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SEASONAL IMPACTS UPON GEOTECHNICAL STRUCTURES

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ABSTRACT

Seasonal and diurnal environmental influences upon geotechnical structures, whilst often being apparent in hindsight, are not always identified during investigation and analysis. This paper attempts to bring to the attention of the geotechnical community that, whilst not necessarily anticipated, seasonal influences do indeed operate. This will be prosecuted through two examples wherein identification of environmental responses was afforded as a consequence of lengthy monitoring periods.

Firstly, the paper will discuss the measured response of a major anchored retaining wall which was part of the *Clearways Five, North and West Lines* project near Hornsby Station in the Sydney metropolitan rail network. Here, support of the proposed Down Relief track was critical and required construction of an anchored retaining wall on the limit of the rail corridor, adjacent to residential properties with below ground basements. The seasonal and daily response of the anchor loads has been recognised and found to relate to temperature change.

Secondly, the impact of underground longwall coal mining upon Main Line Railway operations has been managed to permit unimpeded and safe track operation, with unimpeded mining. In addition to track management, intervention measures were developed for a 100-year old, large diameter, brick arch culvert beneath the Main Southern Line. On-going monitoring of the brick arch culvert has permitted identification of mine subsidence induced effects through isolation of seasonal and diurnal environmental impacts.

Keywords: railway, infrastructure, geotechnical, environmental, thermal, mine subsidence.

1. INTRODUCTION

Monitoring of structures, as pioneered/perfected by Peck and other co-workers, has long been proven to be a viable method of managing construction. It should therefore be no surprise that during the rapidly evolving stages of construction, the monitoring data is primarily compared with either predicted or permissible performance of the structure being monitored. This focus on the events at the time of construction, together with subsequent reduction in monitoring frequency or the complete removal of monitoring altogether, has meant that observation of the “normal” response of structures is rare. In particular, and perhaps not surprisingly, there is a dearth of published monitoring data concerning the observation of the response of structures prior to a project beginning.

The response of a structure or a foundation may involve development and measurement of:

- Ideally, the onset of unacceptable movement or load development associated with collapse of some or all components of the structure/soil system; or
- The serviceability response – i.e. the movements or load generation expected from the selected design/service condition; or
- The “normal” movements or loads not directly predicted by design methods (and often ignored).

In the order listed above, it is to be recognised that the magnitude of the monitored quantities reduce. Issues arise with capturing the onset of significant unacceptable movements while still reliably recording the lesser movements that might arise; issues that need to be recognised in the instrumentation design.

2. MAIN NORTH AND WEST RAILWAY LINES - HORNSBY

The effects of temperature were detected in anchor load cell readings of the anchored-piled wall supporting the Down Relief track constructed as part of the Rail Clearways project at Hornsby. The wall design had to contend with the proximity of underground garage spaces for which detailed structural information was not available. The design was required to limit the influence of the wall upon the nearby basements and the permanent anchors were an integral component of this design. In recognition of the consequences upon rail operations of unacceptable performance of the anchors, a system of load cells and associated data logging hardware was installed to monitor the anchor loads. The data collected from the system could be downloaded as required at the site from the logger and readings at hourly intervals were collected for assessment of the anchor performance.

2.1 Results of monitoring

As a typical example of the response of the load cells with time, the response of Load Cell number 4 is presented in Figure 1. The upper trace is a curve of the measured temperature and is read from the right hand scale, while the remaining results are in terms of load and read from the left hand scale.

It is immediately apparent that considerable scatter was occurring in the readings, related to the change in temperature measured in the data logger. The sudden drop in readings in July 2010 and March 2011 were associated with a phenomenon noted in many data logging systems, where readings are apparently presented in the wrong or a skipped channel order. This problem is infrequent and only becomes apparent after many readings (such as were taken here) and appears related to timing/frequency issues in the logger's software/hardware. These errant readings were located easily and were not an issue for this work. However, it is likely that other applications, involving automated responses to exceeding allowable readings, may be challenged in such a real time scenario.

