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Would Risk Management Have Helped? – A Case Study

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Abstract. To reduce the costs of unexpected geotechnical events in construction projects in Sweden, the Swedish Geotechnical Society has adopted a general methodology for risk management. In this paper, we exemplify how the proposed risk management philosophy could have been applied on a sheet-pile wall, which failed in 1992 in Stockholm because the design did not consider the complex site conditions. Focusing on the design phase, we discuss how geotechnical risks may be managed effectively as a natural part of the engineer's everyday work.

Keywords. Risk management, sheet-pile wall, failure, case study

1. Introduction

Increasing costs and time delays are common in geotechnical construction projects. One major reason is negative outcome of large geotechnical risks. In Sweden, for example, the estimated annual cost for damage related to unexpected geotechnical events is approximately €100 million (SGI 2013). Similar significant failure costs are reported from all over the world (van Staveren 2006, Smith 2008); a recent estimation for the Netherlands gave an annual failure cost of €1 billion (van Staveren 2013).

Geotechnical engineers and contractors are of course well aware of that they work with a material that has lots of uncertainties, but systematic risk management has not yet been accepted as a necessary and efficient everyday tool. Rather it is seen as something for specialists and for large projects only.

1.1. Current progress in Sweden: a methodology and an example

The Swedish Geotechnical Society (SGF), which is the national branch of ISSMGE, has recently proposed a general methodology for geotechnical risk management (SGF 2014), striving to improve the use of efficient geotechnical risk management within the Swedish construction industry. The main part of SGF's proposed methodology consists of a set of requirements on risk management and involved parties. The methodology is developed to be applicable for the whole construction process from the feasibility study to the operation phase.

However, although general methodologies and lists of requirements can be a good start, such guidelines might easily be left collecting dust on the bookshelf, if there are no practical examples or case studies to help engineers with interpretation and application.

To facilitate the introduction and use of the new methodology, we have produced an accompanying report for SGF, containing a case study of a sheet-pile wall, which failed in 1992. The excavation was made for the enlargement of the Equestrian sports centre in Stockholm. The report exemplifies and discusses how a proper risk management could have been carried out throughout the phases of the project. We suggest that if SGF's approach had been taken in the real case, the probability of failure would have been significantly less.

The purpose of this paper is to present SGF's new risk management philosophy for an international audience. The paper first describes the studied sheet-pile wall, after which we exemplify how some of the significant geotechnical risks in the project could have been managed, if the new methodology had been applied.

2. Failure of a sheet-pile wall

2.1. The new Equestrian sports centre

Back in 1991, the Swedish Horse Racing Totalisator Board (in Sweden known as ATG) planned to enlarge the Equestrian sports centre that is located close to Solvalla trotting track in Stockholm. The basement was to be founded on piles in a 4.9-m deep excavation in very to extremely soft clay within sheet-pile walls (Figure 1).

ATG called for tenders on a design–build type of contract for the construction, supplying the tenderers with the site conditions and requirements on the project execution. An important requirement from ATG was that the excavation by no means was allowed to disturb the trotting track; the internationally very prestigious trotting event called the "Elite Race" was scheduled during the execution of project.

2.2. The failure

The failure occurred in 1992 on Friday, March 13(!), while excavating and installing the sheet-pile wall closest to the trotting track. The excavation had reached the first waling level, but horizontal struts had not yet been installed. At that point, the sheet-pile wall failed, causing large movements in the clay: a 10-cm wide crack developed on the trotting track 10 m from the excavation and the bottom of the excavation heaved 0.5 m.

The consequences of the failure were severe, but fortunately no one was injured physically.

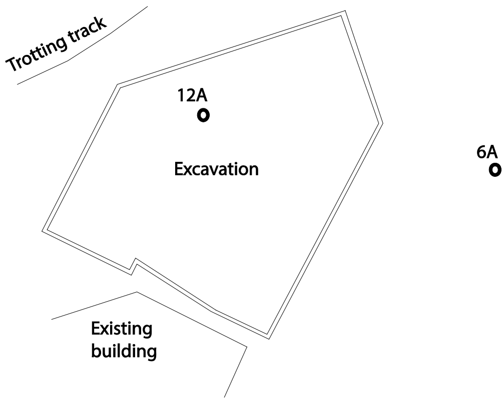

Figure 1. Plan view of the performed excavation.

