

## Extending to Geotechnical Risk Management

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**ABSTRACT:** Both, risk *analysis* and risk *management* are a required for answering today's challenging construction project demands. The targeted result of combining risk analysis with risk management is a successful project, which satisfies the expectations of its stakeholders. This paper aims to assist geotechnical professionals with extending from traditional risk *analysis* towards risk *management*, by presenting some experiences and guidelines. These are derived from geotechnical practice and ongoing geotechnical risk management research, which actually takes place in The Netherlands. It integrates also professional experiences from a number of other countries, such as China, the United States, the United Kingdom and South Africa.

The paper starts with defining and describing the concepts of risk analysis and risk management, while stressing that both complement to each other. Risk analysis and risk management are blended in one geotechnical risk management framework: the GeoQ risk management process. The anticipated (financial) benefits of applying risk management are highlighted as well.

Next, some common barriers are presented, which may prevent geotechnical professionals from extending their activities to risk management. These barriers can be lowered, and in certain occasions even become eliminated. However, this will require the professional's motivation to apply risk management and the availability of at least some risk management tools. In addition, likely some kind of training is needed, for gaining the attitude and skills for applying risk management.

Non-geotechnical decision makers turn up in any construction project and they ultimately determine the amount of resources, such as money and time, to be allocated to geotechnical activities. By gaining risk management skills, in addition to in-depth geotechnical expertise, geotechnical professionals may become even much better positioned for effectively communicating and implementing their precious geotechnical expertise in any construction project.

### 1 INTRODUCTION

*"China presents massive opportunities for the construction industry, and it could be the second largest market in the world in two years"*

This phrase by Scott Hazelton (2007) in an article on the economic outlook of China summarises the fascinating growth of the construction activities in China. In 2006, China used 40 % of the world's output of cement and China accounted for 90 % of the growth in steel demand. In 2006, China was the third largest construction market, behind the US and Japan. With an average growth rate in construction expenditure of more than 9 % per year, it is expected that China will take over Japan's number 2 position already in 2008. Furthermore, contrary to construction growth in many other countries, China's growth covers all sub-sectors, like the infrastructure, residential and non-residential construction, and industrial markets.

While not as impressive as China, also in other regions the construction industry is growing. For instance, in Europe there is a significant growth in the infrastructure markets, which pushes the overall construction industry growth to some 1.7 % per year until at least 2009 (International Construction, 2007a).

However, growth within the construction industry is no free lunch. An increase in complexity of construction projects creates real challenges for the players in the construction industry. Pressures on control of safety, quality, costs, and time are rising. Public expectations on health, safety and limited environmental impact are growing. Finally, we should not forget the impact of the rapid worldwide change of our climate, whether caused by mankind or merely of a natural origin, on construction demands and activities. Just one example in this respect is the Sao Paulo subway collapse, where public was killed by a cave-in during construction. While still under investigation, a representative of the construction firm in charge reported that “heavy tropical rains of this year may have contributed by softening the underground area around the construction site” (International Construction, 2007b).

Therefore, in summary and as stated very clearly in Bulletin No.1 of this First International Symposium on Geotechnical Safety & Risk: today’s practical, educational and research challenges are quite unique to geotechnical engineering. Two main causes drive this situation. The first cause is the inherent uncertainty of ground conditions. Despite the most extensive site investigations programmes, information of ground conditions to some degree remains random, fuzzy and incomplete. As a second cause, our industry seems to embrace the concepts of risk and its management at a slower pace than other industries.

One of the solutions for effectively dealing with this second unfavourable cause is moving forward to a real adoption and application of principles of geotechnical risk *management*. Traditionally, geotechnical professionals do focus on geotechnical risk *analysis*. However, often still in a rather implicit way and merely concerning one project phase. The risk analysis product is a *report*, that may be used during other project phases, and often is not. Risk management follows the entire *process* of a construction project, from the earliest feasibility phase through to operation and maintenance. A typical product of a risk management process is a *risk register*. It requires regular updating and should become an unavoidably item in any project management meeting.

## 2 RISKY CONCEPTS

### 2.1 *The concepts of uncertainty and risks*

Before discussing the concepts of risk analysis and risk management, it might be useful to consider in some detail the so often used words of *uncertainty* and *risk*. What do these words actually mean? Uncertainty is a certainty. We all encounter uncertainty, in our daily professional and private lives. *Uncertainty* can be defined as an absence of information about parts of a system under consideration. Uncertainty is always present, even when information is perceived as complete (Smallman, 2000).

