KTH Architecture and
the Built Environment

MANAGEMENT OF GEOTECHNICAL RISKS IN INFRASTRUCTURE PROJECTS

AN INTRODUCTORY STUDY

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Licentiate Thesis

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Stockholm, Sweden 2005

TRITA-JOB LIC 2007
ISSN 1650-951X

Preface

The present licentiate thesis is concerned with risk management with application to management of geotechnical risks in infrastructure projects. The thesis includes a literature review of the concept of risk and risk management in general to create a basis for further studies of the management of geotechnical risks. The literature review also comprises project risk management in geotechnical engineering and a study of the risk management process in three infrastructure projects executed in recent years. The literature review and the case studies form a foundation for a discussion about the distribution of risks between the actors involved in an infrastructure project as well as the roles of the actors in the risk management process with the aim of creating opportunities for a successful management of geotechnical risks. The thesis has resulted in a description of a qualitative and conceptual methodology of the management in geotechnical risks.

The thesis is the second part of a research project that started at the division of Soil and Rock Mechanics at the Royal Institute of Technology in Stockholm, Sweden, in 2002. The first two years of research have been summarised by Hintze (2004). The work presented in this thesis started in 2003 and is the result of the author's first years of research. The study has been financed by the Development Fund of the Swedish Construction Industry and the Royal Institute of Technology. The thesis shall be used as a platform for the second part of this work which is planned to be concluded in 2007 and presented in a doctoral thesis. Earlier research at the Royal Institute of Technology on similar topics have resulted in doctoral theses by Olsson (1986), Hintze (1994), Sturk (1998) and Isaksson (2002) as well as several articles and conference papers, e.g. Sturk et al. (1998) and Stille et al. (2001).

This thesis is presented as a monograph but parts of it have been presented in the following conference papers:

> Carlsson M, Hintze S and Olsson L, 2004, *Application of System Analysis in Geotechnical Engineering - An Example from the South Link Road Construction*, Nordic Geotechnical Meeting, Ystad, Sweden.
>
> Hintze S, Carlsson M and Stille H, 2004, *Risk and System Analysis Model in Geotechnical Engineering - A Tool for Better Understanding and Decisions*, International Association of Bridge and Structural Engineering Symposium, Shanghai, China.
>
> Carlsson M, Hintze S and Stille H, 2005, *On Risk Management in Large Infrastructure Projects*, 16th International Conference on Soil Mechanics and Geotechnical Engineering, Osaka, Japan.

Two M. Sc. Theses have been carried out within the project. These are:

> Nordström L, 2002, *Risk och riskhantering vid arbete i jord och berg*, M. Sc. Thesis 02/07, Division of Soil and Rock Mechanics, Royal Institute of Technology, Stockholm, Sweden. (In Swedish).
>
> Magnusson C, 2004, *Analysmetoder för identifiering av risker vid sprängning*, M. Sc. Thesis 04/12, Division of Soil and Rock Mechanics, Royal Institute of Technology, Stockholm, Sweden. (In Swedish).

Author's Acknowledgements

This thesis has been carried out at the division of Soil and Rock Mechanics at the Royal Institute of Technology in Stockholm, Sweden. The study was supported financially by the Development Fund of the Swedish Construction Industry (SBUF) and the Royal Institute of Technology (KTH).

I wish to express my honest appreciation to those who in some way have contributed to this work and for the financial support from SBUF and KTH. Some, but not all, are mentioned here.

The study has been supervised by Professor Staffan Hintze and Professor Håkan Stille. Staffan has also been the examiner of the work. I am very grateful for their interest in the project as well as their support and guidance. The accomplishment of this work would have been much more difficult without their assistance. I also wish to express thanks to my friends and colleagues at KTH and Skanska for all help and inspiring and valuable discussions during the work.

The work has been followed by a reference group consisting of people with different knowledge and experience of academic research and risk management in geotechnical engineering. Their participation and support is gratefully appreciated. The reference group has consisted of:

Ph. D. Johan Andersson, JA Streamflow AB.

Professor Georgia Destouni, Stockholm University.

Ph. D. Leif Jendeby, The Swedish Road Administration.

Ph. D. Lars Olsson, Geostatistik AB.

M. Sc. (Civ. Eng.) Per-Olof Sahlström, The Swedish Road Administration/KTH Byggenskap.

Professor Björn Täljsten, Skanska Teknik/Luleå University of Technology.

Finally, I would like to express my sincere gratitude to my family and my beloved Matilda who have encouraged me during the work with this thesis.

Stockholm, October 2005

Mats Carlsson

Summary

There have been several cost overruns, time delays and quality problems reported from infrastructure projects around the world in recent years. The reasons for the reported cost and time overruns are to some extent the result of changes in scope of the projects, inflation and other factors. A considerable part of these problems is however due to the large risks and uncertainties of different nature involved in many infrastructure projects. Furthermore, it is often difficult to assess and manage these risks and uncertainties successfully. In the future it will be important for the construction industry to avoid these cost overruns, time delays and quality problems in order to maintain a fair reputation and a reasonable profitability in the business.

Many of the reported problems are associated with risks and uncertainties related to geotechnical conditions which are not managed sufficiently in the planning, design and execution phase of the projects. In order to achieve a cost-effective and a more predictable outcome of the projects to a cost that can be estimated before the projects begin, it is essential to manage the geotechnical risks and uncertainties involved in an adequate manner. The traditional methods of construction and risk management have proved not to be able to deal with these problems.

Furthermore, the increasing trend towards a broader package of risks as well as the use of new contractual arrangements, the transfer or sharing of risks between public and private sectors, and the rapid evolving methods of construction procurement also require a new approach to risk management in geotechnical engineering.

The main objectives of this study were to:

- Provide a literature review of the concept of risk and risk management as well as the process of project risk management in geotechnical engineering in order to identify those factors that are critical to the performance of the risk management process.
- Study how procurement methods and contractual arrangements affect the distribution of risks between the actors involved in an infrastructure project.
- Examine how the management of geotechnical risks was performed in some recently executed infrastructure projects in order to identify strengths and weaknesses.
- Discuss how the actors involved in an infrastructure projects should act in order to create opportunities for a successful management of geotechnical risks.

To reach the objectives the thesis presents a literature review of risk and risk management in general and in geotechnical engineering in particular as well as a study of the risk management process in three executed infrastructure projects. The literature review includes the concept of risk and uncertainty as well as the management and perception of risks, both on a fundamental level as well as on a more detailed level including the specific issues that are significant in geotechnical engineering. The thesis was based on two main sources of information; a traditional academic literature survey and discussions with some of the actors involved in the case studies. The general perspective in the thesis is on geotechnical risks and uncertainties affecting the contractor and client, both technical and economical. The literature study aimed at, in general, studying the process of management of geotechnical risks frequently present in infrastructure projects. Risks associated with contractual arrangements, organisation, construction methods and environmental issues are not considered explicitly. The management of risks related to the safety of the workers, fire and financial arrangements are not included at all in the thesis.

The case studies include a coarse description of the risk management process performed in the studied projects. The case studies mainly focus on technical aspects in general and risks related to geotechnical conditions in particular. The experiences and conclusions reported from the projects are derived from the literature study of the projects or from those taking part in the risk management process and/or the execution of the projects.

The literature study and the case studies revealed shortcomings and weaknesses in current methods for management of geotechnical risks. Some of these are:

- There is a lack of consistency in analysing and managing risks for different projects and clients and, sometimes, the different actors perform their own risk analyses without any co-ordination.
- The construction industry suffers from an "illusion of certainty", i.e. there is a belief that all risks can be foreseen and procedures for handling unexpected risks are therefore sometimes not established.
- Existing methods of risk management often fail to manage many of the critical risks.
- The risk management process in many projects is based on scientific method in a deterministic framework.
- There is a tendency towards focusing on risks that can be most easily quantified.
- Inadequate follow through from the analysis phase to the control of risks once the project starts to be implemented.
- There are problems with the implementation of the decided risk handling actions in the execution phase.
- The risk analysis is not used as a basis for risk sharing in some projects.
- There is sometimes a weak connection between the risk analysis in the design phase and the management of risks in the execution phase.

A successful management of geotechncial risks requires that an identification of risks and hazards is performed in an early phase of the project in a transparent and objective way by geotechnical engineers with knowledge and experience of risk management. An important issue is to ensure that the identified risks and hazards are managed properly in the execution phase, e.g. through the use of risk registers, monitoring, observational method and technical reviews. The risks and hazards should be communicated to all actors involved in the project and the characteristics of the information should be adjusted to the receivers. Furthermore, it is important to do the right things and not only to do the things right.

Due to the revealed shortcomings and weaknesses, the growing use of new contractual and procurement arrangements and the increasing location of infrastructure projects in urban areas, the current strategy of risk management should be modified. In order to ensure an effective management of geotechnical risks the actors involved in the building process should:

- Ensure that there is a mutual view of the risks and the risk management process in the project.
- Accept that there always will be geotechnical risks and uncertainties.
- Use a top-down philosophy and adopt a comprehensive view of the project in order to focus on the actual problem at hand.
- Allow a multipurpose and systematic investigation of the geotechnical conditions at the planning stage.
- Use design methods that recognizes that the geotechnical conditions are uncertain.
- Give the risk management activities equal importance with other project tasks.
- Ensure that every risk handling actions are fully defined, with a duration, cost, resource requirement, owner, completion criteria etc.
- Use appropriate types of contracts in relation to the risks involved and the desired distribution of the risks between the actors involved.
- Start the identification of geotechnical hazards and initiating events in the early phases of all projects.
- Emphasise appropriate design techniques in relation to the uncertainties involved, e.g. systematic engineering design or conceptual design.
- Monitor and record the actual geotechnical conditions and behaviour during the project execution and review the geotechnical aspects of the design and identify opportunities where re-design could make construction more cost-effective, e.g. by adopting the observational method.
- Communicate the risks to all actors involved in the project in a stringent way that is easy to understand and interpret.
- Collect data during the risk management process which at the end of the project should be used to provide feedback on the effectiveness of the procedures used.

Risk management in geotechnical engineering is a wide and multifaceted subject and there seem to be several problems and shortcomings in the management of geotechnical risks in many infrastructure projects today. As a consequence, there are many ways of continuing this study. The proposal for further research focuses on four issues in geotechnical engineering which the author thinks need more considerations:

- The problem of understanding and identifying critical risks.
- Further studies of methods for estimation of risks.
- The attitudes towards risk and the communication of risks.
- The distribution of risk among the actors involved and the connection to the type of contract and compensation.

Contents

Definitions

The definitions of risk and associated words and concepts are often ambiguous, subjective and not strictly used in everyday language. To make a structural and stringent risk management process possible it is desirable that all words and concept are unambiguous defined and clearly understood among all individuals and actors included in the process.

The definitions used in this thesis are primarily taken from Rowe (1977), Baecher (1981) Ang & Tang (1984), Rosenberg (1989), Hintze (1994), IEC (1995 & 2002), Lewin (1998), Sturk (1998) and Clayton (2001a & 2001b).

Accident
A *damage event* which is evolved under a short period of time.

Consequence
The result of an event expressed in qualitative and/or quantitative terms.

Damage
Loss of resources or fitness for purpose, including e.g. loss of financial resources, personal harm, property loss, environmental damage and insufficient quality.

Damage event
An unintended and, sometimes, unpredictable event that causes *damage* or lead to disturbances on an ongoing process. The duration of the event, i.e. the time between the *initiating event* and the actual *damage* can vary considerably. If the damage event evolves under a short period of time, the term *accident* is used.

Damage object
Objects which are subjected to *damage*, e.g. people, environment, property and business.

Decision
The choice of a certain alternative among several options in order to achieve a certain objective.

Expected value
The overall impact of a *risk* calculated by multiplying the *consequence* of a *risk event* with its associated *probability* of occurrence. It is equivalent to the average impact of the *risk event* which would result if a large number of identical projects were carried out.

Hazard
A threat of a possible *damage event* and an inherent characteristic of a *risk object*.

Initiating event
An event that induces a *damage event* eventually leading to *damage*.

Opportunity
Opportunity is the combined effect of the *probability* and the *consequence* of an event with positive consequences.

Probability
The likelihood or degree of certainty of a particular occurrence taking place during a specified time period.

Project risk
Project risk is a measure of the potential inability to achieve overall project objectives within defined cost, time schedule, quality, environmental impact and technical constraints and can be estimated as the combination of the probability of a *risk event* occurring and its consequences for project objectives.

Residual risks
Those risks which are not *avoided*, *transferred*, *shared* or *mitigated* in the *risk handling* strategy.

Risk
Risk is the combined effect of the *probability* and the *consequence* of an event with negative consequences and can be calculated as the statistical expectation value of the event.

Risk acceptance
The willingness of an individual, group or society to accept a specific magnitude of risk.

Risk analysis
A systematic use of available information to identify *hazards* and to estimate the *risks* to individuals, projects, property or the environment.

Risk assessment
The combined term for *risk analysis* and *risk evaluation*.

Risk assurance
The process that systematically tracks and evaluates the performance of *risk handling* actions against established metrics throughout the construction process and develops further risk handling actions as appropriate. It feeds continuous information back into the other *risk management* processes.

Risk avoidance
An action to reduce the risk through modification or elimination of the sources of the risk.

Risk communication
The relevant oral and written information and feedback to the project participants on current identified risks, risk handling activities and possible emerging risks.

Risk estimation
The process of examining each identified *hazard*, isolating the cause and determining the effect. It also includes risk rating and prioritising where risks are expressed in terms of their probability of occurrence and severity of consequences.

Risk evaluation
Decisions regarding acceptable risk levels and the analysis of different options concerning how to deal with the risks.

Risk event
The occurrence of an event which has the potential to affect the viability of a project.

Risk handling
The process that identifies, evaluates, decides and implements actions in order to set risks at acceptable levels given project constraints and objectives.

Risk identification
The process of recognizing the existence of a *hazard* and defining its characteristics.

Risk management
A systematic application of management policies and procedures in order to analyse, evaluate and handle risks.

Risk matrix
The presentation of the probability and consequence of risks in a matrix format.

Risk mitigation
An action either to reduce the *probability* of a *risk* occurring or to reduce the adverse *consequence* if it does occur.

Risk monitoring
A continuous process of monitoring and re-estimation of *risks*, *initiating event* and *warning bells*.

Risk object
An object including *hazards* that can cause *damage*.

Risk owner
An individual who has responsibility for monitoring, handling and controlling the *residual risks*.

Risk planning
The process of developing, documenting and communicating an organized, comprehensive, and interactive strategy and methods for developing risk handling plans, performing continuous risk assessments to determine how risks have changed, and assigning adequate resources.

Risk register
A list of risks identified in the risk review process, including full descriptive details and cross-references.

Risk response plan
A plan prepared towards the end of the *risk review* for controlling the risks once implementation begins.

Risk review
An overall assessment of the risks involved in a project, their magnitude and their optimal management.

Risk sharing
An action to reduce a *risk* through sharing the risk with another individual or organisation.

Risk transferring
An action to reduce a *risk* through a relocation of the risk from one part to another.

Sensitivity analysis
A technique used to discover how sensitive a result is to changes in the input values of the variables used to calculate the result.

Strategic risk
Any *risk event* which has serious or catastrophic consequences even though the probability of occurrence may be quite low.

System
A composite entity, at any level of complexity, of personnel, procedures, materials, tools, equipment, facilities and software. The elements of this composite entity are used in the intended operational or support environment to perform a given task or achieve a specific objective.

System analysis
A systematic identification of the key factors that affect the project and the dependence between these. System analysis questions the assumption that components of a system are the same when separated out as when they are part of the system.

Uncertainty
A situation or state with a complete lack of knowledge and experience.

Warning bell
An event or a state which indicates that a *hazard* is about to evolve into a *damage event* and subsequently *damage*.

1 Introduction

1.1 Background

Under the last decades there has been an increasing trend that many infrastructure projects have become more expensive than estimated and that the project times have been longer than expected (see e.g. Kastbjerg 1994, Whyte & Tonks 1994, Nylén 1996 & 1999, Clayton 2001a & 2001b and Hintze 2001). The overall quality has also become lower than expected in many projects. Experiences from completed projects show that the main part of these problems and shortcomings arise in the design phase and are realised in the construction phase of the project (Bergström 1989, Chan et al. 1997 and Nylén 1999). Many of the reported problems are associated with geotechnical events, which are not managed appropriately in the design and execution phase (see e.g. Whyte 1994, Nylén 1996, Hintze 2001 and Clayton 2001a & 2001b).

These statements are supported by statistics and observations from the construction industry around the world:

- In a study of 180 projects in the 1960´s undertaken by Merewitz and presented by Kastbjerg (1994), showed that cost overruns of 50 % were frequent. The magnitude of the cost overruns tended to increase with the size and complexness of the projects and was higher in projects using state-of-art technology.
- In Australia, Bromilow (1974) found that only one-eighth of the reviewed buildings contracts were completed within the scheduled completion date and that the average time overrun exceeded 40 %. Similar experiences have been presented by Bromilow et al. (1988) and Chan et al. (1995).
- Kastbjerg studied 41 infrastructure projects and concluded that approximately 32 % of the studied projects had a cost overrun between 50 and 100 %. (Kastbjerg 1994).
- Approximately 6 % of the total cost in the Swedish construction industry is related to the cost for correcting mistakes in design and execution (Josephson & Augustsson 1990).
- The cost for errors is approximately 8 % of the total construction cost in the Swedish construction industry and almost 80 % of this cost is due to conditions established before the execution phase. A few large failures answer for a majority of the total cost of errors as approximately 10 % of the errors answer for 90 % of the cost. If the uncertainty causing the failure could be transformed into a calculable risk, approximately one third of the cost of failures could be avoided (Nylén 1996 & 1999).
- According to a survey performed by Schälin & Pettersson in 1996 the cost for errors in Swedish civil works due to the lack of adequate knowledge of the geotechnical conditions is between three and four billion Swedish kronor each year (Schälin & Pettersson 1996).
- The estimated cost for the new metropolitan highway system in Boston has increased from the original budget of around six billion USD in 1992 to an estimated cost of almost fifteen billion USD in 2004 (www.masspike.com/bigdig).

