Geotechnical Instrumentation NEWS

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John Dunnicliff

Introduction

This is the fifty-ninth episode of GIN. Two articles this time.

More on Fully-grouted Piezometers

Iván Contreras and his colleagues at Barr Engineering in Minneapolis wrote a two-part article for June 2008 GIN, “The Use of the Fully-grouted Method for Piezometer Installation”. Following the article there’s a discussion in which I wrote, “In my view, the rationale for accepting the fully-grouted method is very convincing. Despite that view, owners and their consultants may tend to be wary of what they consider to be a ‘new and radical’ method.” I summarized the experiences of various colleges from around the world who had used the method successfully, saying that and if we’re to convince owners and their consultants, we need as much supportive information as possible.

After reading that article and discussion Daniel Weber, a hydrogeologist with Errol L. Montgomery & Associates, Inc. in Tucson, AZ, sent me an enthusiastic e-mail in support of the method, and I asked him to share his experience with us all. Here it is. I was particularly interested both in the large depths of the boreholes, and also in the fact that, like Erik Mikkelsen and the engineers at Barr, water and cement are mixed first, then bentonite is then added to the water/cement mix to achieve a thick and creamy textured but still pumpable grout.

More on Factors that Influence the Performance of Strain Gages

The article by Osborne and Tan is a real eye-opener for me, in that it so clearly explains what we have to do to make sense out of vibrating wire strain gage readings. Among the various factors that influence the readings, the authors follow up on four previous GIN articles that discussed the influence of temperature. The references for those four are included in the current article.

GINs Available on the Web

Starting with a GIN in 2001, 26 episodes thru December 2008 can now be downloaded from http://www.bitech.ca/news.htm. We plan to post the four quarterly episodes for each year at the end of that year. We’re also looking into the possibility of a search function for words in the article titles and for the names of authors.

Next International Symposium on Field Measurements in Geomechanics (FMGM)

As many of you will know, FMGM symposia are organized every four years, the pervious one being in Boston in September 2007. The next FMGM will be in Germany in September 2011. Watch this space for details.

March Instrumentation Course in Florida

This year’s course was attended by 59 registrants from seven countries. One highlight was a launch of the space shuttle on the first evening of the course, a few miles along the beach. How’s that for scheduling? The next course is expected to be at the same location in Cocoa Beach in March 2011. Details will be on http://conferences.dce.ufl.edu/geotech/ nearer the time, without a guarantee of a launch

Uncertainty and Ground Conditions - a Risk Management Approach

There's a growing acceptance among our geotechnical community that cost- effective management of risk is one of the keys to the success of our construction projects. However, risk may often be assessed and managed in a haphazard way, but a recent book provides us with a guide to formalize a step-by-step procedure for managing risk. The author, Martin van Staveren, is an engineering geologist, working in The Netherlands, a large part of which is below sea level and protected by levees, hence risk management is crucial. I'll be writing a review of the book for the next issue of *Geotechnical News*. The book is published by Elsevier (www.books.elsevier.com), ISBN 0-7506-6958-6.

Closure

Please send contributions to this column, or an article for GIN, to me as an e-mail attachment in MSWord, to john@dunnicliff.eclipse.co.uk, or by mail: Little Leat, Whisselwell, Bovey Tracey, Devon TQ13 9LA, England. Tel. +44-1626-832919.

Khushraho (India). Does anybody know what this means?

In Support of the Fully-grouted Method for Piezometer Installation

Daniel S. Weber

The hydrogeologists at Errol L. Montgomery & Associates, located in Tucson, Arizona, and Rio Tinto's Resolution Copper Company, located in Superior, Arizona, read with great interest the recent discussion by John Dunnicliff in Geotechnical Instrumentation News (GIN) on fully-grouted piezometers (Geotechnical News, June 2008). Also, the articles by Contreras and others presented in the same issue are admirable and confirm work we have been practicing, mainly in the field of mining hydrology, for monitoring deep pore-water pressures in multiple aquifers near mining operations.