The term *risk* and the associated term *hazard* have a lot of definitions, proposed by numerous experts and institutions. *Hazards* can be defined as threats to people and the things that they value. In the view of Carlsson, Hintze and Stille (2005), an uncertainty becomes a risk if a probability is assigned to it.

*Risk* can be defined as the product of the probability and the eventual impact of a hazard (Smallman, 2000). In other words, risk is the product of the probability or likelihood of an undesired event and the consequences of that event. Indeed, it means that the uncertainty of the risk event is two-fold. First, the uncertainty about the occurrence of the risk, which may be expressed in terms of probability. Second, when the event occurs, the uncertainty about the likely consequences can also be expressed in terms of probability. In the context of conventional risk management, uncertain events are usually considered as hazards, with the potential to have *negative* effects. However, uncertain events can also give attractive opportunities with *positive* effects. Including these positive opportunities is a rather modern extension of the common understanding of risk and risk management (van Staveren, 2006).

### 2.2 *The concept of risk analysis*

Risk analysis can be considered as some kind of break-down of the possible risk cause(s) and risk effect(s). It’s purpose is to obtain insight in the way to reduce or even eliminate the particular risk, either by reducing the probability of occurrence of the risk causes, or by taking measures to lower the

effects of the risk, in case of occurrence. A number of well-known and widely applied risk analysis methods are presented in Figure 1.

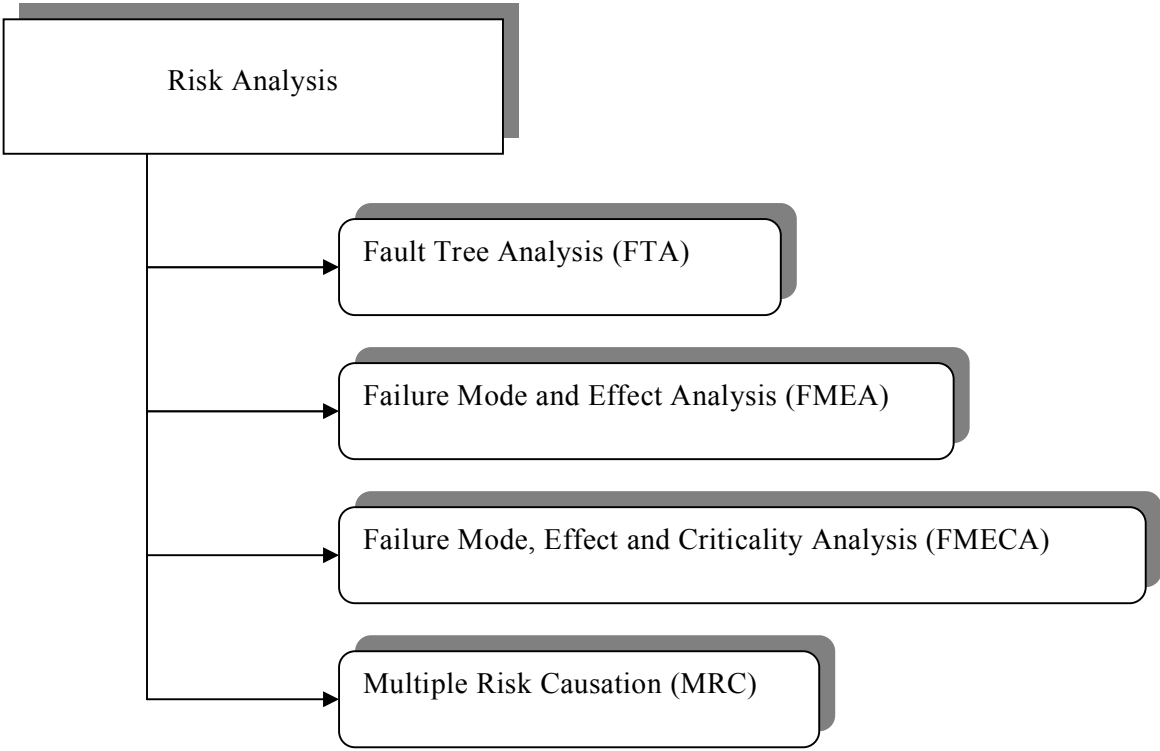


Figure 1 Some risk analysis methods (van Staveren, 2006)