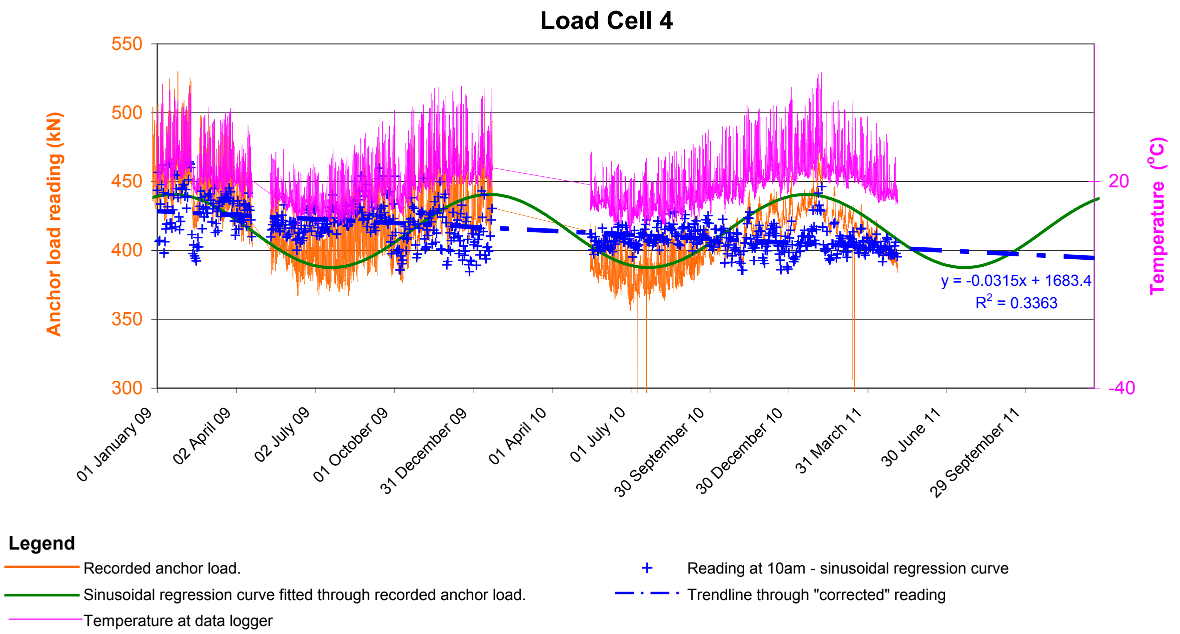
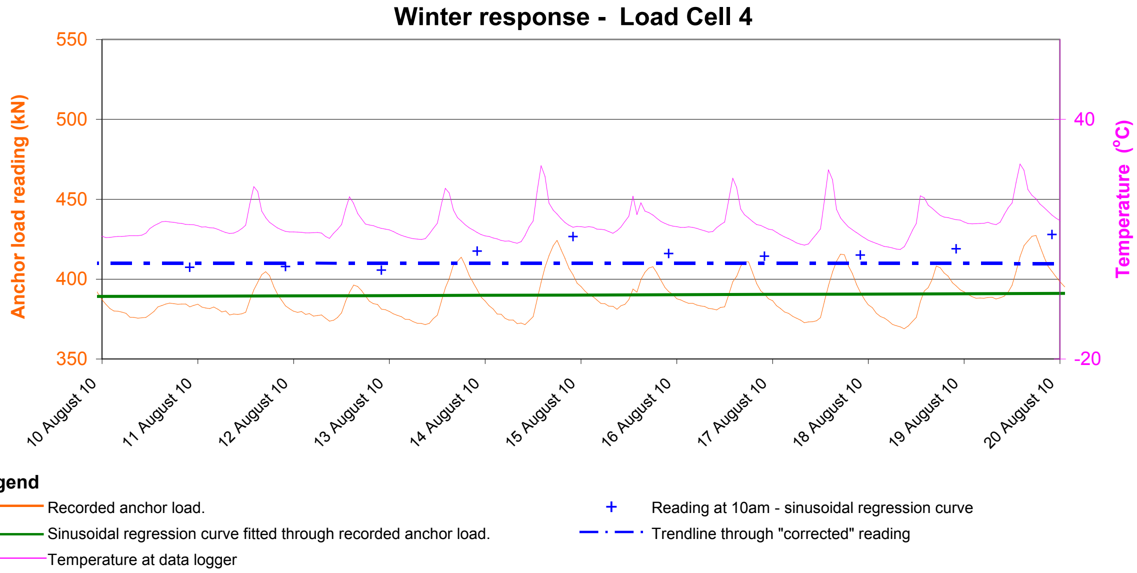


Figure 1: Response of Load Cell 4 - hourly readings versus time since January 2009.

