## Introduction by John Dunnicliff, Editor

*This is the 86th episode of GIN. Three articles this time.*

### People issues

I've often maintained that what I call "people issues" frequently overshadow the importance of technical issues. The article by Martin Beth of Soldata Group presents eight common sense rules for successful monitoring, all of which relate to people issues. In my view this is **MUST READING** by all who have a stake in our goal of obtaining high quality and relevant data.

### More on vibration monitoring

The previous GIN included an article by Bob Turnbull of Instantel titled "The fundamentals of vibration monitoring – things to consider". As a follow-up to this, here's an article by Vincent Le Borgne of GKM Consultants titled "Lessons learned in vibration monitoring". The article presents three case histories and conveys yet again that people issues can often overshadow technical issues.

### General role of instrumentation, and summaries of instruments that can be considered for helping to provide answers to possible geotechnical questions.

The previous two GINs included articles about instrumentation for braced excavations and embankments on soft ground. Here's one about cut slopes and landslides.

### Call for author(s) for one or more articles on monitoring embankment dams

I'd like to publish something similar to the above three article for embankment dams, but am not competent to write it, so I'm looking for a possible author or authors. Some suggestions for content are given below.

It seems to me that the article should have some or all of the following content:

- Monitoring existing embankment dams where there is no evidence of a problem
- Monitoring existing embankment dams where there is evidence of a problem
- Monitoring new embankment dams
- Potential failure mode analysis

It also seems to me that, in contrast to other articles in this series, the types of instruments to be considered for helping to provide answers to the various geotechnical questions are too numerous to be included, but perhaps some general guidance can be given.

***Any takers?***

### Closure

Please send an abstract of an article for GIN to john@dunnicliff.eclipse.co.uk—see the guidelines on www.geotechnicalnews.com/instrumentation_news.php

Yung sing ("drink and win") – China. This from a website with toasts. We lived in Hong Kong for several years in the 1960s and became (very!) familiar with the toast "Yam sing", which we understood to mean "knock it all back without stopping". Does anybody know whether "Yung sing" means the same?

# Eight common sense rules for successful monitoring

*Martin Beth*

## Introduction

Geotechnical, structural and environmental monitoring is becoming a standard requirement on civil engineering construction and mining projects, and the amount of recorded data increases rapidly. It is very important to understand that if the monitored data are not of sufficient quality, or if the data are just data instead of useful information to help reduce risks and enhance operations, then monitoring is a waste of money.

The writer would like, though this article, to help convince decision makers to make the right choices when dealing with monitoring.

This article is based on "The challenges of supplying good quality and useful data for significant projects", presented at the Symposium on Field Measurements in GeoMechanics (FMGM), Sydney 2015.

## Monitoring program and specifications

***Rule number 1: The monitoring program must be designed specifically for the project, and justified by the project needs.*** (See Figure 1)**.**

The key point is to understand the geotechnical and structural behaviour of the site. Each instrument or group of instruments must be aimed at answering at least one specific question, or one specific problem. A common mistake is when the monitoring design of a past project is copied, totally or in part, to other projects. Consequences will be either:

1. Under design: For example, weekly manual survey is still found in some specifications, in cases where the risks and the potential onset of occurrence of the risks would suggest that hourly readings would be more appropriate. As a consequence the risks on site are not adequately covered, giving rise to potential incident or accident. Or
2. Over design: Contrary to what one might think, this is seen nearly as often as under design. In such cases, instruments are installed that were not really needed. The end result is that the site stakeholders will view the monitoring as an unnecessary expense, and not as it should be - a risk minimisation tool.

***Rule number 2: Specifications must be clear, listing clear objectives including accuracy (see note at the bottom of the page about the word accuracy), and leaving some degrees of liberty regarding the methods to be used.***

The major considerations that can help increase the quality of the measurements are as follows:

1. List clear objectives, if possible listing the engineering values to be obtained, the frequency and the required accuracy.
2. If possible, liberty should be given to the monitoring contractors to select the monitoring system they will use to answer these objectives. The designers/specifiers cannot be experts in all the techniques that they may specify. By leaving some liberty to the monitoring contractors the best value for money will be achieved.
3. The required accuracy of instruments should be achievable on-site – this is **not** the same thing as accuracy determined in the laboratory. If possible, the definition of the accuracy should be detailed in the specification, and also the way that it can be measured. Some liberty can be taken with the official international vocabulary of metrology in order to define something that can be estimated. For example, the accuracy might be defined as "the band containing 80% of the values during 12 consecutive hours with no work and temperature variation of less than 10°C". A full article could be written on this subject!
4. The required accuracy should be at a level that is necessary and reasonable. Do not over-specify here, as those monitoring contractors who wish to comply with the specifications will see increased cost, and those who disregard the specifications will end up winning the job. Sometimes we see requirements for +/-0.1 mm accuracy when 0.5 mm or 1 mm would be sufficient.