The following description and example is retrieved from van Staveren (2006). The *Fault Tree Analysis* (FTA) is a schematic representation of any *causes*, which can result into a pre-defined uncertain event or risk. In other words, FTA aims to identify all possible causes, which may contribute to a particular risk. For instance, the risk of a rock-fall at the foot of a mountainous rock-slope can be divided in a set of conditions that ultimately determines the occurrence of the rock-fall. Aspects such as the discontinuity spacing and orientation, as well as the water pressures in the rock mass of the slope will all have their contribution to the rock-fall. FTA is typically a top-down methodology and it represents the causation of risk.

The *Failure Mode and Effect Analysis* (FMEA) can be considered as the opposite of the FTA. This bottom-up methodology extrapolates the occurrence of a certain event, failure or risk to its possible *effects*. If we return to the rock-fall risk, the FMEA considers all possible *effects* when the rock-fall take place, like obstructing a road at the foot of the slope and causing traffic victims. In addition, a remote village can not be supplied anymore, and so on. For reasons of completeness, the *Failure Mode, Effect and Criticality Analysis* (FMECA) is also presented. This extended version of FMEA assesses and rates both the probability of failure and the severity of its effects, with explains the added term *criticality* (Muhlemann et al,1992). By building forward on the rock-fall risk example, the FMECA assesses and rates the probability of occurrence, as well as the severity of the effects of the rock-fall. Due to the structured approach, the FMECA method particularly adds value in those cases demanding a detailed analysis of failures of (geo)technical systems. The FTA, FMEA and FMECA methods provide an in-depth insight in both the causes and effects of the risk of concern. In addition, these tools often identify new risks that would remain hidden within a sole risk identification exercise. Figure 2 illustrates a simplified cause and effect analysis for the rock-fall risk example.

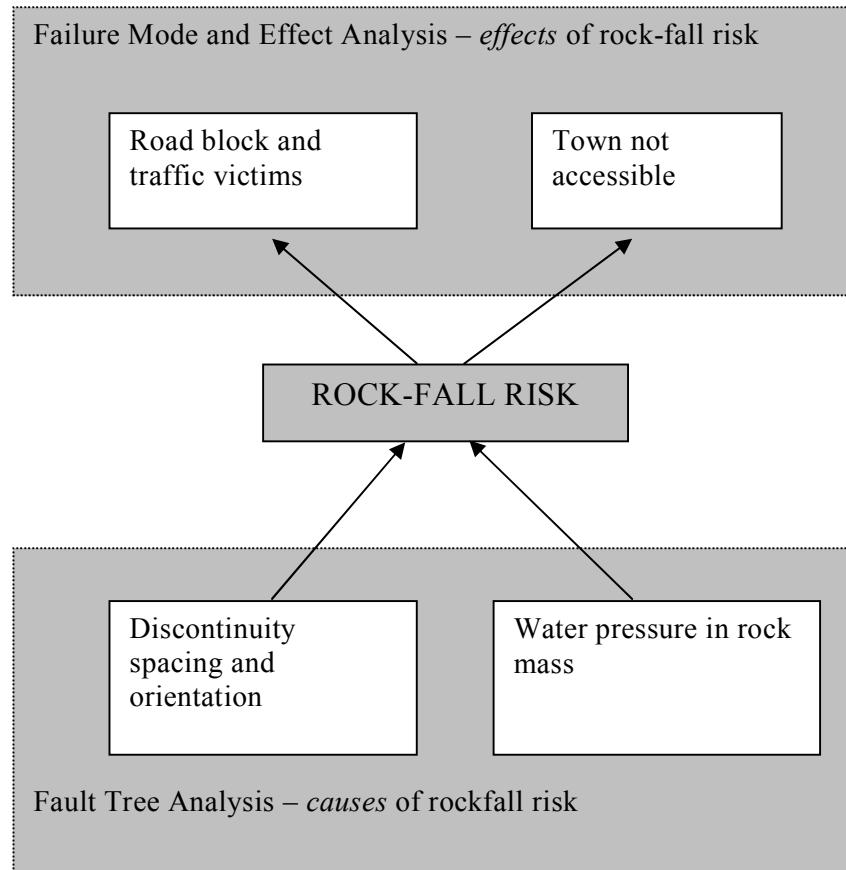


Figure 2 Combined cause and effect analysis of rock-fall risk (van Staveren, 2006)

The FTA and FMEA methods approach analyses one particular risk, by a detailed break down in a number of causes and effects. Acknowledgement of the *causation* of several risks is another significant aspect of risk analysis, because many risks are interrelated. This can be defined as *Multiple Risk Causation* (MRA) (van Staveren, 2006). A major risk event might occur where apparently unrelated risks line up in a risk chain.

