Svenska Geotekniska Föreningen
Swedish Geotechnical Society

Report 1:2014E

Risk management in geotechnical engineering projects – requirements

Methodology

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SGF Report 1:2014E
(English version, translated in 2017)

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Methodology

Linköping 2017

SGF Rapport	Svenska Geotekniska Föreningen E-post: info@sgf.net
Beställning	Svenska Geotekniska Föreningen c/o Ernax Sveaborgsvägen 16 439 73 FJÄRÅS Tel: 031-733 47 03 E-post: info@sgf.net
ISSN	1103-7237
ISRN	SGF-R-14/1-EN
Upplaga	Digital utgåva
Tryckeri	www.sgf.net

Preface

The Swedish Geotechnical Society (abbreviated SGF in Sweden) is the national branch of the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE). SGF is an all-round non-profit association that organises professional geotechnical engineers working for all parties in the construction industry.

SGF publishes method descriptions for geotechnical procedures, for which there is no existing standard. These method descriptions have been produced by SGF's technical committees, which have members from all parts of the construction industry with interest in geotechnical engineering. The SGF method descriptions therefore have the support of the Swedish construction industry. The purpose of the method descriptions is to provide a basis for tendering and quality management in geotechnical works.

In 2009, SGF's committee on risk performed a pre-study, which found a need for risk management tools for the geotechnical engineer working in practice. The prestudy suggested that method descriptions should be prepared for a number of risk management methods, as well as a general description containing requirements on risk analyses.

This report contains requirements on geotechnical risk analyses to be used in practice. The report was prepared during 2012–2013 by SGF's committee on risk. Main authors were Lars Olsson and Håkan Stille, supported by the other committee members. A first draft was presented at a SGF seminar on November 26, 2013. Comments provided at the seminar were taken into account in the final version of the report, which has been approved by the SGF board. This version is titled SGF Report 1:2014, "Hantering av geotekniska risker i projekt – krav.

Metodbeskrivning.” Ann Emmelin (Golder Associates) and Carina Wänglund (Faveo Projektledning) are acknowledged for their time in effort in reviewing the final report.

In 2015, the Development fund of the Swedish construction industry (SBUF) funded a research project, in which it was studied how the suggested requirements can be applied in practice. The project resulted in a report in Swedish, “Hantering av geotekniska risker i byggprojekt: ett praktiskt tillämpningsexempel” (Spross et al. 2015a), in which the foundation of the Equestrian sport centre was analysed from a risk management perspective. A summarising conference paper in English was also presented at the 5th International Symposium on Geotechnical Safety and Risk in Rotterdam (Spross et al. 2015b). At the conference, it became clear that SGF’s risk management methodology was of international interest; hence, SGF decided to financially support a translation into English of the Swedish final report and a minor revision of the Swedish version. Johan Spross (GeoSpross AB) became main translator, supported by Lars Olsson (Geostatistik AB).

As this is an English translation of SGF’s suggested requirements on geotechnical risk management, the report considers the Swedish practice, but the guidelines are to a large extent feasible also internationally. In case of discrepancies in the translation, the revised Swedish version is preferred.

Svenska Geotekniska Föreningen

Linköping in June 2017

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Chapter 1.
Introduction

1.1 PURPOSE OF SGF'S METHODOLOGIES

The purpose of the method descriptions is to be renowned tools for geotechnical engineers working in practice. Using this method description promotes a common view on geotechnical risk management in the construction industry. This makes risk management performed in accordance to this method description an indication of quality that may be useful in tendering of consultancy work and construction, as well as when taking out insurances.

The purpose is however not to aspire to be a code; instead this method description may be used as a support in applying other standards, such as the ISO 31000 Risk Management – Principles and Guidelines and IEC/ISO 31010 Risk Management – Risk Assessment Techniques.

Only the main text, which contains the requirements, is defined as a method description. The appendices provide support for its application.

1.2 PURPOSE OF THE PRESENT REPORT

There is a need for guidelines on risk management to ensure that it is executed with satisfactory quality. This report should be read as a proposal to such guidelines and it defines requirements that should be set on the risk management.

Simply, the purpose of this report may be put as

Enable risk management to be executed with sense, for the right purpose, and in the right way.

This implies that risk management shall be performed in all projects – both large and small ones – but not in exactly the same way in all projects. Thus, the risk management shall be tailored to each individual project, both to each project phase and to the specific roles of the participating parties. In addition, the risk management shall proceed throughout the whole project.

In principle, the requirements defined in this report are satisfied by always having a risk management process that is adjusted to the project needs and by using the process as a complement to the engineers' everyday work. In this report, the term risk management class has been introduced to serve as guidance when the scope of the risk management is to be defined.

1.3 GUIDANCE TO THE READER

The report is divided into two parts. The first part – the main text – contains the suggested requirements on the risk management work. There are two types of requirements: basic requirements that always must be met and requirements that are specific for each activity in the risk management cycle. The requirements are often given as bullet lists, in which the filled bullet points should be read as *shall* requirements and the indented unfilled circles should be read as *should* requirements. *Shall* requirements is mandatory to satisfy, while accompanying *should* requirements indicate non-mandatory goals that are related to the *shall* requirement.

The second part of the report contains appendices that discuss the requirements and provide some background to them.

1.4 THE DEFINITION OF RISK

This report applies the definition by ISO 31000:2009, where risk is defined as "effect of uncertainties on objectives", but with a minor adjustment: only negative effects are considered.

1.5 THE ACTIVITIES OF THE RISK MANAGEMENT CYCLE

Risk management can be divided into a number of activities. First, the project-specific context shall be established. Thereafter, a risk assessment is performed, which implies risk identification, risk analysis, and risk evaluation. Then, the risk owner shall decide whether and how the risks shall be treated; i.e., whether the risks shall be accepted or reduced. The risks shall then be communicated and followed through the project. The activities of the risk management cycle are illustrated in Figure 1. The activity-specific requirements refer to this cycle.

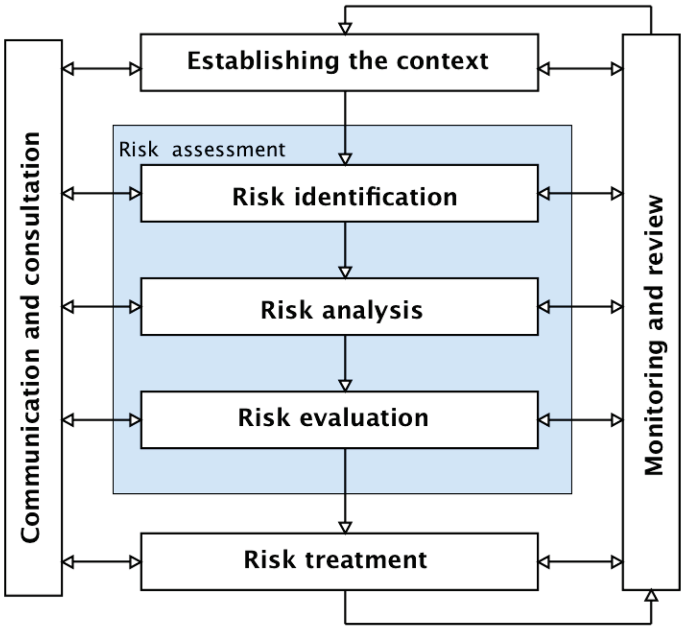

Figure 1 The activities in the risk management cycle (after ISO 31000:2009)

Chapter 2.
Basic requirements on management of geotechnical risks

Geotechnical risk management is a concept describing a general procedure for how to manage uncertainties that may threaten defined goals in geotechnical engineering projects. Section 2.1 presents the four basic requirements that continuously shall be met in order to achieve a satisfactory quality in the risk management of a geotechnical engineering project.

Quality is here defined as

the ability of a product to satisfy or exceed the client's explicitly or implicitly stated, justifiable requirements and wishes

The four basic requirements are in the following chapters complemented by specific requirements on the activities of the risk management cycle.

2.1 THE FOUR BASIC REQUIREMENTS

The following basic requirements shall continuously be met:

I. The scope and object of the risk management shall be established.

> *Comments:*
> Which part of the project (i.e. which work tasks) is to be covered by the risk management?
> Which type of uncertainties and which type of effects will be covered?
> Which type of decisions will be affected by the risk management?

II. The decision maker (risk owner) shall subscribe to the concept of risk.

Comments:
The decision maker is the one who has the responsibility for the project. This is often the project leader.
The decision maker shall be knowledgeable about the project objectives and about the uncertainties that may threaten them.
The decision maker shall be knowledgeable about the general principles of risk management and its opportunities.

III. Engineers with formal responsibilities shall have essential knowledge of risk management.

Comment:
As geotechnical engineering always implies that uncertainties are considered (and that risks are managed), all engineers shall have fundamental knowledge about the various aspects of risk management. They shall also be able to put risk management into context, i.e. adjust the procedure to the engineering problem at hand.

IV. A system for communication and transfer of risk-related information shall be established.

Comment:
Geotechnical engineering projects often take a long time to complete. This requires information to be transferred from one project phase to another.

Chapter 3.
Establishment of the risk management context

The basic requirements on risk management in geotechnical engineering projects are described in Chapter 2. The risk management shall be established, so that the basic requirements are satisfied. The specific requirements on the establishment activity can be divided into procedure-related requirements and requirements concerning geotechnical and structural risks.

3.1 REQUIREMENTS ON THE ESTABLISHMENT OF THE RISK MANAGEMENT IN GEOTECHNICAL ENGINEERING PROJECTS

3.1.1 Procedure-related requirements

- Tailor the established risk management both to the project (or project part) and to the specific project phase[1].

- Identify the risk owner.

  Comment: The risk owner is responsible for the project (or project part) and is thereby responsible for managing the risks related to that responsibility. The risk owner has the right to make decisions on risk treatment.

- The risk owners shall be given resources for the treatment of identified risks.

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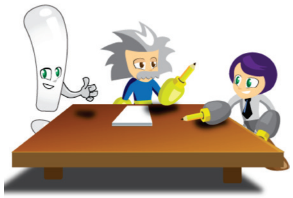
[1] Project phases are exemplified in section C.3.

- The risk management shall be executed by people with competence and skills in risk management. They shall:
  – be skilled geotechnical engineers,
  – be used to asking “What if?”,
  – be able to report back to the responsible decision maker when risk-reducing measures are needed, or have the right to make such decisions on their own,
  – be promoting continuous discussions about possible risks,
  – not be inclined toward a risk-taking behaviour.



- Acceptance criteria shall be established.

