Catastrophic failures – and a few other reasons to use instrumentation to monitor performance

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ABSTRACT

Construction projects in New Zealand are utilising geotechnical instruments to monitor performance on an ever increasing scale. Our urban centres are providing more challenges for our engineers as they design for constrained areas with concern for neighbouring land use. The integration of geotechnical instrumentation providers into our project teams has seen project timelines reduced, safety increased and our clients receiving better value with a superior understanding of their risk. Our requirement to minimise the impact of our project to all affected parties is now paramount to our success.

This paper will outline the benefits of monitoring construction performance and provide some examples of the benefits gained for all stakeholders.

INTRODUCTION

There are few cases as catastrophic in the public domain such as the Vajont Dam and reservoir landslide. There have been many studies reviewing the events of 9th October 1963, most concluding that a 5 – 15cm layer of clay within the limestone provided the slip surface. The known landslide was being carefully managed by adjusting the water levels in the reservoir whilst monitoring the movements. The fateful dropping of the water level induced hydraulic pressures as water in the jointed limestone tried to drain. The stresses imparted led to massive destruction and loss of life.

Appreciating that this was in 1963, we can use hindsight to consider how different it could be in the modern world. The ability to measure pore pressures at significant depth very accurately and in very discreet layers has provided the modern engineer with options that were unavailable at Vajont. The development of consumer electronics has allowed the geotechnical instrumentation industry to access cheap(er), smaller and more accurate instruments than ever before - we must consider these benefits by our projects.

1 INSTRUMENTATION AND RISK

Major construction projects require major investment. It would be unusual in modern times that any such investment would not require a detailed understanding of the risks surrounding the geotechnical parameters.

Worldwide, geotechnical engineering is considered one of the highest risk disciplines within the engineering field. Clients and investors in projects of this nature are innately risk-averse and the more we can do to reduce the risk, the happier they will be. There are many ways that the geotechnical professional can calculate risk and allow a client to make informed decisions. The calculated risks can provide pre-construction reference, but through construction there will always be “unforeseen circumstances”. In a geological setting there will always be a requirement to provide educated assumptions to create models. In reality, we find that ground conditions can often change very quickly, much to the designers’ astonishment and dismay. This astonishment in the engineer’s mind needs to be converted to “peace of mind” when he/she attends the client update meeting. It could be fair to assume that astonishment would not be the only issue on the client’s mind.

The use of geotechnical instrumentation to monitor construction performance can provide an up to date understanding of ground conditions and how the calculated risks have changed or not. The geotechnical engineer gains confidence in their predictions and models, and this assurance is inevitably passed on to their client.

The author freely admits that this scenario is perhaps viewed through rose-tinted spectacles. However, there is significant evidence in many projects throughout New Zealand to suggest that projects with adequate geotechnical instrumentation to monitor construction performance result in very good client relationships. Due to the litigious nature of many projects with significant geotechnical problems, the ability to use case studies from recent times is very limited.

The risks, when understood fully, can be monitored to provide legal backing should conflict arise between stakeholders. The provision of accurate data to show compliance is commonplace in projects, especially in our urban centres. The potential impacts that our projects can have on a significant range of stakeholders has increased as our green field developments decrease and our brown field developments increase.

1.1 Risk example

An example of managing risk through the use of geotechnical instrumentation could be the monitoring of in-situ bridge piers during construction.

Current engineering designs allow for retro-fitting of bridges with "clip-ons" or twinning with replica parallel aligned new bridges. Bridges over waterways will inherently be founded in alluvial, fluvial and estuarine deposits. These deposits will in general, but not always, exhibit seismic risks, not only from tectonic movement but from percussive installation of new piles, caisson or temporary staging.

To ensure security of the existing bridge structures which will commonly be in use throughout the construction phase, we can place tiltmeters on the pile caps. The use of tiltmeters in a wireless mesh network can provide near real-time data of existing structures, including piles. Alarm levels can be set to ensure that notifications are made to the engineer should construction methodologies affect the existing structures.

The initial risk of damaging or affecting the performance of an existing structure can be carefully monitored throughout the project lifetime. All stakeholders can make informed decisions about how they wish to proceed with a quantified risk in comparison to a calculated one.

2 INSTRUMENTATION AND TIMELINES

I am yet to meet a successful geotechnical engineer who doesn't have significant time constraints on his/her projects. As we are all aware, timeliness has an impact on the cost and quality of a project. It is imperative that project scoping allows for a suitable balance of all three: time, quality and cost.

Our modern project management systems include such wondrous tools as milestones and critical paths. The project success can rest, not on the use of these management tools but on construction performance and essentially the engineer's expertise in managing timelines. Geotechnical instrumentation can provide engineers with very accurate data to support their decisions on construction programme. The ability for engineers to know their construction performance in comparison to an "assumed" performance will provide their clients (and their representatives) with confidence and assurance that their project is in good hands.