The reasons for the reported cost and time overruns are partly due to changes in scope of the projects, inflation and other factors. But these factors do not answer for the whole truth. A considerable part of these costs overruns and time delays are due to the fact that infrastructure projects include large risks and uncertainties of different nature which can be difficult to manage in a successful manner (Clayton 2001a and Hintze 2001).

However, all projects and businesses ventures involve risks of various kinds. But uncertainties and risks affecting costs and time schedules seem to be more frequent in infrastructure projects than in other types of projects that generally are more standardised or well defined. Many infrastructure projects are characterized by varying and difficult conditions, long project time schedules, varying and diffused demands, complex contracts, high technical level, large and multifaceted organisations, and political, public and environmental focus (Stille et al. 1998). As a consequence, these projects often include large uncertainties and risks, which affect the performance and the result of the projects.

In addition, infrastructure projects often have long life times and affect its users and the surroundings under a long period of time. This implies that the risks affect many different actors under a long period of time. Other characteristics that affect the management of present risks in many civil engineering projects are a strong project orientation where the project is carried out under new and, sometimes, unknown conditions. Furthermore, the construction process generally includes many different actors which often have limited experience of working with each other and the project organisation is often different in every project.

The uncertainties due to insufficient information or incomplete knowledge of, for example, geotechnical conditions and design methods affect both the technical and financial performance of an infrastructure project. These uncertainties give rise to risks that can lead to reconstruction of part of the works, delay in completion, environmental damage and quality problems and can affect the health and safety of the workers involved. If these risks are not managed adequately, these unexpected events will probably result in negative consequences, e.g. loss of revenue or goodwill, additional costs for construction, operation or maintenance, or time delays. The costs that originate from these risks have to be borne by the contractor, the designer, the client or the society (Clayton 2001a).

Risks and uncertainties in infrastructure projects can, in general, originate from geological, technological, organisational and/or economical conditions and these conditions are often related to each other. The uncertainties regarding these conditions and the complex interaction between these result in a large technical and financial risk in many projects. As the project increases in scope, these uncertainties and obstacles seem to increase as well (Lewin 1998). Additionally, almost every infrastructure project is unique as the conditions and demands vary from one project to another. This implies that the risks are quite different in every project (Sturk 1998).

According to Hintze (1994 & 2001) a great part of the observed cost overruns and time delays in infrastructure projects are due to unexpected geotechnical conditions. Similar experiences from the British construction industry have been reported by Clayton (2001a). Deficiencies and shortcomings in the design and the investigations of the geotechnical conditions and the interpretation of the result from these investigations are responsible for approximately one third of the total cost for errors (Nylén 1996 & 1999).

As been stated previously, there have been many examples of infrastructure projects in recent times that have cost up to twice the budget amount to construct, opened more than twelve months late, performed well below the specified level of reliability or generated less than 50% of the forecast annual revenue. As a consequence, governments, funders and lenders have become unwilling to accept risks inherent in such investments (Lewin 1998). Given the average level of profit in the construction industry, it is vital for both the clients and contractors that these cost overruns and time delays are avoided in the future.

Because of the existence of these risks, uncertainties and shortcomings many authors, e.g. Reilly (1996), Anderson (1997), Sturk (1998), Hintze (2001), Clayton (2001b) and Chapman & Ward (2004a), have proposed a project management with a risk focus for infrastructure projects. In order to achieve a more cost-effective end product and a more predictable outcome of the project to a predictable cost it is essential to handle the existing geotechnical risks. Though, in the light of the mentioned characteristics of many infrastructure projects, the risk management process is not a simple process to perform. The process involves many different actors with different knowledge and experiences, includes many different types of uncertainties and risks, and extends over relative long period of time.

1.2 Objectives

The overall objective of the thesis is to increase the knowledge of the process of management of geotechnical risks in infrastructure projects and find ways to improve the present risk management methods. The meaning of an infrastructure project is here a project including civil engineering works that is large and complex enough to require that, for the success of the project, a structured risk management process is conducted. In smaller or less complex projects it may be enough if an informal management of risks is conducted in the mind of the individuals involved. In an infrastructure project, this is however not enough.

The main objectives of this study are to:

- provide a literature review of the concept of risk and risk management as well as the process of project risk management in geotechnical engineering in order to identify those factors that are critical to the performance of the risk management process,
- study how procurement methods and contractual arrangements affect the distribution of risks between the actors involved in a project,
- examine how the management of geotechnical risks was performed in some recently executed infrastructure projects in order to identify strengths and weaknesses, and finally
- discuss how the actors involved in an infrastructure projects should act in order to create opportunities for a successful management of geotechnical risks.

The results of the study may be used in order to enable an effective risk management process which in the end gives lower life-cycle costs, more effective use of resources and more cost-effective products. Additionally, the result of the study should be a base for further studies in the area of management of geotechnical risks.

1.3 Limitations

The topic of risk management is an extensive subject and consequently the thesis is limited to certain specific issues. The scope of the thesis is outlined in the next section, but the general limitations are presented in this section.

Infrastructure projects are in general considered to include large risks and uncertainties due to the nature of these projects and the number of cost overruns, time delays, quality problems and environmental impact which has been reported in many project recent years have been many. The implication of an infrastructure project is here that, due to the general size and complexity of these projects, it is not enough with one person's subjective and informal assessment and management of risks for the project to meet its objectives. Therefore, resources for a structured risk management to be conducted must exist and some knowledge and experience of risk management have to exist in the project organisation. Risk management in smaller or less complex projects with, for example, less resource for the management of risks is not included in the thesis.

The general perspective in the thesis is on geotechnical risks affecting the contractor and the client, both technically and economically. The literature study aims at, in general, studying the process of the management of geotechnical risks frequently present in infrastructure projects. Nevertheless, the literature review also considers the concept of risk and uncertainty and the risk management process on a fundamental level. However, a complete review of all concepts and methods in risk management in general can not be achieved in the framework of one chapter. In addition, the content in the thesis is to some extent characterised by the author's experiences of risk management in the construction industry.

Risks associated with the contract, organisation and construction methods are only considered briefly in the thesis. Furthermore, the management of environmental risks is not specifically included in the thesis. Risks related to the safety of the workers, fire etc. are not considered at all in the thesis. Risks related to the financial arrangements, e.g. currency changes, inflation and rates of interest are neither considered. Though, these types of risks can be handled in the same way as the risks mentioned in the literature review and the case studies.

The case studies only include a coarse description of the risk management process performed in the three selected projects. The case studies mainly focus on the technical aspects in general and risks related to the geotechnical conditions in particular. The experiences and conclusions reported from the projects are derived from the literature study of the projects or from those taking part in the risk management process and/or the execution of the projects. A limitation in case studies in general is that there are much written about successful projects while unsuccessful projects are not reviewed that much. Furthermore, good experiences are reported, bad are not.

1.4 Scope and Disposition of the Thesis

The thesis is based on two main sources of information; a traditional academic literature survey and discussions with some of the actors involved in the risk management process in the case studies. References are given successively in the thesis and are gathered in the end of the thesis. If no reference is given it is the author's opinion or conclusion that is intended.

To reach the objectives mentioned in sections 1.2, the thesis presents a literature review on risk and risk management in general and in geotechnical engineering in particular as well as a study of three executed civil engineering projects. The literature review includes the concept of risk and uncertainty as well as the management, perception and acceptance of risks, both on a general level as well as on a more detailed level including the specific issues that are significant in geotechnical engineering, see figure 1.1.

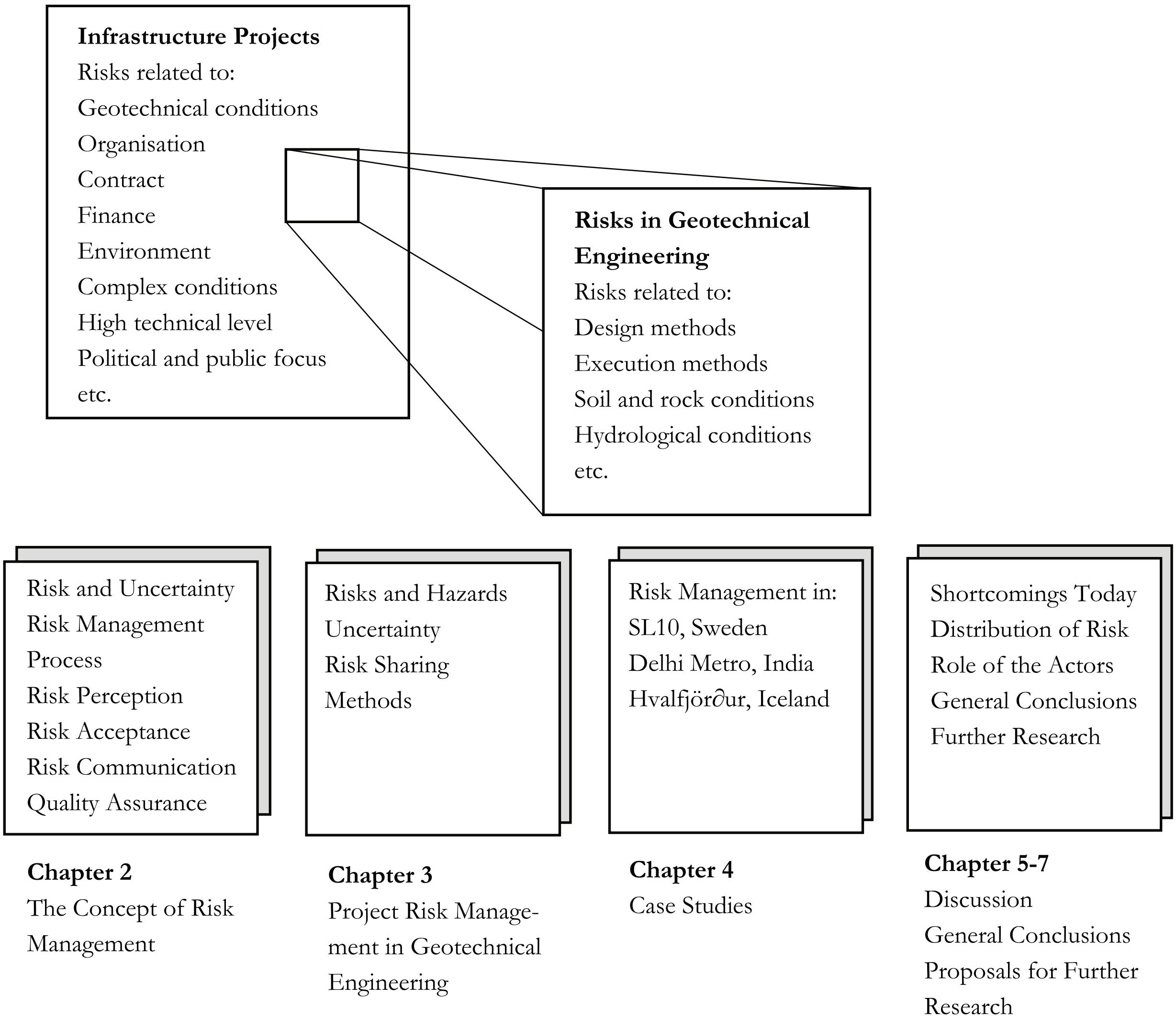

Figure 1.1 The scope and disposition of the thesis.

The aim of the case studies is to study the risk management process in some recent executed infrastructure projects and to evaluate the risk management processes in these projects in order to identify areas for improvement. The obtained knowledge from the case studies shall be used as a platform for the discussion of the role of the actors involved in the construction process and for the proposals for further research in the area. The case studies were selected with the purpose of studying some recent executed infrastructure projects, not older than ten years, including different types of construction and with different geotechnical conditions and decision situations.

The discussion in the thesis is based on the fundamental platform of risk and uncertainty management in civil engineering, a topic that has been considered in several doctoral theses (Olsson 1986, Hintze 1994, Sturk 1998 and Isaksson 2002) and articles (e.g. Stille et al. 2001) at the division of Soil and Rock Mechanics at the Royal Institute of Technology in Stockholm, Sweden.

In order to enable an overview of the structure of the thesis, a short description of the chapters is given below.

Chapter 2, The Concept of Risk Management – comprises a literature review and state-of-the-art mainly related to the concept of risk and uncertainty and risk management in general.

Section 2.1 provides a short introduction to the subject and describes the history of risk management and why it is a key aspect of successful complex projects. Section 2.2 describes the concept of risk and uncertainty, mostly in general terms but occasionally with a focus on geotechnical engineering. Section 2.3 presents the risk management process and describes the different parts of this process. Section 2.4 and 2.5 describes those factors affecting the individual perception of risk and aspects of what is considered to be accepted risk levels. Section 2.6 deals with risk communication, which is an essential factor for the performance of the risk management process. The chapter is ended with some considerations regarding the quality-assurance of the risk management process in section 2.7 and conclusions in section 2.8.

The objective of the chapter is to create a comprehensive picture of the key factors which governs a successful management of risks as well as the different factors affecting the risk management process. This acquired knowledge shall be the basis of the following chapters.

Chapter 3, Project Risk Management in Geotechnical Engineering – is a literature review dealing with project management of risks in geotechnical engineering.

Section 3.1 gives a short introduction into the subject of project risk management on a fundamental level. Section 3.2 and 3.3 consider the special features of the risks and uncertainties that are present in geotechnical engineering. Section 3.4 deals with risk sharing, i.e. how the risks are distributed among the actors involved in the construction process. Section 3.5 presents some selected methods of project risk management which is presented in the literature. The methods are selected with the purpose of review some of the different methods that can be used in the management of geotechnical risks in infrastructure projects.

The aim of the chapter is not to present a complete review of all existing risks, hazards and uncertainties in geotechnical engineering but to provide a fundamental basis of knowledge of these and to point out the most critical risks in many infrastructure projects. Furthermore, the methods of project risk management are presented in order to illustrate some useful examples of these methods, not to be a complete review of all existing methods.

Chapter 4, Case Studies – presents a coarse description of the risk management process in three infrastructure projects that have been executed in recent years on a rather fundamental level.

The presentation is based on a study of the documentation of the risk management process in these projects as well as informal interviews and discussions with some of the people involved in the projects. The studied projects are the contract SL10 (section 4.1) of the South Link Road Construction in Stockholm, Sweden, the contract MC1A (section 4.2) of the Delhi Metro project in New Delhi, India, and the construction of a road tunnel under the fjord Hvalfjörður (section 4.3) located just north of Reykjavik on Iceland. The experiences and conclusions regarding the risk management process made in each project are summarised in each section. General conclusion from the three case studies is given in section 4.4.

The purpose of the chapter is to study some examples of methods for risk management used in executed projects in order to distinguish deficiencies of and opportunities for improvement in these methods and to identify the most important factors for a successful risk management process. These shortcomings and factors of success are discussed in the next chapter. The risk management process in the case studies will generally be described in the perspective of the contractor and consider the risks related to geotechnical conditions.

Chapter 5, Discussion – discusses the shortcomings of the methods for risk management that are used today, the distribution of risk between the actors involved in an infrastructure project and the key factors for a successful risk management process in geotechnical engineering.

Section 5.1 gives a short introduction including some of the issues that have been mentioned in the previous chapters. In section 5.2 the shortcomings in the risk management process are outlined on the basis of the literature review and the case studies. Section 5.3 discusses how the risk shall be distributed between the actors involved in the building process in order to enable a cost-effective and safe execution of infrastructure projects. The role of the client (section 5.4), designer (section 5.5) and contractor (section 5.6) in the risk management process are also discussed in the following sections.

The aim of the chapter is to outline the shortcomings of the risk management in geotechnical engineering today in order to discuss the key tasks for the actors involved in the construction process with respect to the management of geotechnical risks as well as to identify those areas that need further knowledge and research.

Chapter 6, General Conclusion – presents the general conclusions from the literature review, the case studies and the discussion chapter.

The general conclusions consider the management of risks in infrastructure projects in general and in geotechnical engineering in particular. The chapter includes some recommendations for an improved management of geotechnical risks in infrastructure projects.

Chapter 7, Proposals for Further Research – concludes the thesis by suggesting and discussing some of the ways of continuing this study.

Due to the fact that risk management is an extensive and complex subject there are many ways of continuing this study. The chapter presents only some of these ways generally focusing on four issues; the problem of understanding and identifying critical risks, further studies of methods for estimation of risks, the attitudes towards risk and the communication of risks and, finally, the distribution of risk among the actors involved and the connection to the type of contract and compensation.

Chapter 8, References – the final chapter gathers the references made in the thesis in an alphabetic order.

The thesis comprehends concepts from several disciplines, e.g. statistics, geotechnical engineering, decision theory and the study of risk and risk perception. Abbreviations, notations and symbols that are generally used in the disciplines are used in thesis and these are explained successively in the thesis as they occur. Separate sections with abbreviations and notations and symbols have therefore been excluded. However, some definitions of key words and concepts in the risk management process are gathered in a separate definition section.

2 The Concept of Risk Management

The risk management process is influenced by many factors such as the meaning and interpretation of the word risk, individuals' perception of different types of risks, the accepted risk levels and the communication of risks. The chapter includes a literature review principally related to the concept of risk and uncertainty and risk management at a fundamental level. However, there is some degree of connection to geotechnical engineering in some places, e.g. through some examples given in the text. The chapter includes the following topics:

- The Concept of Risk and Uncertainty.
- The Risk Management Process.
- Risk Perception.
- Risk Acceptance.
- Risk Communication.
- Quality Assurance of Risk Management.

The chapter aims at creating a comprehensive picture of the different factors influencing the risk management process as well as identifying the key factors which determine the result of the risk management process. This acquired knowledge shall be used as a foundation for the further study and the following chapters.

2.1 Introduction

The study of risk came up as a new field of applied science in the late 1950´s due to a growing public concern with new technologies and the increasing environmental damage (Hansson 1993). Methods for risk management were first developed and used in industries where a failure could have severe consequences, e.g. the nuclear, process, aeroplane and space industry. The need for risk management was also growing because a change in characteristics of the systems and facilities that was planned. Small systems with long introduction times and local consequences were partly replaced by larger systems with shorter introduction times and large consequences which affected more people in the society. The experience and empirical data of these new systems was also scarce (Rowe 1977 and Andersson 1988).