  Comment: Normally, the risk owner has the right to make decisions as he/she is responsible to reach a certain project goal. Formal acceptance criteria may be established (e.g. based on the company policy) to be a support for the risk owner.

- Risk management supporting organisation shall be established as needed.
  - The supporting organization should neither be too large (i.e. inefficient), nor too small (making it unable to provide the needed support).
  - The need for expert support from a risk analyst should be assessed.

- The risk management shall operate until the project is finished.
  - Routines to follow and for documentation of the risk management work should be established.
  - The necessary time for risk management work should be allowable for engineers to spend during the project life.

3.1.2 Requirements concerning geotechnical and structural uncertainties

The amount of risk management that is needed depends on the effect of uncertainties on the project objectives. This assessment is made by the risk owner based on experience from previous, similar projects. Risk management classes may be used for support (see section E.4).

- A first assessment of the effect of uncertainties on objectives shall be made early in the project.
    - The assessment should consider the robustness of the structure (e.g. in terms of brittle/ductile failure behaviour or critical steps in the construction).
    - The assessment should consider the geotechnical conditions: are there large uncertainties about them; do they vary significantly?
- A risk management class shall be assigned to the project in accordance with the procedure in section E.4.

Chapter 4. Risk identification

Note: risk identification implies (despite its name) primarily the identification of hazards (threats). The related consequences of these hazards should also be identified during this activity.

4.1 REQUIREMENTS ON THE RISK IDENTIFICATION

Unless threats are identified, contingency actions cannot be put into operation. Risk identification is therefore crucial in the risk management cycle. At times, it may be enough to identify the risks and immediately make decisions on whether they must be treated. This may happen if it is obvious that some risk is acceptable or unacceptable.

- Risks shall be identified using a suitable method.
    - Applying SGF's report 2:2014 "Risk identification – methods to find hazards and opportunities. Method description" should be considered.
- Risk identification shall be viewed upon as an engineering assignment.
    - Everyone who can contribute should be engaged.
    - Start out from the project goals.
    - Have a holistic view: consider all aspects of the project
    - Collect information as needed.
    - Differ between threats and consequences.
    - Create a good attitude task of finding risks.
    - Focus on finding risks, not solving the related problems.

- The result shall be documented, so that it may be used throughout the project.

Chapter 5.
Risk analysis

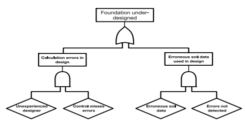
The purpose of the risk analysis is to produce descriptions of the risks in terms of likelihood and consequences to base decisions on in the risk evaluation and risk treatment activities.

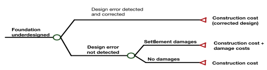
5.1 REQUIREMENTS ON THE RESULT OF THE RISK ANALYSIS

- All identified hazards shall be analysed, unless they were not treated immediately after risk identification.
- The result of the risk analysis shall be documented.
- The risk analysis shall produce basis for decisions.
  - The scenarios causing the consequences should be described.
  - The likelihood of the occurrence of the consequences should be estimated.

5.2 REQUIREMENTS ON THE ASSESSMENT OF THE CONSEQUENCES

- The possible chains of events shall be established.
  - The possible consequences should be described.
  - Tools for risk analysis, such as event or fault trees, should be applied as needed.
- All categories of consequences shall be considered, such as for example (but not limited to) personal injuries, environmental damage, delays, and additional costs.
- Mitigation measures that have been put into operation shall be considered.





5.3 REQUIREMENTS ON THE ESTIMATION OF LIKELIHOOD

- The event (or chain of events) for which the likelihood is estimated shall be described unambiguously.

- Necessary background information should be collected before likelihoods are estimated.
- The way to describe likelihood should suit the specific project.
- Descriptions of likelihood in terms of vague words (e.g. "quite likely ") should be avoided.
- If the likelihood is uncertain, it should be described as a range of probabilities.
- It should be made sure that chains of events are analysed statistically correct.
- Extremely small likelihoods should not be assigned numerical probabilities.
- Anyone estimating likelihoods should have the necessary training in doing so.
- The effect of psychological bias should be counteracted[2].
- For complex situations (e.g. repeated events), external support from experienced risk analysts should be considered.

- The likelihood shall be estimated objectively without considering the severity of the consequence.

[2] For example by working in a group (see e.g. BeFo, 2013)

Chapter 6.
Risk evaluation

In the risk evaluation, the risk owner decides on whether a risk must be treated and, if so, with what measures. This work is often based on criteria that were defined in the establishment of the risk management. However, the risk owner makes the final decision; at this point, there may be more aspects to consider, than what was known in the establishment activity.

6.1 GENERAL REQUIREMENTS ON THE RISK EVALUATION

- The risk owner shall be responsible for risk evaluation.
- The risk evaluation shall take into account both the risk policy of the project/company, as well as its readiness to take risks.
- The risk evaluation shall consider the joint effect of consequences and their likelihood.
  - Mixed decision criteria, such as risk indices that are mathematical products of probability and consequence, should not be used solely.
  - If the decision is complicated, formal decision analysis should be applied.
  - Risks should be clearly described (see Appendix H).
  - The total exposure to risk should be considered, if exposed to more than one risk.
- All relevant categories of consequences shall be considered in the risk evaluation.

6.2 REQUIREMENTS ON TOOLS AND METHODS FOR RISK EVALUATION

- The tools that are applied in the risk evaluation shall be modified to what is needed.

  Comment: In some cases, a simple screening using a risk matrix is the most suitable method; in other cases, a more qualified method is called for.

6.2.1 Requirements on risk matrices

- The likelihood classes and consequence classes of the risk matrix (Figure 2) shall be clearly defined.
  - Likelihood should be defined based on probabilities.
- The risk matrix shall be calibrated, if cells in the matrix are the basis for decisions.
- The risk matrix shall accommodate different types of consequence categories.

6.2.2 Requirements on the application of formal decision analysis

- Experts on risk analysis shall be consulted when formal decision analysis is applied.

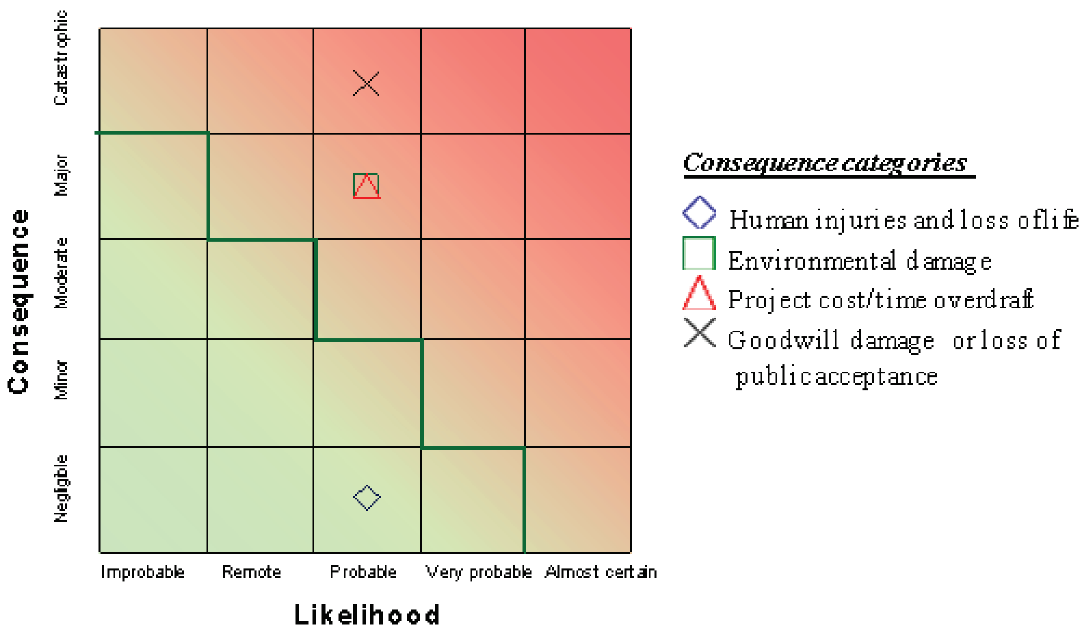


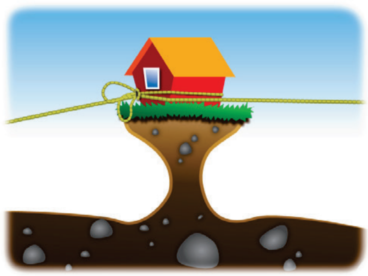
Figure 2. Example of a risk matrix.

Chapter 7.
Risk treatment

Risk treatment concerns the measures that are applied to reduce to risk, if the risk is not accepted.

7.1 REQUIREMENTS ON THE RISK TREATMENT

- The risks that the risk owner decided on treatment for shall be treated.
- Someone shall be appointed responsible for the execution of the risk treatment.
    - Contractual aspects should be reviewed in due time, so that the risk owner in the treatment activity can be identified.
- Use one or several of the following principles to reduce an unacceptable risk:
    - Reduce the possible consequences of the hazard.
    - Reduce the likelihood of the hazardous event, for example by monitoring programs.
    - Transfer or share the risk with someone else, for example with insurance.
    - Apply the observational method for complex design situations.



- The introduction of new risks caused by risk-treating measures shall be assessed by identifying hazards in the new situation.
- The decided risk treatment shall be communicated to the production unit in a document suited for the execution of the work.
    - Avoid introducing new documents that only concern risks.
- The execution of the risk treatment shall be confirmed.

Chapter 8.

Risk communication

8.1 REQUIREMENTS ON THE INTERNAL RISK COMMUNICATION

- Risk communication shall be continuous throughout the whole project between all involved parties and between all relevant project phases, both internally and externally.
- Internal risk communication shall be initiated at the beginning of the project.
    - Risks should be described with the most suitable method.
    - The possibility of misunderstandings should be considered.
- All involved parties shall be informed about and involved in the risk management work.
    - Risks should be discussed at all meetings (if relevant).

8.2 REQUIREMENTS ON THE EXTERNAL RISK COMMUNICATION

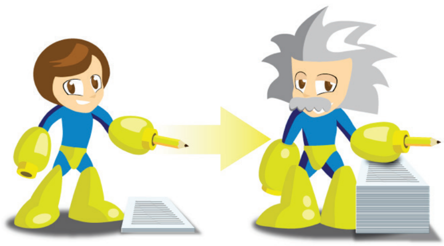
- The external risk communication shall be planned in due time.
    - Risks should be described with the most suitable method.
    - The possibility of misunderstandings should be considered.
- External risk communicators shall be appointed.
    - Guidelines for external risk communication should be prepared.