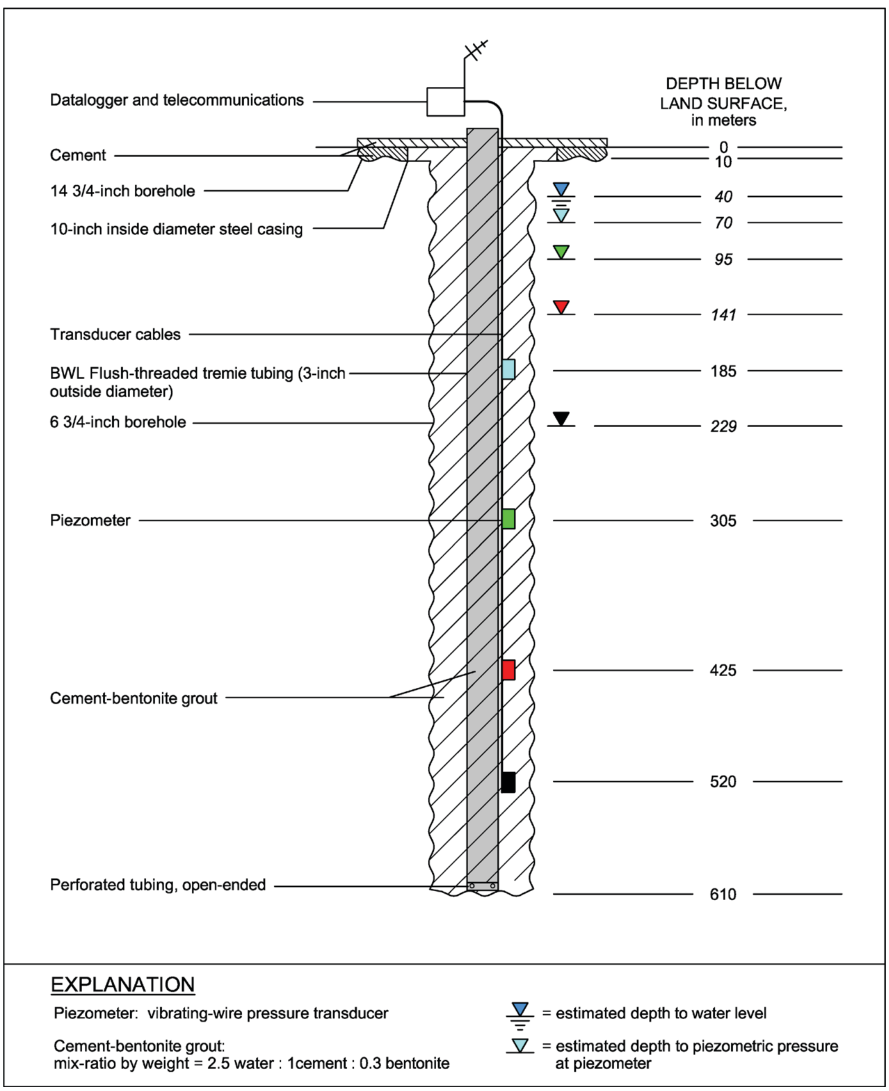

Figure 1. Schematic diagram of typical construction for fully-grouted nested piezometers in a borehole. To achieve the required strength of the cured grout, water and cement are mixed first. Bentonite is then added to the water/cement mix to achieve a thick and creamy textured, but still pumpable grout.

Here are two construction schematics for your "library of believers". Figure 1 shows our practice of grouting boreholes and resulting hydraulic head configuration, depicting downward hydraulic gradient. Figure 2 shows a more complicated construction procedure for deep well installation (total depth about 1,800 m). In this set-up, we strap our piezos to the outside of intermediate casing for monitoring pore-water pressures in an upper aquifer and a thick confining unit. We use a grouting service company (e.g., Halliburton) to pressure grout the annulus prior to drilling and construction of the lower part of the well. Both installations currently monitor piezometric pressure changes during dewatering operations of a large underground mine near Superior, Arizona.

We will be presenting this work at a Deep Groundwater Characterization session during a National Ground Water Association meeting here in Tucson this spring (Weber, D.S., Hall D.G., Keay T.K., Thomasson, M.J., and Davis, L.A., 2009. *Using Fully-grouted Nested Piezometers for Deep Aquifer Characterization*, NGWA Ground Water Summit, April 19-23, 2009, Tucson, Arizona, USA). Contributions in GIN are in our references and sincerely appreciated. For more information, please contact me at the e-mail address below, or Todd Keay at tkeay@elmontgomery.com, or Greg Ghidotti at Gregory.Ghidotti@riotinto.com.