To deal with these changes and new prerequisites, researchers from different areas integrated in a new interdisciplinary discipline called risk analysis. The aim of this new discipline was to increase the knowledge about risks in general. In the beginning the research was primarily focused on the psychological factors of risks. This research was followed by studies of risk perception, decision theory and risk communication.

Risk management evolved as a discipline in the United States in the 1960's due to increasing costs for business insurances which resulted in a demand for preventive measures to reduce business risks and new management functions. This early research has been developed under the last decades and is today used in many businesses, e.g. in financial businesses and in public business. Nowadays, risk management is a widespread used methodology in many industries, e.g. nuclear power, process, economy and industrial (see e.g. Otway 1987 and Grimvall et al. 1995).

The interest in risk management in the construction industry started to grow in the 1990´s due to the increasing number of complex projects including large uncertainties and risks, e.g. the development of large scale infrastructure projects in urban areas. Today some form of risk management is performed in almost every project, though with different scope and methods. The early methods for risk management in civil engineering were, to a large extent, subjective and did not take the entire project into consideration. However, there seems to be a trend towards more objective methods which aims at taking the entire life-cycle of a project into consideration. Furthermore, due to lack of knowledge and economical and personal resources in the risk management process, most risk management in the past has been performed on an informal and intuitive basis based on engineering judgement (Andersson 1988).

The management of risks and uncertainties in future infrastructure projects will probably become a more complicated process than before due to increasing dependence on advanced technology and the location of complex infrastructure systems in urban areas with tight time schedules and rigid cost limits. The physical constraints and technological challenges will become more demanding and there will also be the need to take a much wider range of interests into consideration in the planning, design and execution phase. In addition, an increasing consideration has to be taken to public interests and relations. Therefore, there will be a greater range of risks to be considered and the management of the risks will become more diverse (Lewin 1998).

Risk management in civil engineering has earlier been discussed by e.g. Terzaghi (1961), Ang & Tang (1984), de Mello (1988), Hintze (1994), Sturk (1998), Jaafari (2001) and Clayton (2001a & 2001b). Construction risks in general have been discussed by Thompson & Perry (1992). Risks related to organisational and contractual matters in underground projects have been considered by, for example, Tengborg (1998). Environmental risk and uncertainty management has been discussed by e.g. Balson et al. (1992), Asante-Duah (1998) and Norrman (2004).

2.2 The Concept of Risk and Uncertainty

The concept of risk and uncertainty originates from the economic theory of incomplete information. According to Knight (1921) "*a situation is said to include risk if the randomness facing an economic agent can be expressed in terms of specific numerical probabilities*". These probabilities can be objectively specified or reflect the individuals own subjective beliefs. On the contrary, situations is said to include uncertainty when the agent can not or does not assign actual probabilities to the alternative possible occurrences.

The word risk is an ambiguous and a multidimensional word having various meanings to different individuals and is used with different meaning in different businesses and in everyday language. Research have shown large discrepancies between the public and experts when it comes to the definition of the word risk and the perception of risks. The word's origin is uncertain, but it probably originates from the Latin word "*risiqum*" which aims at accidents at sea or the Arabic work "*risq*" which means something that has been given to you from Allah. A lexical definition of the work could be danger, uncertainty, doubt or responsibility. Risks are generally connected to uncertainty and to the lack of knowledge and the knowledge about risk is therefore, in a sense, the knowledge of the unknown. Furthermore, it is a value-laden word which has a negative meaning to most people. Many researchers have tried to make the concept of risk as objective as possible, but on a fundamental level it is an essentially value-laden concept since risk often takes a "threat perspective". However, risk has a positive side as well, opportunity, which is often ignored (Hillson 2001, Ward & Chapman 2003 and Hansson 2004).

The word "*risk*" is, as stated before, used with different meanings in many situations which are not sufficiently distinguished between. The word is usually related to a decision situation with several alternatives. Therefore, the definition used should be related to the present decision situation. Some of the definitions used in the literature are (see e.g. Rowe 1977, Hintze 1994, IEC 1995 and Hansson 2004):

(i) An unwanted event which may occur.

(ii) The cause of an unwanted event which may occur.

(iii) The probability of an unwanted event which may occur.

(iv) The consequence of an adverse event which may occur.

(v) The statistical expectation value of an unwanted event which may occur.

(vi) A measure of variance or distribution.

The definitions according to (i) and (ii) are particularly used in everyday language and rarely in a technical context. Definitions according to (iii) and (iv) are often used when the size or seriousness of the risk is to be determined. In many situations, e.g. in engineering applications, risks are so strongly associated with probabilities that the word risk is used to represent the probability of an event rather than the event itself. The analysis of consequences has often been achieved by replacing the cost with utility or by discounting the cost to present value. Thus, this introduces aspects of subjectively into the process.

The fifth definition was developed in risk analysis with the aim of quantifying the total amount of risk associated with a specific event and is often used in a technical context, see Hintze (1994) and Hansson (2004). An expectation value is a probability-weighted value and has the benefit of being is additive. This definition is often used in risk-benefit analysis in the systematic comparison of risks with benefits. This is also the standard meaning of risk in many branches. The sixth definition is often used in an economical context.

However, there are at least two limitations with the expectation value approach (Slovic 2000 and Hansson 2004). First, probability-weighing is controversial. Events with very low probability and very large consequences can be perceived very differently from events with moderate probability and consequences. For example, proponents of a precautionary approach against risks maintain that the management of large but improbable accidents should be given higher priority than what would ensue from an expectation value analysis. Second, the expectation value approach only assesses risks according to their probability and consequence. Studies have shown that the calculated risk is not the only aspect of the implicit decision basis (Corotis 2003). For most people, other factors than the calculated risk level effect their decisions regarding risk, e.g. how risks and benefits are distributed or connected and social factors. So, if the expectation value method is used it must be remembered that the size of the risk is not all that is needed to judge whether a risk can be accepted or not. Additional information about its social context is also needed.

Ward and Chapman (2003) discuss the meaning of the word risk in detail in the context of project management. They argue that the current risk management processes induces a restricted focus on the management of project uncertainty. The reasons for this is that the word "risk" usually is associated with events rather than more general sources of significant uncertainty and because it often has a threat perspective. Furthermore, they argue that a focus on "uncertainty" rather than risk could enhance project risk management, providing an important difference in perspective, including, but not limited to, an enhanced focus on opportunity management. Due to the ambiguous interpretation and underlying appraisal they suggest the usage of the more generally applicable word "uncertainty" instead of the word "risk" and that the established concept of project risk management should be transformed into project uncertainty management. Uncertainty management is about identifying and managing all sources of uncertainty which give rise to and form the perception of threats and opportunities. The key concern is the understanding of where and why uncertainty is important in a project context, and where it is not.

Though, risks and uncertainties surround every human activity and influence everything we do. Risks and uncertainties are therefore unavoidable in the design and execution of an infrastructure projects. In these situations risks are often strongly associated with probabilities and the word risk is used to represent the probability of an event rather than the event itself. According to the traditional definition of probability, the probability of an event A, denoted $p(A)$, is the relative frequency of this event, a, from an infinite number of trials, n, i.e. (Johnson 2000):

$$p(A) = \lim_{n\to\infty} \frac{a}{n}$$

In reality, there are however seldom an infinite number of trials. Significant for many technological systems is that there are none or few data available since many systems are only built in small numbers and accidents rarely occur. As a consequence of this, there are no long and stable series of data and the estimation of risks can not be based on logical models or empirical data. Depending on the amount of information that are at hand when estimating the probability there are different methods available (see figure 2.1).

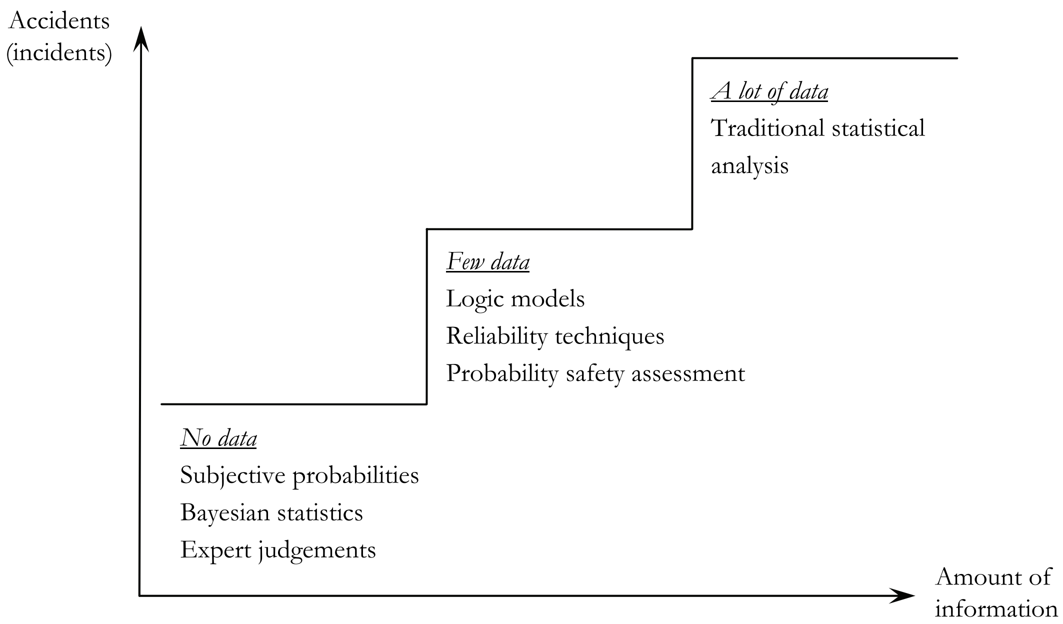

Figure 2.1 Methods for estimating probabilities (after Mattsson 2002).

In some situations, a way of estimate the risks are to use incident instead of actual accidents. The incidents are often more numerous than the accidents and sometimes traditional statistical analysis can then be used. Another way of dealing with this problem is to use a logical model of the system in combination with reliability properties of the components in the system. The estimation of risks can also be based on expert judgement, engineering knowledge and/or a small number of data. In these situations the use of Bayesian statistics can be appropriate (Benjamin & Cornell 1970 and Ang & Tang 1975 & 1984).

Bayes' theorem, first presented by reverend Thomas Bayes in 1763, rests on two fundamental principles. Firstly, a bayesian statistician is always expressing knowledge in terms of probability by using subjective degree of belief and there always exists a complete set of probalistic beliefs. Secondly, when additional information is at hand the prior probability assignments are updated with the use of Bayes´ theorem (Benjamin & Cornell 1970).

According to the theorem the probability is first subjectively assigned from available data with certain likelihood, a so called a' priori-distribution. The a' prior-distribution is assigned before the projects starts, usually from expert judgements. This first estimation is updated with new information during the construction to a' posterior-distribution.

If B is an event and $A_1, A_2, \ldots, A_n$ are partitions Bayes' theorem can be written:

$$P(A_i|B) = \frac{P(B|A_i)\,P(A_i)}{\sum_{j=1}^{n} P(B|A_j)\,P(A_j)}$$

where $P(A_i/B)$ is the posterior probability of event A_i given information B
$P(B/A_j)$ is the probability of getting information B given the outcome A_i (likelihood)
$P(A_j)$ is the prior probability of A_j

This approach is especially appropriate in projects where more information is obtained throughout the project, e.g. by the use of a monitoring system (Hintze 1994 and Stille et al. 2003). It can be argued that this is a highly subjective way of estimating risks, but it must be remembered that other methods also include some degree of subjectively, e.g. in formulating models or estimating parameter values. The estimation of probabilities in situations where there are no data available has been further discussed by Thorne & Williams (1995) and Bailey (1997). The assessment of subjective probabilities has been considered in the context of decision analysis by, for example, Stael von Holstein (1970), Hansson (1991) and Sturk (1998).

The extents of the risks are generally specific to each project and the risks can be divided into different groups depending on their characteristics. In the literature, there exist several models to divide the risks into different groups. One model to classify risks is according to the information available and their consequences into:

- Deterministic risks – risks which are similar every year, e.g. the number of injured in traffic or at work in a large region.
- Random risks with large variations – risks which show large deviations from year to year, e.g. the number of injured in traffic in a small region.
- Catastrophes - risks with low probabilities and large consequences which are concentrated in time and space, e.g. earthquakes and hurricanes.
- Uncertainty – risks with unknown or unpredictable consequences, e.g. accidents affecting the environment.

Another way of classifying risks is to divide the risks into risks that are specific for a project and risks that are global. The project specific risks are risks that are directly related to the development, the design and the operation of a facility. Technical risks, financial risks and organisational risks are examples of project specific risks. Examples of global risks are political and environmental risks, and risks with "force majeure" and public relations. According to Leung et al. (1998) risks in a construction project can be categorised into external risks, e.g. financial, political and environmental risk and force majeure, and internal risks such as related to planning, design, construction and maintenance.

Uncertainty generally arises due to a complete lack of knowledge. In order to understand the source of the uncertainty the uncertainties are often categorised. The categorisation and meaning of the uncertainties are in general arbitrary and depends on the purpose. The uncertainties can in general be categorised into (Bedford & Cook 2003):

- Aleatory uncertainty that arises due to the natural variability in a system.
- Epistemic uncertainty that arises through the lack of knowledge of a system.
- Parameter uncertainty is the uncertainty about the "true" value of a parameter in a model.
- Model uncertainty describes the uncertainty in the models that are used. Of course, all models are false in some way but some are more false than others.
- Volitional uncertainty is the uncertainty that an individual will do what has been agreed on.

Due to the complete lack of knowledge it is not even meaningful to use probabilities in situation where uncertainty arises. Therefore, the uncertainty has to be handled with different methods. Aleatory uncertainty can be estimated through measurements and statistical methods or by expert knowledge. Epistemic, parameter and model uncertainty can not be measured but can, for example, be quantified by experts. Model uncertainty is central in consequence analysis where the predictive quality of a model is important. Volitional uncertainty can be estimated by means of preference behaviour.

2.3 The Risk Management Process

As for the word risk, there exist several definitions of which activities that are included in the risk management process. According to the International Electrotechnical Commission the risk management process includes risk analysis, risk evaluation and risk reduction/control (see figure 2.2). The risk management process is a process which can be defined as "*a systematic application of management policies and procedures in order to analyse, evaluate and mitigate risks*" (IEC 1995). According to figure 2.2, the risk assessment process includes risk analysis and risk evaluation, but not the risk reduction/control.

According to another standard from IEC the project risk management includes (IEC 2002):

- Establishing the context of project objectives.
- Risk identification.
- Risk assessment, including risk analysis and evaluation.
- Risk treatment, impact mitigation and probability reduction.
- Review and monitoring.
- Communication (including consultation).

This standard provides a general introduction to risk management, its processes and influencing factors.

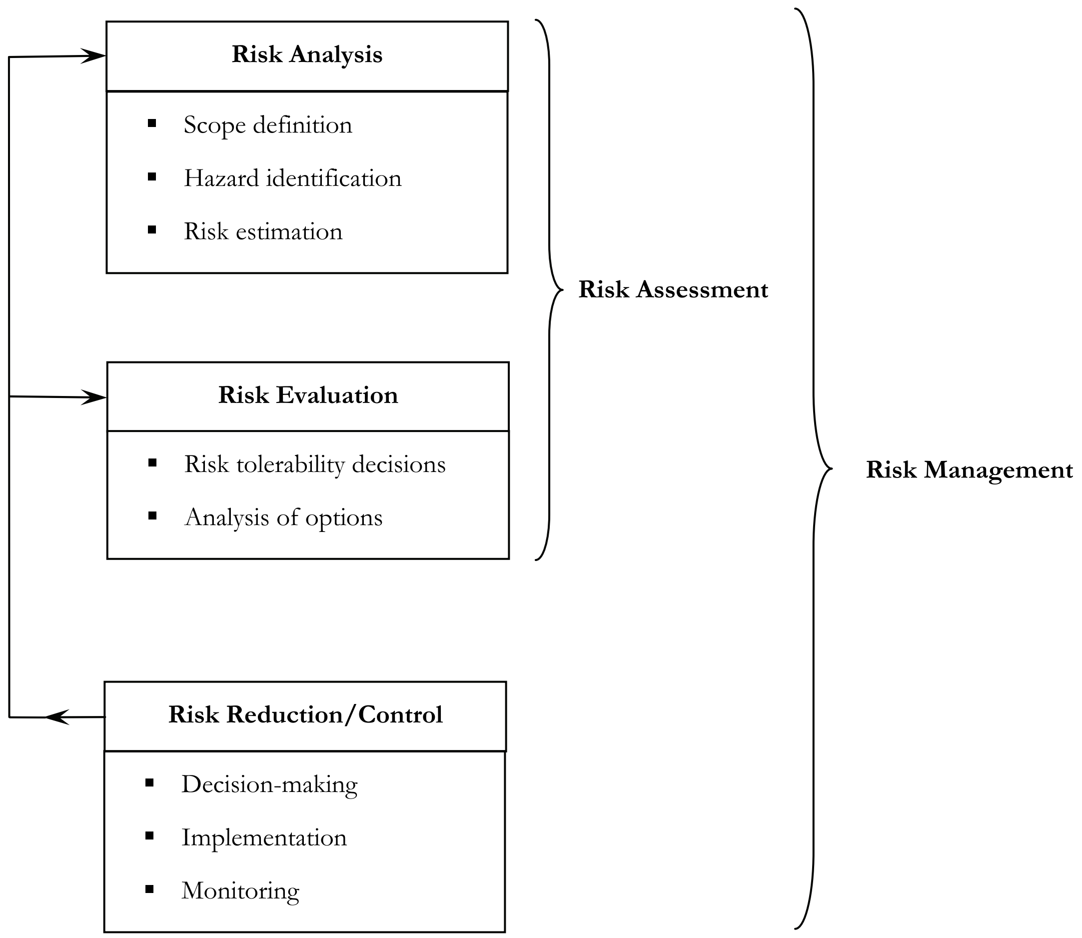

Figure 2.2 A simplified relationship between risk analysis and other risk management activities (IEC 1995).