Shrivastava et al (1988) developed a risk model for the avoidance of industrial crises, which gives insight in this interrelationship or causation of risks. Their risk causation framework distinguishes so-called *HOT* failures, Human, Organisational or Technological failures that are *event initiators*. In addition, they introduce so-called *RIP* factors, which are Regulatory, Infrastructural and Political factors that act as *event accelerators* (Smallman, 1996). The human, organisational and technological failures trigger a certain risk or crisis, while the regulatory, infrastructural and political factors accelerate and increase the risk or crisis. Figure 3 applies this approach to the rock-fall risk and illustrates how apparently very different factors contribute the risk of rock-fall.

<b>"HOT" FAILURES (EVENT TRIGGERS)</b>		
<b><i>Human</i></b> Limited experience of the engineer	<b><i>Organisational</i></b> No standard design check by a senior engineer	<b><i>Technological</i></b> Failing measurement of water pressures in discontinuities
<b><i>Ultimate Risk</i></b> Slope instability by a rockfall		
<b><i>Regulatory</i></b> No regulation available for rock slope design	<b><i>Industry structure</i></b> Severe price competition with selection on lowest price only	<b><i>Political</i></b> None
<b>"RIP" FACORS (EVENT ACCELERATORS)</b>		

Figure 3 Multiple Risk Causation for a rock-all (van Staveren, 2006)

### 2.3 *The concept of risk management*

Risk needs to be *managed*, in order to stay successfully in business. As mentioned by Waring and Glendon (1998), many organisations suffer large cumulative losses from a myriad of apparently little incidents. Sound risk management contributes to the direct and broader stakeholders of the organisation, as well to society as a whole (Elliot et al, 2000). Thus risk management is not only a prerequisite in trying to avoid major (construction) disasters, but also to minimise the expenditure of clients and to improve bottom line financial results of firms. This applies in particular to the inherently risky construction industry.

But what is risk management anyway? Similar to the term risk, also the term *risk management* has many definitions. According to Clayton (2001) risk management it is simply the overall application of policies, processes and practices dealing with risk. Risk management should therefore be a well-defined and understood responsibility within the entire project organisation. Here a major problem occurs: in most project organizations dealing with construction risk management is *not* yet a well-defined and understood responsibility within the entire organization.

Stacey et al (2006) raises attention to the fact that traditionally non-risk design approaches are applied. This is the case in the mining industry, but it seems also the case in the geotechnical construction industry, at least according to my experience. By applying a risk management approach, for instance the GeoQ approach which will be introduced later in this paper, sound decisions on for instance design options can be much more easily made by often non-geotechnical decision makers. Also the other way around, by defining pre-set risk levels at management or even board level, (geo)technical designers will be able to translate these accepted risk levels to technical design requirements, which may result in a true risk-driven design and construction process.

## 4 BLENDING THE CONCEPTS IN A RISK MANAGEMENT FRAMEWORK

### 4.1 Comparing risk analysis and risk management

Above we have discussed the concepts of risk analysis and risk management. Table 1 provides a idealized summary from the main characteristics of both concepts. Obviously, in the real world the differences between risk analysis and risk management are often not that clear. However, it may help us to understand the fundamental differences between both concepts, as well as the fact that we need both concepts jointly together in order to realize successful construction projects. In other words, we need *both* risk analysis and risk management at the same time through all phases of our construction projects.