Daniel S. Weber, Hydrogeologist, Errol L. Montgomery & Associates, Inc., Tucson, AZ 85719, email: dweber@elmontgomery.com

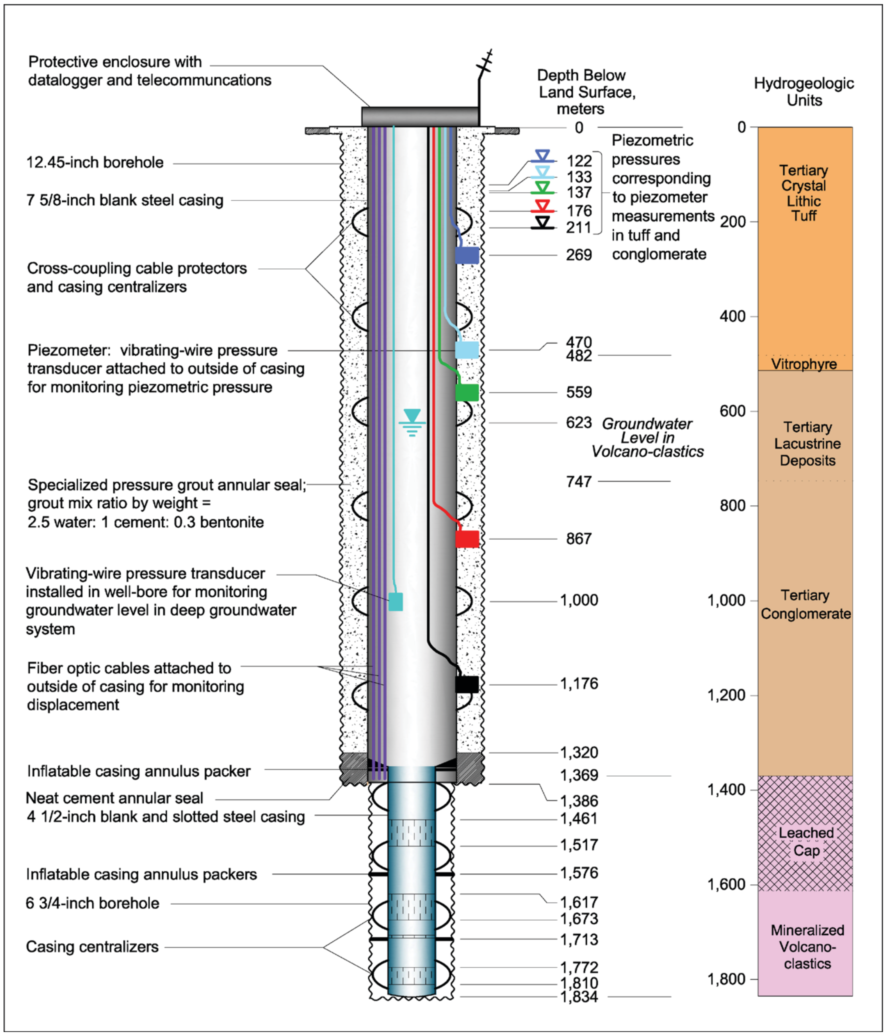

Figure 2. Schematic diagram of well construction for specialized installation of fully-grouted nested piezometers in the annular seal of deep groundwater monitoring well for Resolution Copper Mining, Pinal County, Arizona.

Factors Influencing the Performance of Strain Gauge Monitoring Systems

Nick Osborne
G. H. Tan

Load monitoring of support struts in deep excavations plays a crucial role in confirming the stability and safety of the excavations. Much of this monitoring is undertaken by strain gauges which are linked to automated alarms via real-time systems. The success of the monitoring is directly linked to the performance of these sensitive strain gauges, the reliability of the real-time system and the interpretation of the data. However there are numerous factors that can interfere with this monitoring process, corrupting the quality of the data, resulting in a loss of confidence in the system, therefore making the instrumentation worthless. The emphasis must be on the production of high quality data, which can dependably be processed and rapidly given to the end user for interpretation, in a seamless process from strain gauge to computer or mobile phone. To achieve this, the potential malignant influences need, where practicable, to be identified, understood and removed. They can range from Electromagnetic