The first phase of the risk management process, *the risk analysis*, is the process of estimating the probability of hazards and the consequences of these. This process is a basis for the decision-making regarding the risks. According to IEC (1995) the risk analysis process can be defined as a "*systematic use of available information to identify hazards and to estimate the risk to individuals and populations, property or the environment*". Hence the events are in space and time, stochastic processes play an important role. In general, the risk analysis aims at answering three fundamental questions (Clayton 2001b):

- What can happen?
- How likely is it?
- If it happens, what are the consequences?

The risk analysis can be used with different objectives in different phases of a project. In the design phases it can be used as a design tool. In the operating phase the risk analysis can by used in order to maintain the risk focus, to analyse problems and the effects of changes in the system and to secure that the risk level do not exceed the prescribed risk levels.

In general, the risk analysis includes three phases; scope definition, hazard identification and risk estimation. The scope definition includes a definition of the objectives and the extent of the project as well as a definition of the project in system terms (see section 2.3.1). The hazard identification includes the identification of both potential hazards that can affect the project negatively and opportunities that can affect the project positively (see section 2.3.2). The risk estimation includes initial estimation of the probability and the consequence of identified hazards and opportunities (see section 2.3.3).

The risk analysis provides the framework and the tools to understand the risks and hazards in the project through a description of the process of events, which can lead to some kind of damage, i.e. in a wide sense loss of resources, e.g. economical, technical or personal damage. Furthermore, the risk analysis describes events that may initiate and lead to a realization of a hazard. In order to describe the damage process the following definitions can be used (Sturk 1996 and Clayton 2001b). A hazard is a threat of potential damage and is an inherent property of a risk object. The damage event is an event causing damage. The initiating event is an event triggering a damage event. Warning bells or damage indicators indicate that a hazard is about to be realized. An understanding of the hazards and the process from the initiating event to the damage will lead to a more cost-effective execution of a project. See also section 3.1 where these definitions are further discussed.

The risk analysis work will generally focus not only on technical and geological problems but also on the management of the project organisation related to the design commitment. The success of the risk analysis is dependent on a thorough search for existing information as well as sufficient knowledge and experience is brought to identify hazards and risks and to estimate probabilities and consequences. High-quality communication and transferring of correct information are other key factors to carry out successful projects. The risk analyses can be considered to be a part of the quality assurance.

The risk analysis should be a living document, which should be updated when changes in the project have occurred or damage has occurred. The document should not be closed until the project is finished. One of the major advantages of risk analysis is that it on a fundamental level increases the risk awareness of all the individuals involved. Further advantages are that it allows profitable opportunities to be examined that would otherwise be judged too risky and that it leads to a positive motivation to manage risks of adverse events as far as it is practically possible (Hintze 2001 and Clayton 2001a).

There exist a large number of risk analysis and statistical tools which can be used in the risk management process. Many of these tools were developed in other businesses than civil engineering, but can with none or smaller changes be used in civil engineering projects. Some of these tools have been described by for example Rausand (1991), Hintze (1994), IEC (1995 & 2002), Sturk (1996), Bedford & Cooke (2003) and Stille et al. (2003). Methods for risk assessment for assessing environmental risks have been considered by e.g. Covello et al. (1993). Some common methods within civil engineering are listed together with suggested references in table 2.1.

Methods of risk analysis can roughly be divided into qualitative and quantitative methods depending on their level of precision. The qualitative methods have a descriptive nature and are often used in the purpose to identify those risks that should be further studied with a quantitative method. The quantitative methods aim at estimating both the probability and the consequence of the risks. Examples of qualitative methods used in civil engineering projects are expert brain-storming, checklists, preliminary hazard analysis, hazard and operability analysis (HAZOP) and What-if analysis. Common quantitative methods are fault and events trees, see e.g. Sturk (1996) and Stille et al. (2003).

Table 2.1 Risk management tools with some selected references.

Tool	***Application***	***Reference***
Fault tree analysis	Identification of hazards, initiating events, warning bells, etc. and the description of event sequences and the relationship between these	Benjamin & Cornell (1970) Ang & Tang (1984) International Tunnel Association (2002)
Event tree analysis	Description of event sequences and consequences	Benjamin & Cornell (1970) Ang & Tang (1984) International Tunnel Association (2002)
Decision tree analysis	Ranking of decision alternatives based on expected cost	Raiffa (1970) Olsson & Stille (1980) Sturk (1996)
Influence diagrams	Risk and hazard identification and description of the interaction between these	Marshall & Oliver (1995) Jensen (2001)
Rock engineering systems (interaction matrices)	Risk and hazard identification and description of the interaction between these	Hudson (1992) Stille et al. (2003)
Monte Carlo simulation	Calculating expressions including stochastic variables	Hammersley & Handscomb (1964) Baecher & Christian (2003)
β - method	Calculating expressions including stochastic variables	Thoft–Christensen & Baker (1982) Olsson (1986)
Markov processes	Description of uncertainties	Ang & Tang (1984) Bedford & Cook (2003)
Kriging	Description of uncertainties	Goovaerts (1997) Deutsch (2003)
Hazop analysis	Risk and hazard identification and description of the interaction between these	Rausand (1991) Kletz (1992)
Paired comparison	Ranking of decision alternatives based on preferences	Mac Berthouex & Brown (1994) Kirwan (1994)
Point estimate	Calculating expressions including stochastic variables	Harr (1987) Alén (1998)
Analytic hierarchy process	Ranking of decision alternatives based on preferences	Saaty (1990) Berggren et al. (2000)

Other methods used in other industries which might be used in infrastructure projects are for example FMEA (Failure Modes and Effect Analysis), MORT (Management Oversight and Risk Tree), SMORT (Safety Management and Organisation Review Technique), THERP (Technique for Human Error Rate Prediction), SLIM (Success Likelihood Index Method), Multirisk and Markov analysis. These methods are extensively described by Rausand (1991), International Tunnel Association (2002) and Bedford & Cook (2003).

In order to handle the limited amount of data generally available and the stochastic processes involved in the risk analysis process, computer simulation methods are often used, e.g. Monte Carlo simulations. Even if these methods are useful in many situations, there are often some limitations when using these techniques which are important to have in mind. For example, there seems to be overdependence in simulation, lack of data and empirical validation, assumptions of independence and that a certain output can be generated by different input (Brillinger 2003).

The second phase in the risk management process, *the risk evaluation*, comprises decisions regarding acceptable risk levels and the analysis of different options concerning how to deal with the risks.

The third and last phase, *the risk reduction and risk control*, includes decisions regarding how to deal with the risk, implementation of the risk management plan into the project plan and the monitoring of the risks during the project.

A more detailed flow chart of the risk management process is shown in figure 2.3.

Effective risk management methodology requires involvement of the entire project team and also requires help from external experts, knowledgeable in existing risk areas. The risk management process should consider technical issues as well as human elements and organizational issues. Successful risk management projects generally have the following characteristics (Lewin 1998):

- Feasible, stable and well understood user requirements.
- Experienced and highly skilled personnel.
- A close relationship between all actors involved in the project.
- A planned and structured risk management process.
- A project strategy consistent with accepted risk level and risk handling strategies.
- Continual reassessment of project risks and associated risks during the entire project.
- Aids to monitor effectiveness of risk handling strategies.
- Formal documentation and communication.

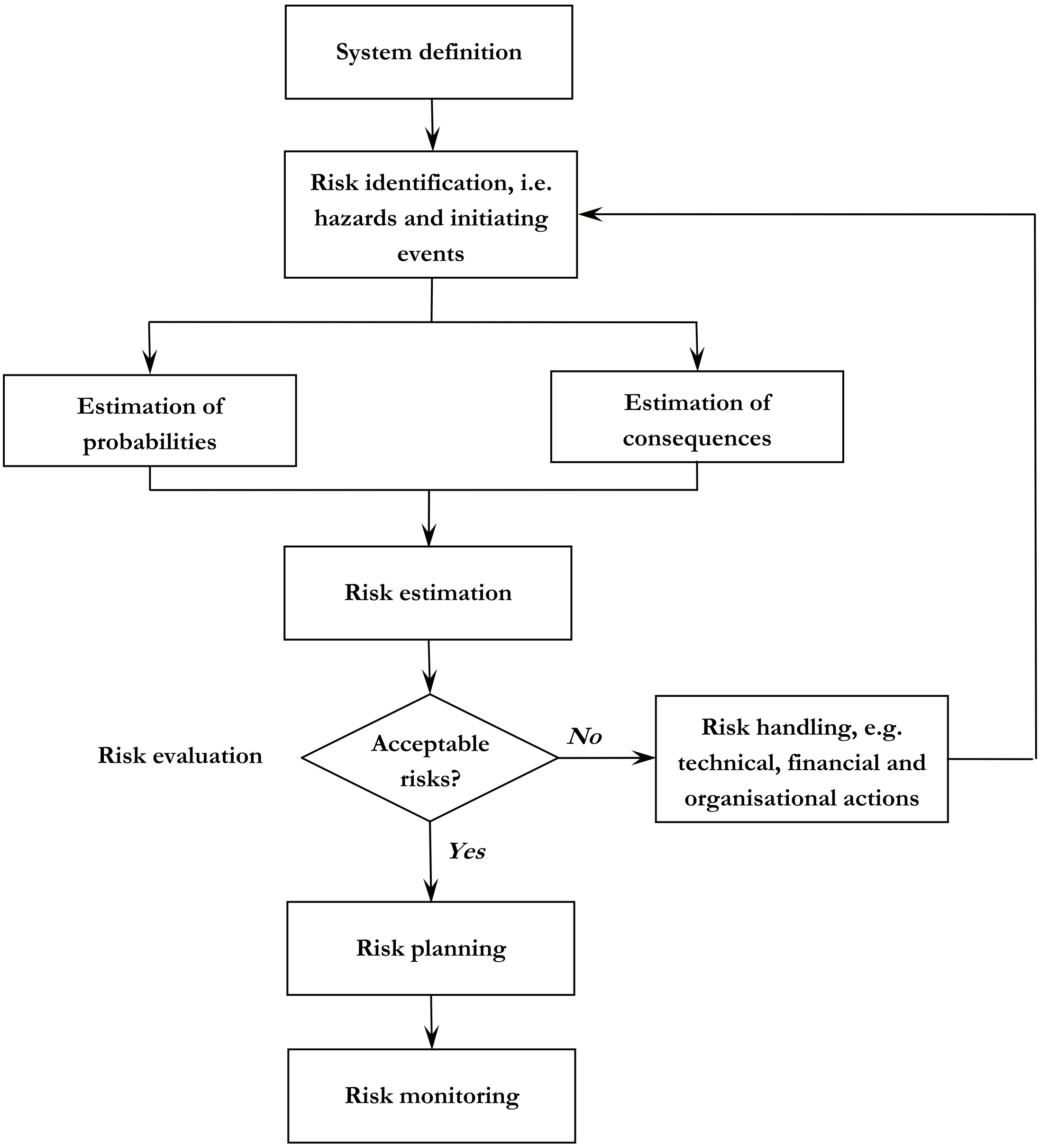

Figure 2.3 The structure of the risk management process (after Hintze 1994 and IEC 1995).

The risk management process is most effective when it is started during pre-project planning in order to ensure that, as many as possible, critical risks are identified and addressed with mitigation actions incorporated into the project plan (Uher & Toakley 1999, Clayton 2001a & 2001b, Hintze 2001 and Kolveit & Grønhaug 2004). Furthermore, in an early project phase the possibility to influence is high and the accumulated resources used low. Early information gives data that helps the project planning and the decision-making. As the project progress, new information improves insight into the risk areas. This allows development of more effective project strategies. The work carried out in the planning and tender stage must be utilised and updated during the start up and construction phase. Therefore, a successful risk management is dependent on early planning and continuous and strict execution. Comprehensive planning and monitoring enables an organised, comprehensive and iterative approach for identifying and evaluating the risks. This also gives adequate handling options, which are necessary for optimising the project strategy.

A successful risk management system requires that the needs and demands of the client are specified and well understood. Policies shall be formulated and the project organisation shall be composed to meet these needs and demands. Furthermore, the risk management actions should be designed in the planning phase and implemented into the project plan. The performance shall be measured and reviewed during the execution of the project. The entire process and especially the review could be assisted by an independent expert group, "review team", consisting of experts not directly involved in the project but with experience from similar projects (HSE 1997), see figure 2.4.

According to Elms (2003) all significant risk management work must be based on a system framework. The need for this can be seen on several levels. For example, the concept of probability is based on set theory so the assessment of probabilities requires the boundaries to be meaningful. Furthermore, a successful organisational risk management can never be performed without knowing the structure and processes of the organisation. In this context, a system is the rules and guidelines which is set up in order to define (e.g. describe a boundary), analyse and solve complex problems. The quality of the systems can be examined with the help of six diagnostic criteria; balance (e.g. between elements), completeness, cohesion (e.g. structure and interaction), clarity and consistency (i.e. properties versus requirements). A base for systematic risk management is the recognition that construction work will always involve uncertainties (Lewin 1998). It is also important to consider structural and culture differences in the organisation in formulating the risk management system (Uher & Toakley 1999).

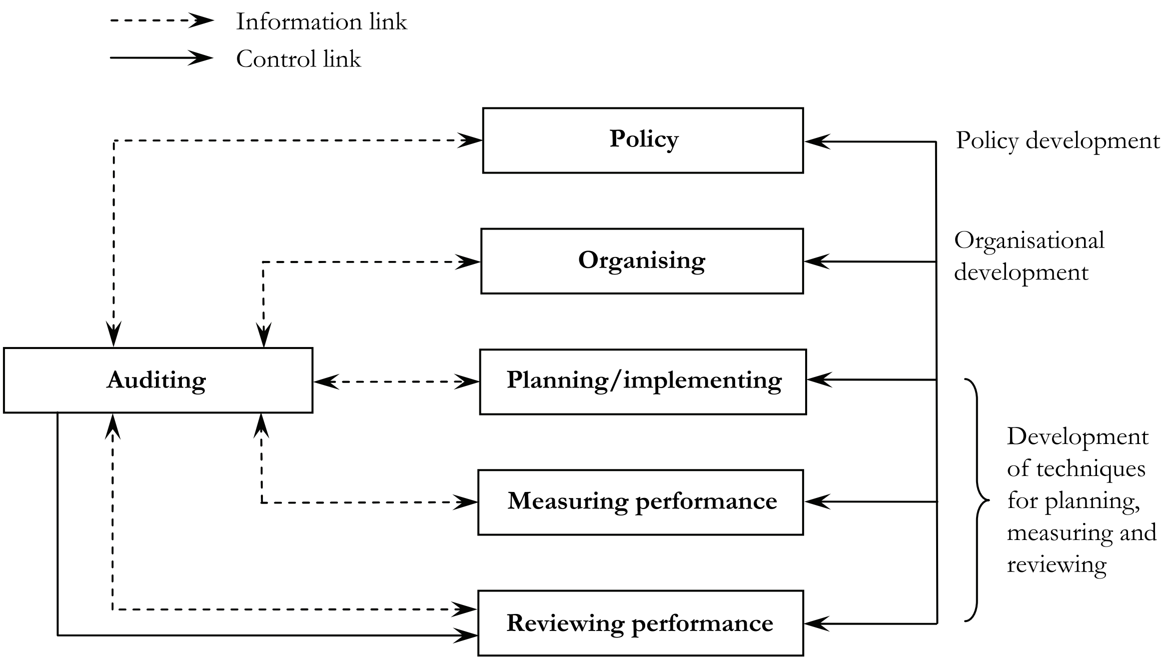

Figure 2.4 The key elements of a successful risk management system (HSE 1997).

2.3.1 System Definition

The risk management process begins with a definition of the project in terms of conceptual systems, see e.g. Stille et al. (2003) and Carlsson et al. (2004). The system analysis is the key to the problem identification and almost all civil engineering projects can be expressed in system terms in order to make the understanding of the characteristics and correlation of the risks more straightforward.

According to IEC (1995) a system is defined as a "*composite entity, at any level of complexity, of personnel, procedures, materials, tools, equipment, facilities and software. The elements of this composite entity are used in the intended operational or support environment to perform a given task or achieve a specific objective*". Usually, the elements are supposed to perform their task under a specific period of time. The components interact through processes and events and affect the behaviour of the system through their arrangement, properties and behaviour initially, during and after failure. These interactions are at least as important as the individual parts of the system. When the components and the boundaries of the system are recognized and understood, the risk identification and risk estimation is often much easier. Examples of systems in an infrastructure project are chains of command and information, the contract, the project organisation, the project execution and geotechnical structures.

It is important to remember that a system is a conceptual model, which implies that different people may describe the same physical object with different system descriptions. The description depends for instance on the purpose of the description and personal experiences. Systems in the building industry are characterised by long life times and close interaction with the nature. For an overview of systems in underground engineering see e.g. Stille et al. (2003).

The likelihood that the system will fulfil its task or achieve a specific objective can in a wide sense be expressed as the reliability of the system. In a narrow sense it is the probability that a system will not attain each specified limit state (i.e. reach failure) during a specified reference period (Thoft-Christensen & Baker 1982).

The relationship between the reliability, R, and the probability of failure, p_f, is:

$$R = 1 - p_f$$

If the resistance of the system is denoted with R and the load effect on the system with S for a specified failure mode, then the failure condition is:

$$R - S \leq 0$$

The probability of failure is consequently:

$$p_f = P(S \geq R) = P(R - S \leq 0) = P(R / S) \leq 1$$

If *R* and *S* are two independent random variables with associated distribution functions, the probability of failure can be calculated as (Thoft-Christensen & Baker 1982):

$$p_f = P(R/S \le 1) = \int_{-\infty}^{+\infty} F_R(x)\, f_S(x)\, dx$$

where $F_R(x)$ and $f_S(x)$ can be illustrated as in figure 2.5.