Chapter 9.
The review process

The review process concerns both how each risk is managed and how the risk management process is working.

9.1 REQUIREMENTS ON THE REVIEW OF RISK TREATMENT

- After a decision to treat a risk, the following shall be decided:
  – what shall be reviewed after the executed treatment?
  – who shall do the review?
  – How often shall the review be performed?
  – How shall identified deviations be managed?
  – How shall the review be documented?



9.2 REQUIREMENTS ON THE REVIEW OF THE RISK MANAGEMENT PROCESS

- The risk management process shall be reviewed, as needed.
  - In a review of the risk management process, the following should be included:
    – the use and acceptance of risk management procedures should be documented,
    – the occurrence of unidentified hazards should be documented,
    – the plausibility of the likelihood estimations should be compared against the outcome.
- Lessons learned from the project shall be documented.

  Comment: Lessons learned include near misses, occurred damage, and risk treatment actions that were found effective.

Appendix A
Terminology

A.1 THE DEFINITION OF RISK

Risk is for this report defined as the effect of uncertainty on objectives. This definition may be somewhat contradictory to the everyday use of the word "risk" as a negative event that possibly could affect you. A possible positive event is instead often called "chance".

The ISO 31000:2009 defines, however, risk as:

The effect of uncertainties on objectives
Note 1. An effect is a deviation from the expected — positive and/or negative.

Thus, ISO includes both positive and negative events in the concept of risk and puts the emphasis on the uncertainty. In this report, however, we have kept the old meaning of risk, and limit the discussion to only negative events, but the presented principles can straightforwardly be applied on positive event as well.

A.2 THE DEFINITION OF QUALITY

In this report, we apply the following definition of quality:

the ability of a product to satisfy or exceed the client's explicitly or implicitly stated, justifiable requirements and wishes

We base this deformation on SQA Swedish Quality Assurance, which makes the following definition of quality: "all properties of a product, service, or process, that provide its ability to satisfy or preferably exceed the client's explicitly or implicitly stated needs and expectations". (SQA's definition is a development of the definition made in the Swedish standard SS 02 01 04: "all properties of a product that provide its ability to satisfy the client's explicitly or implicitly stated needs”). To this, we have added that the requirements must be “justifiable”.

A.3 GEOTECHNICAL TERMINOLOGY

Geotechnical engineering
Geotechnical engineering is the branch within civil engineering that concern the engineering behaviour of soil and rock, as well as methods for construction occurring on the ground or within the ground.

Geotechnical uncertainties
Geotechnical uncertainties include not only geotechnical and geological conditions, but also technical uncertainties in the construction work and contractual uncertainties.

Geotechnical engineering project
A geotechnical engineering project is here defined as a construction project or that part of a larger project, in which geotechnical construction work constitutes the majority of the work and/or has a significant impact on the project result.

Geotechnical risk
A risk related to geotechnical uncertainties.

A.4 TERMINOLOGY OF RISK MANAGEMENT

Risk management
Procedures in a geotechnical engineering project applied to keep risks at an acceptable level.

Risk owner
The person that is responsible for the project or project part, which means that this person is responsible for managing the risks related to the project or project part.

Risk treatment
Procedures to keep a specific risk at an acceptable level.

Hazard
Condition that may threaten goals from being fulfilled.

Likelihood
Measure of the possibility that a hazard occurs.

Probability
The term probability is used according to its statistical definition in this report.

A.5 TERMS FROM ISO 31000:2009

The following terms are defined in accordance to the definition in ISO 31000:2009. The definitions are published with permission of the copyright holder (SIS Förlag AB).

Event
occurrence or change of a particular set of circumstances

Note 1 to entry: An event can be one or more occurrences, and can have several causes.
Note 2 to entry: An event can consist of something not happening.
Note 3 to entry: An event can sometimes be referred to as an "incident" or "accident".
Note 4 to entry: An event without consequences can also be referred to as a "near miss", "incident", "near hit" or "close call".

Stakeholder
person or organization that can affect, be affected by, or perceive themselves to be affected by a decision or activity

Note 1 to entry: A decision maker can be a stakeholder.

Consequence
outcome of an event affecting objectives

Note 1 to entry: An event can lead to a range of consequences.
Note 2 to entry: A consequence can be certain or uncertain and can have positive or negative effects on objectives.
Note 3 to entry: Consequences can be expressed qualitatively or quantitatively.
Note 4 to entry: Initial consequences can escalate through knock-on effects.

Risk
effect of uncertainty on objectives

Note 1 to entry: An effect is a deviation from the expected — positive and/or negative.

Note 2 to entry: Objectives can have different aspects (such as financial, health and safety, and environmental goals) and can apply at different levels (such as strategic, organization-wide, project, product and process).

Note 3 to entry: Risk is often characterized by reference to potential events and consequences, or a combination of these.

Note 4 to entry: Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence.

Note 5 to entry: Uncertainty is the state, even partial, of deficiency of information related to, understanding or knowledge of an event, its consequence, or likelihood.

Risk analysis

process to comprehend the nature of risk and to determine the level of risk

Note 1 to entry: Risk analysis provides the basis for risk evaluation and decisions about risk treatment.

Note 2 to entry: Risk analysis includes risk estimation.

Risk assessment

overall process of risk identification, risk analysis and risk evaluation

Risk treatment

process to modify risk

Note 1 to entry: Risk treatment can involve:

— avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk;
— taking or increasing risk in order to pursue an opportunity;
— removing the risk source;
— changing the likelihood;
— changing the consequences;
— sharing the risk with another party or parties (including contracts and risk financing); and
— retaining the risk by informed decision.

Note 2 to entry: Risk treatments that deal with negative consequences are sometimes referred to as "risk mitigation", "risk elimination", "risk prevention" and "risk reduction".

Note 3 to entry: Risk treatment can create new risks or modify existing risks

Risk management

coordinated activities to direct and control an organization with regard to risk

Risk identification

process of finding, recognizing and describing risks

Note 1 to entry: Risk identification involves the identification of risk sources, events, their causes and their potential consequences.

Note 2 to entry: Risk identification can involve historical data, theoretical analysis, informed and expert opinions, and stakeholder's needs.

Risk evaluation

process of comparing the results of risk analysis with risk criteria to determine whether the risk and/or its magnitude is acceptable or tolerable

Note 1 to entry: Risk evaluation assists in the decision about risk treatment.

Likelihood

chance of something happening

Note 1 to entry: In risk management terminology, the word "likelihood" is used to refer to the chance of something happening, whether defined, measured or determined objectively or subjectively, qualitatively or quantitatively, and described using general terms or mathematically (such as a probability or a frequency over a given time period).

Note 2 to entry: The English term "likelihood" does not have a direct equivalent in some languages; instead, the equivalent of the term "probability" is often used. However, in English, "probability" is often narrowly interpreted as a mathematical term. Therefore, in risk management terminology, "likelihood" is used with the intent that it should have the same broad interpretation as the term "probability" has in many languages other than English.

Appendix B
The working process of risk management

In principle, there is always risk management in geotechnical engineering projects, even if this today often is done *ad hoc*. To make the risk management reliable, the procedure must be both systematic and structured. We recommend the working process described in the following.

B.1 THE STRUCTURED WORKING PROCESS IN RISK MANAGEMENT

The same structured process is recommended for all types of projects and project phases that are included in a project.

The risk management has three main parts:

- Establishment of the risk management in the project (purpose, extent, responsibilities, etc)
- Risk assessment, which contains
  - Risk identification,
  - Risk analysis, to make us understand them and enable us to describe them to others,
  - Risk evaluation, which implies a decision on whether we can accept the risk as it is, or whether some measure is required.
- Risk treatment, which is the measures applied to change the risk.

The activities in the work process, according to ISO 31000, are shown in Figure 3. The figure implies that:

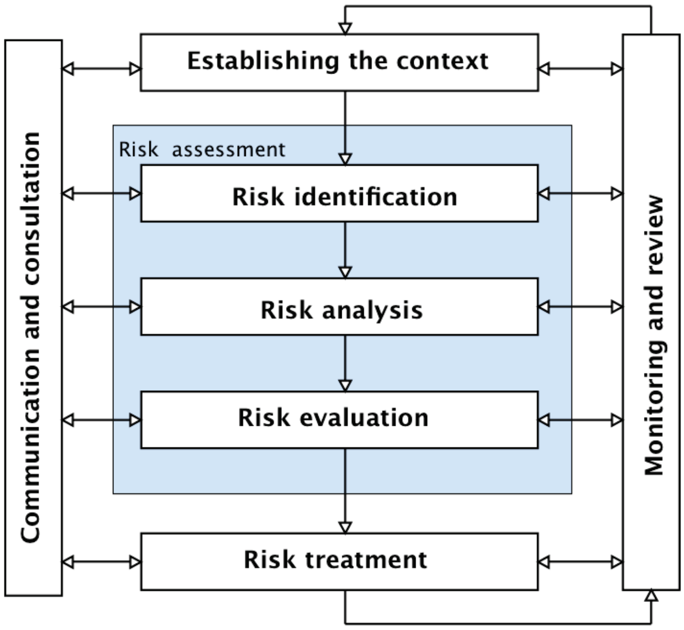


Figure 3. The activities of the risk management process, according to ISO 31000:2009.

- Risk management is not isolated from the rest of the project, but requires communication both with the other parts of the project and with the surrounding world. This is a very important aspect of risk management.
- Risk management is a cyclic procedure that continues throughout the whole project, for example through monitoring and reviews.

B.2 ESTABLISHMENT OF RISK MANAGEMENT

The term establishment refers in this case to the organisation of the risk management work, i.e. to adjust it to the project or project part at hand. Proper establishment is essential for the quality of the risk management.

The establishment includes:

- A decision on the extent of the risk management.
- Enabling the means for carrying out the risk management, both in terms of having qualified staff and economical aspects (allotted working time for this work).

- Enabling the communication with the relevant people within and outside of the project.
- Create routines for documentation and monitoring of the risk management.
- Decide on criteria for when risk treatments are needed.

B.3 RISK ASSESSMENT

Risk assessment includes identification, analysis, and evaluation of the risks (Figure 3). The risk assessment ends when there is a clear understanding of the risk and a decision has been made regarding whether the risk can be accepted or not. (Not accepting the risk implies that it must be treated with some measures.)

B.3.1 Risk identification

Risk identification implies finding the threats against the project and their potential consequences. This concerns both the geotechnical conditions and the construction methods.