In recognition of the observed seasonal temperature variation, a sinusoidal curve with a period of 365 days was fitted through the load cell data. After comparing the actual readings and the fitted curve, it became apparent that the bulk of the readings were in the lower range of the scatter; further, by reference to the cyclic annual nature (with constant mean and amplitude from assuming each year the seasonal impact is identical) of the sinusoidal curve, the running mean of the readings was becoming slightly below the fitted sine curve. To better assess the long term performance of the anchors it is possible to subtract the seasonal impact related sinusoidal curve from the actual data readings (here taken at 10AM to limit the quantity of data) and to add this adjusted difference to the mean of all the raw readings and this is plotted in Figure 1 as crosses. The addition of the mean does not imply that the load in the anchors is exactly that value but it provides a consistent method of comparing loads with time. The trend line through these "corrected" loads clearly shows a small inferred load drop.



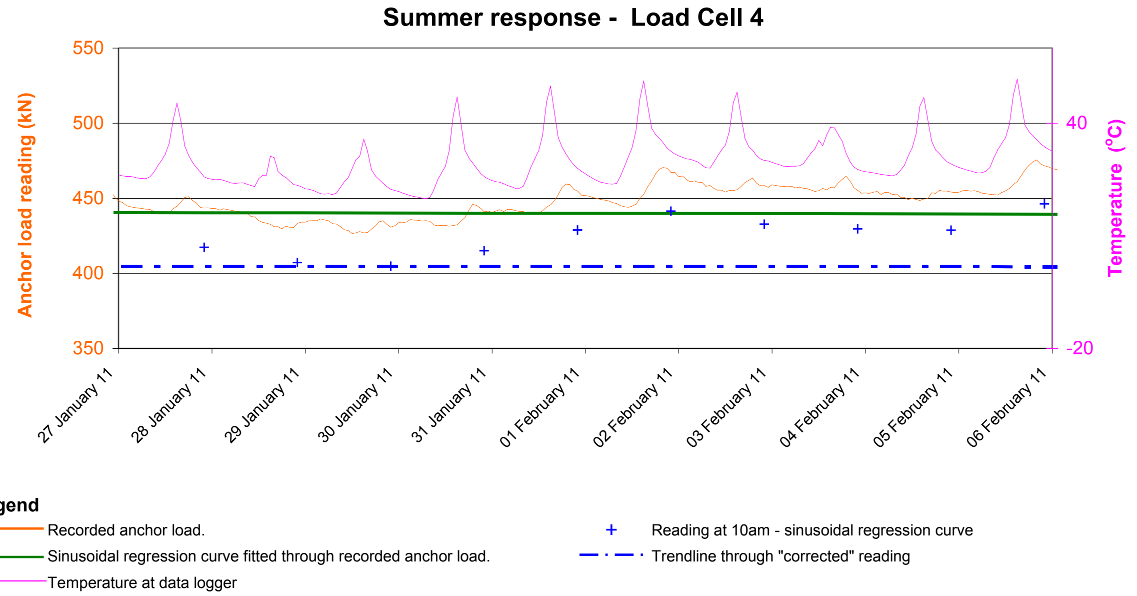


Figure 2: Summer and winter response of Load Cell 4.

It is clear that summer and winter have different effects upon the load cell readings. The summer readings display an increased impact from the hotter sun during the day, with taller spikes in temperature as measured at the logger, but a muted load cell reading variation in comparison with winter. It is likely that the variation in the angle at which the sun strikes the logger and the load cells along the wall combine to produce this response. It is noted that the 10 days of readings depicted during summer in Figure 2, does not reflect the generally better fit evident in Figure 1 over summer.