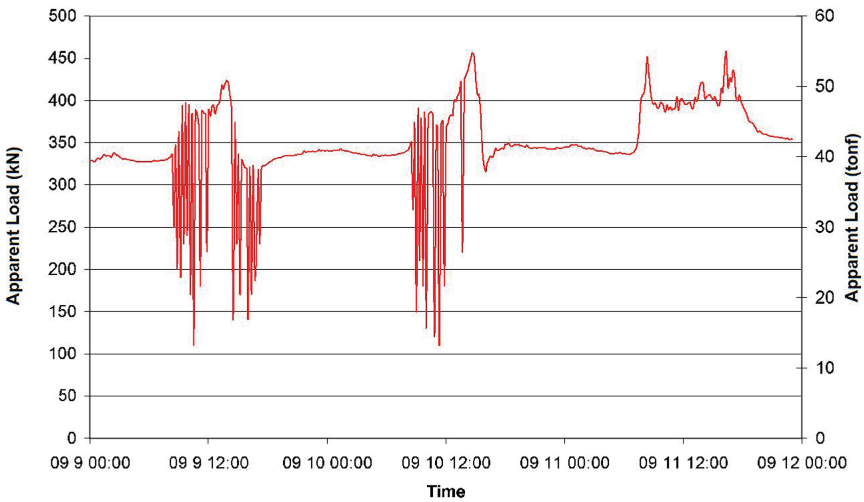

Figure 1. Impact of EMI noise on measurement of apparent load.

Interference (EMI), temperature, various construction activities to total system failure.

Following on from a paper presented at the symposium on Field Measurements in Geomechanics (FMGM) in Boston in September 2007, with sections reprinted with permission from ASCE, experiences of strain gauge monitoring in Singapore are reviewed. Here for deep metro excavations 25% of all temporary struts are required to be monitored in real-time by strain gauges, producing vast amounts of monitoring data, making quality data essential. The key problem areas are discussed and recommendations made to maximize the production of high quality and reliable monitoring systems.

Impact of Electromagnetic Interference

As vibrating wire strain gauges operate at a frequency between 600 to 1500 Hz, they are subject to EMI. This compromises the accuracy of the readings by introducing noise into the raw data, which can be very difficult to separate from genuine data, and therefore can be processed and calculated as load. There are numerous potential sources of EMI noise on construction sites including: arc welding, machinery ignition, power generators and power cables on the site. The noise takes one of two forms. First, as a general underlying trend impacting the overall accuracy of data by increasing its spread. Second, as a high voltage surge, causing a spike in the load readings when, for example, a machine ignition is started. Electronic noise tends to result in a reduction in strain gauge reading, whereas magnetic noise increases the strain gauge readings. With the advent of real-time monitoring and data processing at ten minute intervals or less, the impact of this interference becomes even more significant. A reduction in strain gauge reading results in a general questioning of the accuracy of the strain gauge monitoring as the accuracy range appears wider and there is no obvious reason for a reduction. The consequences of a sudden increase in readings are more dramatic and can result in monitoring alarms being reached, with the potential for work to stop unnecessarily.

The influence of EMI noise can be clearly seen in Figure 1. During the working day on 9 and 10 September 2005, EMI from a generator and power cable caused 200kN (22.4 tonf – tons force) fluctuations in apparent load. The lunch hour can be clearly seen, when the generator was turned off. By 11 September the noise had been identified and the generator removed, hence more stable readings were obtained.

Recent developments demonstrate that there is a more permanent solution to eradicating EMI. This lies in how that frequency of the vibrating wire strain gauges is actually measured. Traditionally frequency has been measured by the Frequency Counting Gating (FCG) method, which counts the number of pulses within the FCG over time, to determine the frequency and consequently incorporates any EMI. However if the same signal is transformed into the frequency domain by fast Fourier Transform (FFT), the resonant frequency can be clearly identified as the value at which the amplitude peaks, thus eradicating any EMI. Dataloggers using FFT are available both in Singapore and world-wide and should

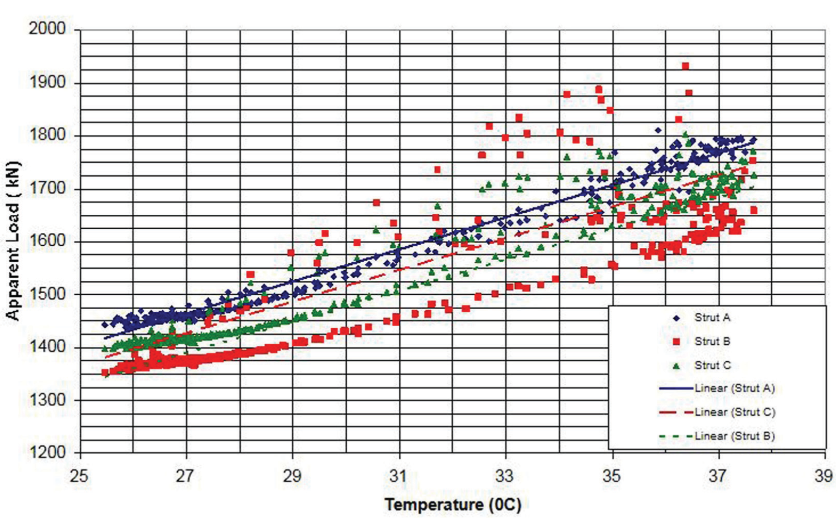

Figure 2. Impact of temperature on apparent strut load.

always be employed within the real-time system.