B.3.2 Risk analysis

Risk is associated to uncertainties regarding the occurrence of the unfavourable event and the possible consequences. Therefore, both the uncertainties and the consequences must be analysed, so that they may be described and communicated within the project. The risks must be understood by all concerned parties in the project. How the risks are described depend on the project and the severity of the risk; thus, the description may vary from very simple ones to very advanced ones.

B.3.3 Risk evaluation

Decisions must be made on what to do with the identified and analysed risks:

- Accept the risk as it is.
- Investigate the risk further, possibly with external help.
- Treat the risk with some countermeasure.

In this activity, the methods may vary from the simple to the advanced; for example, we have the simple "let's not take that risk, because treating it right now is so cheap, in comparison to the cost in case the unfavourable event occurs", and the more advanced evaluations that may require a complex decision analysis. At times, decision criteria are established during the establishment activity. They may be illustrated in a risk matrix.

B.3.4 Risk treatment

Risk treatment includes measures to change the risk so that it can be accepted. Such measures may strive to:

- reduce the probability of the occurrence of the unfavourable event.
- reduce the consequences if the event occurs.
- transfer the risk to someone else, for example by taking out an insurance.

B.3.5 Communication

All concerned parties in the project must be aware of the identified risks. Thus, the risk communication must be fully functional both within the project organisation and between all parties. In addition, the communication must work between project phases, so that risks identified in one phase are not forgotten when the project moves on to the next phase. In some projects, communicating risks with the surrounding world may also be favourable. In conclusion, the importance of risk communication cannot be stressed enough!

Note: Risks are currently often discussed at project meetings, even when a structured risk management not has been established, but we believe that the structured procedure adds value to the project.

B.3.6 Monitoring and review

Follow-ups shall be made both of risk-reducing measures and of the actual risk management procedure, to keep it up-to-date throughout the project or the project phase. Risk management is a continuous process – not a one-time event at the start of the project!

Appendix C
Some aspects of the risk management work

C.1 WHAT IS QUALITY?

In this report, we employ the following definition of quality:

the ability of a product to satisfy or exceed the client's explicitly or implicitly stated, justifiable requirements and wishes

This implies that:

- The risk management is carried out for someone (the client)
- The risk management shall be favourable for the client by satisfying (or exceeding) the client's requirements and requests.

Consequently, risk management is *not* an isolated activity that is carried out for its own sake.

This concept is comparable to an example from literature about innovation (Anthony, 2012): the customer entering a hardware store to buy a 6 mm drill is in fact not interested in the actual drill, but in a 6 mm wide hole to reach the final goal: the hanging of a painting.

Risk management is a tool. The purpose of managing risks is to ensure the quality of the product by avoiding unexpected events and letting the decision maker to decide on which risks that are acceptable. There exist published checklists (see section J.2.1) that are prepared for various situations to ensure the quality of the risk management, but such checklists are often perceived as too constrictive and less focused on achieving the quality described above.

C.2 PROJECT RISKS AND RISKS IN A PROJECT

In risk management, there is a difference between "project risks" and the risks in a project. Project risks affect the whole project, i.e. such risks are comprehensive and may threaten the completion of the project. Such risks should be managed as a decision problem, preferably in the beginning of the project.

Risks in a project affect only a part of the project (e.g. assembling a structural part). This type of risks is normally collected in a risk register.

C.3 MANAGEMENT OF UNCERTAINTIES AND RISK IN GEOTECHNICAL ENGINEERING

In all geotechnical engineering projects, we estimate the geotechnical hazards in some way – no matter the size of the project. This task is a part of engineering. The purpose of doing so is to be able to make a reasonable assessment of the existence of hazards in the project – or rather, which hazards that require treatment in some way.

The procedure for assessing hazards is defined by which project phase that is present and by which party (e.g. client or contractor) that performs the risk analysis. Some examples:

- The client may consider time, costs, and political risks.
- The designing engineer may consider the risks associated with the design.
- The contractor may consider time, costs, and the procedures for executing the work in the most rational way.

As previously emphasised, the risk management is carried out to achieve a goal with larger probability. Note that the goal may vary between the various phases in a construction project. Table 1 shows the participators of each phase, the produced product, and the requirements set on the product. The table also indicates the minimum requirements on the risk management for each phase and which aspects that must be communicated to subsequent project phases. As the table refers to geotechnical engineering projects, only maintenance is covered in the operational phase; thus, decommissioning of the structure is not considered. However, decommissioning of temporary structures such as sheet-pile walls is considered to be part of the construction phase.

Table 1. Overview of the risk management in all project phases.

	Project phase					
	Feasibility study	**Design**	**Tendering**	**Purchase**	**Construction**	**Operation**
Involved people	Consultant	Designer	Bidding con-tractors	Client Contractor	Contractor	Owner
Product	Report	Tender documents	Tender	Contract	Completed construction	Maintained structure
Product requirements	Identification of advantages and disadvantages with the project	Technically correct, relevant, and calculable	Competitive	Fair and predictable	Satisfactory quality; within time plan and budget	Reliable over time
Risk management tailored to the project phase						
Goal of risk management	Identifying essential hazards and consequences	Identifying questions and hazards to be monitored during construction	Basis for choice of construction method. Basis for pricing and risk reserve	Basis for fair assessment	Identifying critical work procedures and resources	Identifying maintenance need
Communication to next phase	Hazards and risks Unique conditions, complexity, requirements on robustness	Geotechnical conditions: uncertainties and risks	Interpretation of tender documents; presumed work procedures	→	Specific maintenance requirements	

Table 1 is valid regardless of the type of contract. The difference between design–bid–build contracts and design–build contracts lays in that design–build contracts contain the contractor's design (based on performance requirements defined in the tender documents). If the contractor makes the design, an additional risk management process will be needed that will correspond to the one made in the design phase of a design–bid–build contracts. If desired, this additional risk management can be ordered by the client in the tender.
The management of uncertainties and risks is nothing new for the geotechnical engineer, but the applied procedures are often less structured and *ad hoc*. However, in general there is always some assessment of the risks in a project, though the assessment is at times of a limited extent, because it is obvious that nothing more is needed for the considered project or project phase.

Risk assessment may span from the simplest considerations to very complex expert analyses. Some examples:

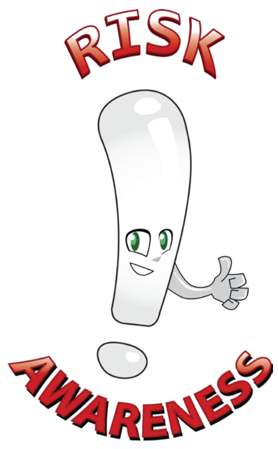
- Assessment based on experience
  "I have reviewed the foundation design and I found no problems."

- Qualitative analysis
  The risks are identified and their significance are – possibly – roughly estimated.

- Semi-quantitative analysis
  The risks are identified and classified with respect to significance.

- Quantitative analysis
  The risks are identified and described with likelihoods.

Also when it comes to choosing methods for risk treatments, common sense is useful. Complex decision-theoretical methods should not be used unless they are needed.



C.4 RISK MANAGEMENT IS A PART OF THE ENGINEER'S EVERYDAY WORK

That risk management is a part of the engineer's everyday work may seem obvious, but this cannot be stressed enough. Risk management must be carried out by skilled practising engineers. Only skilled engineers can see the big picture and creatively identify and disarm the threats against the project. Consequently, risk management is a parallel work to “ordinary” geotechnical engineering, giving additional perspective and understanding, as well as improving the quality of the engineering work.

C.5 WHY MANAGING RISKS?

Hubbard (2009) provides a short, straightforward definition to risk management:

Being smart about taking chances

Another perspective is that risk management enables conscious and well thought-out choices regarding the occurrence of unfavourable events that cause damage.

C.6 RISK MANAGEMENT MUST BE TAILORED TO THE PROJECT

The Risk management must be adjusted to the project, its participators, its phases, and the type of risks. This is highlighted in for example ISO 31000.

Some examples of aspects of the risk management that need to be adjusted to the project’s specific requirements and needs are discussed in the following.

C.6.1 Who carries out the risk management?

In small low-risk projects, risk management is one of the project leader’s responsibilities, without him/her having access to additional risk support. (Low-risk projects are considered to be project with small uncertainties, well-known ground conditions, well-known working methods, and/or small possible consequences in case of the occurrence of an unfavourable event.
In complex high-risk projects, there may be a need for an appointed group of people with different skills and experiences that assists the project management in managing the risks.
In projects in between, i.e. in most geotechnical engineering projects, risk management is also among the project leader’s responsibilities, but in some cases additional support may be justified.

C.6.2 The risk management process

In a small project, risk management may be integrated into the project management, without having a specific risk management process.

In large projects, it may be justified to implement a well-defined and documented risk management process.

C.6.3 Methods of risk management

The available toolbox of risk management methods ranges from informal brainstorming in a small project at a project meeting, at which risks are documented in an Excel sheet and followed up at regular meetings, to the wide spectrum of more complex methods that may be required in a complex project. These methods include for example tools for risk assessment, registration, and monitoring and reviews. There may also be a need for documenting the risks in a database that is always updated and accessible for many users.

C.6.4 Aids for managing the risk management

In small projects, specific aids for managing the risk management may not be needed, while larger projects may require integrated risk management toolboxes. It is important that the right amount of aid is found: too complicated tools may be counter-productive and cause unnecessary work for simpler projects, while too simple tools may not be sophisticated enough to manage the risks in a complex project.

C.6.5 Requirements on reports

In some projects, the result of the risk management may be documented along with the usual project documentation, while there other projects may require specific risk reports tailored to fit specific stakeholders within and outside of the project.

C.6.6 Review and update of the risk management process

The necessary frequency of reviews and update of the risk management process depends not only on for how long time the project will go on, but also on the amount and severity of the identified risks. In short, low-risk projects, possibly one or two updates is sufficient, while longer projects with more substantial risks require more frequent reviews – possibly every month – especially when there are defined sub-targets or when there are changes or deviations from the original plan.

C.7 SUMMARY OF APPENDIX

This appendix may be summarised as:

Make sure that risk management is carried out sensibly, for the right purpose, and in the right way.

Consequently, risk management shall be carried out in all projects, both small and large ones. However, risk management shall not be carried out in accordance to some predefined, stereotype template, but in a way that is tailored to the project, to the project phase, and to the participator that is responsible for this part of the project. Lastly, it should be emphasised that risk management shall be continuous throughout the whole project.