The construction work had to be stopped and significantly re-planned, causing an enormous cost increase. The final design included extensive soil improvement with lime–cement columns. Moreover, the trotting track had to be taken out of service, while securing the area. Fortunately, the Elite Race was not scheduled until two months later.

2.3. Causes to the failure

The failure was investigated by two geotechnical experts appointed by both the owner and the contractor. The experts concluded that the failure had occurred because the overall stability of the excavation was too low. The contractor's design did not consider the complex geotechnical conditions at the site, e.g. the very large variation in undrained shear strength of the clay reported in the geotechnical investigation.

However, in favour of the contractor, additional geotechnical investigations performed after the failure indicated that the soft clay had even lower shear strength (9–11 kPa) than the tender documents had stated (10–16 kPa). In addition, the owner should have pointed out that soil improvement might have to be considered, according to the experts. The timeframe for the bidding was also rather short, given the complex geotechnical conditions.

A settlement was agreed on by both parties through mediation.

3. SGF's risk management methodology

In the following, we present how a successful risk management should be executed, according to SGF (2014), which applies the ISO-31000 (2009) definition of risk: "effect of uncertainties on objectives".

3.1. The cyclic geotechnical risk management

A geotechnical construction project consists of several phases: feasibility study, design, tendering, construction, and operation (the phases can differ slightly depending on the type of calling for tenders). As each phase has its own objective, a systematic risk management requires that risks are managed both continuously and repeatedly throughout the project (Figures 2-3). A similar cyclic process is suggested by van Staveren (2006, 2009, 2013). Figure 2 follows the ISO 31000 flow chart. For each step in the flow chart, SGF (2014) provides a set of requirements and guidelines. They concern for example qualifications of the staff that manages risks, establishing the risk owner, which criteria that should be used in decision-making, and how to document and communicate risks.

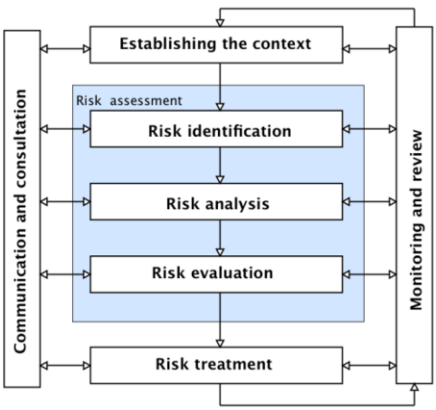

Figure 2. The risk management cycle performed in each project phase (SGF 2014).

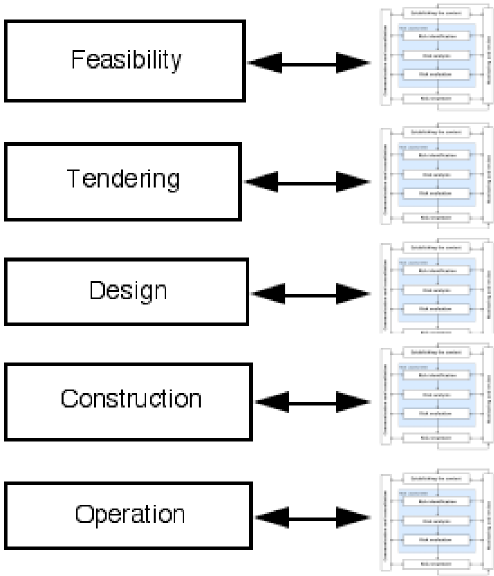

Figure 3. The risk management cycle (Figure 2) should be followed in each project phase.

4. Risk Management Applied on the Equestrian Sports Centre

In this chapter, we exemplify how the structured risk management (Figure 2) could have worked out, had it been applied on the Equestrian sports centre. We focus on one project phase: the contractor's risk management in designing the sheet-pile wall and determining the excavation procedure.

4.1. Establishment of Risk Management

The first step of risk management in each project phase is to establish

1. the scope and objective of the risk management,
2. the risk owner,
3. the available resources in terms of competence and working hours,
4. how to document and communicate risks, and
5. criteria that will be used when deciding on risk treatment.

How that could have been done is exemplified in the following.

(1) The scope and objective is at this point to choose a design for the sheet-pile wall and excavation procedure with respect to safety, the owner's requirements, and possible profit.

(2) The contractor's project manager for the excavation is the risk owner, because this person is responsible for the objective (a safe and profitable excavation design). Thus, the project manager has the authority to manage the risks and is accountable for doing so.