Temperature Effects

The issue of temperature impact on strain gauges has been long recognized and has been discussed in earlier episodes of GIN:

- Boone S.J. and Crawford A.M. (2000). "The Effects of Temperature and Use of Vibrating Wire Strain Gauges for Braced Excavations", Geotechnical News, Vol. 18 No. 3, September, pp 24-28.
- Druss D.L. (2000). "Discussion: The Effects of Temperature and Use of Vibrating Wire Strain Gauges for Braced Excavations", Geotechnical News, Vol. 18 No. 4, December, p 24.
- Boone S.J. and Bidhendi H. (2001). "Strain Gauges, Struts and Sunshine", Geotechnical News, Vol. 19 No. 1, January, pp 39-41.
- Hashash M.A. and Marulanda C. (2003). "Temperature Correction and Strut Loads Interpretation in Central Artery Excavations", Geotechnical News, Vol. 21 No. 4, December, pp 30,31

However, temperature impact remains an issue. Singapore lies 1.5 degrees North of the equator and experiences minimal seasonal variation in temperature, but a significant diurnal range, with temperatures fluctuating from a low of 20^{0}C (68^{0}F) to a high of 36^{0}C (98.6^{0}F) , posing temperature issues on a daily basis. For a 25m (82ft) deep excavation in soft marine clay on the Circle Line project an apparent increase of about 30kN (3.36 tonf) per 1^{0}C (1.8^{0}F) was measured on three different struts over four day Comparing this to a theoretical increase of 48kN (5.376 tonf) per 1^{0}C (1.8^{0}F), in the case of full end restraint, this equates to only 62.5% of the increase manifesting itself as an increase in strut load. The critical factors in mobilizing the full effect of the temperature lie in the relative stiffness of the retaining system and the ground. Dependent on the ground and retaining system, it is not unusual to see temperature increase push the retaining wall system back into ground, with movements of the order of 2mm (0.08 inch) having been observed on a stiff 1.5m (4.9 ft) thick diaphragm wall. This phenomenon has seen recorded elsewhere in Singapore and in locations in the USA.

... temperature can have significant implications on the work, by apparently pushing the strut over its design capacity.

Measured strut loads are very important for monitoring control of excavations. Although the temperature range is relatively small in Singapore, and therefore the impact on apparent load is less than in most other places in the world, this does not lessen the importance of temperature effects; in fact it can become a daily problem when using real-time monitoring. Typical daily fluctuations due to temperature alone of 330kN (36.9 tonf) are observed, generally across the full length of the strut as it is the ambient air temperature driving the increase in apparent load. The maximum design load of a strut, using moderately conservative soil parameters, is used as the level for suspension of work, with an alert set at 70% of this capacity. If temperature effects are not properly accounted for, temperature can have significant implications on the work, by apparently pushing the strut over its design capacity. However, it should be remembered that the ultimate capacity of the strut is far higher than the design capacity. A number of different solutions to this problem include painting struts white, and daily spraying to reduce temperature impact. It is suggested that the most appropriate solution is to account for the theoretical temperature effects during design and to add them to the monitoring control values to ensure that work is not impacted unnecessarily.

Construction Effects

As the excavation proceeds the load in the struts increases and occasionally decreases, dependent on the various construction activities. It is important to understand all these contributory factors fully, and to interpret the strain gauge results in conjunction with the construction activities. If this isn't done, genuine strain gauge data may be dismissed as inaccurate, and valid data may be ignored, leading to a reduction of confidence in the monitoring. The impacts from construction are numerous and varied, ranging from the more obvious such as impact and damage by construction plant to the more intricate load changes during preloading. Some of the more notable effects experienced in Singapore are detailed below.