The requirements on the risk management are satisfied by always adjusting the risk management to the needs and using it as a complement to all other engineering tasks in the project. However, if the project culture has immature risk awareness, the risk management will never be satisfactory (Hutlett, 2001).

Regardless of how the risk management is tailored for the project, it shall be carried out systematically, so that it is structured, documented, and transparent. Otherwise, the risk management may be flawed, which in itself is a threat to the project, because this may cause a false confidence that all risks have been managed successfully.

Risk management shall always be carried out:

- Adjust it to the project.
- Work in a structured way, so that no aspect is forgotten.
- Make sure that the risk communication works.
- Document what has been done and what needs to be treated.
- Keep the risk management alive.

Appendix D
Comments on the establishment of the risk management

D.1 GENERAL REQUIREMENTS

D.1.1 Risk owners

The risk owner shall make the decision regarding the acceptance of the risk after the risk analysis. As risk management is a part of the regular engineering work, the person that is responsible for achieving some goal shall also be responsible for managing the risks that are associated with this goal.

D.1.2 Risk management classes

The establishment of the risk management may be described with the risk management classes 1–3, which define the required extent of the risk management and the required skills of the participating people. The risk management classes and how they are selected are described in Appendix E.

The definition of the classes is based on the probability that satisfactory quality is achieved in the project, i.e. that the defined goals are fulfilled.

D.1.3 Competence requirements

The people working with risk management should have the necessary competence and possibility to

- consider the relevant aspects (i.e. they have experience of construction and geotechnical engineering),
- consider the relevant aspects in the right way (i.e. they have knowledge about risk analysis and they have an acceptable risk awareness),
- communicate with those who have the opportunity to treat the risk.

It must be assured that the above competence requirements are satisfied. In addition to being a skilled engineer, it is particularly important that the risk manager has a sufficient understanding of the methodology of managing risks, so that no risk is underestimated or neglected. Note that:

- A vital aspect is the awareness of subjective factors that may affect the risk assessment.
- The risk management must also be aware of the common situation of growing risk proneness, i.e. taking more and more risks; this often occurs when it is found that it might be difficult to achieve the goal in the project.

The quality assurance of the participating people's skills is an issue for the company management. The right skills may be assured through education (and possibly certification) or, in simpler cases, through self-assessments with questionnaires.

D.1.4 Documentation

All identified risks shall be documented and the decisions made by the risk owner shall be followed up.

Note that the choice of risk management class is a risk in itself, because if a too low class is chosen, the risk management procedure will be too simple.

D.1.5 Acceptance criteria for risks

Whether a risk is acceptable or needs treatment is a decision made by the risk owner. However, the risk owner may be assisted by general decision criteria that are defined already during the establishment activity of the risk management. The criteria may possibly be defined by the company management.

D.2 WHAT AFFECTS THE ESTABLISHMENT?

Anyone responsible for engineering work shall also be responsible for the associated risk management. To ensure that risk management is carried out satisfactorily, a supporting organisation may be needed. Adjust the size of the organisation so that it can fulfil its purpose, but there is no need to oversize it.

There are a number of aspects that affect the establishment of the risk management, which are discussed in the following:

- The project phase
- The project complexity, size, and organization
- Geotechnical and constructional uncertainties
- Other risk management in the project
- Requirements from stakeholders

D.2.1 Adjustment to the project phase

The different project phases have different goals. The risk management must therefore be adjusted, so that the relevant threats against these goals may be identified. The choice of risk management class is made in accordance with section D.1.2.

A special risk concern the communication of risks between the project phases, because there are often different people involved in the different phases, and there may be different organisations that carry out the risk management work. To make this communication between phases work is a task for the person that is responsible for the project part. The means for this communication must be established early.

<u>Feasibility study</u>

In this project phase, the risks are mainly "project risks" (see section C.2). The main issue from a geotechnical point of view is whether there are any major geotechnical considerations that may cause severe problems in the project.

In this phase, there is no need for formal establishment of the risk management; risks may be identified through informal interviews and checklists. However, there may be issues where a more formal analysis is appropriate, which implies that the risk management is categorised as class 3.

<u>Design / preparation of tender documents</u>

The outcome of this phase will greatly affect the outcome of the project. The exposure to geotechnical risks must be carefully considered and documented for the subsequent phases. Geotechnical Category is often defined in this project phase. The Geotechnical Category describes the magnitude of the uncertainties, which implies that this choice greatly affects the subsequent risk management. The risk management of this phase should therefore be extensive.

The result of the risk management of this phase must be communicated to the subsequent phases. This is vital for a successful risk management.

Tendering

In this phase, many possible executions of the design are evaluated – also from a risk perspective. Lack of time is common in this phase, so having a high-quality documentation of the risks from previous phases is favourable.

A simplified establishment of the risk management is often sufficient.

Construction phase

The execution of the design is often associated with geotechnical hazards affected by the choice of construction method. A well-considered establishment of the risk management is recommended. It is particularly important that the risk management is integrated with the work planning and its documents. The risk management class may be chosen based on section E.4.

Operational phase

Possible risks such as settlements and landslides are normally already managed. Therefore, this project phase usually only requires monitoring and follow-ups of the executed risk treatments.

D.2.2 The complexity, size, and organisation of the project

The risk management shall reflect the project's complexity and size, as well as it shall be adjusted to the project organisation. Most geotechnical engineering projects are small and have a small organisation, even though they often are a part of a larger construction project. The complexity varies and may be significant, in particular in urban areas. Note that a small project may be more vulnerable than a large project when it comes to economic consequences.

D.2.3 Other risk management in the project

In addition to the procedures described in this report, there may be other requirements related to risks stated in national laws or in contracts. Such other requirements should be integrated with the common risk management, so that the work becomes rational – i.e. unnecessary work in parallel is avoided.

Control plan according to the Swedish Planning and Building Act (2010:900)

In the Swedish Planning and Building Act (2010:900), there is a requirement on control plans that must be initiated by the client and established (and possibly supplemented) by the local municipality's Building Committee. The control plan ensures that the technical requirements are satisfied.

Reviewer for cases in Geotechnical Category 3

In some complex cases, the client hires a special review to analyse risks and to identify critical steps in the execution of the design. The reviewer is independent and does not take part in the regular risk management work. The reviewer does not consider risks associated with project quality. It is recommended that the treatment of the risks identified by the independent review is properly documented and administrated in the same way as all other risks.

AMA Anläggning 13 – a Swedish guideline for technical requirements in construction

Chapter C of AMA Anläggning 13 states that written documentation of the job planning shall be prepared by the contractor and be communicated to the client.

The written documentation shall include:

- a detailed description of the work procedures, including its various stages
- limitations in the work execution (work order, tollgates, equipment, loadings, working hours, water levels, etc)
- description of main risks
- monitoring plan including alarm limits
- preventing and remediating measures

Environmental risks and risks regarding work environment

The management of risks regarding the work environment is often integrated in all other risk management in projects. Environmental risks may also be included. Such risks should be managed by people with special competence in the respective field.

In other projects, work environment risks and environmental risks are managed separately.

D.2.4 Specific requirements from project parties

In some cases, the client may require that the contractor perform a risk analysis. We would like to stress that the risk management shall be established so that the result is useful. The risk management shall not be an end in itself that the contractor considers a nuisance.

D.3 COMPETENCE

People that manage risks shall be skilled in geotechnical engineering and construction, as well as in risk management. Regarding risk management, it is crucial to understand both the basic principles and the psychological biases that may affect the assessment of a threat. To ensure this, it may be beneficial to let a professional risk analyst support the risk management work with advice or education of the staff.

People managing risks

- shall allot time for this work, and be allotted time for this work by the employer, as a part of their everyday engineering work.
- shall have the ear of the management

D.4 COMMUNICATION

The system for communication about risks between the involved internal and external parties should be outlined in accordance to Chapter 8.

D.5 PROCEDURES FOR THE SYSTEMATIC WORK

To ensure that the risk management is systematic, procedures for monitoring and documentation is needed. Such procedures shall be tailored to the project and its normal communication routines, so that additional, separate documentation is avoided.

The communication should highlight:

- the project phases and work procedures that have been covered
- the identified risks
- the decisions on risk treatments that have been made
- how the performed risk treatments will be followed up.

D.6 DECISION CRITERIA

Decision criteria are set by the decision making body that is responsible for the project, for example the executive group of the company. The criteria should normally be worked out together with someone that is skilled in risk management.

D.7 STANDARDS AND CODES

There are a number of standards and codes on how to establish risk management successfully. Some are listed in section J.2.1. In such documents, there are many good advices, but remember to employ them sensibly, so that the right quality for the project at hand is achieved. This will make the risk management accepted and the project will get a risk-aware culture

Appendix E
Risk management classes

There are three risk management classes, where the lowest class concerns the simplest geotechnical structures.

E.1 DESCRIPTION OF THE RISK MANAGEMENT CLASSES

The definition of the risk management classes is based on the likelihood that satisfactory quality and project goals are achieved in the project. Consequently, the definition is not based on the quality of the risk management work; the risk management is a tool and not a goal in itself. The likelihood of not achieving satisfactory quality is assessed for the case of not establishing any risk management.

Risk management class 1
Small likelihood of not achieving satisfactory quality.

Risk management class 2
Some likelihood of not achieving satisfactory quality.

Risk management class 3
All other cases (i.e. when it is likely that satisfactory quality is not achieved or when it is hard to assess whether satisfactory quality will be achieved).

E.2 SELECTING THE RISK MANAGEMENT CLASS

The Risk management class is assigned in the establishment activity (Chapter 3). When selecting the risk management class, the following factors and how they affect the probability of not achieving satisfactory quality shall be considered: the issue, the geotechnical uncertainties, and the consequences.

- The issue
    - is the issue unique?
    - is there a lack of knowledge regarding the issue?
    - are there any specific requirements regarding methods of analysis?

- The geotechnical uncertainties
    - consider the geotechnical and geological conditions
    - consider the technical uncertainties (construction and execution of the design)
    - consider the contractual uncertainties

Regarding geotechnical uncertainties, the Geotechnical Category may provide some guidance; though Geotechnical Categories are not defined for all project phases (see section E.4).

- The consequences
    - possible damage to person and environmental damage
    - possible economic loss (to be considered also for minor projects)

E.3 SPECIFIC REQUIREMENTS DEPENDING ON CLASS

The risk management classes define the extent of the risk management and the required competence of those who do the risk management work.

