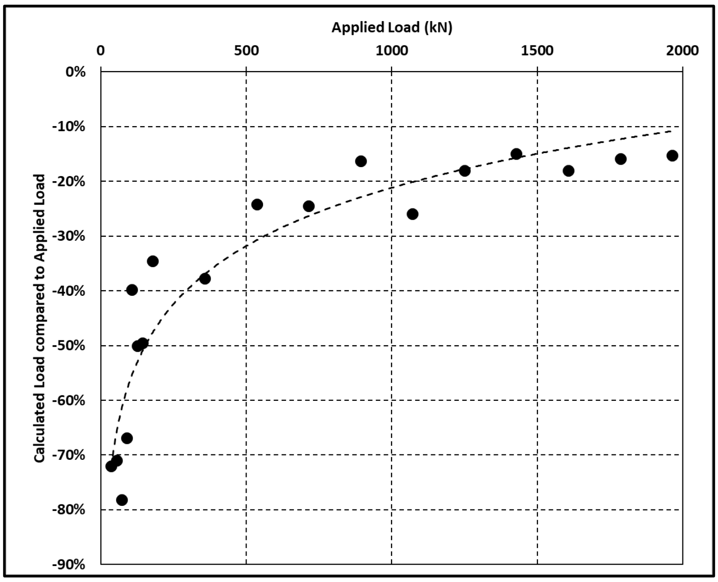


Figure 5: Results of pre-installation test.

A closer examination of the measurements revealed differences between the applied loads (calculated using the pressure gauge fitted to the hydraulic jack) and the calculated loads (derived from the average of the strains measured by the three functional strain gauges). However, the differences can be seen to be reducing as the applied loads increased and were tending towards a value between 10% and 20% less than the applied load at applied loads above 1500kN (figure 6). This supports the arguments put forward by Batten (1999) but could also have resulted from conformance errors in the system used to apply the loads or not enough time being allowed for each applied load to stabilise.



Applied Load (kN)	Calculated Load (kN)	Difference (%)
0.0	0.0	0.0
35.7	10.0	-72.1%
53.6	15.6	-70.9%
71.4	15.6	-78.2%
89.3	29.5	-66.9%
107.1	64.5	-39.8%
125.0	62.4	-50.1%
142.9	72.2	-49.5%
178.6	116.9	-34.6%
357.1	222.4	-37.7%
535.7	406.1	-24.2%
714.3	539.6	-24.5%
892.9	747.1	-16.3%
1071.4	793.2	-26.0%
1250.0	1024.4	-18.0%
1428.6	1215.2	-14.9%
1607.1	1317.9	-18.0%
1785.7	1501.6	-15.9%
1964.3	1665.1	-15.2%

Figure 6: Analysis of the pre-installation test.

4. On site measurements

Programme constraints meant that Insufficient time was available to reconsider and redesign the propping arrangement and they were installed as shown in Figure 7.