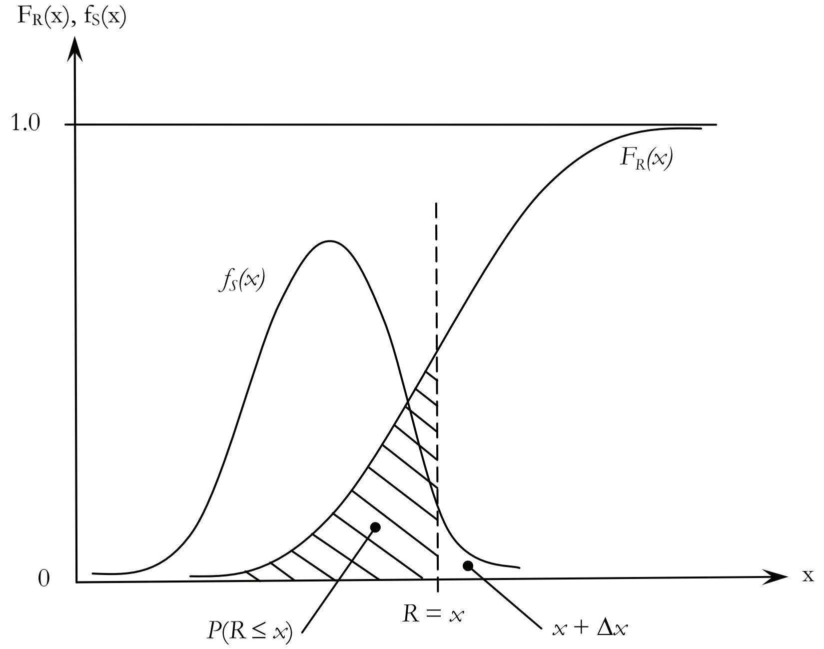

Figure 2.5 Basic R–S problem, a $F_R(x)$ and $f_S(x)$ representation (Melchers 2002).

Since a negative resistance is usually impossible the lower limit of the integration in practice may be replaced by zero in most situations. However, this may be inconvenient and even inaccurate if *R* or *S* or both are modelled by distributions unlimited in the lower tail, e.g. the Gaussian distribution. This is often disregarded when choosing an appropriate distribution for a random variable (Melchers 2002).

The resistance, *R*, and the load effect, *S*, must of course have the same dimensions. Here $F_R(x)$ is the probability that $R \le x$ or the probability that the actual resistance *R* of a component is less than some value *x*. The term $f_S(x)$ represents the probability that the load effect *S* acting on a component has a value between *x* and $x + \Delta x$ in the limit as $\Delta x \rightarrow 0$, see figure 2.6. It should be noted that the probability of failure is not given by the area of the overlap of the two density functions $f_R(x)$ and $f_S(x)$ in figure 2.6, which is a common misunderstanding.

An exact solution to the integral above does not generally exist. The probability of failure can then be calculated by the use of simulation methods or numerical techniques. However, for a few distributions of *R* and *S* it is possible to calculate the probability of failure analytically, e.g. when both *R* and *S* are normal random variables (see e.g. Melchers 2002). The safety margin *R–S* then has a mean and variance given by established statistic rules, see e.g. Johnson (2000).

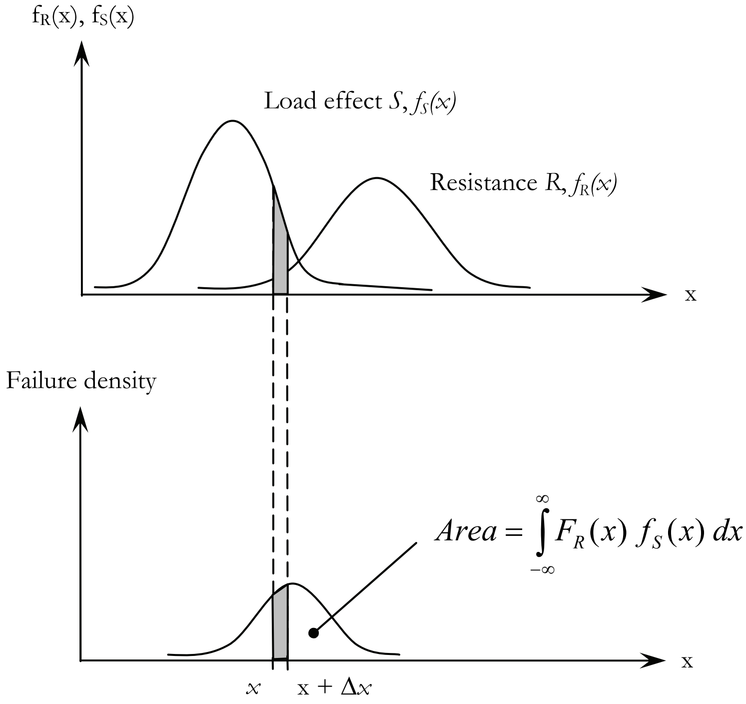

Figure 2.6 Basic R–S problem, a $f_R(x)$ and $f_S(x)$ representation (Melchers 2002).

In the civil engineering profession failure usually means a structural failure of the physical asset which leads to damage. However, in risk management, this meaning must be extended with a financial dimension (Lewin 1998). The performance should be evaluated against the client's original objectives, including costs and quality. If these objectives are not reached, the project as a whole has failed even though the physical asset may still be intact. The risk management process should focus on the whole life-cycle of the project and on a comprehensive picture rather than on the physical asset alone.

Systems in civil engineering consist of combinations of components of different nature and with different characteristics. The probability of failure depends on the characteristics of the components, the degree of correlation between these and their arrangement. Therefore, the calculation of the probability of failure of a system rests on a stringent and unambiguous description of the components and on that the relationships (degree of dependence) between the components are clearly understood. The two main arrangements of components are series and parallel system.

Series Systems

A series system is commonly known as a weakest link system since the system fails as soon as one component fails. If the components are considered to be independent the probability of failure can be calculated as one minus the probability that no component fail (Thoft-Christensen & Baker 1982), as:

$$p_f = 1 - \underset{i=1}{\overset{n}{\pi}}(1 - p_i) = 1 - (1 - p_1)\cdot(1 - p_2)\cdot \ldots \cdot(1 - p_n)$$

where p_i is the probability that component *i* fails and *n* is the number of components.

If the components are not independent, the correlation between the components also determines the behaviour of the system. The probability of failure is then governed by the reliability index for the components for a certain time period, the number of components, *n*, and the correlation between the components, ρ, and can be expressed as:

$$p_f = 1 - \int_{-\infty}^{\infty} \left[\phi\left(\frac{\beta_e + \sqrt{\rho} t}{\sqrt{1-\rho}} \right) \right]^n \varphi(t)\, dt$$

where ϕ and φ denote the distribution and density function for the standard Gaussian random variable and β_e is the reliability index of the elements. The reliability index of the components can be expressed as:

$$\beta_e = \frac{\mu_i - S_i}{\sigma_i}$$

if the strength, R_i, of element *i* is modelled with a Gaussian distribution with mean value, μ_i, standard deviation, σ_i, and S_i is the load effect.

This is illustrated in figure 2.7 for a system with equal probability of component failure p_i. The probability of system failure increases with decreasing correlation between the components and the number of elements. If the components are totally correlated ($\rho = 1$) then all components fail if one component fails, i.e. $p_f = p_i$. Thus, in a reliability point of view it is favourable to have few components when the components are uncorrelated or highly correlated components if the components are numerous.

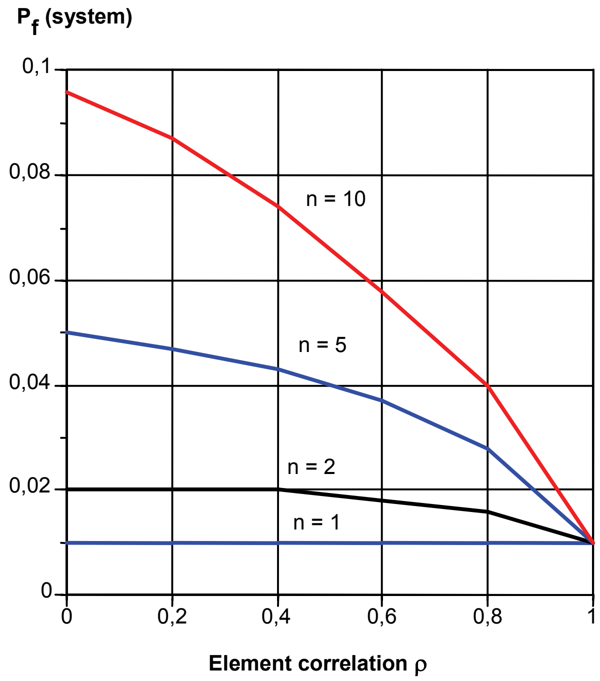

Figure 2.7 *Probability of failure for a series system with p_i = 0.01 as a function of the correlation coefficient ρ and the number of elements n (Thoft-Christensen & Baker 1982).*

Different potential slip surfaces in a natural slope is an example of series systems as the slope will fail as soon as one slip surface fails, see figure 2.8. Groups of sliding surfaces with similar geometry can be seen as sub series systems in the total system.

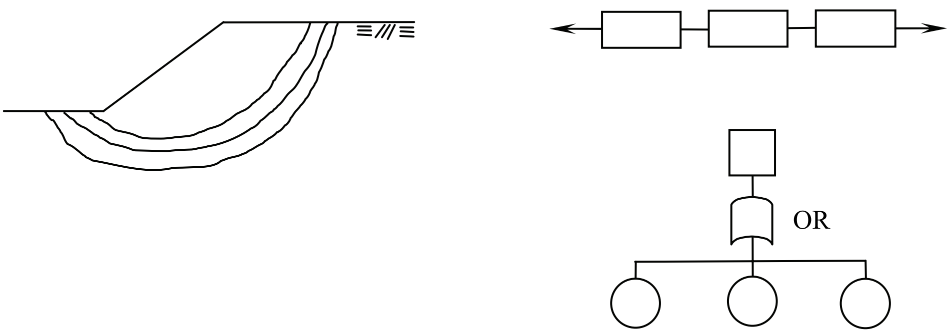

Figure 2.8 *System selection considerations of a slip surface – reliability block diagram and fault tree (modified after Carlsson et al. 2004).*

Parallel Systems

A parallel system fails when all the components fail. If the components are independent the probability of failure can be expressed as:

$$p_f = \overset{n}{\underset{i=1}{\pi}} p_i = p_1 \cdot p_2 \cdot .... \cdot p_n$$

where p_i is the probability that component *i* fails.

If the number of elements is denoted with *n*, the element correlation is ρ and the reliability index of the system and the elements are β_S and βe respectively, then:

$$p_f = \phi(-\beta_S) \quad and \quad \beta_S = \beta_e \sqrt{\frac{n}{1+\rho(n-1)}}$$

where ϕ is the standard normal distribution function.

The behaviour of a parallel system is not only governed by the number of components, the probability of failure of each component and the correlation between the components as the series system, but also how the components are loaded, see e.g. Thoft-Christensen & Baker (1982) and Olsson (1986). The probability of system failure decreases with an increasing number of components and increases with a higher degree of correlation as shown in figure 2.9 for a system with equal probability of component failure.

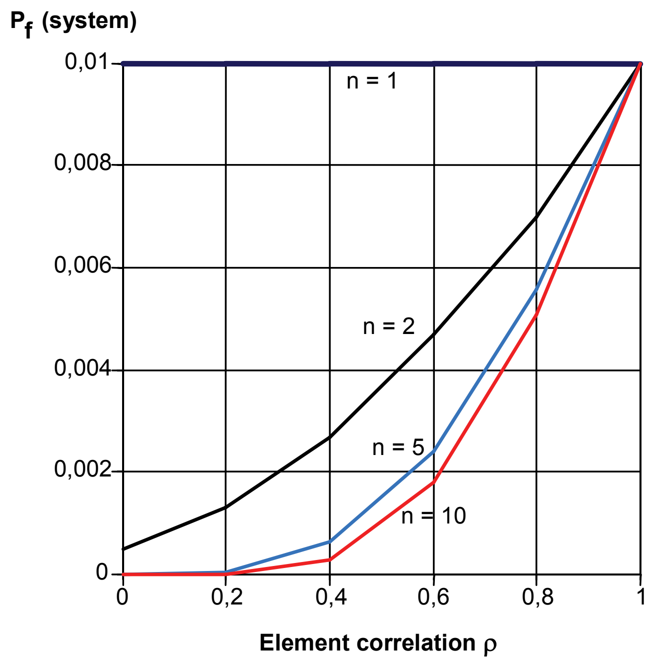

Figure 2.9 *Probability of failure for a parallel system with ductile elements with p_i = 0.01 as a function of the correlation coefficient ρ and the number of elements n (Thoft-Christensen & Baker 1982).*

A slip surface in a clay slope can be considered as a parallel system of soil elements, where all elements must fail before failure occurs along the slip surface, see figure 2.10. Note that although the elements are physically connected in a series, the system is a parallel system.

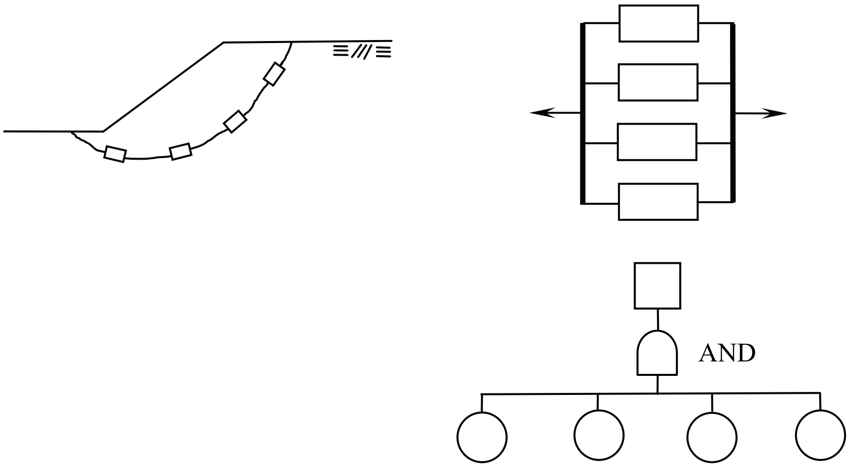

Figure 2.10 System selection considerations of a slip surface – reliability block diagram and fault tree (modified after Carlsson et al. 2004).

Combinations of Series and Parallel Systems

In reality, civil engineering projects and structures often consist of complex systems where different parts can be described as series systems and other parts as parallel systems. An example of a parallel system is illustrated in figure 2.11 where it is assumed that only the diagonals, i.e. element 1 to 6, can fail.

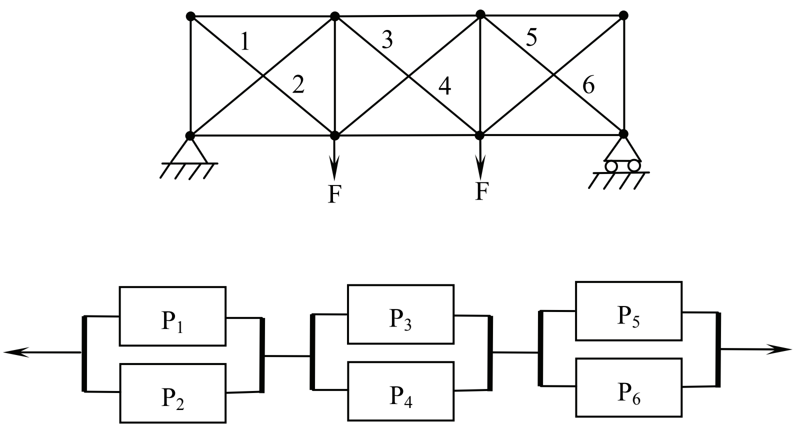

Figure 2.11 Reliability block diagram of a combined system (Thoft-Christensen & Baker 1982).

In the example with a slip surface in a clay slope, figure 2.8 and 2.10, there are an infinite number of possible slip surfaces and the slope will fail if anyone of these fails. Thus, the system is a series system where each link is a parallel system, see figure 2.12. It should be noted that in practice, when the probability of failure is calculated, the most dangerous slip surface is the basis for the calculation, and no regard is taken to the series system. However, as the different slip surfaces are very close to each other, they are probably highly correlated, and thus the system probability of failure is approximately the same as the element (single slip surface) probability of failure according to figure 2.10.

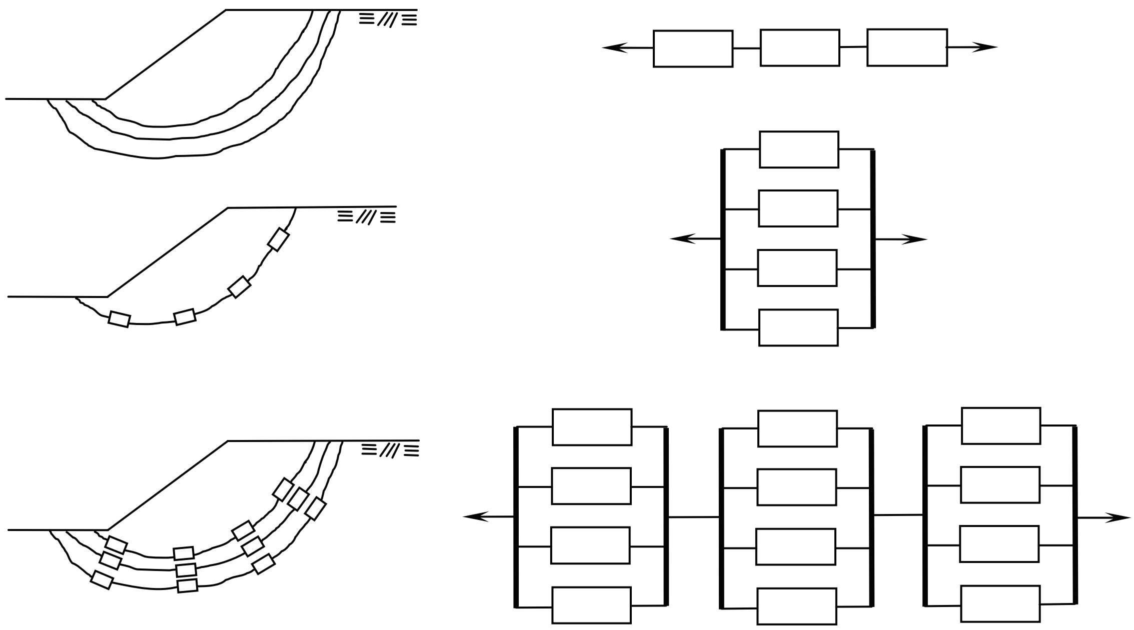

Figure 2.12 System selection considerations of a slip surface (modified after Carlsson et al. 2004).