*Figure 1. Unsuitable design, under design and over design.*

Note. The word "accuracy" is used throughout the text. Depending on the instruments used, "accuracy" is correct, but for some instruments a more appropriate word is "precision" or "accuracy of change".

5. Clarify how the specified requirements will be enforced, and specify clear financial penalties in case of non-compliance. Be aware that a specification for uninterrupted measurements with less than four hours downtime for repairs will lead to high service cost for those who respect the specifications. Indeed, the monitoring contractor will need to have one or more highly trained specialist(s), equipped with all repair and replacement equipment, paid on-call, and probably housed in close vicinity to the project.

## Monitoring budget and procurement

***Rule number 3: Ensure that there is an adequate monitoring budget. Allocating an insufficient budget might end up in wasted money.***

Often given insufficient attention, sometimes forgotten, the budget allocated to the monitoring will have a major influence on the quality and usefulness of the data that will be obtained. For geotechnical construction a general rule of thumb is that 1% to 2% of the construction budget is generally adequate for a comprehensive monitoring program. Of course this in only a general idea as, following rule number 1, the extent of monitoring depends on the project needs, in particular the degree of risk. On a site with no risks the budget can be zero, on a site with complex issues the budget could be 4% or more. With proper monitoring put in place, risks can be significantly reduced, therefore potentially saving huge costs. Alternately, if the monitoring budget is too low, the data provided may be of such bad quality that it will prove unusable, and whatever small amount was spent on the monitoring will be wasted money.

***Rule number 4: No low-bid procurement for services of the monitoring contractor***

Selecting the monitoring contractor based on low-bid is not recommended. In North America the practice is very much state/province dependent, but in most cases the low-bid method is selected, whether in public or private tenders.

In Europe the technical proposal is now considered carefully in public tenders, and acceptance is regularly given to the best proposal after an analysis of both cost and technical issues. However in private tenders, i.e. when the monitoring contractor is selected by the construction contractor, then in most case the low-bid will be chosen.

This brings further case to the defenders of the fact that the monitoring contract is better placed directly with the owner, rather than through a construction contractor. This subject has already been much discussed in previous GIN issues.

One could argue that it is up to monitoring contractors to avoid low bidding. It is a complex decision to decide on the financial limit below which it is better not to do the job. But accepting a contract below that financial limit will result in not being able to provide quality data, thus putting both the job and the company's reputation at risk.

## Project management

***Rule number 5: Provide strong enforcement of the specifications.***

It is important for the owner and the project designer to ensure they will have the power to demand high quality data during the project duration. It is not as trivial as it may appear to enforce, during the contract, what was stated in the specifications: the pressure of the day-to-day site activities, the complexity of leveraging on a contractor or, even more complicated, a construction contractor's subcontractor, all lend themselves towards cutting corners and taking liberties with the specifications. Financial penalties are a possible way to maintain this pressure. This is only achievable if the specifications state clearly the rules, enforcement and verification of those rules.

## Monitoring contractor

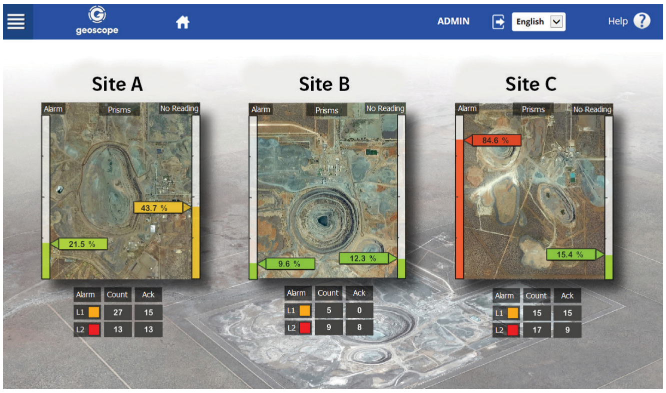
***Rule number 6: Ensure that the monitoring contractor's team is experienced and focused on data quality.***

Even with modern day automatic instruments, the final quality of the monitoring relies mainly on the quality of the monitoring contractor's team on site and off site.

The project manager on a large monitoring site acts as the leader for the whole team. The project manager is in a difficult position in that he is also the guarantor, on behalf of his company, of the financial success of the project. A good project manager will understand the necessary balance between financial and technical success. The search for data quality must be at the forefront of the whole company and hierarchy to ensure the proper decisions are taken, even in difficult times.