Welding is one of the construction effects that can result in erratic strain gauge readings. High heat generated from the welding of additional horizontal supporting systems providing lateral stability to the main strut member can result in high and sudden apparent increases in the strut loads. Welding of these supports usually commences after the struts are preloaded. The impact generally follows the same pattern, a sudden drop in readings of apparent load, probably associated with EMI noise, followed by a sharp increase which, depending on exact proximity can lead to increases in the order of 600kN (67.2 tonf). Again dependent on the proximity of the gauge to the welding, on completion the affected gauge may not recover to its original reading, but instead remain at its elevated level. This apparent load is obviously not representative of the overall load in the whole strut. However once this effect is identified from the readings and construction activity, the strain gauge readings can be adjusted to account for it.

Another construction impact on temporary supports, and their strain gauges, is the effect of casting of permanent components of a top-down excavation. During the casting of a 1.5m (4.9ft) thick roof slab, the impact of the curing and expansion of the slab influenced the apparent load in two layers of struts above the roof slab. A significant drop of 500kN (56 tonf) was recorded across the full excavation, followed by an increase several days later and a return to the ongoing trend of the load. Once clearly identified, this pattern can be easily linked to construction activity, and not used to cast doubt on the accuracy of the strain gauge results.

Negative loads in the top struts are commonly observed in deep excavations in soft clays. This is frequently blamed on the instruments themselves and regarded as erroneous readings. However, investigations into a number of these cases have identified that the strain gauges are functioning well and indicating genuine loads. Independent checks by cut-off tests and inserting jacks have demonstrated that these struts are in tension. This can be attributed to a combination of factors: the loads in the struts at the higher levels tend to be originally low, therefore a only a small loss is required for negative numbers; loss of the preload; and the movement patterns of the retaining wall as the excavation progresses. With soft clays, movements in excess of 100mm (4 inches) have been recorded, with these deep seated movements occurring below excavation levels. As the excavation progresses, stiffer struts with greater preloads are used. Combined with these large movements below the struts, the retaining wall can rotate about the strut, resulting in a small backward movement into the soil at the higher level. This is also reflected in inclinometer readings.

Real-time Systems

To make the most effective use of strain gauge data for deep excavations it is prudent to link the instruments, via a datalogger, to the office computer and mobile phones in a seamless fully-automated machine to machine (M2M) system. It is strongly recommended that the capacity for data transfer of any such system is in minutes and that a wireless system be utilized. However by implementing such a system two noteworthy problems need to be considered.

First, the potential high number of alert alarms generated. Erroneous alerts can lead to a loss of confidence in the system and potentially a genuine alert being 'lost' amongst the false alarms. An understanding of the potential problems can reduce false alerts, combined with alerts going only to knowledgeable personnel who are fully cognizant of the construction work being undertaken.

... a clear understanding of ... how the construction activities impact on the data are crucial to the interpretation of strain gauge results...

The second and potentially more serious problem lies with the robustness of the real-time system itself. The simile, a chain is only as strong as its weakest link, rings very true when applied to any real-time system. Any failure of any component within the system compromises the whole monitoring scheme, leading to an absence of results. Apart from the strain gauges, the potential number of points that can fail within the system are numerous. These include the cabling, the datalogger itself, the phone system, the power and the server. Failures of all of these components have been experienced. To ensure that the system is fully automated and seamless, all these areas need to be rigorously checked, and fail safes written into the systems to inform the system manager if any of these components fail, rather than assuming that all are functioning smoothly.

Conclusions

It is clearly evident that strain gauges are essential in monitoring and controlling internally braced deep excavations in the urban environment, and particularly if challenging ground conditions are encountered. With the increasing sophistication of real-time systems that produce vast quantities of data, combined with M2M capabilities that allow automated alerts, and strict alarm limits on the monitored loads, the results from strain gauges are under very close scrutiny. Therefore quality data and a clear understanding of both the monitoring system and how the construction activities impact that data are crucial to the interpretation of strain gauge results. Without this, confidence in the performance of the system is lost, resulting in the dangerous practice of results being ignored as errors, and/or numerous unnecessary alarms impacting the construction progress.

To maximize the potential of strain gauges, dataloggers using FFT processing must be utilized. Quality installation must be carried out by skilled personnel who are aware of the problems described in this article and the potential of compromising the data. Data interpretation should also be by skilled engineers who are fully aware of the design predictions for the excavation, the excavation progress and the potential impact of the excavation on the strain gauge results. Finally the processing system that takes data from the strain gauges to the end user must be seamless and robust, such that this component does not fail and lead to a complete breakdown of the whole system.

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