Using GeoRM to Communicate Geotechnical Risks Between Engineers and Managers

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Abstract. Rijkswaterstaat has recently stated that the use of GeoRM is obligatory for projects with major geotechnical risks. Underground construction of freeways in high-profile areas, such as the business district Zuidas in Amsterdam or railway links in densely populated areas, always introduce major geotechnical risks. It is not uncommon for these locations to have all the facets that require strong geotechnical risk management: underground construction occurs adjacent to high-rise structures, locations have a very busy surface area, there are financially dependent stake-holders and concerns prevail after issues on earlier projects.

Rijkswaterstaat and their consultant firms are tackling this by forming a strong bridge between engineering and management using geotechnical risk management (GeoRM). In this article its main focus is translating the language of technical risks into managerial terms of cost, delay and reputation. Then actions are translated back again into countermeasures, which are often technical in nature. With a unique approach of subdividing and quantifying risks into sub-risks all the way down to a construction activity level, engineers have the ability to talk directly to the decision makers. To this end a visualization tool has been developed to assess and evaluate risk and counterfeit measures with management staff. The teams involved believe risk reduction is about real-life measures that require a level of detail and knowledge of the actual construction activities to be performed.

This approach has led to real risk-reduction activities, for example: additional investigations into underground obstacles (e.g. existing steel anchors) and actions for removing them beforehand, preventing stagnation later. But also: site investigation activities associated with specific construction methods like soil injection which may turn out to be unfeasible if soil parameters don’t come out as expected.

Keywords. geotechnical risk management, GeoRM, communication, project management, cost, delay, reputation, Zuidasdoek

1. Introduction

1.1. Geotechnical Risk Management

In the last five years the Dutch infrastructure body Rijkswaterstaat has been strongly promoting geotechnical risk management in an effort to reduce the high impact of geotechnical failures within its projects. A national programme called “Geo-Impuls” (Pereboom et.al., 2014) has been implemented to reduce the failure costs in civil engineering and the body has set a goal for the current period of 100 projects implementing geotechnical risk management before the end of 2015.

In view of reducing overall geotechnical risk, geotechnical risk management should not only be implemented by the early adapters, but also amongst a wider geotechnical engineering community including those known as followers and late-comers (Van Staveren, 2011), hence geotechnical risk management is now being enforced as a contractual requirement within Rijkswaterstaat projects.

One of the first large-scale metropolitan infrastructure projects where geotechnical risk management is being completely implemented from the start of the project is Zuidasdoek in the Amsterdam business district.

1.2. Zuidasdoek Project

Zuidasdoek comprises expansion of the Amsterdam South railway station to become the primary long-distance train hub for Amsterdam, expansion of the A10 freeway from eight to twelve lanes and construction of over one kilometer of cut and cover freeway tunnel through the heart of the central business district. Thus increasing freeway capacity and improving liveability and urban (re)development potential.
Specifically this project has five important factors that lead to a high geotechnical risk:

- underground construction occurs directly adjacent to high-rise structures, rail and subway lines and the existing A10 freeway (see Figure 1);
- geotechnical conditions are unfavourable (soft soil and high phreatic level);
- the construction sites have a very busy surface area;
- there are financially dependent stakeholders;
- concerns prevail after issues on earlier projects.

It may be understood that managing geotechnical risks on this project is a great priority. Particularly building damage and unavailability of the running train lines, subway line and freeway, although unlikely, may have serious consequences.

2. Implementing Risk Management

2.1. The Geotechnical Risk Management Process

Risk management follows the common GeoRM approach as proposed by Van Staveren (2011) according to the following steps:
1. Collect historic data and experience from previous projects or project phases;
2. Identify risks;
3. Quantify risks and prioritize;
4. Develop risk mitigation measures;
5. Carry out risk mitigation measures;
6. Assess level of risk and decide whether or not more risk mitigation is necessary to reach an acceptable level of risk.

For this project geotechnical risks are incorporated into the total project risk report which is quantified and assessed by management on a quarterly basis. The effects of risks are traditionally reported as minimum, maximum and most likely values of delay and cost, should the risk occur, along with a probability of occurrence.

Delays are calculated using a probabilistic planning model, and the delay is included in the total cost as a cost-of-delay using a fixed conversion ratio. At each quantification cycle the enforced countermeasures are taken into account and the level of risk ideally shows a steady downward trend. Then risk countermeasures for the next phase are evaluated and decided upon.

2.2. Examples of Results

In the site investigation phase the use of GeoRM led to economic and effective risk reduction even before the design phase started. The following examples show how GeoRM led to alternate action and reduction of project risk.