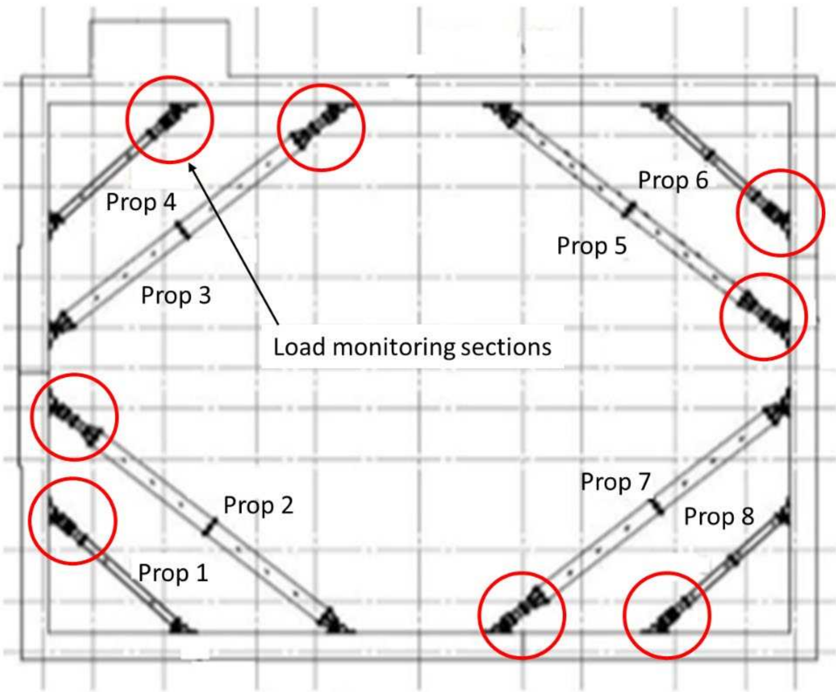


Figure 7: Propping arrangement on site.

The measurements were recorded at hourly intervals, collected remotely and automatically processed from strain into load by a "real-time" monitoring system using the following equation.

$$\text{Load} = E.\varepsilon.A$$

where E = Young's Modulus (kN/m^2), ε = change in average microstrain from the four gauges and A = cross-sectional area (m^2). A Young's Modulus of 210 kN/mm^2 was used for the steel

The system allowed easy analysis of the measurements such as plotting all of the strain gauges for a particular prop on the same graph as shown in figure 8.

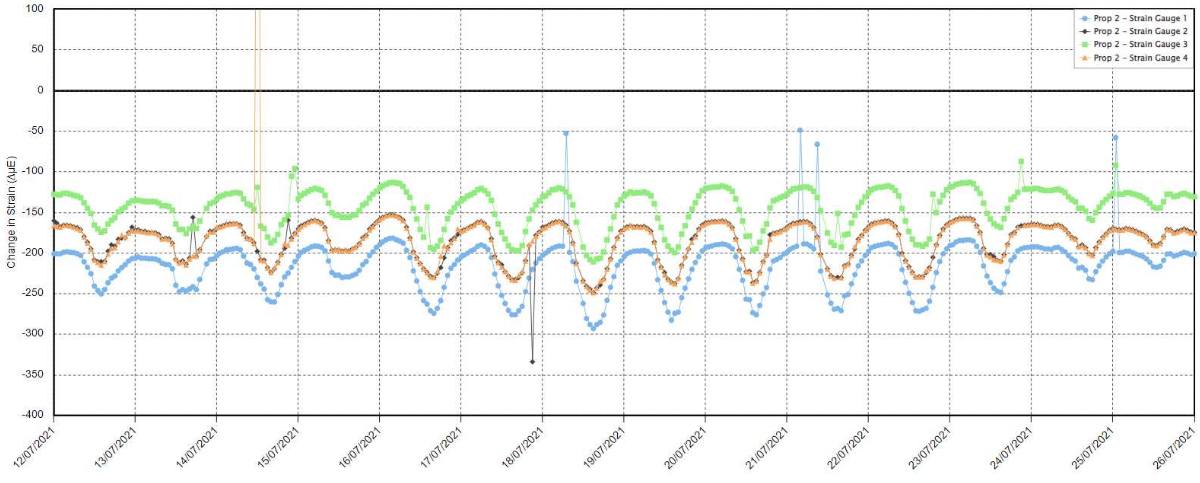


Figure 8: Strain gauge measurements on prop 2.

For the prop shown, it is easy to identify that the gauges on the sides of the load monitoring section (gauges 2 and 4) were recording strains that are very similar and mid-way between the strains that were recorded by the gauges on the top and bottom faces of the load monitoring section (gauges 1 and 3). It can also be seen that the load is following a diurnal pattern of behaviour. This can also be investigated using the "real-time" system by plotting the trend for the calculated load on the same graph as the trend for the average temperature recorded by the four gauges on the same prop as shown in figure 9.