*Figure 2. Team work and understanding what we measure. Credit: Comet Photoshopping / Dieter Enz*

The whole team should be trained regularly to be able to perform tasks in an optimum manner. Many monitoring tasks appear simple at first, but can easily lead to false results when not carried out properly. At least one engineer, not necessarily the project manager, should be the quality "control tower", capable of solving any specific technical difficulties, and training the team to check their readings and to detect their own mistakes. It is desirable to have a good proportion of the monitoring team, and especially those in direct contact with the owner and



Site A

| Alarm | Count | Ack |
|---|---|---|
| L1 🟧 | 27 | 15 |
| L2 🟥 | 13 | 13 |

Site B

| Alarm | Count | Ack |
|---|---|---|
| L1 🟧 | 5 | 0 |
| L2 🟥 | 9 | 8 |

Site C

| Alarm | Count | Ack |
|---|---|---|
| L1 🟧 | 15 | 15 |
| L2 🟥 | 17 | 9 |

*Figure 3. Weather map approach: "board" showing a summary of three sites on one page.*

the project designer, coming from a geotechnical or civil engineering background. The quality of the monitoring service is significantly increased when what is being measured is understood. See Figure 2.

## QA/QC

***Rule number 7: Ensure quality control on the measurements, and actively maintain the monitoring systems.***

First, instruments must be installed properly. For many instruments, poor quality of installation will render future measurements impossible or will deliver very poor quality data. Ideally "final control sheets" are put in place, which list, for each instrument, the quality control to be carried out. When possible the control consists of applying a known variation to what is being measured, and checking on the final output (the report or the monitoring database screen) whether the variation is correct. It is surprising how many mistakes can be detected using this method. Typically, these include factors of 10 or 1000, inverted axes, etc.

After installation comes the monitoring. Many clients question the reason for having the expense of data managers and data control on site. A common comment is "the instruments are automatic, so you do not need anybody on site". But without continuous quality control, the systems, whether manual or automatic, will quickly drift. Such control can be automatic though data analysis algorithms, but human brain power is also necessary. Data managers analyse the alarms and conduct corrective actions if necessary, they check the manually acquired data, and they are in charge of carrying out detailed quality checks on selected instruments.

Finally, depending on the accepted level of risk, sufficient spares parts and redundancy must be provided and included in the budget.

## Data to information

***Rule number 8: Include added value tools to maximize the use of the monitoring data.***

The primary deliverable of any monitoring system are valid measurement data. This is a major achievement in itself. But the next question to address is: how can the usefulness of the monitoring data be maximised for the users, considering that data are useless if not understood?

With this objective in mind, all the following are important features:

- Data integration (all data, from all sources, in a single system)
- Data fusion (cross correlation of information from different sources)
- Alarm velocity and data velocity (rapid delivery of the alarm and rapid analysis of its causes)
- Alarm management (acknowledgement, by whom, why, etc.),
- Weather map approach or dashboard. This is the ability to display in a very simple and effective way a huge volume of more or less complex data, so one can understand what's going on at a glance, in a similar way to a meteo map on your TV screen summarizing the calculations of some of the biggest computers on earth. See Figure 3 for example, where three sites are summarized on one page, showing for each site the number and percentage of sensors not reading (for example disconnected if automatic, or the planned frequency is not respected if manual), the number and percentage of alarms of type 1 and type 2 (count L1 and count L2), and the number of alarms that have been acknowledged (i.e. controlled and commented by an operator). The colors of the squares and side bars help to understand at a glance the status at the monitoring site.
- Journal (the monitoring system records a journal of internal or external events that is presented alongside the data to help the analysis)

## Conclusion

The factors influencing the success, partial failure, or total failure of a monitoring project are numerous, starting from the design phase, through to procurement of the monitoring contractor, installation of the instruments, to data collection, pre-analysis, data presentation and reporting.

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# Lessons learned in vibration monitoring

*Vincent Le Borgne*

## Introduction

Vibration monitoring is growing in popularity as a complement to geotechnical monitoring because infrastructure work generates noise and vibration that can have deleterious effects on structures and people. To ensure compliance with local ordinances and to protect sensitive structures, long-term vibration monitoring is more and more commonly used. The relevance of vibration monitoring was recently brought to the attention of the readers of Geotechnical Instrumentation News (GIN) by Turnbull in a March 2016 article entitled "The fundamentals of vibration monitoring - things to consider". The article provides an overview of the technical requirements of vibration monitoring.

Our company has worked on several major projects in which vibration monitoring was a key component in addition to "traditional" geotechnical monitoring. In each of the projects detailed in this article, the first and perhaps most important thing to be decided was the goal of vibration monitoring. These goals led to the choice of the acceptable vibration limits and the appropriate sensors and data loggers. Finally, the method of data collection was determined according to the requirements of the client and the technological limitations of the equipment used. In addition to giving examples for each of the steps, we will explain how, despite following this basic methodology, unforeseen issues and human elements end up playing key parts in the lessons learned in vibration monitoring.