A suitable example for increasing knowledge of construction performance over calculations could be the use of hydrostatic profile gauges (see Figure 1) to measure settlement in conjunction with vibrating wire piezometers (see Figure 2) for pore pressure. As New Zealand's towns and cities develop, the roads and infrastructure required to support that growth need to be built. Prime land is almost always consumed by the residential and industrial sector of construction, leaving marginal land for the infrastructure. The marginal land in many towns and cities consists of estuarine, alluvial, colluvial or organic deposits (commonly dunes interspersed with peat). These ground conditions provide significant challenges to the geotechnical engineer when considering the timeline of projects.

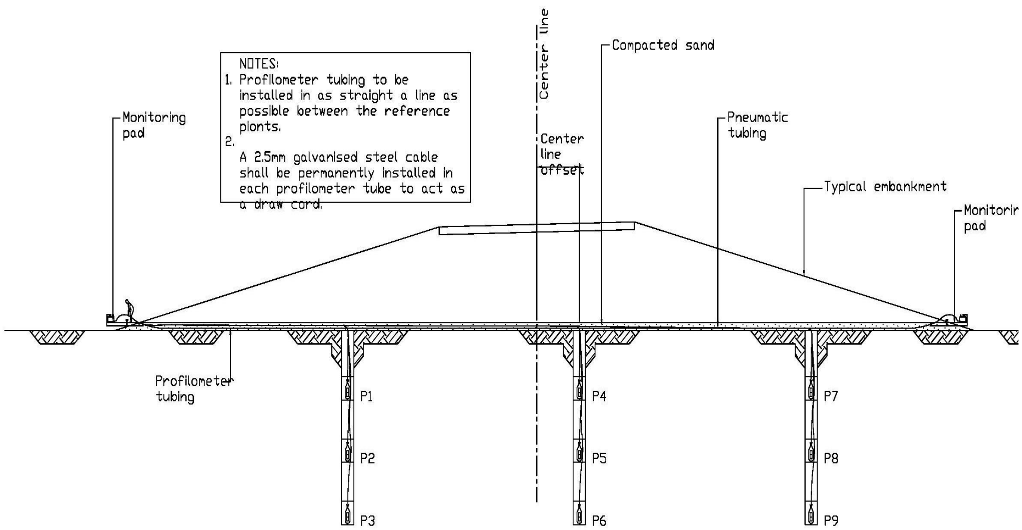
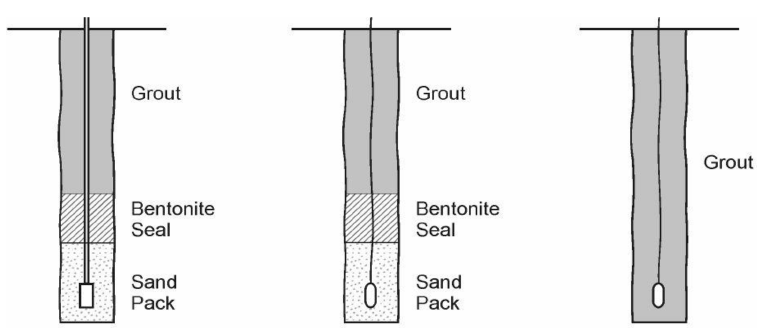


Figure 1: Typical profilometer tubing installation beneath an embankment (including piezometer)



(a) **(b)** **(c)**

Figure 2(a): Traditional standpipe piezometer with sand pack
Figure 2(b): Diaphragm piezometer with sand pack
Figure 2(c): Fully grouted piezometer

One of the most significant issues will be settlement of the ground with specific consideration to consolidation and pore pressure dissipation. In the past, a significant amount of calculation and a reasonable amount of conservatism were used to ensure pre-load activities achieved their aims. In more recent times we have seen fill quantities, density calculations and survey provide a more accurate picture. The use of a hydrostatic profilometer in conjunction with heavy duty vibrating wire piezometers can now provide significant improvements in timelines for all stakeholders.