Another example of a combined system is the supporting system, e.g. for a sheet pile wall, with anchors that are pre-tested before they are loaded (Carlsson et al. 2004). According to Swedish design codes, the wale beam and the anchors are designed to be able to resist a load situation when one anchor has lost its bearing capacity. Thus, the system fails if two or more adjacent anchors fail. Therefore, the system consists of a series system where each element consists of a parallel system. One of the links in the parallel system is a series system with two elements. This system is shown in a reliability block diagram in figure 2.13.

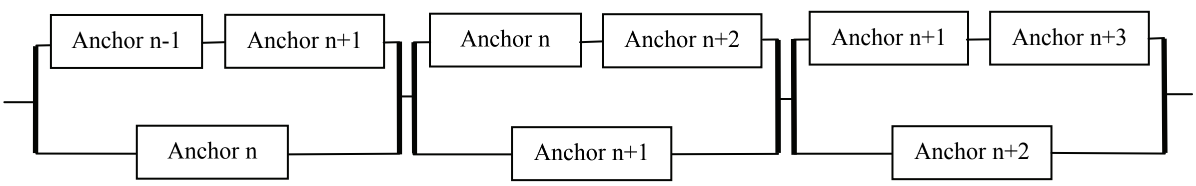

Figure 2.13 Reliability block diagram of an anchor system (Carlsson et al. 2004).

2.3.2 Risk Identification

The identification of hazards and the associated risks is often considered to be the most important single step in geotechnical risk management. If a risk is not identified it cannot be managed in a later phase in the process. Therefore, for the success of a project it is essential that the identification of risks is performed properly and by the individuals best suited for the task.

According to a study by Whyte (1995) the cost for the risk identification phase is often between 0.2-0.5 % of the total budget of a project. The cost for damage due to unexpected events can, however, easily exceed 10 % of the total value of the project. Of course, these figures depend of the size and complexity of the project at hand. Nevertheless, the relation between the cost for risk identification and cost for damage due to unexpected events are probably similar in different types of projects.

The identification of risks is a process of a structured speculation of all possible critical conditions that might affect the project. Risk identification recognizes the existence of hazards and opportunities as well as defining their characteristics (Clayton 2001b). According to Lewin (1998) the aims of the risk identification are to:

- Identify all significant types and sources of risk and uncertainty associated with each of the investment objectives and the key parameters relating to these objectives.
- Determine the causes and the initiating events of each risk.
- Decide how different risks are related to each other and how risks should be classified and grouped for estimation.

The process of identifying and responding to risks is iterative with an increasing level of detail (Lewin 1998). First, the risks connected to each objective, key parameter or principal activity is identified and documented. It is essential that every aspect of the project is analysed. The first attempt should be free from checklists and other constraining documents, e.g. in the form of "brainstorming" sessions, to avoid restraining the process of discovery. Risk specialists and other individuals who can add value to the process should attend in the "brainstorming" session. After that, the identified risks are documented, e.g. in a risk register.

Second, the process in the first step is repeated with the support of checklists, risk matrices or other risk aids. Identified risks should then be listed in the risk register for further review and analysis with a first indication of the significance of each risk and degree of dependency between the risks. The analysis and understanding of risk groupings and relationships is often easier if the risks are represented in the form of priority influence, risk/response or other diagrams, which should be appended to the risk register with suitable cross-references. Any new assumptions identified at this stage should be entered into the risk register.

The process of risk identification may be based on either experience of similar projects from the literature, on discussions with qualified and experienced personnel or organisations or by the use of risk identification tools (see table 2.1). In order to structure the risk identification process, the hazards can be grouped into general and specific risks. The general hazards can be considered on a general level for the entire project while the specific hazards must be considered for each part of the project. Examples of general and specific hazards, respectively, are given in table 2.2.

Table 2.2 Examples of general and specific hazards (International Tunnel Association 2002).

General hazards	***Specific hazards***
Contractual disputes	Accidental occurrences
Insolvency and institutional problems	Unforeseen adverse conditions
Interference of authorities	Inadequate design, specification and programmes
Third party interference	Failure of major equipment
Labour disputes	Substandard, slow or out of tolerance work

It is important to examine and identify project specific potential hazards by reducing them to a level of detail that permits an evaluator to understand the significance of any risk and identify its origins and causes, i.e. the risk objects and the initiating events (Hintze 1994 and Carlsson et al. 2005).

Although there is a limited amount of information in the early phases of a project this information must be analysed. Hazards that may have adverse consequences for the outcome of the project must be identified as well as the opportunities to improvements. During decomposition, hazards are identified from experience from similar projects, brainstorming, interviews, checklists and guidance in the project plan (Hintze 2001).

The risks can initially be ranked by probability and consequence of occurrence before beginning to focus the further analysis on those most critical. Critical risks need to be documented and may include the initiating events as well as planned management controls and actions. It may also include an initial assessment of the consequences to focus the risk evaluation effort. A risk watch list should be initiated as part of risk identification.

Risk management is often considered to be the answer to all problems but it is not. It can not hope to identify all risks to a project. Even though extensive work is done to identify all risk, there will always be risks that are not foreseen and, therefore, not identified. Experience show that these unidentified risks often are the most dangerous risks for the viability of the project. These unidentified risks will occasionally arise as “surprises”, both nasty and good, in the construction phase and have to be managed properly. However, these are often not completely unforeseen and can come from issues that have been poorly managed or incorrectly assessed (Lewin 1998).

One of the most crucial issues for the risk management process is therefore to identify as many of the risks as possible. However, as unidentified risks wills always exist, the risk management process, the working activities and the organisation have to be designed and flexible enough so that these can be identified and included in the process and procedures for this must be established. When responses to unidentified risks need to be made, the project team needs to be prepared to trade-off between objectives and to de-scope the project if required. In spite of the fact that unforeseen risks will always exist, with a sound system of risk management these risks will be less common and good “surprises” can be taken advantage of by concentrating not only on threats but on opportunities as well when identifying risks to the project (Hillson 2001).

2.3.3 Risk Estimation

When the risks are identified the size or seriousness of the risks must be estimated. This is done in the risk estimation phase. Risk estimation is a problem definition phase in the risk management process, which quantifies potential risks in terms of probability and consequences. The aim of the risk estimation is to estimate the total expected damage cost (the total risk) of a project in economic terms and to classify and prioritise the risks (Hintze 1994).

The results from the risk estimation form the basis for the most part of the risk handling actions and it is probably the most difficult and time consuming part of the risk management process. Despite its complexity, risk estimation is an important phase of the risk management process because the standard and the quality of the estimation determine the effectiveness of a risk management process (Lewin 1998).

The risk estimation begins with a detailed study of the risks that have been recognized in the risk identification phase. The objective is to gather enough information about the risks in order to estimate the probability of occurrence and the consequence on cost, time schedule, quality, environment, worker safety and health, client satisfaction etc. if the risk is realised.

In practice, the distinction between risk identification and risk estimation is often unclear because there is some risk estimation occurring during the identification process. For example, in the process of interviewing an expert it is logical to pursue information on the probability of its occurrence, the consequences, the time associated with the risk (i.e. when it might occur) and possible ways of dealing with it. The latter actions are part of risk estimation and risk handling, which often begin during risk identification.

When working in complex project there can never be a conclusive knowledge of the hazards and the risks, sometimes not even when the project is finished. Therefore, the probability of the risks is unknown to a large extent. When there is statistically sufficient experience of an event, its probability can be determined by collecting and analysing that experience. For new and untested technologies or technologies used in a new situation this method is not appropriate (Hansson 2004). This is also the situation in many infrastructure projects where the conditions are different in every situation.

One common way to avoid these difficulties is to estimate the probability of failures through a careful investigation of the various chains of events that may lead to such failures, so called fault and event trees. By combining the probabilities of various sub events in such a chain, the total probability of an event can be estimated. Though, there are several problems with this (Hansson 2004). First, an event can happen in more ways than we reasonable can imagine. There is no method by which all chains of events that may lead to an accident in a complex technological system can be identified. Another problem is that the total probability can be very difficult to determine even if we know the probability of each individual event due to correlation between the events. In spite of these difficulties, the construction of fault and event trees can be an efficient way to identify weaknesses in a complex technological system. It is important, though, to keep in mind that an exhaustive list of negative events can not be obtained, and that the total risk levels can therefore not by determined in this way.

Technological risks depend not only on the behaviour of the components in the system, but also on human behaviour. The risk associated with a specific technology can differ drastically between organisations with different attitudes towards risk and safety. In addition, the human behaviour is often much more difficult to predict than technological components.

Another issue which should be considered is that it is humans that make estimates of probabilities. Psychological studies indicate that there is a strong belief in the estimates of probabilities by experts and that the possibility that the estimates are wrong tends to be ignored. Therefore, it is essential to make a clear distinction between those probabilities that originate in experts´ estimates and those that come from observed events (Hansson 2004). Furthermore, the estimation of probabilities is influenced by bias, for example due to perceptual factors and heuristics.

The estimate of the consequences shall not only include the immediate cost of the consequence but also costs that can arise in the future. The consequence is usually the sum of the immediate cost (base cost), costs for shortages in function and costs for future corrections and maintenance due to the damage event in a life-cycle perspective.

The probability of occurrence (or frequency) and extent of consequences may be classified according to a specified classification system in order to prioritise the risks. The classification system should be designed in agreement with the requirement and the scale of the project as well as the risk objectives specified in the project plan. Generally, the frequency classification system could by common for all types of risks while the consequence classification system has to be different for different types of risks. Though, it should be preferable that the different consequence classification systems should be coordinated so that a common risk classification can be used for all types of risks involved (International Tunnel Association 2002).

The design of the classification systems may be based on statistics, experience from similar projects and/or on expert judgement. Frequency classification may be made as the number of events in relation to a specific unit, e.g. per year, per thousand working hours or per section of work. However, it is often more suitable to use a classification that relates the number of events in relation to the total number of the events in the project, see table 2.3. In order to maintain the usual interpretation of risk distributions being logarithmic in nature it is often recommended that a step of ten units between the central values in the classification of frequencies (International Tunnel Association 2002).

Table 2.3 An example of classification of frequency of occurrence (International Tunnel Association 2002).

Frequency of occurrence classification			
Class	*Interval*	*Central value*	*Descriptive frequency class*
1	> 0.3	1	Very likely
2	0.03 – 0.3	0.1	Likely
3	0.03 – 0.003	0.01	Occasional
4	0.003 – 0.0003	0.001	Unlikely
5	< 0.0003	0.0001	Very unlikely

The classification of consequences can be done in a similar way as for the frequency of occurrence. Typically, though, the selection of consequence classes and the severity of these often vary due to the scope and nature of the project as well as the nature of the consequence. For example, the unit of the consequence classes are in general different for the consequences of structural failure, injury of workers, damage to property, economical loss or loss of goodwill (International Tunnel Association 2002).

Since the risk tolerance depends on the risk perception of each individual and organisation, it is necessary to establish a scale of risk for each organisation involved in the project and for each major risk. Typically, a scale of 1 to 4 or 1 to 5 is used to classify the risks. An example from Clayton (2001b) is given in table 2.4.

Table 2.4 An example of classification of consequences (Clayton 2001b).

Consequence classification		
Scale	*Effect*	*Increase of cost or time (% of total cost or time)*
4	Very high	> 10%
3	High	4-10%
2	Low	1-4%
1	Very low	<1%

The risk classification can be made either qualitative or quantitative. In qualitative risk classification a risk matrix is often used, see table 2.5, which defines the combinations of frequency and consequence that is negligible, acceptable, unwanted and unacceptable. These definitions of accepted risks can, of course, be complemented with other classifications such as "accepted after mitigation actions" or "accepted with increased monitoring" depending on the project characteristics and level of analysis. The risks that are classified as "unacceptable" and "unwanted" must be handled in some way to make them acceptable (see section 2.3.5).

The risk matrix should be designed specifically for each project on the basis of the accepted risk level and the overall risk policy in the project as well as the scope and extent of the project. In some situation the risk matrix can be considered to be too inaccurate to provide reliable risk estimates. However, the use of a risk matrix is often a simple, convenient and straightforward way to estimate the risks.

Table 2.5 An example of a risk matrix (after International Tunnel Association 2002).

	Consequence				
Frequency	*Disastrous*	*Severe*	*Serious*	*Considerable*	*Insignificant*
Very likely	Unacceptable	Unacceptable	Unacceptable	Unwanted	Unwanted
Likely	Unacceptable	Unacceptable	Unwanted	Unwanted	Acceptable
Occasional	Unacceptable	Unwanted	Unwanted	Acceptable	Acceptable
Unlikely	Unwanted	Unwanted	Acceptable	Acceptable	Negligible
Very unlikely	Unwanted	Acceptable	Acceptable	Negligible	Negligible

If the risk classifications in table 2.3 and 2.4 are used, the following risk matrix according to table 2.6 can be obtained:

Table 2.6 An example of a risk matrix (modified after Clayton 2001b).

Risk estimation		
Degree of risk	*Risk level*	*Risk mitigation*
1-5	Trivial	None
6-10	Significant	Consider more cost-effective solutions or improvements at no extra cost.
11-15	Substantial	Work must not start until the risk has been reduced, additional resources required.
16-20	Intolerable	Work must not start until the risk has been reduced. If risk could not be reduced, the project should not proceed.

When a qualitative analysis is considered to be too coarse a quantitative analysis is requested. The total project risk can then be estimated as the sum of the risks of all identified hazards, where the risk for each hazard is the product of its frequency and consequence, as:

$$Total\ risk = \sum (risks\ of\ all\ hazards) = \sum_{i=1}^{n} p_i \cdot C_i$$

where *i* is the number of an identified hazard, p_i is the frequency and C_i is the consequence of that hazard, and *n* is the total umber of identified hazards. If both the frequency and consequence is represented as single values, the total risk is also represented as a single value, see figure 2.14.

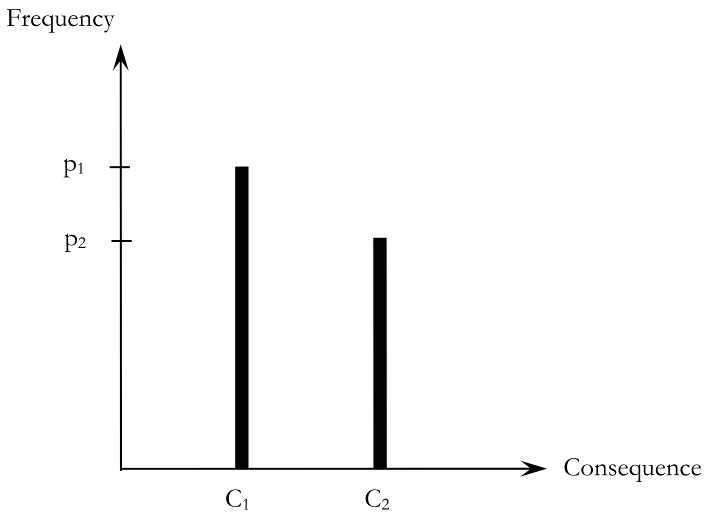

Figure 2.14 Risk represented as a single value (Hintze 1994).

This approach has the limitation that it does not describe the uncertainties of the included estimates of the frequency and consequence. Though, if each frequency and consequence is considered as a stochastic variable an estimation of the uncertainty involved can be achieved. Each variable is then assigned a frequency distribution instead of a single value. The frequency function and the consequence function are often represented as a distribution function and a cumulative function respectively (Hintze 1994).The risk, $E_i(c)$, of damage object *i* can then be calculated as:

$$E_i(c) = \int_{-\infty}^{+\infty} f_X(x)\, c_X(x)\, dx$$

and the total risk as:

$$E_{total\ risk}(c) = \sum_{i=1}^{n} E_i(c)$$

where X is a stochastic variable which describes the damage event, $f_X(x)$ is the frequency (probability) function and $c_X(x)$ is the consequence function of X, see figure 2.15. The total risk is then a frequency distribution and can then be obtained by the use of numerical techniques or simulation methods.

The uncertainties in a reliability assessment can, according to Melchers (2002), be divided into phenomenological, decision, modelling, prediction, physical and statistical uncertainty, and human factors. Most of these uncertainties are in general difficult to consider when the probability of failure is determined. Therefore, the "exact" risk is probable impossible to determine and the nominal risk based on experiences and/or expert judgement have to be use. Alternative approaches for assessing risk probabilities have been discussed by e.g. Hillson (2004).

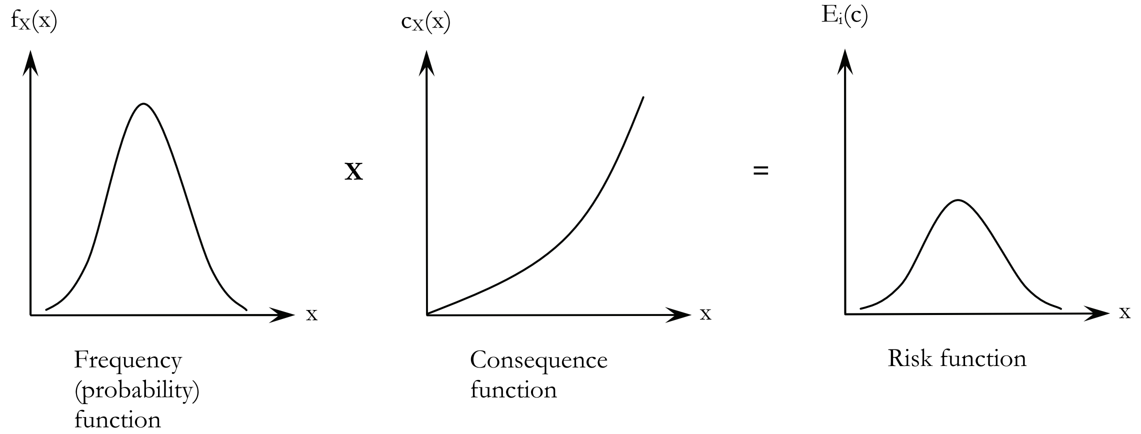

Figure 2.15 Risk represented as a distribution function (after Hintze 1994).