E.3.1 Requirements on the extent of the risk management

<u>Risk management class 1</u>
Risks shall be:

– identified
– analysed and evaluated on a general level
– communicated

<u>Risk management class 2</u>
Risks shall be:

– identified
– analysed

– evaluated
– communicated

<u>Risk management class 3</u>
The extent of the risk management is carefully tailored to the specific case.

E.3.2 Requirements on the participating people

<u>Risk management class 1</u>

- The engineer shall understand uncertainties and how they are managed in everyday geotechnical engineering projects.
- The engineer shall be aware of subjective factors that may affect the risk assessment.

<u>Risk management class 2</u>

- The engineer shall have education and experience in risk management.

<u>Risk management class 3</u>

- The engineer shall be supported by an expert in risk management

E.4 UNCERTAINTIES AND THE SELECTION OF THE RISK MANAGEMENT CLASS

The larger uncertainties – both in geotechnical and constructional – the more extensive risk management should be established. The selection of the class shall also consider the robustness regarding the type of structure, the construction method, and in the sense that the primary damage does not cause disproportionately large secondary consequences.

The magnitude of the uncertainties is dependent on both the natural variability in geology and other factors in the surroundings, as well as the extent of our knowledge of the variability. Both the quality of the tender documents and the geotechnical uncertainties and assessments have a significant impact on the required extent of the risk management work.

When designing in accordance to Eurocode 7, the aforementioned factors are reflected in the selection of either Geotechnical Category (which depends on the geotechnical complexity) or safety class (which depends on the risk for damage to person). These selections may give some guidance in the selection of risk management class. Geotechnical Category 1 implies a limited risk management, in contrast to Geotechnical Category 3 and, especially, safety class 3, for which cases the establishment activity shall be carefully executed. Note, however, that depending on the choice of construction method, the amount of risk management may need to be adjusted. Table 2 shows recommendations for risk management class for possible combinations of Geotechnical Category and safety class.

Table 2. Risk management classes can be selected based on Geotechnical category and Safety class.

	Geotechnical category		
Safety class	GC 1	GC 2	GC 3
SC1	1	2	3
SC2	1	2	3
SC3		3	3

The selection of Geotechnical Category includes identifying geotechnical risks to the project. If Geotechnical Category has not been selected, the decision tree presented in Figure 4 may be used for guidance.

In addition to the decision tree, some advice and guidelines are available in the IEG report series 2008–2010 (Commission for Implementing the Eurocodes to Swedish Geotechnical Engineering), see e.g. Report 2:2008 – “Basics”.

The selection of safety class is made in accordance to the following:

“The structural part shall be classified in one of the following safety classes based on the level of personal injury structural failure may cause (Eurocode EN-1990):

- Safety Class 1: (low) small risk for severe damage to person.
- Safety Class 2: (normal) some risk for severe damage to person.
- Safety Class 3: (high) large risk for severe damage to person.”

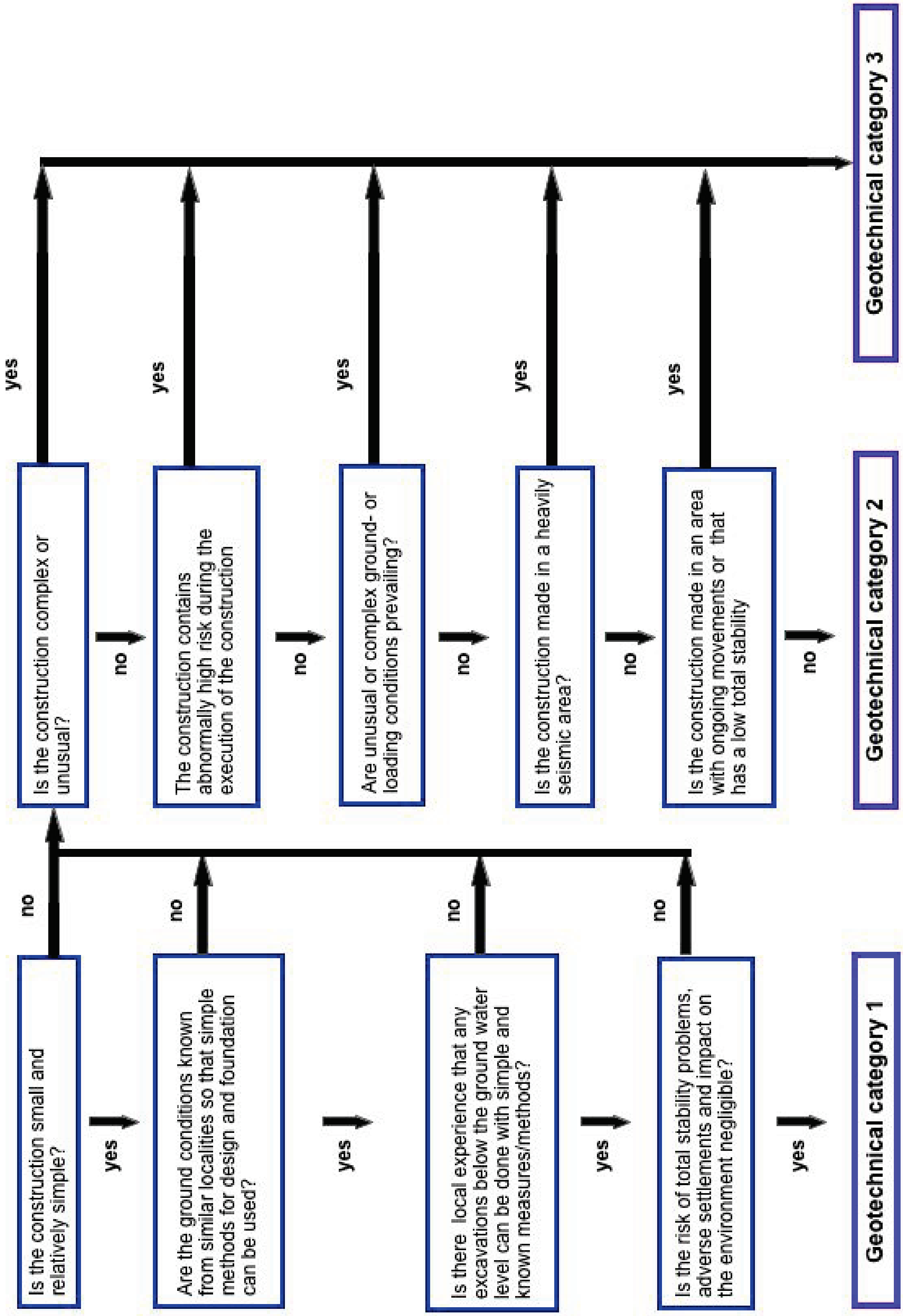


Figure 4. General decision tree for selection of geotechnical category (IEG report 2:2008).

Appendix F
Commentary to risk identification

F.1 RISK IDENTIFICATION IS AN ENGINEER'S TASK

Identifying technical hazards to a project is a task for the engineer that performs the "ordinary" engineering work, such as structural design, and it requires the same knowledge, understanding, and creativity. However, risk identification requires the engineer to see the project from another view; now the engineer represents the aggressive Mother Nature that is "out to get you".

F.1.1 Engage everyone who can contribute

Just the introduction of a risk identification – starting to talk about risks – is favourable to the project; the effect should not be underestimated. We recommend that meetings are arranged, at which the involved parties may introduce themselves and tell the others about the risks that they are concerned about (see also Gawande, 2011). The discussions that usually follow contribute to the understanding of the possible problems that the project faces. Start by identifying what aspect that is threatened. To make the risk identification work, it must be focused on those aspects that are the most important to the project (or project part), i.e. its goal.

Being more than one person identifying risks is favourable also because the effect of psychological bias may be avoided or reduced. Such bias may have the consequence that risks are underestimated or neglected (Smith et al. 2006).

F.1.2 Take a holistic view

Successful risk identification must be holistic, so that it is clear how the details affect each other. In other words, the project must be considered as a system. A good advice is to visualise the system schematically and draw lines to indicate how the various aspects of the project affect each other.

Collect information
Before the risk identification is finished, information from similar projects regarding unfavourable events should be collected. To only trust the subjective experience of the participating people may be misleading. Though, keep the creative atmosphere in the group and try not to restrain it.

F.1.3 Identify threats, not consequences

Because the purpose of risk management is to identify and possibly act against the things that threaten the project goals, the risk identification should focus on describing the threats, not the subsequent consequences. An example: the statement "the sheet-pile wall fails because of heave caused by high groundwater pressure" is not describing a threat, but a consequence of a threat that has been realised.

"High groundwater pressure", however, is the threat here, which should be analysed together with its possible consequences during the risk analysis and the risk evaluation activities.

F.2 ENCOURAGE THE RIGHT ATTITUDE

Some experience risk identification as a negative process that deviates from the regular understanding that problems are something to *solve* when they show up. To be successful in risk identification, it is important to leave the negativity behind, and to encourage a spirit of "creative pessimism". There are supportive tools available to keep focused on risks (and their counterpart possibilities); see for example de Bono (2009).

F.3 TOOLS AND GUIDELINES

Report 2:2014 – "Risk identification: methods to find threats and possibilities" – (in Swedish) provides some guidance to a number of common risk identification methods. Some examples are brainstorming and interviews, which probably are among the most common when it comes to geotechnical risks. The report also covers other supportive tools. They are briefly described in the following.

Checklists
Checklists are based on experience from previous risk identifications. At times, they are prepared as a general checklist. A Swedish example in civil engineering is Checklista riskhantering (Fia, 2005).

Risk breakdown structure (RBS)
An RBS is normally visualised hierarchically as a schematic tree. The RBS shows a possible risk structure; i.e. how risks on different levels are connected.

Work breakdown structure (WBS)
A WBS is used to plan upcoming work activities, but may also be used as a checklist to make sure that no part of the work is forgotten in the risk identification.

F.4 DOCUMENTATION OF RISK IDENTIFICATION

The result of the risk identification shall be documented in a way that makes is accessible for future use in the risk management. It is recommended to document both the raw material – e.g. minutes from meetings – and an edited version that keeps track of the identified threats. This may have the form of a list.

Appendix G
Commentary to risk analysis

G.1 CHAIN OF EVENTS

Consequences often occur at the end of a chain of events. Therefore,

- Clarify the chain of events, preferably graphically. For example, event trees, fault trees or bowtie diagrams may be useful.
- Avoid breaking up the chain of events into many pieces; otherwise it is likely that the probability estimations become erroneous.
- Define the events clearly and unambiguously.