(3) Managing the risks is at this point a natural part of the engineers' work in designing the sheet-pile wall. Thus, the risk management procedure may have to be performed repeatedly, until all issues have been resolved, as the risk treatment may introduce new risks that also must be managed.

(4) Once a satisfactory design is found, documentation (e.g. drawings, project specifications, and monitoring plans) are prepared. This documentation communicates the remaining risks to the construction phase. One of the requirements in SGF (2014) is that risks should not be documented separately, but instead in the customary working documents (such as method statements) that are closely studied on the construction site anyway.

(5) The criteria for deciding to treat a risk are based on established geotechnical practice and the engineer's experience from previous projects, but of course with due regard to the possibly large consequences.

4.2. Risk Identification

In designing the sheet-pile wall and the excavation procedure, the engineers must carefully consider the conditions at hand to find the risks that may threat the objective. The greatest damage often is found in projects that never were managed with a risk perspective.

There are various procedures for identifying risks; a well-known example is brainstorming. van Staveren (2006) discusses such methods in detail. A few examples of possible risks regarding the sheet-pile wall are listed in Table 1.

4.3. Risk Analysis

The identified risks are analysed in terms of likelihood and consequences to form the basis of the decision to accept or treat the risk. The analysis can be made either qualitative or quantitative, for which the latter requires significantly more knowledge about the conditions.

In this paper, we from now on focus on the risk for failure caused by bottom heave of the clay cut; but in reality, all identified risks must be managed in a similar way.

A rough calculation of the stability against bottom heave indicates very low safety factors against bottom heave in the cut ($FS \approx 1.15$–1.3). Considering the limited geotechnical investigations and expected uncertainty, even lower safety factors are possible. This implies that bottom heave is quite possible during the excavation.

4.4. Risk Evaluation

During risk evaluation, the project manager (i.e. the risk owner) decides on whether the risks are acceptable or whether further analysis is needed. Reviewing the rough calculations from the risk analysis, the project manager realises that the risk related to bottom heave is too large; thus, the decision is made to treat the risk.

Table 1. Examples of identified risks in a first design.

Threat	Consequence
An unsafe design is chosen for the sheet-pile wall and excavation.	The sheet-pile wall fails, delaying the project, injuring staff, and damaging machinery and the trotting track.
The design is not possible to construct for practical reasons.	The excavation must quickly be re-designed, delaying the project.
Bad cooperation with the owner, who tries to meddle, despite the design–build type of contract.	Increased workload on contractor's staff.

4.5. Risk Treatment

The very low safety against heave indicates that the excavation will be complex; therefore, as a first measure, external expertise is brought into the project organisation. The experts will assist both in the risk management and in designing the excavation.

The designing engineers suggest that the short-term risk for heave is treated by

- unloading a part of the driving force,
- enforcing a stepwise procedure for both excavation and subsequent casting of a heavy concrete slab for increased gravity load on the bottom,
- making sure that the work can proceed quickly and not allowing any unsupported pits during weekends,
- keeping excavated material accessible, in case counter pressure suddenly is needed in the pit, and
- applying an observational approach for the excavation procedure to facilitate adjustment to the actual ground conditions by careful monitoring and planning of contingency actions (Peck 1969, CEN 2004).

Based on the risk treatment, an updated design is prepared (Figure 4). A corresponding excavation procedure is described in the following.

1. Excavation to level +1.5 m both within the planned pit and on an 8-m wide unloading zone outside the pit.
2. Driving of sheet-pile walls.
3. Driving of piles for the foundation.
4. Excavation in trenches to level +/– 0 m.
5. Installation of wale beams.
6. Installation of temporary struts across the cut (Figure 5).
7. Excavation in the whole cut to level +/– 0 m.
8. Careful excavation by stages to level –2.6 m (each stage is 13 x 5 m) without damaging the piles.
9. Casting of the concrete slab after each stage.
10. Installation of struts against the concrete slab on two levels after each stage.
11. Removal of temporary struts.

Although the risk management cycle (Figure 3) now is completed, the risk management does not stop here, because the updated design is not without risks. New risks can be identified in reviewing the excavation procedure, for example.

5. Risk Management of the Updated Design

5.1. New Risk Identification

The hired experts assist in identifying risks associated with the updated design and the corresponding excavation procedure (Table 2).