2.2 Conclusions with respect to environmental response of anchored wall

It is found that temperature measurements can provide a rationale for proposing the impact of seasonal effects being evident in load cell readings of an anchored pile wall. The daily environmental impact, as evidenced in the load cell readings and the temperatures recorded in the logger, is less well correlated, however a difference between diurnal summer and winter responses is clearly observed. Notwithstanding that the measurements display a complexity, thought to be a result of such effects as the orientation of the load cell within the wall and/or logger position, the trend with seasonal influences is reasonably well catered for by the methodology adopted. The resulting compensated trend line through “corrected” data permits the capture of trends previously masked by the seasonal trends in the readings. A rational assessment of the load cell readings the result.

3. MAIN SOUTHERN LINE INFRASTRUCTURE AT MYRTLE CREEK

3.1 Myrtle Creek culvert (MCC)

The Main Southern Rail Line crosses Myrtle Creek Culvert (MCC) just north of Tahmoor station, upon a filled embankment some 10m high that runs from rim-to-rim of the creek “valley”. MCC consists of a brick arch constructed in the early part of the 20th century (c1917), with an inverted horseshoe shape of brick on-edge masonry. The brickwork was (and remains) in good condition. An impression of MCC can be obtained by reference to photographs in Leventhal et al (2012) [companion paper in this proceedings] which included details including the site setting, the longwall mining being conducted and issues related to the management of mine subsidence influences upon the Main Southern Railway line near Tahmoor in the Southern Tablelands of NSW.

3.2 Predicted subsidence impact

As expected, mine subsidence impact upon Myrtle Creek consisted of vertical subsidence, horizontal whole body displacement both towards and then following the longwall face, closure of the creek sides and upsidence in the base of the creekline. Creek closure was identified as the critical design condition for the brick arch culvert and the primary intervention measure consisted of steel ribs. The anticipated displacement response was closure of the ribs in the horizontal direction with extension in the vertical direction. The potential culvert failure mechanism did not involve a snap-through buckling collapse mechanism, principally as a consequence of analogy with a thick walled cylinder.

An important feature in understanding the response of MCC to mining induced creek closure is recognition that the brick arch culvert response was *strain-driven* rather than the conventional engineering concept of a soil-structure interaction stress-driven response. The importance of this is that when subsidence related creek closure displacements cease, so too does further impact upon the culvert structure. The mine subsidence mechanics at ground surface are strain-driven by complex realigning of strata to accommodate strains involved in creation of the longwall mining goaf.

3.3 Response of Myrtle Creek culvert to retreat of LW25

After appraisal of monitoring results (tape extensometer readings in the plane of selected ribs), it became apparent that the culvert produced monitoring results that were initially as predicted, but which then became counter-intuitive (and were believed anomalous). The response was investigated and became recognisable as the structure responding to a thermally driven environmental influence, as reflected in the temperature readings within Figures 3 and the horizontal and vertical closure across the ribs in MCC in Figure 4, upon which subsidence impacts were superimposed. The temperature values in Figure 3 clearly demonstrate both the annual response and diurnal high frequency variation, as would intuitively be expected. The tiltmeter data has internal temperature compensation in the instrument and the plotted cumulative deflection is not temperature sensitive, unlike the rib responses.