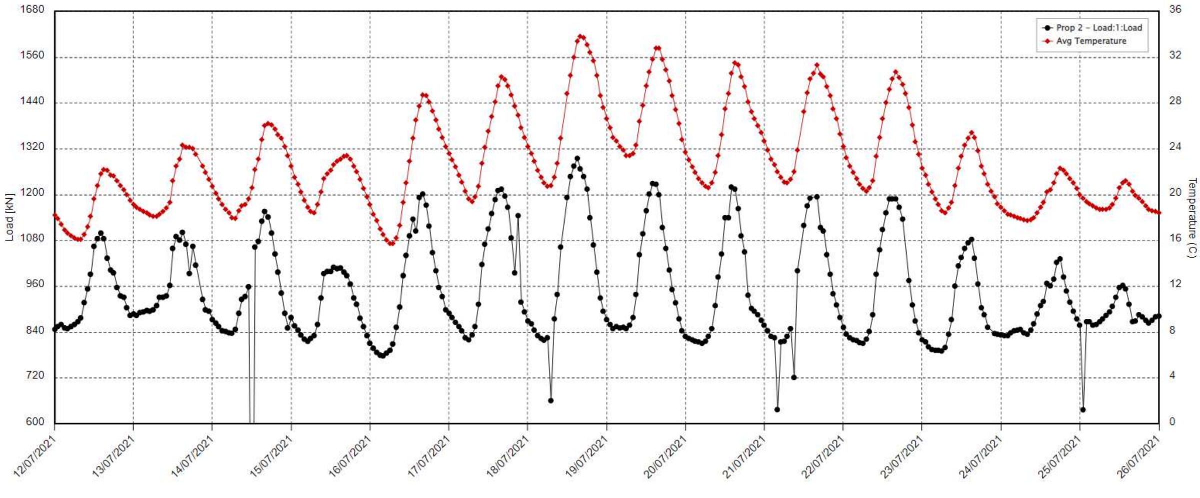


Figure 9: Calculated load and average temperature for prop 2.

The relationship between the temperature recorded by a strain gauge and the measured strain can also be examined by the “real-time” system as shown for one of the gauges in Figure 10.

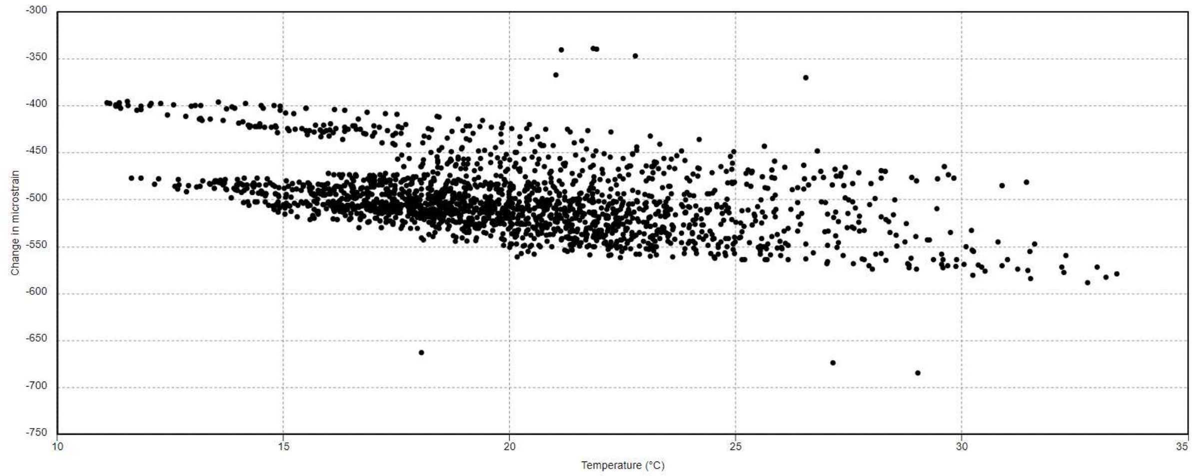


Figure 10: Temperature vs. microstrain relationship for Prop 2.