5.2. New Risk Analysis

The newly identified risks are analysed in detail. For example, the probability related to risks associated with practical issues, like damaging piles or struts, can be compared to similar situations in previous projects. As the number of struts and piles are significant, the engineer may judge the probability of damaging them as likely.

For risks with severe consequences, more formal procedures to take expert judgement into account in assessing probabilities can be useful to minimise psychological biases. One example is expert elicitation (O'Hagan et al. 2006).

5.3. New Risk Evaluation

After analysing the risks, the engineer may decide to either accept them or treat them. For example, after reviewing the probability of damaging struts and piles, the engineer may try to decrease that risk.

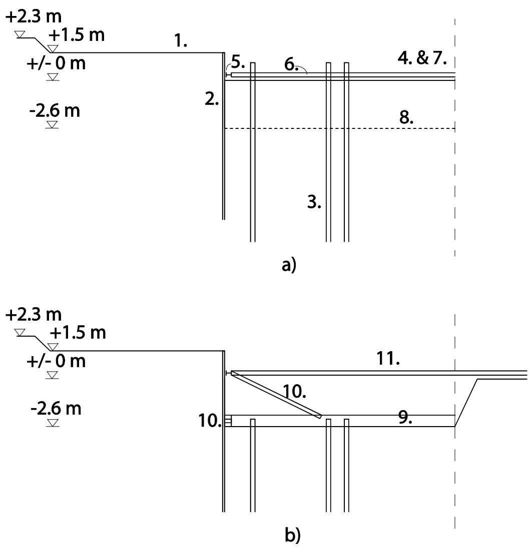

Figure 4. Suggested updated design after risk treatment. Numbers refer to the listed procedure.

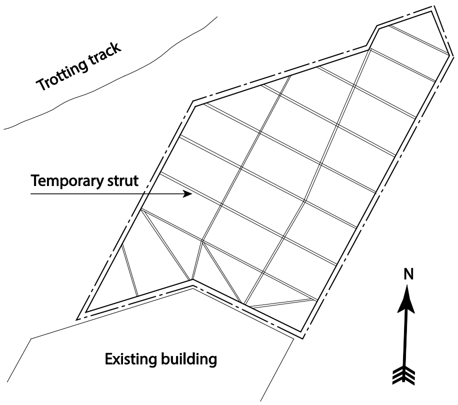

Figure 5. Plan view of the excavation after step 6.

5.4. New Risk Treatment

The risk owner works out a risk treatment plan that aims at lessening (1) the probability of mishap, by carefully preparing the working plan and setting strict requirements on machines and qualifications for drivers, and (2) the consequences of a mishap by preparing countermeasures, such as having a material ready to fill up the excavation.

Table 2. Examples of identified risks for the updated design.

Threat	Consequence
The piles are damaged during the excavation.	The piles must be replaced.
The concrete to be casted to provide counter pressure cannot be put in place quick enough.	Heave occurs.
A strut is damaged during the excavation to the bottom level.	The strut must be replaced, which delays the project and increases the cost.
Public authorities significantly limit when construction is allowed during the day to limit noise pollution.	The suggested design cannot be executed, as the work cannot proceed with enough speed. A new design must be prepared.

6. The importance of risk communication

In almost all projects, the risk management needs to be communicated within working groups and to subsequent project phases, preferably both orally and in written documents. Otherwise, the result of the risk management might be lost and the risk remains nonetheless. Thus, poor risk communication is a risk in itself! Important aspects of risk communication are covered in van Staveren (2006).

7. Concluding Remarks: Yes, Risk Management Would Have Helped!

Comparing the real outcome of the excavation with our study, we are confident that risk management would indeed have helped. We base this on the following observations.

The main cause to the failure was that the contractor did not fully appreciate the magnitude of the geotechnical difficulties and, perhaps, also lacked risk awareness. This led to a sheet-pile wall not designed with the required expertise. But if the requirements in SGF (2014) had been followed,

- risk management would have been implemented in the construction phase,
- persons in charge would have had a risk awareness,
- risk owners would have been appointed,
- responsible engineers would more likely have had the necessary competence of risk management in relation to the complexity of the situation,
- the geotechnical uncertainties would have been assessed and a suitable (high) level of risk management would have been used.

Lastly, we would like to stress that risk management helps avoiding problems in all projects. Thus, it is a tool for all engineers in their everyday work in all project phases, and not just for a few appointed experts.

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