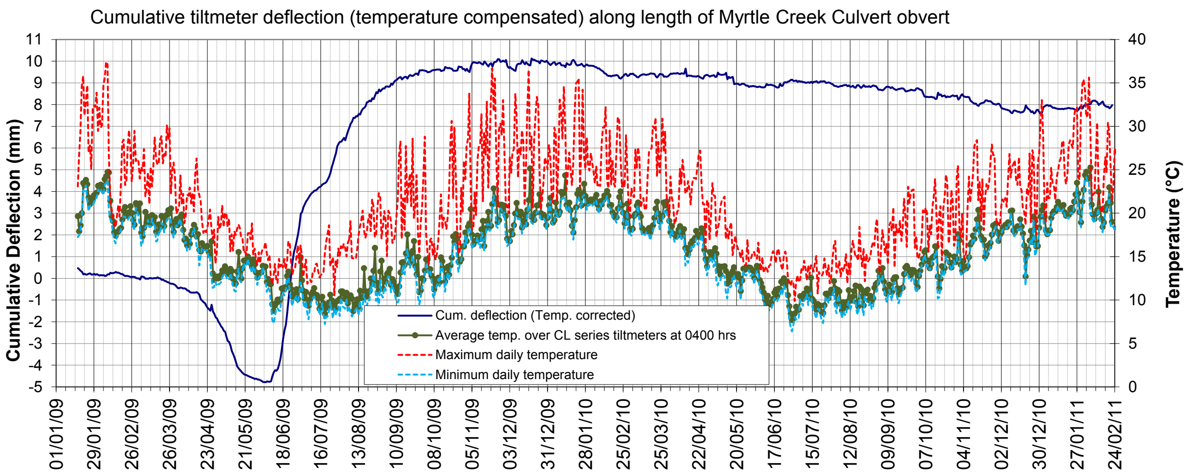


Figure 3: Seasonal temperature measured at MCC from tiltmeter derived data.

The magnitude of the seasonal response of the rib instrumentation was not expected, principally (it is reasonable to say) because the magnitude of the initially observed (combined) responses was believable, and that a history of monitoring was not in place sufficiently in advance of mining influences reporting to MCC. It is noted in this interpretation that MCC has been under the influence of the seasonal and daily environmental influences for the last century. Presumably, this applies to many other, if not all, similar brick arch culverts (and other geotechnical structures).

The response of MCC to the retreat of LW 25 was predominantly as a thick-walled tube. It is clear from the response of the ribs that an environmental seasonal response is observed, with higher frequency diurnal responses overprinting the annual seasonal response. Translational off-sets to the seasonal response have been assigned to the valley closure influences induced by mine subsidence. By way of illustration, the interpretation of the combined seasonal, diurnal and subsidence impacts upon the intervention elements is provided within Figure 4 for two of the monitored ribs, being the vertical and horizontal responses for Rib 1, which is the westernmost rib (UP side) and Rib 17 which is near the centre of the culvert length. [Ribs 1 and 17, out of a total of 38 ribs, are illustrative of the measurements obtained from the ribs within the culvert].