G.2 THE TWO-STEP ANALYSIS

The risk analysis and risk evaluation may be divided into two levels: a general analysis and a more detailed. A good start is to make a rough risk analysis and risk evaluation with the purpose of assessing those risks that obviously are acceptable or obviously require treatment. This is a sort of screening procedure. The assessments are based on rough calculations on the safe side when it comes to the magnitude of consequences and likelihood.

The remaining risks, for which no conclusion could be made, are thereafter analysed in more detail. This also includes risks, for which the treatment cost was too substantial to be accepted immediately. This two-step analysis may save quite a lot of work in the risk analysis.

G.3 ASSESSMENT OF CONSEQUENCES

G.3.1 Procedure and supporting tools for consequence assessment

When assessing which consequences (and their magnitude) that may follow the realisation of a threat, a possible scenario must be created in terms of a chain of events. The chain may be created both by starting at some possible damage, going backward in time, and at some possible threat, going forward. For both cases, relevant questions are “how could this happen?” and “what may this lead to?” Such questions are asked for every event in the chain.

Some supporting tools are described in the following: case histories, what-if method, event trees, and fault trees.

Case histories

Failures that already have occurred may illustrate possible chains of events. Such documentation may be used as a checklist.

What-if method

This is a method similar to brainstorming. The method is based on the question “what will happen if…?” The question is then repeated until all consequences are found.

Event trees

This is a graphical method that starts with some event (a threat) and unfolds toward possible consequences (Figure 5). Literature and tutorials on the subject cab easily be found on the Internet.

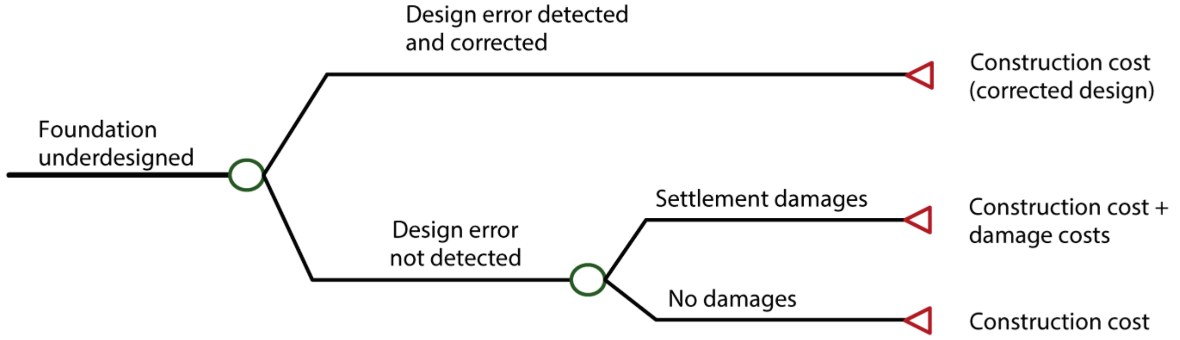


Figure 5. Event tree

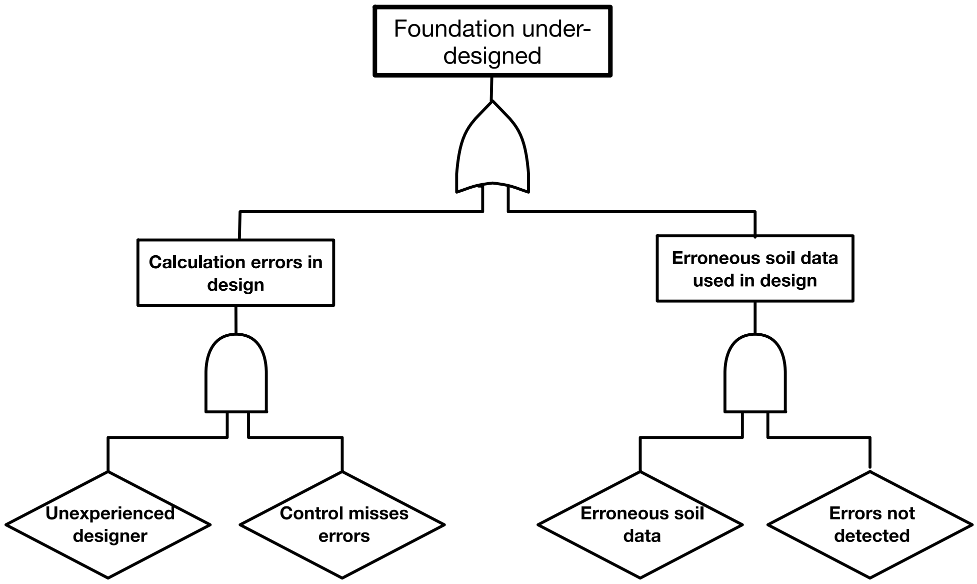


Figure 6. Fault tree

<u>Fault trees</u>

This is also a graphical method, but it starts with the last event in the chain and unfolds backward to find possible causes to the event (Figure 6). Literature and tutorials on the subject can easily be found on the Internet.

A good tactic to become pessimistic enough about the chain of event is to imagine an early morning phone call before you have left from home: "the sheet pile wall has failed!" Now, try to give possible explanations to the event and possible consequences that the failure may cause.

G.4 DESCRIPTION OF THE LIKELIHOOD

To describe the likelihood of an event, the event must be unambiguously defined. This may be checked in a "clairvoyance test". A clairvoyant person knows all *facts* about the universe both in the past, in the present, and in the future, but the person cannot make interpretations or inference. For a future event to pass the test, such a person must with certainty be able to predict whether the event will happen or not; thus, there is no room for vague terminology in the description, because a clairvoyant person cannot interpret them (Beyth-Marom et al. 1985).

Do not consider the consequences when the likelihood is assessed. In subjective assessments, the likelihood is often defined to large, if the consequences are significant. There are a number of possible psychological biases that may cause systematic errors to the assessment. Some examples are:

- Expert bias
- Conservative bias
- Anchoring effect
- Availability heuristic
- The law of small numbers

The reader is referred to Larrick, R. P. (2004), Montibeller, G. and von Winterfeldt (2015) for further discussion of psychological biases.

G.5 HOW TO DESCRIBE LIKELIHOOD

How likely a consequence is to occur can be described in different ways. At times, a purely verbal scale consisting of likelihood classes is used (likely, unlikely, etc.). The classes may be described verbally. Similar scales, where the classes are defined with probability ranges, are also used, and sometimes numerical probabilities.

The methods provide different views of the likelihood. If some likelihood is described with a numerical probability, the reader will interpret will interpret the likelihood to be more precise, than if verbal descriptions are used. Budesco et al. (2012) showed that the person describing the likelihood favours verbal descriptions, while the receiving person favours numerical values.

Purely verbal descriptions

The purely verbal descriptions that are based on classes on an ordinal scale (in which the classes are only ordered) have several disadvantages (Hubbard & Evans, 2010):

- The classes are not defined.
- The interpretation of the meaning of the classes varies significantly between different people.

Table 3. Example of verbal descriptions of likelihood (FIA, 2005)

Likelihood class	Description	Definition [percent]
1	Very low, will hardly occur	< 1
2	Low, will probably not occur	1 – 5
3	Moderate, might occur	6 – 15
4	High, will probably occur	16 – 50
5	Very high, will occur	> 50

Verbal descriptions with defined ranges

One way to reduce the arbitrariness of the verbal descriptions is to define each class with numerical probabilities. Budesco et al. (2012) recommend the use of both verbal and numerical descriptions. An illustrative example is presented in Table 3. Note that this is an example; in a real project, the descriptions must be adjusted to the actual conditions.

Probabilities

Descriptions with probabilities make it possible to describe an uncertainty more precisely. Philosophically, there are different types of probabilities. For this purpose, we apply subjective probabilities, which also are known as Bayesian probabilities. If the probability of an event is uncertain, this uncertainty may be indicated by using a range of probabilities instead.

G.6 SOURCES OF ERROR WHEN ASSESSING PROBABILITIES

When assessing probabilities, a number of error sources may affect the assessment (BeFo 2013). It is therefore appropriate for those estimating probabilities to have education in the practice.

G.6.1 Erroneous assessment of probability for a chain of events

If both event A and event B must occur for event E to occur, we have that

$$P(E) = P(A) \cdot P(B),$$

which implies that the probability of event E is less than the respective probabilities of event A and B.

G.6.2 Negligence of available information

Only some specific information is considered, and more general information that also is available is neglected.

G.6.3 Difficulty in estimating very small probabilities

To estimate very small probabilities is difficult. Thus, avoid breaking down chains of events into too small sub-events, but stop where it feels reasonable to assign a probability.

G.6.4 Difficulty in assessing repeating events statistically correct

To assess the risk associated with repeating work tasks, statistical calculations that apply statistical models is needed, e.g. a binominal distribution. If in doubt, consult an expert.

G.7 GUIDELINES AND TOOLS FOR LIKELIHOOD ESTIMATION

To estimate probabilities is difficult, because there are many psychological pitfalls known as “biases and heuristics” that may cause erroneous estimations. There is to our knowledge no practical guideline available, but we recommend the following publications on the topic: Kahneman (2011), O’Hagan et al. (2006), O’Hagan och Oakley (2004), Olsson (2000) och BeFo (2013). Fault trees may also be useful (see section G.3).

Appendix H
Commentary to risk evaluation

H.1 TOOLS AND GUIDELINES FOR RISK EVALUATION

Tools used in the risk evaluation shall be adjusted to the project at hand. In some cases, a simple screening presented as a risk matrix is more suitable; in other cases, a more complex method may be justified.

H.1.1 Risk matrices

The risk matrix is likely the most common tool in risk evaluation. For each risk, its likelihood and severity of consequences are presented (see Figure 2). Normally, the risk is presented as a dot in one of the matrix squares (or several dots, if several consequence categories are involved). In Figure 2, likelihood and consequence are presented in verbal terms, but the matrix is accompanied by a table, in which these classes are defined in terms of probabilities and appropriate measures for consequences. The axis scales are often logarithmic in risk matrices.

We would like to stress the following:

- To allow for a stringent risk evaluation, the risk matrix must be calibrated so that each square corresponds to a certain risk level. These risk levels form the base for decisions regarding acceptability and should be adapted to the specific project.
- Each square in the matrix may correspond to a large range of probabilities and consequences. A risk matrix needs to be developed, so that these values can be defined more precisely.

H.1.2 Methods for decision analysis

In more complex cases, formal decision analysis may be advisable to apply in the risk evaluation. People applying such methods shall be trained in this skill.