*Figure 1. The geophone system and the historical building to be monitored.*

## Project 1

### *Technical requirements*

In this project, vibration monitoring was required for the construction of a tunnel linking a water treatment plant and Lake Ontario. Vibration had to be maintained below a certain threshold for several reasons: to ensure the well-being of residents; to protect private buildings and homes; and to protect a historical building that was identified as being more prone to vibration-induced damage. Near the historical building, peak particle velocity (PPV) of 2 mm/s at frequency below 100 Hz was chosen as the threshold not to be crossed. For other buildings, the threshold was 8 mm/s at less than 4 Hz, 15 mm/s between 4 and 10 Hz and 25 mm/s above 10 Hz. The threshold is varied as a function of frequency because low frequency vibration is much more damaging than high frequency vibration for any given PPV. Sensors and loggers were thus chosen according to these requirements.

Stations were installed at eight locations clustered around shafts and close to the historical building. The installation next to the historical building is shown in Figure 1. The assembled system is anchored to the concrete slab, and the old stone and mortar wall behind can clearly be seen. There are whiter parts in the wall where the mortar has been repaired before, showing that this building is indeed weakened and requires extra caution.

To minimize long-term costs to the client, vibration data are uploaded daily, automatically to the client's server, where engineers can access it. This is achieved by hooking up a cellular modem to the logger and setting up scheduled data transfers. This passive method of data retrieval is well-suited for this application since we were confident that the generated vibration from tunnel construction would never exceed the threshold, thus eliminating the need for real-time alarms.

## Lessons learned

Despite a smooth start, unforeseen equipment failures forced us to quickly review our setups and devise an action plant to ensure as little data as possible would be lost. Of the failures, the most common one was unreliable cellular modem communications. The modems would hang and generate issues in the transferred data, and create doubts regarding system reliability. There was a very real risk that tunnel construction would go on without our system continuously providing evidence that bylaws and other requirements were being followed. In this context, a well-prepared contingency plan is a necessity to ensure full protection for the client.

Beyond these hiccups, the main lesson learned from this project is not about choice of instruments, installation or data analysis. The main challenge proved to be communicating efficiently with the client. On several occasions, we have gone over with the client how the system works, how to configure it and how to extract data. Despite offering training sessions and providing several training documents, the client still had difficulty maintaining and using the vibration monitoring equipment.

There was a fairly high turnover rate for the people in charge of this equipment, and information would be lost from person to the next. Compounding this issue, the people in charge have often been temporary student workers, which almost guarantees their contract ends before their successor is hired and thus that they had not passed on their knowledge correctly before leaving. In the context of ensuring compliance to the project requirements, it is necessary to plan with the client how knowledge will be transferred from us to them and maintained within their team.

In short, the general outline of vibration monitoring was followed: vibration sources and limits were identified; instruments and measurement locations were chosen accordingly; and the system was set up according to the requirements. The main lesson drawn from this project is that for the system to work as intended, communication with the client and technological transfer are almost as, if not more, important than the technical aspects of the system.

## Project 2

### *Technical requirements*

Large cracks running along several hundred meters in a large wastewater sewer compromised security during infrastructure work in the vicinity of the tunnel. A collapse of the sewer could lead to flooding with wastewater in a very densely populated area. Given the length and the width of the cracks (over 5 cm), very stringent vibration criteria were set: vibration should never exceed 2 mm/s for low frequency. Similarly, cracks should not open or close at all during infrastructure work in the vicinity. In consequence, two main types of instruments were used: 12.5 mm-range vibrating-wire crackmeters and geophones.

In both cases, data are retrieved in a trailer where an engineer continuously monitors vibration and crack deformation. The vibration dataloggers are linked to a cellular modem which can transfer data to a server. Special software monitors incoming data and sends out alarm e-mails as needed.

In most projects an alarm e-mail sent out within 15 minutes of vibration exceeding the threshold is considered satisfactory. The major public safety risk that a collapse would cause made

*Figure 2. A geophone installed in a wastewater tunnel.*

it preferable that an engineer would monitor the data in real-time to make any work stop in under a minute.

### *Lessons learned*

The unique work conditions of a large wastewater sewer pose significant difficulties. Work in sanitary sewers is accompanied by a slew of worker safety rules. Installation of instruments was conducted by workers accustomed to confined spaces who had never installed geotechnical instrumentation. The first step was to prepare a course to teach them how to install the instruments in the tunnel. This was achieved with hands-on demos that had the workers install instruments on a concrete jersey (a modular road barrier) and with preparation of drilling templates with every tool needed properly identified. Despite thorough preparation, we rapidly came to the conclusion that it was necessary to be available during installation should any issue arise. It would be very difficult and costly to fix an improperly mounted or damaged instrument and we made sure to provide whatever help we could through an unreliable radio link. In addition to these considerations, working in a sewer raised logistical issues. Workers wear a special combination with respirators, heavy boots, a rubber dry suit, a radio, and three pairs of gloves that hinder their.