Table 1 Comparing the key aspects of risk analysis and risk management

RISK ANALYSIS	RISK MANAGEMENT
Product focus	Process focus
Considers one project phase	Considers all project phases
One problem approach	Multi-problem approach
Considers interest of one stakeholder	Considers interests of many stakeholders
Mono-disciplinary	Multi-disciplinary
Technical focus	Holistic approach

### 4.2 GeoQ: a risk management framework

A risk management framework which integrates risk analysis and risk management has been developed in the Netherlands since 2001. This so-called GeoQ approach, where Q stands for quality, is a cyclic risk management process for the ground in relation to construction activities (van Staveren, 2006). The main objective of GeoQ is to manage the risky ground during all phases of a construction project, from the feasibility phase right through to the maintenance phase by six generic risk management steps. Chapman and Marcetteau (2004) show that about half of projects are significantly delayed, and of those delays, about half were caused by adverse ground conditions. The risk-driven GeoQ process expresses for instance the need for timely and adequate site characterization, appropriate foundation design and effective monitoring during foundation construction. These activities are often under resourced and are frequently the first to be cut when pressures to save project costs are applied (van Staveren and Chapman, 2007).

The GeoQ method is quite new. However, considered from some distance, it will quickly become clear that many of the elements of GeoQ are quite well-known. In fact, GeoQ is literally a deepening of existing risk management procedures, such as *MARIUN* (MANaging Risk and UNcertainty) in the United Kingdom and *RISMAN* (RISK MANagement) in The Netherlands. The latter is in use since 1995 and successfully applied for many large and smaller infrastructure projects. However, a detailed and fit for purpose translation of these systems towards management of ground-related risk, with its

own characteristics, was still missing. In practice, systems like RISMAN, proved to be more of a one-moment risk *analysis* tool, rather than a risk *management* tool during the entire construction process.

4.3 *Six risk management phases*

As mentioned, the GeoQ risk management approach distinguishes six generic project phases and Figure 4 presents them. The phases are the feasibility phase, the pre-design phase, the design phase, the contracting phase, the construction phase and the operation and maintenance phase. The position of the contracting phase depends on the type of construction contract. Contracting will occur just before construction in case of conventional contracts. For design and construct type of contracts, the contracting phase is before the design phase or even before the pre-design phase. For very large or rather small projects the number of project phases can be extended or combined. This will not affect the GeoQ process, as long as the six GeoQ steps are strictly performed in each project phase.