The graph confirms that there is a relationship, but it is not a simple one and therefore applying correction factors is not easy and moreover doing so would mask the affect of the temperature variations, which may be important in the overall context of the problem. The real problem is not necessarily that the diurnal variations due the temperature swings cause changes in the calculated loads, it is that they cause regular and repeated issuing of alarms as the thresholds are crossed (see figure 11).

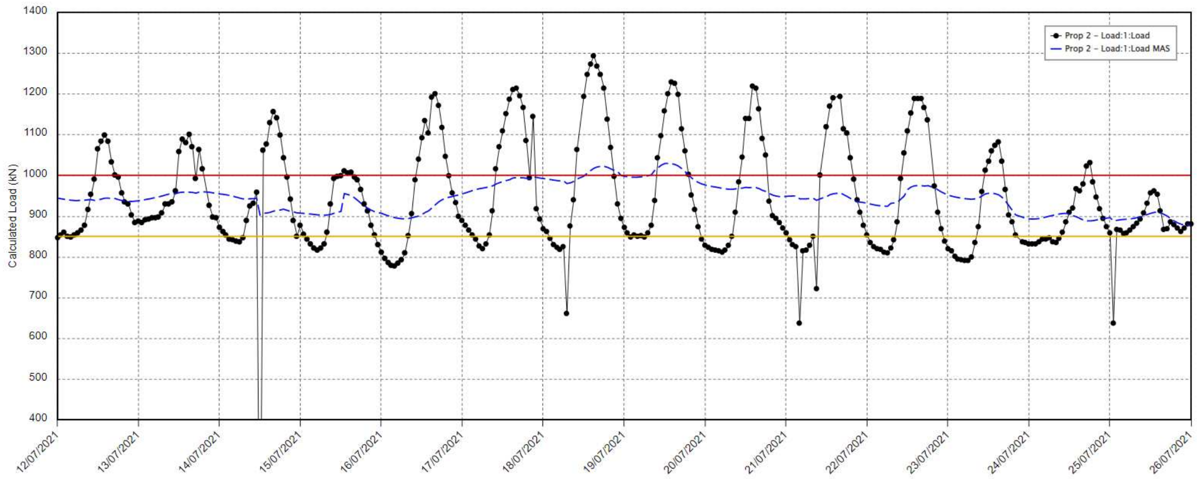


Figure 11: Analysis of calculated load for prop 2.

This can be handled through data management processes such as only issuing the alarm when the threshold is first crossed and not issuing alarms again until the measurements have passed over the threshold in the reverse direction, all of which can be handled by a remote system. Another way of handling it though is to calculate the measurements of load as a moving average over a suitable period (in this case 24 hours) as shown by the broken blue line in Figure 11. If the system can also be programmed to compare the moving average value against the thresholds and only raise alarms when this condition is met, the number of alarms will be significantly reduced without removing the obvious diurnal trends from the graph.

5. Conclusions and lessons learned

This paper has presented measurements of the strains in steel props used to help support an excavation and it has illustrated the uncertainties that can exist in such measurements when they are used to calculate loads. In the first instance, during a controlled test, the calculated loads were seen to be up to 30% lower than the applied loads in the expected range of the loads for the project. The difference was however seen to decrease as the applied load increased. In addition, the on-site measurements showed significant diurnal variations, which fluctuated up to 30% higher and 20% lower than the red threshold value. These variations will cause multiple triggering of alarms when static thresholds are used and the paper shows how a “real-time” monitoring system can be used to analyse the measurements and reduce the number of alarms to a manageable level.

A system of wireless nodes was used to collect and transmit the measurements to the “real-time” monitoring system and despite the small size of the site there were occasions when the data was not successfully transmitted and it was necessary to visit the site to reset the equipment. Relay nodes were helpful and a significant benefit was found in the fact that the wireless nodes stored data locally, which could be retrieved manually from the node and uploaded to the system manually. Not all wireless systems allow this.

Acknowledgements

The authors would like to thank Conquip Engineering UK Limited for providing the opportunity to perform this study and for fabricating the load monitoring sections and the props. The skill and diligence of Geotechnical Observations’ monitoring personnel is also acknowledged.

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