Due to the high water level and flow, protective equipment for the instruments had to be designed. After installation of each geophone, a metal cover was bolted on top to protect it from impacts from smaller debris and to deflect heavy debris carried by water. Geophone casings were also filled with epoxy resin to make them fully waterproof and their cables were fed into a flexible metal conduit that was bolted to the wall. This is illustrated in Figure 2, where a geophone installed inside the tunnel, with the protective cover, the conduit for the cable, and one of the large cracks running alongside are displayed. Similar protection was provided to the crackmeters. This was all done because maintenance would have proven challenging. Access is difficult and restricted, cables ae bolted to the wall and vision and dexterity are severely limited in the tunnel. Flowing water during rainstorms did not significantly affect vibration measurements. Water flow barely registered on the geophones and was not anywhere near the 2 mm/s threshold. Finally, crackmeters showed that the cracks expand and contract as the tunnel heats up and cools down. The main goal of this project was to ensure that the tunnel would remain stable during construction work. It did remain stable and no crack opening or contraction were observed beyond thermal effects.

Project 2 brought up a plethora of challenges that needed very careful planning. In this project, as a follow up to project 1, we have seen the value of putting a deliberate effort into communications with the client from the very beginning of the planning stages. Doing so ensured rapid and correct installation of the instruments. To sum up, conducting a successful vibration monitoring project goes beyond simple technical considerations.

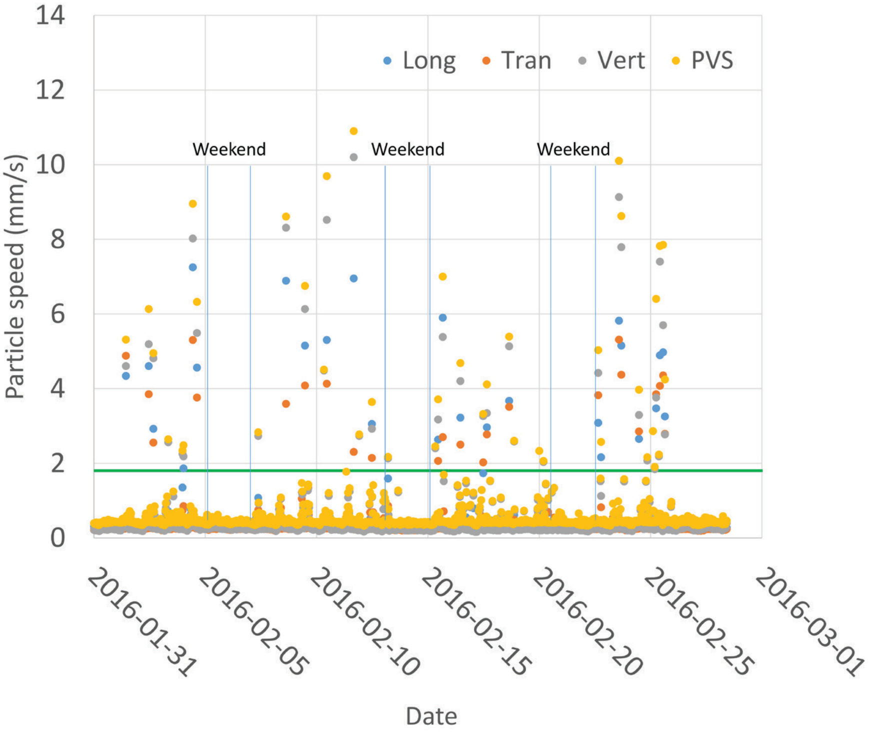

*Figure 3. One-month sample of vibration measurements near a shaft.*

## Project 3

### *Technical requirements*

The last project is a new 5 km long sewer tunnel being constructed underneath a densely populated area. Similar to project 1, vibration had to be monitored around the shafts and along the tunnel route. In addition to vibration monitoring, "traditional" geotechnical instruments were installed (inclinometers and multipoint borehole extensometers) to measure the effects of tunneling and to ensure that no convergence or settlement would threaten the surrounding structures. Lastly, noise monitoring was also undertaken to ensure compliance with bylaws concerning noise emissions.

### *Lessons learned*

It was estimated that the blasting schedule would pose almost no risk of damaging buildings. Indeed, 25 mm/s is the accepted threshold for modern buildings and the blasting schedule was designed to keep vibration much lower for any single event. Monitoring was thus mostly meant to reassure residents, because humans feel vibration up to ten times less intense than those that normally pose a threat to buildings. Having this system in place also ensured that if any blasting event was higher than expected, it would be quantified and any resulting damage could be assessed subsequently.