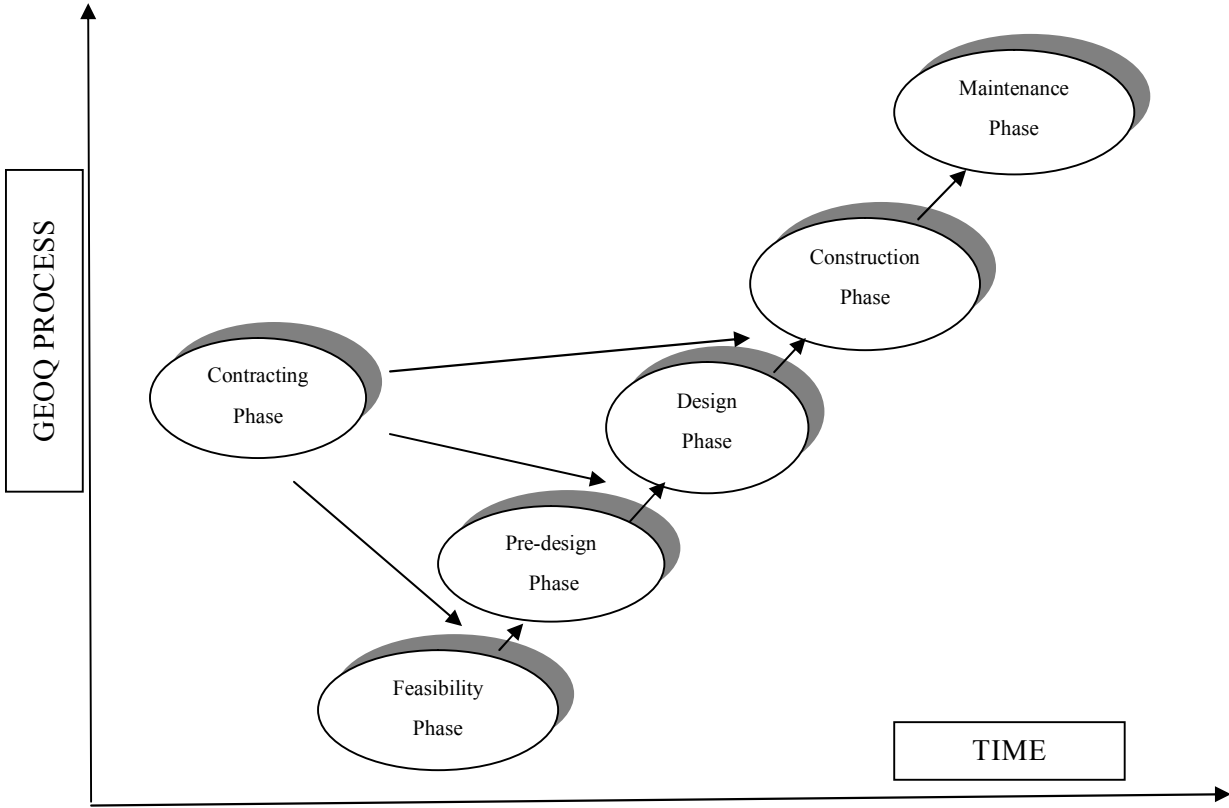


Figure 4 The six GeoQ phases

4.4 *Six risk management steps*

While the six GeoQ risk management *phases* are flexible, the six GeoQ risk management *steps* are quite rigid. These steps should be applied one by one in a structured way. Figure 5 presents the six generic GeoQ steps of gathering project information, identifying risks, classifying risks, remediating risks, evaluating risks and finally mobilizing all relevant risk information to the next project phase are introduced and discussed. In each distinguished project phase these six generic risk management steps have to be carried out, in order to implement proper ground-related risk management (van Staveren, 2006).

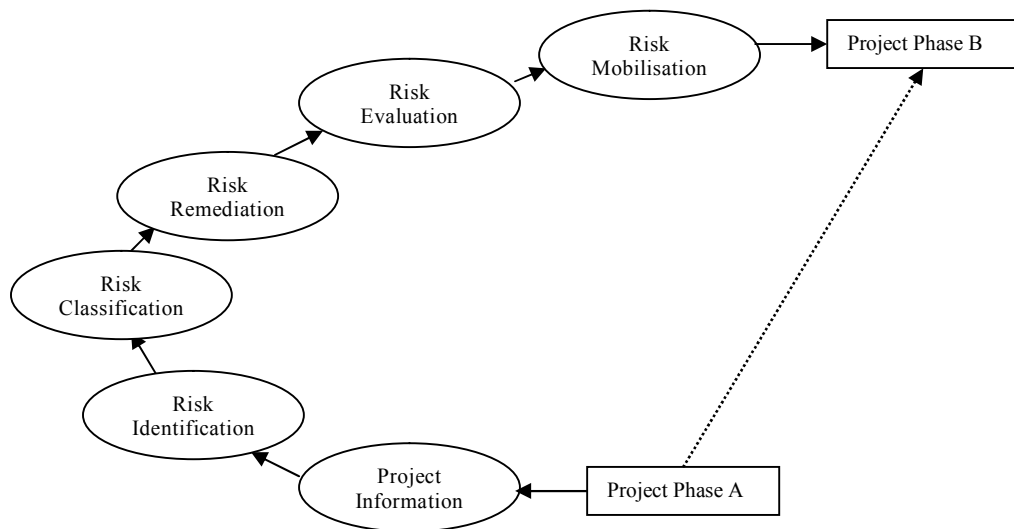


Figure 5 Six cyclic GeoQ steps

### 2.5 Anticipated benefits of risk management

It is a pity that the bottom line benefits of risk management are so difficult to measure. In particular in the ground-related sectors of the construction industry, evidence about bottom line improvement by the application of risk management is still hardly available. But we have to realize that risk management is embedded, already for years, in many companies in other industries. These firms clearly consider their bottom line results, as many of them are listed multinationals. Therefore, risk management would at least pay back its investments.

Some research of the benefits of risk management in the construction industry has been found. For example, according to research in the United States by the Construction Industry Institute (CII) of the University of Texas, a 1:10 cost-benefit ratio can be expected, as a result of better contracting practices by improved risk allocation (Smith, 1996). A study of Perry (1981) of two major transportation tunnel projects resulted in estimated cost savings between 4 % and 22 %, by the application of risk management practices. Finally, while considering that different sources estimate the failure costs in the construction between 10 and 30 % of the turnover, and that profit margins in the construction industry are typically between 2 and 4 % of the turnover, there appears a huge gap for (financial) optimisation, to which proper risk management might give a considerable contribution. In this respect, applying risk management within the (geotechnical) construction industry deserves a fair chance.