2.3.4 Risk Evaluation

Decision-making is central importance in all engineering applications. The decision between different action alternatives with different risk levels is a central issue in the risk management process. The risk evaluation is the process in which judgements are made on the tolerability of the risk on the basis of risk analysis taking factors such as socio-economic, technological and environmental aspects into account. The process of decision-making regarding risks in an infrastructure projects involves a system of three groups of actors in the society, see figure 2.16.

These groups are connected to each other and more or less overlapping and should not be seen as separate entities. For example, in a road investment financed by tax money the decision makers are, in general, the road administration and the government, the risk carriers are the road-users and the society are the beneficiaries and cost-takers (Grimvall & Lindgren 1995).

Decision theory came up as a new field of science in the 1950´s aiming at improving the decision-making process. Decision theory in civil engineering was used for the first time in the 1960´s (Benjamin & Cornell 1970). However, the practical application so far has been limited. The aim of the decision analysis is, of course, to come forward to the most optimal decision among several decision alternatives. This can seem to be trivial but it is generally not, since there can be several decision criteria, decision-makers and a lot of uncertainty involved in the decision-making process. Decision theory in civil engineering has been discussed by for example Ang & Tang (1984), Freeze et al. (1990), Einstein et al. (1992) and Sturk (1998).

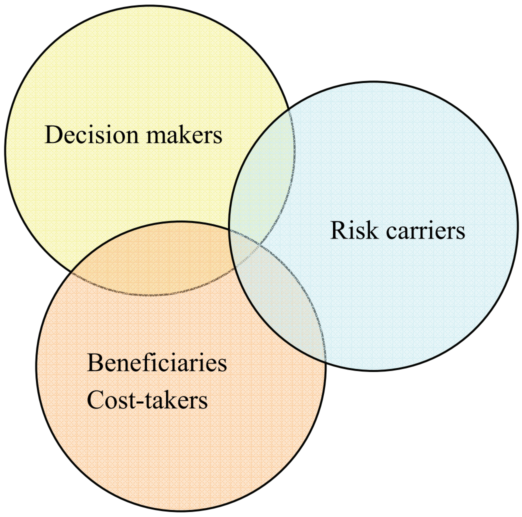

Figure 2.16 Actors influencing the decision process in large infrastructure projects (Grimvall & Lindgren 1995).

The decision-making of accepted risk level is a process involving a series of basic steps. It can add value to almost any situation, especially when the possibility for serious or catastrophic outcomes exists. The steps can be used at different levels of detail and with varying degrees of formality, depending on the situation. The key to a successful decision process is to complete each step in the most simple and practical way to provide the information the decision-maker needs (Carlsson et al. 2005). Some situations are so complex that detailed methods for risk assessment are needed, but most situations can be addressed with more simple methods. The information about the possibility for one or more unwanted outcomes separates risk-based decision-making from more traditional decision-making. Most decisions require information not only about the actual risk, but also about other things as well such as likelihood, consequence and context. This additional information can also include such things as costs, schedule requirements and public perception. In risk based decision-making all of the identifiable factors that affect a decision must be considered. Decision analysis generally includes four main parts as illustrated in figure 2.17 (Raiffa 1970).

Firstly, an identification and definition of all the possible decision alternatives is made. This can be facilitated by the use of system analysis tools, e.g. decision tree analysis and event tree analysis (see e.g. Raiffa 1970 and Hansson 1991). Secondly, a definition of the decision criteria on which the decision shall be based has to be established. In general, there exist several decision criteria in a decision situation in an infrastructure project, see below and e.g. Hansson (1991) and Hintze (1994). Thirdly, an analysis of possible outcomes is conducted where each decision alternative is evaluated with respect to the appropriate decision criteria. The fourth and last step consists of an estimation of the probability of each possible outcome. The decision alternatives can then be ranked with respect to the decision criterion used. The decision process ends with a basis for decision or recommendations to the decision-maker, which shall support the decision-maker to make the most optimal decision (Sturk 1998).

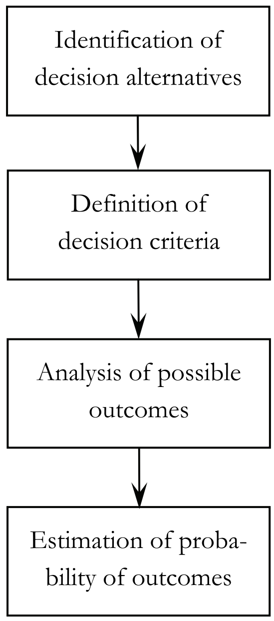

Figure 2.17 The decision process (after Raiffa 1970).

Many decisions in an infrastructure project have to be made under risk or uncertainty when the likelihood or outcome, or both, of a hazard is unknown at the time for the decision. In decision theory, a distinction is often made between decisions under risk, certainty or uncertainty. A decision under risk is a decision when the likelihood of a certain outcome is known. Different outcomes are obtained for different decisions, but the likelihood and outcome of each of these can be estimated. A decision under certainty exists when it is known that a certain action leads to a certain outcome. When there is a genuine lack of information the decision has to be made under uncertainty. Then the likelihood or outcome, or both, are unknown or sometimes not even meaningful to consider.

Traditional risk management is not possible in situations including uncertainty and the uncertainty must be assessed with conservative assumptions, monitoring system and/or redundancy. The definition of these decision situations differs from everyday usage. In everyday language, the term uncertainty often means a state of mind rather than absence of information. In these definitions the term risk is defined as a measurable uncertainty, something that can be quantified. Though, it can be argued that uncertainty, as a matter of fact, is just a lack of information (Hansson 2004).

From a decision-maker's point of view, it is optimal to have quantified risks so that they easily can be compared and prioritised. Therefore, the crucial issue is the determination of probabilities and consequences. As been mentioned before, when there is statistically sufficient experience of an event, e.g. the breakdown of an electrical component, the probability can be determined by collecting and analysing that experience. For new and untested technologies or technologies used in a new situation this method is however not appropriate. This is also the situation in many infrastructure projects where the conditions are different in every project. In these situations estimations of the risks have to be based on expert judgements, subjective estimates etc.

There are occasions when decisions are influenced by concerns about possible risks although there is only a vague idea about what these risks might be. However, it would not be realistic to take all such risks into account. To decide when the possibility of these types of risks should be considered Hansson (1996) has proposed four criteria that can be used to support an intuitive judgement. These are:

(i) Asymmetry of uncertainty - asymmetry is a necessary but insufficient condition.

(ii) Novelty - unknown risks come mainly from new and untested phenomena.

(iii) Spatial and temporal limitations - if the risks have these limitations, the urgency of the possible unknown effects are reduced.

(iv) Interference with complex systems in balance - many systems in balance are irreversible and uncontrolled interference with these systems is connected with a high degree of uncertainty.

For an evaluation of the best decision under some conditions of uncertainty a decision criterion is needed. A decision is influenced by several factors, e.g. the opinion, the risk policy, social and cultural factors, and knowledge and experience of the decision-maker, and can be different at different times (Hintze 1994). Several decision criteria have been discussed in the literature, see e.g. Ang & Tang (1984), Morgan (1993) and Mattsson (2000). The decision criteria can be divided into four broad categories. These are (Mattsson 2000):

- Technology based criteria, e.g. "use the best technology available".
- Criteria based on rights, e.g. "reduce the risk so it is below some prescribed figure".
- Utility based criteria, e.g. cost-benefit analysis and cost-effectiveness analysis.
- Hybrid criteria, which is combination of those above.

The most used decision criterion in civil engineering is the utility based criteria (Ang & Tang 1984 and Edlund & Högberg 1986). Among the utility based criteria there are some different sub criteria, e.g. "maximum expected monetary outcome", "minimax" and "maximax". For a detailed description of these the reader is referred to Edlund & Högberg (1986) and Hintze (1994). Which decision criterion that is chosen depends on the objectives with a project, the decision situation and the preference of the decision-maker among other factors. According to Morgan (1993) it is important that the decision frameworks is carefully and explicitly chosen and that these must be kept logically consistent.

The optimal decision among several action alternatives with different risk levels is normally based on a cost-benefit analysis with an expected monetary value criterion, see e.g. Rowe (1977) and Ang & Tang (1984). The most used sub criterion is probable to maximise the expected monetary outcome of the project, which is also called a Bayes decision criteria. The expected utility can be estimated as the sum of all exclusive outcomes (consequences), *u*, times their probability of occurrence, *p*, as:

$$E(u) = \sum_{i=1}^{n} p_i \cdot u_i = p_1 \cdot u_1 + p_2 \cdot u_2 + ... + p_n \cdot u_n$$

Other sub criteria can be to minimise the damage on the environment or to minimise the project time. When there are major uncertainties involved or when the consequences are difficult to predict the ALARP-principle could be used, i.e. the risks should be managed so that the residual risk is as low as reasonable possible. As a result of the uncertainties generally involved in a complex project, decisions must be based on trade-off between different factors, e.g. cost, utility, safety, probability of failure and uncertainty. The optimal decision is the decision that minimises and/or maximises some or all of these factors. The cost-benefit analysis should include the effect of the uncertainties on a given decision.

The risk evaluation reveals those risks that can be left untreated and those that had to be managed further given a certain decision criterion, the risk policy and the risk acceptance criteria, see figure 2.18.

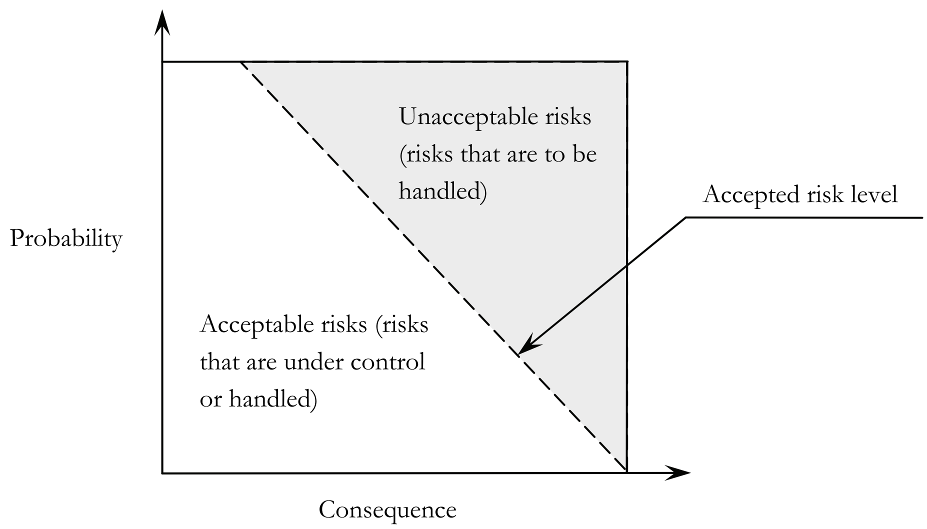

Figure 2.18 A representation of acceptable and unacceptable risks given a decision criterion and a accepted risk level.

2.3.5 Risk Handling

In practice, it is almost impossible to avoid all risks. Therefore, there are some residual risks in most projects that have to be handled during the project execution if they exceed the acceptable risk level. As Clayton (2001b) stipulates: *"Risks can be managed, minimised, shared, transferred, or accepted. They can not be ignored"*. Risk handling can be defined as the risk management phase that includes specific methods and techniques to deal with risks that can not be accepted without further attention, see figure 2.19.

Risk handling should cover all phases of a project from inception to close-down. The risk handling strategy and the risk handling actions have the most effect when they are implemented early in the project phase. Furthermore, it is often less costly to take actions in an early phase of a project than later in the execution of the project (Hintze 1994 and Stille et al. 1998).

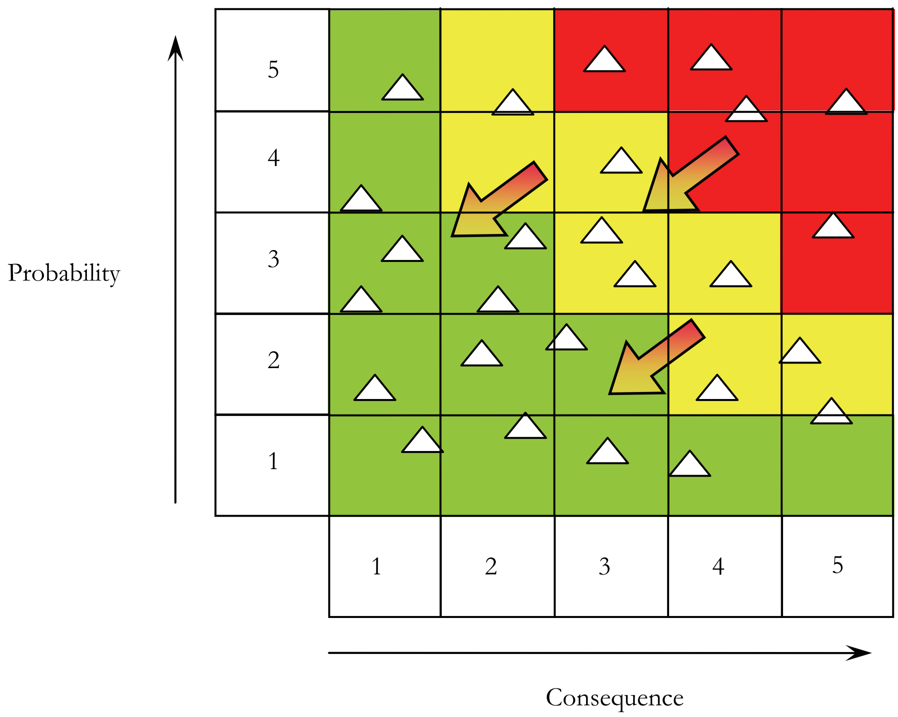

Figure 2.19 Handling of risks into acceptable risk levels.

A specific project risk group that assesses the risks should be put together in the beginning of the project in order to handle the risk which exceeds the acceptable risk levels (Lewin 1998). The risk handling process begins with an identification and evaluation of handling approaches which are gathered and formulated in a risk response plan. These should be proposed to the project decision-makers, who select the appropriate actions for implementation. The risk handling phase must be compatible with the risk policy and any additional guidance that the project plan provides. A critical part is the refinement and selection of the most appropriate handling options.

An important task of this phase is the process of recognising at what stage and in what way risks can be handled and who is most suitable to do so. In order to ensure that all risks are handled in some way the risk policy should assign each risk an owner who has the responsibility for the risks to be managed in the intended way (Lewin 1998 and Melvin 1998).

There are five main ways in which risks can be handled within the context of a risk management strategy (see e.g. Lewin 1998, Clayton 2001b and Hintze 2001). These are:

(i) Risk avoidance.

(ii) Risk retention.

(iii) Risk transferring.

(iv) Risk sharing.

(v) Risk mitigation.

Risk avoidance means that the risks are avoided through a complete avoidance of a risky activity, e.g. by changing the location, and is sometimes called risk elimination. If a *risk retention* strategy is used, the risks are left untreated. Risk retention is thus a conscious choice of taking no actions to handle a specific risk and is sometimes called passiveness. *Risk transferring* means that the risks are transferred to another individual or organisation which is willing to take the risk, e.g. through insurance, or to another set of risks, e.g. by changing a work activity or the type of construction. In *risk sharing* the risks are shared with another individual or organisation, e.g. by a joint-venture. This handling action is a combination between risk transfer and risk retention. *Risk mitigation* means that the risks are reduced or eliminated by reducing its probability of occurrence and/or its consequence through preventive or limiting handling actions. An example of framework for deciding the method for handling risks depending on likelihood and severity is illustrated in table 2.7.

Table 2.7 An example of framework for deciding the method for handling risks (after Flanagan and Norman 1993).

	Likelihood				
Severity	Improbable	Rare	Possible	Probable	Very likely
Negligible	Retain	Retain	Retain	Retain	Retain
Small	Retain	Retain	Partial insure	Partial insure	Partial insure
Moderate	Retain	Partial insure	Insure	Insure	Insure
Large	Insure	Insure	Insure	Insure	Insure
Disastrous	Insure	Insure	Cease activity	Cease activity	Cease activity

According to a survey conducted by Baker et al. (1999) risk mitigation is the most common risk handling action. Almost 90 % of the companies in the survey used risk mitigation as the most important risk handling action. Risk transfer and risk sharing was used by around 55 % of the companies and risk avoidance and risk retention approximately 30 % each. However, Baker et al. conclude that when construction companies eliminate risk, they generally do so either by not placing a bid or tendering at a very high price. Furthermore, the construction industry places relatively little importance on technical risks in general.

Risk mitigation is often the risk handling action that first comes in mind in the context of risk management. The procedure for risk mitigation is different whether it is the probability or consequence that shall be reduced, see e.g. Hintze (1994). Reducing the probability means that the probability of an initiating event is reduced. In order to reduce the probability the parameters that determines the distribution function, i.e. the mean value and/or the standard deviation, must be reduced, see figure 2.20. The mean value can be reduced by, for example, using the most appropriate technique or equipment in relation to the present geological condition, the surroundings etc. The standard deviation can be reduced by using methods that reduce the uncertainty, e.g. expert judgement, additional site investigations and education of the personnel involved in the project.