With event-based and general monitoring of blasting in mind, an automated data collection system with cellular modems was put in place to ensure that data were transmitted rapidly to the server. Specifications required that the blasting foreman must be alerted within 15 minutes by the construction contractor if any vibration crossed the threshold. To this end, the specifications written by the city engineers required alarms to be sent out to the construction contractor upon 2.5 mm/s peak vector sum (PVS) for any frequency. This type of arrangement is fairly common to ensure that work cannot continue while generating harmful levels of vibration.

Peak vector sum is defined by the following equation:

$$PVS = \sqrt{tran^2 + vert^2 + long^2} \quad (1)$$

in which *tran*, *vert* and *long* are respectively the transverse, vertical and longitudinal PPV. However, the datalogger could only relay alarms on the PPV and not on the PVS. This raises the issue that each axis could be below 2.5 mm/s PPV while their PVS is above 2.5 mm/s, and no alarm e-mail would be sent out. As a compromise, alarms are relayed if any one of the axes are above 1.8 mm/s, which leads to a maximal possible peak vector sum of 3.11 mm/s according to equation (1). Lower values could have led to too many false positives and hampered progress of the tunnel construction. Figure 3 shows the measured *tran*, *vert*, *long* and PVS values over a one-month period. The green line at 1.8 mm/s shows the alarm threshold. It can be seen that the measured vibration are typically much lower than the 1.8 mm/s threshold, blasting events have created PPV as high as 11 mm/s. There are also clear lulls during weekends where little to no vibration is measured.

The automated system was required and expected by the client to be functioning twenty four hours per day. Clients and construction contractors expect this to be a cheap and straightforward affair that requires little to no maintenance. However, the large number of components (batteries, casing, logger, sensors, and cellular modems) make these goals difficult to reach. The loggers and cellular modems are finicky and sometimes unreliable, occasionally requiring to be reset on-site. Having staff available to check on the systems weekly and to replace batteries and recharge units, made vibration monitoring much more involved than originally planned.

This project proved to be fairly straightforward once the technical issues were settled. A lesson to be drawn from this project is that, vibration criteria can be chosen for their effects on residents rather than only to protect buildings and infrastructure, and systems were designed to provide automated alarm e-mails.

## Conclusions

In every vibration monitoring project, technical requirements come first: frequency range, sensitivity, measurement range, etc. Choosing thresholds according to the specific needs is possibly the most critical decision for this type of monitoring. Other important considerations include that humans are much more sensitive to vibration than structures and that there can be older, more sensitive structures. However, creating a good monitoring project that fulfills its duty also requires deliberate planning and communication with the client, from the planning phase to its final execution. This is an often overlooked point that proves to be very important in vibration monitoring, perhaps even more so than in "traditional" geotechnical monitoring because it is chiefly implemented for safety, legal and wellbeing reasons.

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# General role of instrumentation, and summaries of instruments that can be considered for helping to provide answers to possible geotechnical questions. Part 3.

*John Dunnicliff*

## Introduction

This is the third in a series of articles that attempt to identify:

- The general role of instrumentation for various project types.
- The possible geotechnical questions that may arise during design or construction, and that lead to the use of instrumentation
- Some instruments that can be considered for helping to provide answers to those questions.

Part 1, covering internally and externally braced excavations, was in December 2015 GIN.

Part 2, in March 2016 GIN, covered embankments on soft ground. This Part 3 is about cut slopes and landslides in soil and in rock.

The following points were made in the introduction to Part 1, and also apply here:

- Of course it is recognized that there may be additional geotechnical questions and also additional instruments that are not described in this article.
- The sequence of geotechnical questions is intended to match the time sequence in which the question may be addressed during the design, construction, and performance process, and does not indicate any rating of importance.
- The suggestions for types of instruments is not intended to be dogmatic, because the selection always depends on issues specific to each project, and is influenced by the personal experience of the person making the selection. In the tables some of the most likely instruments that can be considered are listed, with other possible types in parentheses.
- The tables include the term “remote methods” for monitoring displacement. An overview of these remote methods is given in a December 2012 GIN article by Paolo Mazzanti (www.geotechnicalnews.com/instrumentation_news.php). Readers who want to learn more about these methods may want to consider participating in the annual International Course on Geotechnical and Structural Monitoring held in Italy (www.geotechnicalmonitoring.com), where they are discussed in detail.

## Cut slopes in soil

### *General role of instrumentation*

It is imperative that, prior to planning an instrumentation programme for a cut slope in soil, an engineer first develop one or more working hypotheses for a potential behaviour mechanism. The hypotheses must be based on a comprehensive knowledge of the locations and properties of stratigraphic discontinuities.