## 4 COMMON GROUND RISK MANAGEMENT BARRIERS

### 4.1 Introduction

So far, this paper intended to present some rather straightforward insights in geotechnical risk analysis and its complement, geotechnical risk management. The anticipated benefits of risk management are at least promising. It is therefore quite remarkable that the adoption and application of risk management, thus the extension of risk analysis during more project phases, is quite slow in the construction industry in general and in its geotechnical sub-sectors in particular. The fact that this paper is written for the *First International Symposium on Geotechnical Safety & Risk*, in 2007, says a lot.

Why? It might have to deal with the mindset engineers. They easily consider something as wrong, if it does not prove to be completely right. It is a way of *digital thinking*: it is one or zero. This type of black and white approach is often very useful for the technical solutions within construction projects. However, the realisation of the *construction project* includes a *construction process*, from

the early feasibility stage via pre-design, design, construction towards operation and maintenance. It includes both so-called hard technical approaches and the soft social approaches. Blockley and Godfrey (2000) taught us that trying to optimise a construction *process* by using solely black and white thinking is not productive at all. Simply, because it disturbs the inherent subtle and dynamic character in each phase of a construction *process*, with all of its internal and external, as well as technical and social influences.

This situation demands for a non-conventional approach. Just developing more risk management frameworks, protocols and tools, the technical approach, seems not sufficient for adopting risk management within the social systems of project organizations. It seems required to consider the actual barriers to implement geotechnical risk management in project organizations from three different but interrelated aspects:

1. *motivation* of individual professionals to apply geotechnical risk management;
2. *tools* required to apply geotechnical risk management;
3. *training* required to apply geotechnical risk management.

Within the Netherlands, in 2007 a joint Delft Cluster research project has been started to study these aspects and to draw some general guidelines for successfully implementing geotechnical risk management in project organizations, by giving the right attention to these three elements of motivation, tools and training. The remaining part of this chapter will briefly introduce some of the risk management implementation barriers encountered from these three perspectives. The next chapter will present some possible solutions. Because of the fact that the mentioned research project has only recently started, both the presented barriers as well as the presented solutions are still indicative and incomplete. However, these may give a glance towards the near future, when more knowledge in this field will be developed and geotechnical risk management becomes more easily and effectively implemented in all kinds of construction project organizations.

### 3.1 *Motivation as a barrier*

While most professionals will *say* that they are dedicated and motivated to apply geotechnical risk management approaches in their own practice, their *acting* is often quite different. It could be even worse. In my professional experience I meet professionals who work in organizations where even the *word* risk is considered as a taboo. Risk equals to problems in these organizations. Instead of dealing pro-actively with potential problems and using its often hidden opportunities, such organizations and their professionals tend choosing, often rather unaware, to neglect potential problems and thus risk, until the moment that they really occur and often expensive (re-)action is required. Obviously, professionals working in these kind of organizations are not stimulated and probably also not motivated to apply any kind of explicit risk management.

### 3.2 *Tools as a barrier.*

Another often heard argument is the apparent lack of appropriate risk management tools. Again, these professionals say that they are really motivated to apply risk management principles in their geotechnical practices. However, they say their organizations do not have the appropriate risk management *tools*, and therefore they are not able to apply risk management in their daily geotechnical activities. Clearly, state-of-the-art (software) tools can be highly valuable to assist risk management processes, but just paper and pencil is already sufficient for starting with any risk management process. Additionally, many existing technologies and tools within the geotechnical practice, such as site investigation techniques and finite element design software, can be used very easily in a risk-driven way. In other words, the apparent lack of tools seems often to be used as some kind of an alibi for a lack of real motivation to apply risk management.

### 3.3 *Training as a barrier*

After risk management motivation and tools, the third element of concern is the (lack of) training as a barrier to implement and apply geotechnical risk management in construction project organizations. This appears to be a real barrier, in two ways. Firstly, many engineers are educated and trained to

avoid uncertainty as much as possible, for instance by applying rather conservative safety factors in their geotechnical design. Of course we need suitable safety factors within the geotechnical discipline, but in the same time we need to remain critical about them as well. As presented by van Staveren and Chapman (2007), just sticking to the ruling design codes and standards with their recommended safety factors is not sufficient anymore in today's demanding construction industry.

Even more worrying is the fact that formal training of applying risk management principles within the geotechnical construction industry seems to be in its very early development stage. Not only developing a risk aware attitude lacks in most formal engineering education and training, also training of the skills to apply risk management is not yet included in most existing programs. Clearly, this situation provides also a huge barrier to apply geotechnical risk management in practice: the involved professionals are often both unaware about risk management and not skilled to apply it.