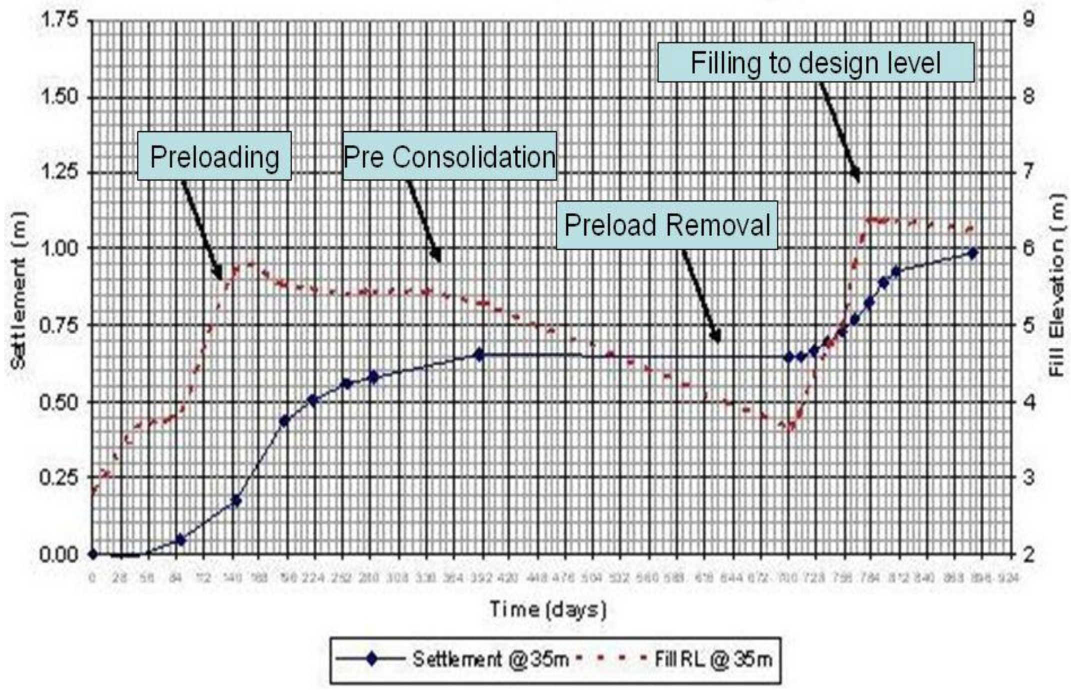


Figure 3: Profile tube settlement versus time

The comparative methods below (Table 1) show significant reasons any of the options should be considered. The choice of method would, however, depend on the size of the project. It is clear that if the programme timeline can be reduced, the hydrostatic profilometer & piezometer combination will provide full assurance to the engineer and the client that the construction is performing to the required standard.

Table 1: Comparison of construction performance monitoring methods

Method	Pros	Cons
Calculations & conservatism	Cheap (in the short term)	Assumptions galore Higher construction costs
Fill quantities & survey of settlement plates	Provides the engineer with known performance from single points in fill and surface	Impedes Construction Construction damage likely Single point measurements at depth
Hydrostatic profile gauges & vibrating wire piezometers	Provides full cross section at original ground level All instrumentation away from construction traffic Provides assurance of all pore pressure & settlement parameters	Relatively expensive for set-up Requires specialist technicians

3 INSTRUMENTATION AND SAFETY

The integration of safety into the construction process and final product has become imperative to project success.

Project stakeholders may include national and local government, public and private companies, and the end users including the general public. The Health and Safety in Employment Act 1992 section 19(b) states “That no action or inaction of the employee while at work causes harm to any other person.”. This is a very important statement to understand when major projects have our staff, construction staff and the public involved.

It should be noted that the Act views engineers’ responsibilities at a higher level than the general public. Section 2A(2) states “a person required by this Act to take all practicable steps is required to take those steps only in respect of circumstances that the person knows or ought reasonably to know about.”. It must be noted that this includes action or in-action for site activities as well as design requirements. There may also be implications surrounding the registration of the engineers covered in the Chartered Professional Engineers Act 2002.

The use of geotechnical instrumentation on major projects can provide a near real-time understanding of any hazards which might affect stakeholders and be detrimental to the project success.

3.1 Safety Example

A suitable example of this could be an inner-city roading project. There are numerous public stakeholders, from current road-users through to owners and visitors to large high-rise buildings. The implications of cut-slope failures can vary from structural damage through to injury or even death. There are very few geotechnical engineers who would like to have any of these litigations on their CV.

Although geotechnical instrumentation will not stop any cut-slope failures (in normal circumstances and quantities), the ability for an engineer to make informed decisions as soon as parameters reach critical levels can minimize and even eliminate any damage or injury.

An engineer can specify to install vertical inclinometers or ShapeAccelArray™ prior to any works being carried out on site. These instruments can provide accurate measurements of lateral deviation at any depth specified along with direction of movement. In the case of ShapeAccelArray™ we can also measure dynamic acceleration which in New Zealand is very important with the seismic risks we have. The correlation of this data along with construction activity can provide a very good understanding of whether initial design parameters are being met or exceeded. The use of alarm levels for construction development will provide surety to all stakeholders that the programme can be met, or not, as the case may be.

CONCLUSION

The use of geotechnical instrumentation should always be considered, no matter what size of project is being scoped. The use of a systematic approach to planning monitoring programs is encouraged with Dunnicliff 1988 providing a 20 step approach to planning a monitoring programme.

The suitability of instrumentation and the technology levels required will normally be dependent on project size and thus budget. Although this paper lists the examples of higher technologies it should be noted that the use of the humble crackmeter and/or survey markers can be just as effective when monitoring construction performance.

A note of caution should also be raised when dealing with complex technologies and complex engineering tasks. I would recommend that we do not simply dismiss the reliance on calculations for construction performance but blend the two methods into a hybrid. The prediction of construction performance alongside measured parameters can then be used for review throughout the project lifetime. A significant use of the "observational method" (Peck 1969, 1972) should also be considered to provide back-up to any measured responses to construction.

Unfortunately the geotechnical instrumentation can also highlight the performance of the geotechnical engineer and how safe their position is with their client due to their predictions for construction performance. I would therefore suggest a close working relationship with the geotechnical instrumentation team. An understanding of their work will pay dividends to project success.

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