Instrumentation can be used to define the groundwater regime prior to excavating a slope. Results of measurements during excavation can be used as a basis for modification of the designed slope angle. Measurements of ground movement and positive or negative groundwater pressure can assist in documenting whether or not performance during and after excavation is in accordance with predicted behaviour. Measurements can also be used to document whether short- and long-term surface and/or subsurface drainage measures are performing effectively. If evidence of instability appears during or after construction, instrumentation plays a role in defining the characteristics of the instability, thus permitting selection of an appropriate remedy.

A very important subset is the case of a cut slope in clay. Here negative pore water pressures generated during excavation can give rise to temporary stability, the lifetime of which will be related to the height of the slope and the slope angle. Therefore monitoring the negative pore water pressures is an effective way of assessing the stability of a cut slope in clay. In some instances the stability may be maintained for long enough to undertake temporary works within the excavation and thereby save on expensive stabilisation measures.

### *Summary of instruments that can be considered for helping to provide answers to possible geotechnical questions*

Table 4 lists the possible geotechnical questions that may lead to the use of instrumentation for cut slopes in soil, together with possible instruments that can be considered for helping to provide answers to those questions.

## Landslides in soil

### *General role of instrumentation*

If there is evidence of slope instability, its characteristics must be defined so that any necessary remedial measures may be taken. The question *how much ground is moving?* can be answered by use of instrumentation. The question *why is the ground moving?* will not be answered by instrumentation alone: the answer of course also requires a

Table 4. Some instruments that can be considered for monitoring cut slopes in soil

| Possible geotechnical questions | Measurement | Some instruments that can be considered |
|---|---|---|
| What are the initial site conditions? | Pore water pressure | Open standpipe piezometers<br>Vibrating wire piezometers installed by the fully-grouted method<br>Flushable piezometers<br>(Pneumatic piezometers) |
| | Surface displacement | Conventional surveying methods<br>Remote methods<br>(Tiltmeters)<br>(Fiber-optic instruments) |
| | Subsurface displacement | Inclinometers<br>In-place inclinometers<br>(Time domain reflectometry)<br>(Fiber-optic instruments) |
| Is the slope stable during excavation? | Surface displacement | Conventional surveying methods<br>Remote methods<br>(Tiltmeters)<br>(Time domain reflectometry)<br>(Fiber-optic instruments) |
| | Subsurface displacement | Inclinometers<br>In-place inclinometers<br>(Time domain reflectometry)<br>(Fiber-optic instruments) |
| | Pore water pressure | Vibrating wire piezometers installed by the fully-grouted method<br>Flushable piezometers |
| Is the slope stable in the long term? | As for “Is the slope stable during excavation?” | As for “Is the slope stable during excavation?” |
| | Rainfall, for possible correlation with any displacement | Rain gauges |
| | Load in tiebacks | Load cells |

**Table 5. Some instruments that can be considered for monitoring landslides in soil**

| Possible geotechnical questions | Measurement | Some instruments that can be considered |
|---|---|---|
| What are the post-landslide conditions? | Pore water pressure | Open standpipe piezometers<br>Vibrating wire piezometers installed by the fully-grouted method<br>Flushable piezometers<br>(Pneumatic piezometers) |
| | Surface displacment | Conventional surveying methods<br>Remote methods<br>(Tiltmeters)<br>(Fiber-optic instruments) |
| | Subsurface displacement | Inclinometers<br>In-place inclinometers<br>(Time domain reflectometry)<br>(Fiber-optic instruments) |
| Is the slope stable in the long term? | As for "What are the post-landslide conditions?" | As for "What are the post-landslide conditions?" |
| | Rainfall, for possible correlation with any displacement | Rain gauges |
| | Load in tiebacks | Load cells |

complete geotechnical investigation and analysis. Instrumentation also plays a role in monitoring the long-term stability of the slope after remedial measures have been taken.

#### *Summary of instruments that can be considered for helping to provide answers to possible geotechnical questions*

Table 5 lists the possible geotechnical questions that may lead to the use of instrumentation for landslides in soil, together with possible instruments that can be considered for helping to provide answers to those questions.

### Cut slopes in rock

#### *General role of instrumentation*

The general role of instrumentation is identical to the role for cut slopes in soil, as discussed above. However, when planning to monitor the stability of rock slopes, it is important to recognize that if the slope is subject to a brittle failure mode, movement will be sudden. In such cases, geotechnical instrumentation may not be appropriate to forewarn of instability. It may be more appropriate to develop an area-wide correlation between rainfall intensity and slope instability, and to use rainfall measurements to warn of potential problems.