2.2.1. Historic Data from Previous Projects

Before setting out site investigation, previous projects were consulted, their designers were interviewed, and extensive historic geotechnical data was gathered.

One previous project reported damage and leakage during and after driving of sheet pile walls. Normally the existing freeway embankment is classified as sand and receives little attention in site investigation due to its stable properties. Due to the information available from interviews with those involved in earlier projects in the area a decision could be made to give particular attention to finding debris in the freeway embankment. This was done using simple and cheap shallow boreholes (manual) and short CPT’s. The debris was mapped in a 3D model and can now be tackled with the right preparative equipment. This is a sharp contrast to the legal battle that ended the previous project.
Another concern was that of vibrations from construction works causing damage to particularly sensitive equipment within adjacent buildings. Now previous project experience showed measurements were available from earlier construction activities and near zero vibrations were measured in these structures. This led to downsizing of this particular risk without any additional investment.

2.2.2. Site Investigation Programme

On the other hand, tunnel construction next to adjacent high-rise structures remained a major project concern. To this end advanced site investigation was proposed and executed in the form of borehole pressiometer testing. This is a costly and specialist method which helps engineers to accurately predict soil deformation around the construction works. It was made possible within the existing budget because other components were previously downsized due to their low risk quantification.

For example the risk of subsidence of the new freeway embankment outside the tunnel area is relatively low. Although more settlement may occur, it can be easily compensated on-the-fly by additional preloading, which is not very costly. On the other hand it would require extensive and costly laboratory testing to accurately determine deformation parameters for the whole freeway embankment. So, following the risk approach, lab testing for embankment settlement was downsized.

Finally the historic geotechnical data that was available, even prior to site-specific soil investigation, turned out to comprise an overwhelming 3600 points, as shown in Table 1 and Figure 2.

Table 1. Historically available site investigation

<table>
<thead>
<tr>
<th>CPTs</th>
<th>standpipe piezometers</th>
<th>mechanical boreholes</th>
<th>manual boreholes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2274</td>
<td>484</td>
<td>392</td>
<td>66</td>
</tr>
</tbody>
</table>

2.2.3. Obstacles

One rather disconcerting risk was the potential for sub-surface obstacles to prevent installation of soil retaining walls.

Based on the risk quantification an additional investment was made into tracing potential underground obstacles, including debris and anchors affixed to adjacent buildings. The anchors could conflict with the proposed tunnel position. Using magnetometer cone penetration testing a series of soil anchors was subsequently identified which directly crossed the proposed tunnel wall location (see Figure 3).

These anchors were initially reported in archives to be ‘temporary’ and may have led to a claim by the contractor and standstill during construction works. Now the anchors have been reported in a 3D subsurface model and can be dealt with before construction starts.
2.3. Evaluation of GeoRM Process

Although a different mindset is required to acquire historical data, carry out interviews and determine and quantify risks before setting out site investigation and design, it has been shown that extensive benefits are possible by following a GeoRM approach first.

On the other hand, prospective clients should note that the GeoRM process takes more time than directly setting out a standard site investigation programme and should implement this in their project planning.

Also, some specific issues arise to which an improved approach is proposed as described below.

3. Risk Management Developments

3.1. Problems with Traditional Methods

Traditional risk management as proposed in the RISMAN method (Van Well-Stam, et.al., 2003) is common but has certain practical inconveniences that are recurrent in all projects.

3.2. Lack of Overview

Although the cyclic process of defining and mitigating risks is effective, the implementation is still pain-staking and tedious. This relates specifically to the way risks are reported and discussed. This typically occurs in one of two ways:

1. With tables (i.e. Excel)
2. With a project database (i.e. Relatics);

Typically, tables of risks are used as shown in the examples in Figure 4. They are quick to adapt by a single individual, but when applied to complex projects they quickly become large, illegible and lose focus. Although database systems promise structure, they are seldom dedicated to risk management. Because the databases are usually set up for document control or systems engineering most database systems are intrinsically still just lists, with the added disadvantage of poor accessibility to users.

3.3. What’s the Cause, What’s the Effect?

Any engineer working with RISMAN or similar is familiar with the unsolvable discussion that occurs when “causes” and “undesired effects” are formulated. It is not clear where to put the cause and where to put the effect. For example, one engineer may establish building pit leakage as a cause for building subsidence, where another considers damage during wall installation to be the cause, and building pit leakage to be the undesired effect thereof.

When discussing with managerial staff this problem is exacerbated because at managerial level only effects in terms of cost, delay and reputation are useful.