Two common methods are decision trees, in which the cost for consequences and treatments can be weighed together and compared (see e.g. Olsson & Stille, 1980), and the Analytic Hierarchy Process, in which the possible alternatives are ranked (see e.g. Saaty, 1990).

H.1.3 Simulation methods

A method for risk evaluation that lately has been recommended by many authors is Monte Carlo simulation (see e.g. Hubbard, 2009). The simulation produces the probability density function for the consequence and allows the user to directly assess the probability of exceeding a certain consequence level (Figure 7).

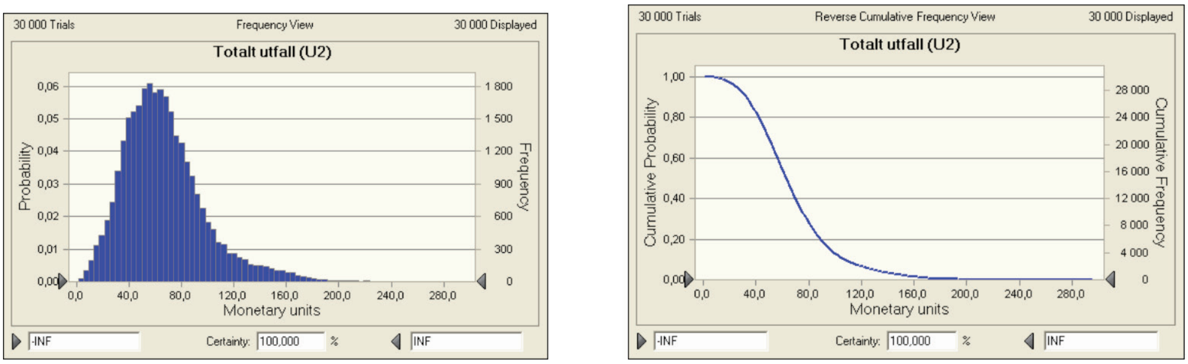


Figure 7. The result of a Monte Carlo simulation of a possible consequence (Olsson et al. 2007).

Appendix I
Commentary to risk communication

I.1 WAYS TO DESCRIBE RISKS

I.1.1 Verbal descriptions

Risks may be described informally with words; however, the hazard of being misunderstood must not be underestimated! Words may be interpreted in many different ways. Making comparisons to well-known concepts is one way to overcome this problem.

I.1.2 Risk matrices

Risk matrices provide one way to illustrate exposure to risk in a general sense that is easy to understand.

I.1.3 Risk maps

In some cases, risks have a spatial component; e.g., groundwater drawdown. Such risks can be illustrated with contour lines (isolines) on a map. However, risk maps can easily be misunderstood, if the contour lines are interpreted as absolute. Consequently, risk maps should be used with caution.

I.1.4 Bowtie diagrams

Bowtie diagrams offer an excellent way to illustrate risk, because it presents the chains of events both before and after a damaging event, as well as when possible contingency actions may be put into operation. The diagram may be considered a combination of a fault tree and an event tree, but more clearly presented than having them separated. A bowtie diagram is presented in Figure 8.

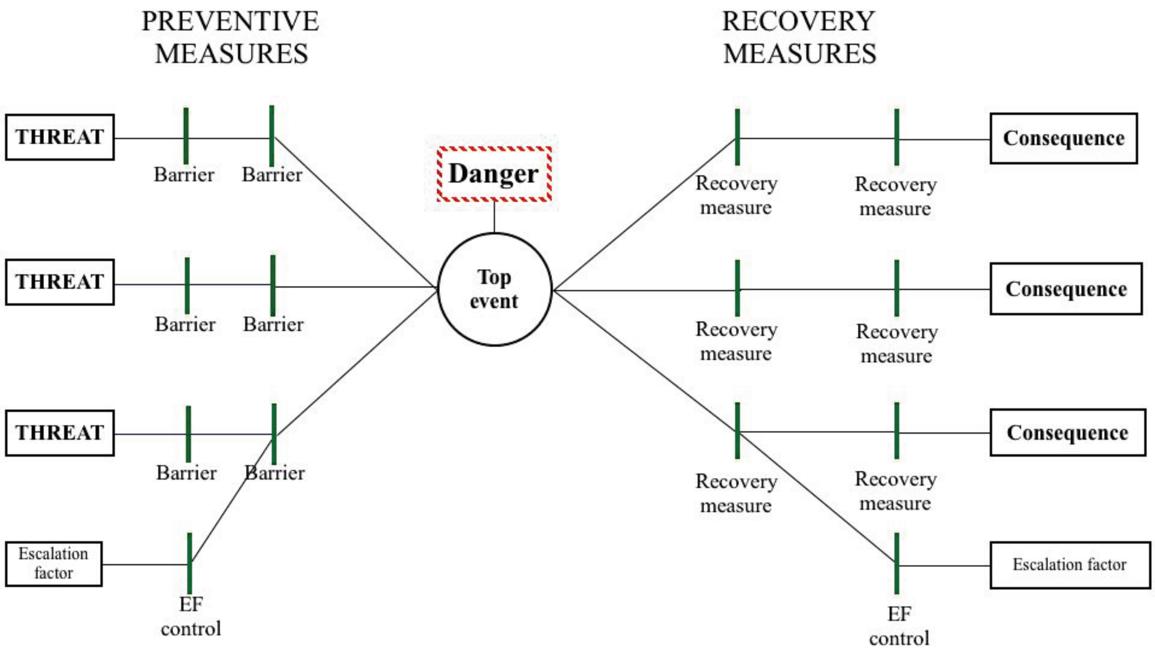


Figure 8. A bowtie diagram.

Appendix J
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J.2 SUGGESTED READING

J.2.1 Literature on quality in risk management

Handbok riskanalys SRV

NS 5814 Krav til risikovurderingar

DS/INF 85 Risikoanalyse: Krav, terminologi

Rouhiainen, V. 1992. QUASA: a method for assessing the quality of safety analysis. Safety Science, 15, 155-172

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Study on Quality Evaluation of the Risk Analysis CHINA SAFETY SCIENCE JOUR, Year 2001, Issue 2, Page 65-70

J.2.2 Literature on risk identification

SGF:s Metodbeskrivning nr 2. Riskidentifiering, - Metoder för att hitta hot

Kahneman, D., 2011. Thinking, fast and slow.

J.2.3 Literature on risk matrices

Clemens m.fl., 2005. The RAC Matrix: A Universal Tool or a Toolkit? *Journal of System Safety, March-April 2005*

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J.2.4 Literature on tree methods

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J.2.5 Literature on decision theory

Haas & Meixner An Illustrated Guide to the ANALYTIC HIERARCHY PROCESS

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Baecher, G., Christian,J., 2003. Reliability and Statistics in Geotechnical Engineering. Wiley

Stille, H., Andersson, J., Olsson, L., 2003. Information based design in rock engineering. SveBeFo Rapport 61

www.rmcapability.com Have a look at Guidance sheets

SGF Rapport/Report

1:93	Rekommenderad standard för CPT-sondering.
1:93E	Recommended Standard for Cone Penetration Tests.
2:93	Rekommenderad standard för vingförsök i fält.
2:93E	Recommended Standard for Field Vane Shear Test.
1:95	Rekommenderad standard för dilatometerförsök.
1:95E	Recommended Standard for Dilatometer Tests.
2:95	Några pionjärprofiler i svensk geoteknik. SJ Geotekniska Kommission 1914–1922.
3:95	Proceedings of the International Symposium on Cone Penetration Testing, CPT´95.
4:95	Kalk- och kalkcementpelare. Vägledning för projektering, utförande och kontroll.
4:95E	Lime and Lime Cement Columns. Guide for Project Planning, Construction and Inspection.
1:96	Geoteknisk fälthandbok. Allmänna råd och metodbeskrivningar.
1:99	Tätskikt i mark. Vägledning för beställare, projektörer och entreprenörer.
2:99	Metodbeskrivning för Jord-bergsondering.
3:99	Metodbeskrivning för Viktsondering.
1:2000	Geotekniken i Sverige 1920–1945.
2:2000	Kalk- och kalkcementpelare. Vägledning för projektering, utförande och kontroll.
1:2001	Fälthandbok – Miljötekniska markundersökningar (ersätts av 1:2004).
1:2003	Att bygga med avfall. Miljörättsliga möjligheter och begränsningar för återvinning av avfall i anläggningsändamål
1:2004	Fälthandbok – Miljötekniska markundersökningar.
2:2004	Armerad jord och fyllning – Nordisk vägledning.
3:2004	NGM 2004 – XIV Nordic Geotechnical Meeting. May 19th – 21th 2004.
1:2006	Metodbeskrivning för Jb-totalsondering
2:2006	Metodbeskrivning för installation av inklinometerrör
1:2008	Användning av restprodukter inom EU
1:2009	Metodbeskrivning för provtagare med standardkolvprovtagare. - Ostörd provtagning i fikornig jord
2:2009	Åtgärdsmål vid in-situsanering. Formulering och kontroll av åtgärdsmål.
1:2010	Förorenade byggnader. Provtagning och riskbedömning.
1:2011	Stimulerad reduktiv deklorering. En praktisk handledning
2:2011	Klorerade lösningsmedel i mark och grundvatten – Att tänka på inför provtagning och upphandling
3:2011	Hantering och analys av prover från förorenade områden - Osäkerheter och felkällor
1:2012	EYGEC 2012 - Setting the scene for future European geotechnical research
2:2012	Triaxialförsök – en vägledning
3:2012	SGF:s dataformat
4:2012	Metodbeskrivning för jord- bergsondering
1:2013	Fälthandbok - Geoteknik
2:2013	Fälthandbok förorenade områden
1:2014	Hantering av geotekniska risker i projekt – Krav
2:2014	Riskidentifiering - metoder för att hitta hot och möjligheter
1:2015	Förbättrad utvärdering av resultat från jordbergsondering/MWD
1:2016	Jordarternas indelning och benämning
2:2016	Akustisk Jb-sondering, Resultat etapp 2
1:2017	Metodik för bestämning av skjuvhållfasthet i lera - en vägledning

The Swedish Geotechnical Society (SGF) was founded in 1950 and consists of approximately 1500 members with at least two years of practical experience of geotechnical engineering. In addition, SGF consists of approximately 30 corporate members, including universities, public authorities, consultancy firms, contracting firms, and manufacturers.

The purpose of SGF is to facilitate the development of geotechnical engineering, foundation engineering, engineering geology and geo environmental technology from a national and international perspective.

SGF is the Swedish branch of the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE).

SGF's report series includes methodologies, monographs, and proceedings from conferences and workshops.

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