## 4 MODERN GROUND RISK MANAGEMENT SOLUTIONS

### 4.1. *Introduction*

The content of the previous chapter might easily bring us in a rather gloomy mood. However, the sun is shining behind the clouds and risk management barriers can be solved as well. The following paragraphs provide some first steps in the right direction.

### 4.2. *Becoming motivated*

Probably most, if not all, geotechnical professionals will be motivated to do a good job. Therefore, there will be a hidden motivation in almost every professional to apply risk management, if this professional becomes aware of the fact that it will help himself and his team, organization, client and even society to do a good job. My experience proves that just one or two days training in risk management awareness with your professional team can bring this hidden motivation to the surface. Insights from the social sciences, such as some practical psychology and sociology, provided by a dedicated trainer can be really helpful. Furthermore, easily prepared and performed tests, such as the Risk Maturity Test (Hillson, 1997) may act as a very effective eye-opener towards the actual risk maturity of individual professionals and their teams and organizations. Once the intrinsic motivation has been surfaced, the way towards an sharp increase in risk maturity is free.

### 4.3. *Becoming tooled*

With just some out-of-the-box thinking, almost every technology and tool applied in today's geotechnical engineering can be effectively used in a risk-driven way. Examples are site investigation tools such as cone penetration testing, geotechnical design software with the possibility to perform sensitivity analyses, concepts like the observational method with using geotechnical monitoring equipment, and so on.

In addition, a lot of actual risk management tools are widely available. An example is team-based risk identification and classification, by support of information and communication technology. Figure 6 shows a typical setting, in which a team of professionals, either mono-disciplinary or multi-disciplinary, participate a risk management session in a so-called Electronic Board Room (EBR). The laptop computers and easy to use risk management software allows them to brainstorm anonymously on risk identification and classification. These individual professionals can build forward on the results of their team members, while unfavorable team effects are limited because their any input remains unidentified by team members.

### 4.4. *Becoming trained*

In addition to the specific training in risk awareness, as mentioned above to uncover the hidden professional motivation to apply risk management, formal training is required to apply available risk management frameworks, such as GeoQ, in the engineering and construction practice. This niche has been discovered and interesting developments have been started.



Figure 6 A typical setting of an EBR-facilitated and team-based risk session. (© with permission of GeoDelft)

Examples are this 1<sup>st</sup> International Symposium on Geotechnical Safety and Risk and the new international journal *GeoRisk*. The Delft University of Technology in The Netherlands initiated the MSc course *Geo Risk Management* (van Staveren, 2007), (van Staveren and van der Meer, 2007). Furthermore, the Delft Geo Academy of Dutch National Institute for Geo-Engineering GeoDelft starts in 2007 an international post-academic course on geotechnical risk management. Highly likely, similar initiatives started already or are starting soon in other countries.

## 5 CONCLUSIONS

Geotechnical risk management can not be neglected anymore in today's construction industries, which grow both in size and complexity. Risk analysis complements risk management. Both are required and can be blended in modern frameworks, such as the GeoQ approach for geotechnical risk management.

However, apart from the availability of risk management concepts and tools, its real *implementation* and application within project organizations is still difficult. Serious barriers exist with regard to the professional's motivation, the over-emphasis on risk management tools and the lack of formal geotechnical risk management training. Some solutions, still indicative and incomplete, have been presented and seem to be promising to overcome these barriers. A lot of near future research, and in particular experimenting with risk management in real projects, is warmly recommended for effectively responding to today's global construction challenges. By gaining risk management skills, in addition to in-depth geotechnical expertise, geotechnical professionals may become even much better positioned for effectively communicating and implementing precious geotechnical expertise in any construction project, which may serve their organizations, their clients and their societies.

One final remark is required at this stage. It should be noted and taken seriously that, similar to any system, the application of any ground risk management system, including GeoQ, is definitely not a guarantee that nothing will go wrong within our construction projects. Explicit geotechnical risk management is still rather young and has not yet fully developed. Geotechnical risk management is literally a deepening of existing risk management procedures. All joint efforts for further development are welcome. Apart from growing our own experiences, further development can be highly supported by learning from theories, practices and lessons of other sectors or disciplines.

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