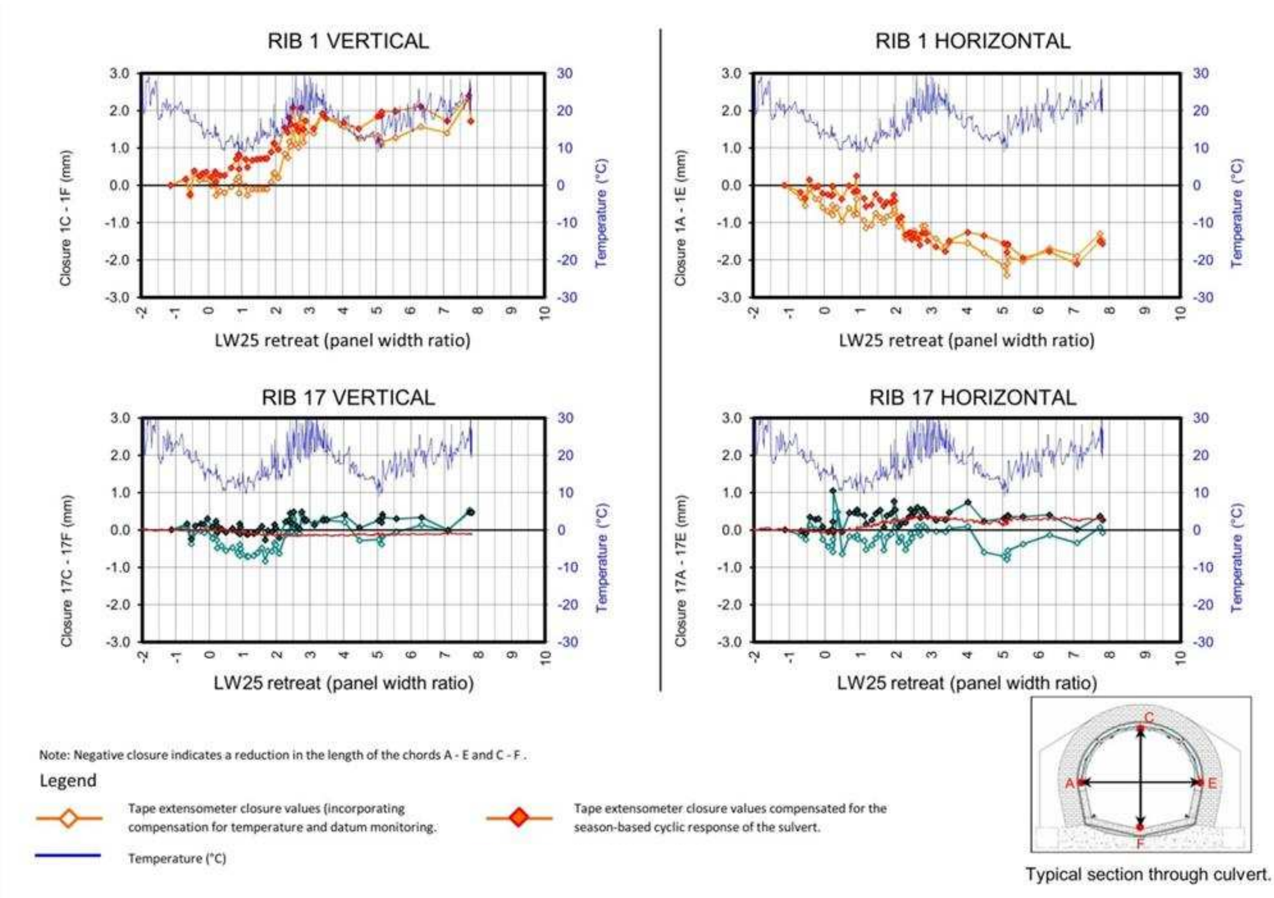


Figure 4: Response of two ribs within MCC to the retreat of LW25.

The readings (with temperature and instrument corrections) are shown as the open circles, whereas the readings adjusted for seasonal correction are depicted with the solid dots.

The challenges associated with the initial interpretation are illustrated with reference to the uncorrected response of Rib 1 in the vertical direction. The early time response is indicative of a different, out of step horizontal and vertical reaction by the rib to retreat of LW25, whereas the seasonally compensated readings illustrate that the main response (both vertical and horizontal) did not occur until a retreat of about 2 panel widths passed MCC. Whilst a similar response is seen for Rib 17, the compensated responses at Rib 17 are suppressed and could be considered minor at most. This demonstrates that there was little nett response in the centre portion of the culvert.

This is an important issue when attempting to manage the response of the culvert to creek closure, since trigger levels for displacements are of similar magnitude to the seasonal responses (“breathing” of the culvert), and this becomes a challenge for investigators, miners and regulators in recognition of the response and management of it. The benefit of long lead-time monitoring is important.

Other responses observed in Figure 4 include:

- the general sinusoidal response of the readings prior to compensation which mimic the seasonal response;
- that a slight lag existed between the seasonal temperature variation and the response of the ribs (attributable to thermal inertia);
- that there remained some minor variation following the seasonal compensation, which is assigned to diurnal influences;
- the westernmost Rib 1 responded with horizontal closure and reciprocal vertical extension, consistent with an arched frame response. The response in the central portion of MCC, as illustrated at Rib 17, was much suppressed.

The maximum displacement from the seasonally compensated tape extensometer readings attributed to creek closure was 1.7 mm and the maximum amount of vertical opening was 1.9 mm (both recorded at Rib 1). The closure response along the culvert was variable, with the greatest response at each end and the least within the mid-section. Having noted that, it is clear from the figures that the ribs along the length of MCC have responded to mine subsidence induced creek closure during the retreat of LW25.

3.4 Conclusions with respect to environmental response of Myrtle Creek culvert

The brick arch culvert has existed for about 100 years, and has presumably responded to environmental influences through cyclic expansion and contraction. Annual response of the steel ribs, and by inference the brick arch culvert itself, is recognisable within the monitoring results together with higher frequency daily diurnal responses. Subsidence induced creek closure has been imposed upon these cyclic events, and through corrections to readings for seasonal impacts has been identified within the monitoring results. Strengthening of the brick arch culvert at Myrtle Creek was prudent given the results inferred from the monitoring.

4. CONCLUSION

When the seasonal and daily response of a structure to environmental effects is not insignificant in comparison with the serviceability response, the benefit of designing and implementing a monitoring regime to assess these environmental effects (beforehand in particular) will be apparent.

5. ACKNOWLEDGEMENTS

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