#### *Summary of instruments that can be considered for helping to provide answers to possible geotechnical questions*

Table 6 lists the possible geotechnical questions that may lead to the use of instrumentation for cut slopes in rock, together with possible instruments that can be considered for helping to provide answers to those questions.

### Landslides in rock

#### *General role of instrumentation*

The general role of instrumentation is identical to the role for landslides in soil, as discussed above.

#### *Summary of instruments that can be considered for helping to provide answers to possible geotechnical questions*

Table 7 lists the possible geotechnical questions that may lead to the use of instrumentation for landslides in rock, together with possible instruments that can be considered for helping to provide answers to those questions.

Table 6. Some instruments that can be considered for monitoring cut slopes in rock

| Possible geotechnical questions | Measurement | Some instruments that can be considered |
|---|---|---|
| What are the initial site conditions? | Joint water pressure | Open standpipe piezometers<br>Vibrating wire piezometers installed by the fully-grouted method<br>(Pneumatic piezometers) |
| | Surface displacement | Conventional surveying methods<br>Remote methods<br>Crack gauges<br>(Tiltmeters)<br>(Fiber-optic instruments) |
| | Subsurface displacement | Fixed borehole extensometers<br>In-place inclinometers<br>(Acoustic emission monitoring)<br>(Time domain reflectometry)<br>(Fiber-optic instruments) |
| Is the slope stable during excavation? | Surface displacement | Conventional surveying methods<br>Remote methods<br>Crack gauges<br>(Tiltmeters)<br>(Time domain reflectometry)<br>(Fiber-optic instruments) |
| | Subsurface displacement | Fixed borehole extensometers<br>In-place inclinometers<br>(Acoustic emission monitoring)<br>(Time domain reflectometry)<br>(Fiber-optic instruments) |
| | Joint water pressure | Vibrating wire piezometers installed by the fully-grouted method |
| Is the slope stable in the long term? | As for “Is the slope stable during excavation?” | As for “Is the slope stable during excavation?” |
| | Rainfall, for possible correlation with any displacement | Rain gauges |
| | Load in tiebacks | Load cells |

Table 7. Some instruments that can be considered for monitoring landslides in rock

| **Possible geotechnical questions** | **Measurement** | **Some instruments that can be considered** |
|---|---|---|
| What are the post-landslide conditions? | As in Table 6 for "What are the initial site conditions?" | As in Table 6 for "What are the initial site conditions?" |
| Is the slope stable in the long term? | As in Table 6 for "Is the slope stable in the long term?" | As in Table 6 for "Is the slope stable in the long term?" |
| | Rainfall, for possible correlation with any displacement | Rain gauges |
| | Load in tiebacks | Load cell |

# Case History V

## extract from Suit is a Four-letter Word

*(Hugh Nasmith, 1986)*

This case history illustrates the hazard of filling a report with an excess of detail and comments.

A major high-rise office building with several levels of underground parking was planned for an urban development. A geotechnical firm was employed to carry out and report on subsurface conditions. Test drilling established bedrock (a horizontally bedded sedimentary rock) at a shallow depth and the borings were extended to the full depth of the proposed excavation. A professor of geology was retained by the geotechnical consultant and asked to examine and describe the core. His report was very thorough and comprehensive. The age, lithology, structural discontinuities, mineralogy, jointing, bedding, and fossils were described and discussed in detail, even though the report was based on an examination of discontinuous small diameter core. The entire geological description was incorporated in the geotechnical report which became part of the contract documents.

In the course of drilling and blasting the bedrock to excavate for the basement and footings, considerable overbreak occurred which the contractor was obliged to backfill with lean concrete. Blasting was carefully controlled by an explosives expert hence the overbreak could not be attributed to poor procedures.

The contractor claimed for an extra as a result of the overbreak and his "expert" claimed that the contractor relied on the geological description of the core as thinly "bedded" and accordingly made little allowance for overbreak. Photographs taken during construction showed horizontal beds 1.0 to 1.5 meters thick which in terms of mass rock would not be regarded as thinly bedded.

It was concluded that the contractor had a valid claim and was paid an extra. This claim might not have been allowed if the report had merely reported the rock type, elevation and percentage of core recovery (RQD) and included representative photographs of the core.

From a practical point of view the small diameter of the core made it unsuitable for determining the spacing of the bedding planes. It is unlikely that the geologist or the geotechnical engineer anticipated that the rock description would be used to predict the behaviour of the rock when excavated. If the professor had realized the importance that would be attached to the term "thinly bedded" he would no doubt have considered the use of the term more carefully. An examination of a nearby rock outcrop would probably have been more informative than the core fragments. A cynic might suspect that the contractor only studied the description of the rock in detail when he realized the extent and cost of the overbreak.

When you pad out a report with a mass of extraneous detail and comments, you are providing answers to questions which have not been asked and the answers you have given may well be wrong or misleading.