3.4. Level of Detail

This discussion makes apparent why the level of detail is also important. When creating a traditional “list” of risks, basically the team that has the highest level of detail, also has the lowest impact in the total risk profile. Consider a geotechnical team with an extensive list of potential geotechnical causes for building subsidence like “damage to sheet piles during installation”, “soils softer than expected”, “soil densification due to vibrations” and “leakage at interlocks”. Each item individually scores low and doesn’t show up in red in the risk tables. Then consider the team working on permits which perhaps had a little less time and simply states the item “problems acquiring permits and project stagnation”.

In the risk list each individual geotechnical risk ends up at the bottom of the list, even though
the total sum of these risks may be greater than
the bundled up groundwater risk item.

For the Zuidas dock project this discrepancy
occurred regarding expected underground
obstacles. Because engineering judgement
indicated there was high risk, obstacle risks were
detailed carefully. Individual risks where listed
such as “damage to foundations due to
unidentified debris”, “encountering non-
removable permanent anchors” and
“encountering temporary anchors which were not
removed”. This adversely resulting in a low risk
quantification and the risks initially went
unnoticed. However, after tallying up these
individual risks into a single “encountering
obstacles” risk it quickly became apparent that
obstacles could be a serious problem.

An approach where all risks are kept simple
and top-level is conceivable. Experience shows
however that countermeasures are not easily
conceivable without any level of detail. This
approach leads to a situation where it is hard to
address any actual risks and the risk table
becomes no more than an abstract and static
topic of conversation.

The example above made the team recognize
that risks are not lists, but chains of events which
combine to make the total project risk. This has
led to introduction of the well-known fishbone
diagram (Ishikawa, 1976) for risk management
rather than lists, directly solving both the cause-
and-effect and level-of-detail problems as shown
in Figure 5.

3.5. Mapping Risk

The newly developed risk visualization tool has
been developed with other goals in mind:
- mapping technical risks into managerial
terms of cost, delay and (damage to)
reputation;
- allowing the cost and effect of
countermeasures to be compared by
management;
- allowing engineering teams to work
together on specific risks without losing
the big picture;
- making risk assessments easily reusable
between projects;
- allowing the likelihood of a risk
occurring to be calculated based on
more than just engineering judgement,
but also on empirical data.

3.5.1. Cost and Delay

The currently implemented risk tables contain
expected values for adverse effects in terms of
cost and delay or other priorities like safety,
quality and reputation. To make these more
apparent, these can now be mapped into the
fishbone diagrams as shown in Figure 5. The
thickness of lines quickly shows what is causing
the biggest expected cost or delay. When
applying countermeasures, the effects on risk can
be reported as shown in Figure 6.

![Figure 5. Mapping risks and their causes. The thickness of lines shows the contribution to the project total, in this case the expected delay (shown values are fictionalised).](image)

![Figure 6. The effect of countermeasures (dashed line) can be quickly visualized (shown values are fictionalised). CM = countermeasure](image)

Because of the cause and effect structure, it
becomes possible to delegate important risks to
specialist teams for further assessment and
reduction, without worrying about tedious
maintenance of the risk tables. For example the
risk of building pit leakage may be further
detailed by an expert team along with
countermeasures as shown in Figure 7.

Again it must be re-iterated that a certain
level of detail is required before engineers are
capable of providing risk reduction measures.

In a similar fashion branches can be
exchanged with other projects to make risk
assessments more reusable, rather than building
them up from scratch for each project.
**4. Conclusion**

Application of Geotechnical Risk Management (GeoRM) has proved to be an effective tool to reduce geotechnical risks including the project Zuidasdok up to this stage. In particular performing interviews with engineers from previous projects has led to good decisions on where to focus risk mitigating countermeasures.

The authors note, however, that real risk reduction is only possible if subdivision occurs down to causes at a more detailed engineering level. This is difficult to communicate to managerial staff especially if risks are not presented in clear effects such as cost, delay and reputation.

A visualization tool has been developed as a next step forward from traditional risk tables.

This tool has a fishbone cause-and-effect structure and has the following advantages:

- Clear presentation of effects in managerial terms such as cost, delay, safety, quality and reputation;
- Risks are easily interchangeable between teams and between projects without tedious maintenance of risk tables. A branch of risks can easily be delegated to a team, without affecting the big picture.
- Effects of the countermeasures that are proposed by engineers can quickly be visualized and assessed.

**5. Discussion**

Furthermore current expert judgement of the effect of risks in terms of cost and delay are adequate, but determining a realistic likelihood of unfavourable events occurring remains difficult. Currently, research continues into filling geotechnical risk branches with appropriate probabilities based on project experience. More readiness to share real data from projects all around the world, is certainly a key element in this equation.

**References**