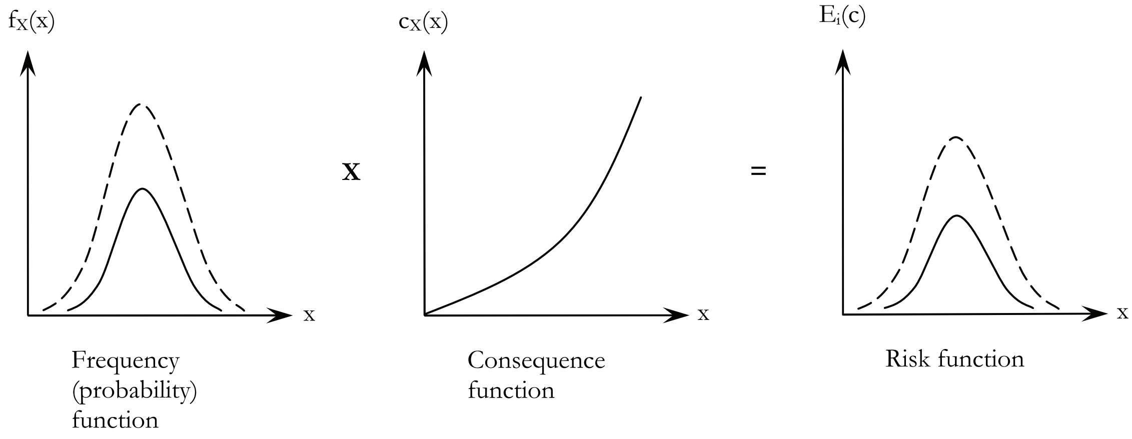

Figure 2.20 Reducing the risk by changing the frequency (probability) function (modified after Hintze 1994).

Risk mitigation is sometimes restricted to the concept of reducing the consequence and *risk attenuation* is used for reducing the probability. This is because they not only represent different axes on the probability-consequence map, they also operate in different areas, with mitigation usually via commercial/contractual mechanisms and attenuation via technical solutions (Lewin 1998).

Reducing the consequence implies that the consequence function is changed, e.g. by reducing the cost for a specific damage event or taking actions to limit the consequence to a certain level (Hintze 1994), see figure 2.21.

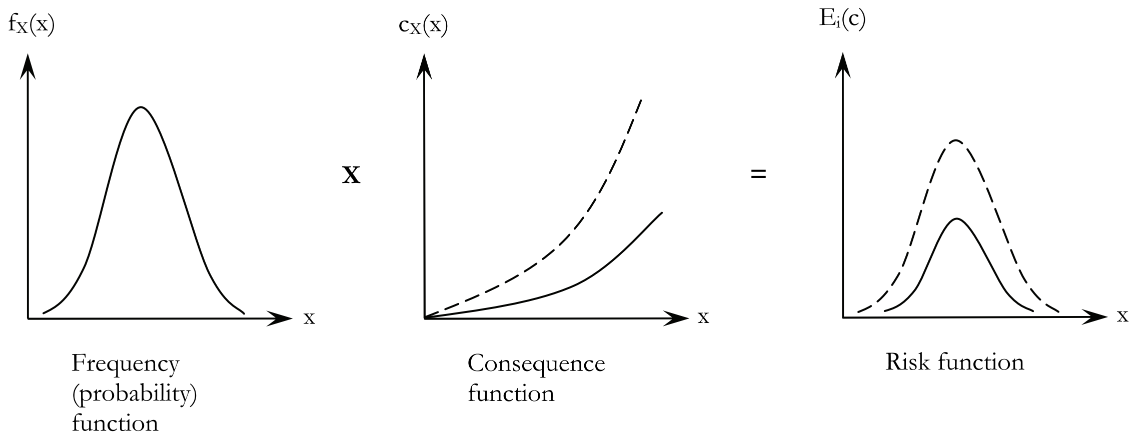

Figure 2.21 Reducing the risk by changing the consequence function (modified after Hintze 1994).

Reducing the consequence can be achieved either by conduct preventive actions if the consequence is on an acceptable level or actions that reduce the consequence if it is on an unacceptable level, see figure 2.22. Examples of preventive actions are underpinning of existing buildings, establishment of a quality program and the use of a monitoring system. Re-design and change of working methods are examples of consequence reducing actions. Pre-planning of countermeasures and knowledgeable personnel at the site are further examples of consequence reducing actions.

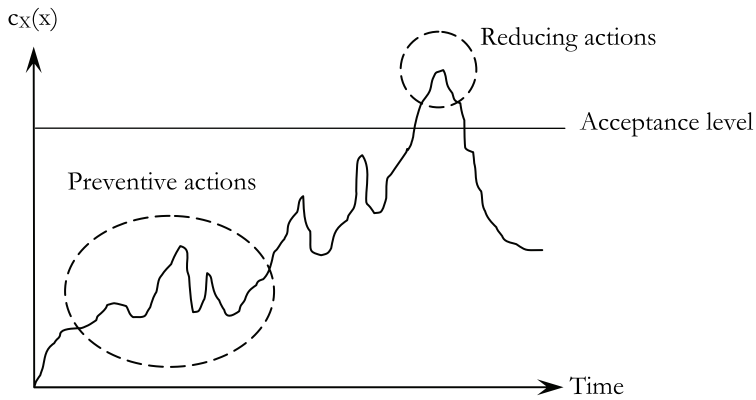

Figure 2.22 Preventive actions and reducing actions (after Hintze 1994).

A survey by the Confederation of the British Industry in 1994, presented in Clayton (2001b), revealed that some companies in the British construction industry were using a very high minimum acceptable rate of return instead of identifying and handling the risks in the tender phase. Baker et al. (1999) have reported similar experiences. The rate of return was used to judge the acceptability of the project in the hope that this would provide a built-in contingency margin to cover risk. However, this rather rough approach of risk management has several drawbacks. First, it excludes projects with low risks and with good return which is lower than the acceptable rate of return. Second, handling of risks is the key of effective risk management and most risks can be handled in some way. The choice of not handling the risks is a rather defensive approach.

The survey also showed that in many projects the risk handling was sometimes undertaken only at a rather superficial level. If more attention was paid to it, fewer hazards would probably result in damage events. It is normally not sufficient just to “take a margin” for risk since this results in little risk handling being done and a low risk awareness in the project. This would probably also lead to increasing project costs in the long run. If implemented correctly a successful risk management strategy reduces any adverse variations in the financial returns from a project. However, risk management itself might reduce the average overall financial returns from a project because it involves direct costs, e.g. increased capital expenditure or the payment of insurance premiums. However, this is often an acceptable outcome because of the risk-avert profile of many clients, investors and lenders (Lewin 1998).

In recent years there has been an increasing use of insurance arrangement in order to reduce the risks in a project (Tengborg 1998). There are insurances available for the client, designer and contractor in different phases of a project. Insurances against cost increases or time delays due to difficult conditions do normally not exist. In general there are few statistical data on which the insurance companies can base their estimation of the risks and, therefore, the insurance premium has to be based on experiences from similar projects and/or expert judgement.

2.3.6 Risk Planning

Risk planning is the detailed formulation of actions for the management of identified risks that have been accepted in the decision-making phase (Hintze 2001 and Carlsson et al. 2005). Risk information is translated into decisions and risk handling actions (both present and future) and these are implemented in the project plan, see figure 2.23. Risk planning is an ongoing process throughout the life-cycle of the project and includes, for example, describing and scheduling the activities and the organisation to control, document and communicate risks associated with the project. It is the process to:

- Develop and document an organized, comprehensive and interactive risk management strategy throughout the project.
- Determine the methods to be used to execute a risk management strategy.
- Plan for adequate resources in time and space.

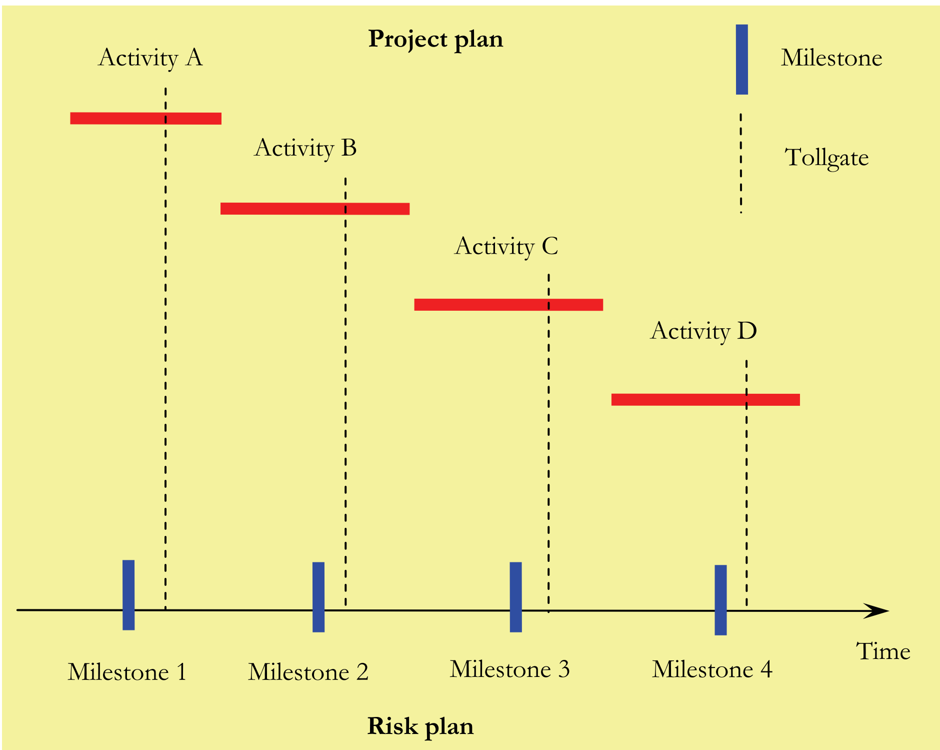

Figure 2.23 Translation of risk information into the project plan (after Hintze 2001).

The identified risks are often gathered in a risk register together with the decided risk handling actions. A risk register is a way of gathering all the risk data so that the information can be effectively communicated in the project. An example of a risk register is presented in table 2.8. A typical risk register might include the following (Clayton 2001b):

- The identified hazards in the project.
- The damage events resulting from these hazards.
- An estimation of the risk.
- The risk handling plan and mitigation actions with the objective of keeping the risks at an acceptable level.
- The time for response and who is responsible for the response (the risk owner).
- The expected effect of the response.
- The part that carries the economical consequence of the risk if it should be realised, and an estimation of the cost associated with the handling of the risks.

Table 2.8 An example of a risk register (Clayton 2001b).

No	*Risk*	*Owner*	*Mitigation plan*	*Last review*	*Critical date*	*Importance*	*Action*	*Closed*
2822	Footbridge piling	KG	Additional ground investigation	26/07/00	Closed	1	Trial holes	Y
5215	Unexpected land conta-mination found	CE	Apply previously prepared detailed procedure	19/01/00	Ongoing	1	Control plan no. 07-01	N
3.5	Dene holes	CE	Establish existence	19/01/00	Ongoing	1	Radiological surveys, historical records	N
3.14	Swallow holes	CE	Establish existence	19/01/00	Ongoing	2	Radiological surveys, historical records	N
11.4	Lignite mining	KG	Investigate as necessary	19/01/00	Ongoing	1	Allow for removal	N

The decided risk handling actions should be incorporated into the project plan in order to enhance that no risks and planned actions are forgotten during the project execution. The re-evaluation of the risk register should be a separate issue on the agenda of every project meeting.

2.3.7 Risk Monitoring

A key task at this stage of the management process is the monitoring of hazards included in the residual risk analysis, risk mitigation strategy and the risk response plan (Hintze 1994 & 2001 and Lewin 1998). All identified hazards need to be monitored regularly including those in the remaining stages of the investment life-cycle, not only the hazards occurring in the present stage.

The risk monitoring process is a continuous process of monitoring and re-estimation of risks, initiating events and warning bells, see figure 2.24. The monitoring process systematically tracks and evaluates the effectiveness of risk handling actions against established standards. Monitoring results may also provide a basis for developing additional handling options and identifying new risks or abandon some identified risks. If necessary, the project management should re-examine the risk handling approaches for effectiveness while conducting assessments. As the project progresses, the monitoring process should identify the need for additional risk handling options.

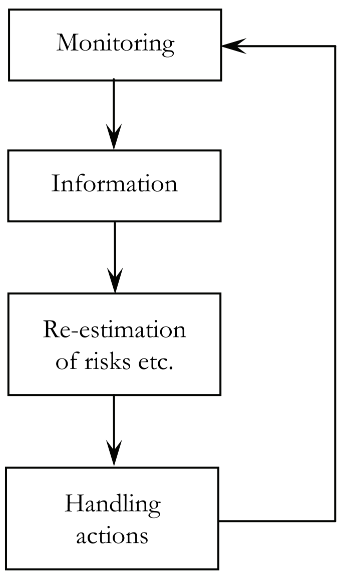

Figure 2.24 The risk monitoring process.

Any significant changes in already identified risks or new risks that are identified should be reported and assessed immediately (Lewin 1998). Regular monitoring of the risks can be undertaken by studying events, situations or changes (trends), which could potentially affect risks during the normal management and progress of a project. These trends must be systematically identified, analysed and monitored on a regular basis. Ideally, these should be considered at regular progress meetings involving key members of the management team.

An effective monitoring effort provides information that show if handling actions are not working and which risks are on their way to becoming actual problems. The information should be available in sufficient time for the project management to take corrective action since it generally elapse some time before the corrective actions becomes effective. The performance of the project risk group is crucial to effective risk monitoring. They are the "front line" for obtaining indications that handling efforts are needed and about their desired effects.

Finally, the fundamental qualities of the project, whether or not it is worthwhile, should be continually assessed and a risk review set in hand when events occur which appear to have significantly altered the risk profile of the project.

2.4 Risk Perception

The research on risk perception started in the mid 1970's and was mainly based on quantitative methods, e.g. questionnaires. In the studies of risk perception the standard approach is to compare the degree of severity that subjects assign to different risks factors, so called subjective risk, to the expectation values that have been calculated for the same risk factors, so called objective risk. The underlying assumption is that there is an objective and knowable risk level that can be calculated with the expectation value method. This is a questionable assumption since it is often argued that there exists no objective risk since the risk is relative and only exist in the minds of individuals or the society as a whole (Corotis 2003).

The individual's perception of risk depends on several factors (Douglas et al. 1982, Rosenberg 1989 and Slovic 2000). Some of these are:

- Voluntary or involuntary risk.
- Known or unknown risk.
- Potential damage.
- Expected utility.
- The time factor.
- Who the risk affects, e.g. the society or the individual personally.
- Personal factors, e.g. sex, age, education, personality and attitudes.
- Social factors according to the theory of culture divided into egalitarian, hierarchic, individualistic and fatalistic factors, e.g. moral, values and social group.
- Accessibility.
- Attitudes towards the part that is causing the risk.
- The decision-maker's perceived ability of controlling the risk.

In 1978 Slovic presented the psychometric model which states that all perception of risk can be explained by two dimensions, fear and news value. Some criticism against this model was that the utility also affects the risk perception and that experts and the public often have different risk level even though the structure is similar (Mattsson 2000).

The literature reveals the following conclusions regarding the factors influencing the perception of risk (Rowe 1977, Sjöberg 1978, Starr & Whipple 1980, Harr 1987, Rosenberg 1989, Persson 1991 and Hansson 2002):

- Even if the estimated risk is higher, a voluntary risk is generally preferred to an involuntary risk.
- The accepted risk is larger if the risk affects someone else.
- New techniques are perceived to be more severe than widespread techniques.
- Risks with large probability and small consequences are preferred to risks with small probability and large consequences.
- Larger risks will be accepted if the benefits are great.
- There is an upper limit for which consequences that are accepted despite the probability of occurrence.
- Risk is more important than the utility in many attitudes.
- Risk has a moral dimension since it, on an fundamental level, is intolerable to expose people of risk.
- People's emotional reaction towards risk is governed by the negative expectations of fear.
- Experts have a different attitude towards risk than the people in general.
- People in general are quite rational when it comes to risks they are familiar with, but irrational when it comes to uncommon risks.
- The more we know about a risk the less it seems.
- Risks that can affect us in a near future are perceived more severe than risks in the future.
- Risks with established technology are preferred to risks with new technology.
- The demand for risk reducing action depends on the extent of the damage.
- Risks that are accessible are considered to be more probable.

The probability of failure or damage is usually very small in most civil engineering applications while the consequences can be severe. A risk situation including a potential damage event with a very small probability of occurrence but with a serious consequence has shown to be especially difficult to evaluate. This is because an uncertainty of which of the different parts of the risk that is the most important factor for the perception of risk. Furthermore, different parts have different values to different decision-makers. For some decision-makers the probability of occurrence is most important for the risk perception. For others the consequence is the most important factor for the risk perception. The existence of very small probabilities is though a special characteristic that must be regarded explicitly according to Hintze (1994), since these have been found to affect the perception towards risk and therefore the risk acceptance. These must be treated separately in the establishment of accepted risk levels.

Furthermore, the probability generally loses its meaning when it becomes sufficiently small. For most decision-makers it is indifferent if an event has a probability of occurrence of 10^{-4} or 10^{-6} even though the probability is 100 times higher in the first case (Star & Whipple 1980). Studies of risk perception have also shown that small probabilities seem to be overestimated by most decision-makers. Since it often is much easier to apprehend and estimate the consequence of a damage event, the consequence part of the risk is often given more value than the probability part (Sjöberg 1978).

The psychological factors influencing the perception of risk are especially important in an infrastructure since there are so many actors involved in the project. These factors are generally not considered in the decisions criterion used and must therefore be addressed separately (Hintze 1994). Risk perception in the construction industry has been studied by e.g. Akintoye & MacLeod (1997). They conducted an extensive interview with the focus on risk perception and risk management and found that the construction industry seems to be mostly risk averse since the actors use risk transferring as their primary risk handling action.

2.5 Risk Acceptance

The decisions that are made in the risk management process are not only dependent on the size or seriousness of the risk, but also on the risk acceptance of the decision-makers. Thus, when the risks have been estimated, it must be determined whether the risks are acceptable or not. The decision that a decision-maker is willing to make is dependent on the specific risk level that can be accepted by that person, the client or the society. It is important to stipulate the accepted risk level before any decisions regarding budget, time schedule, technical solutions, construction methods, etc. is handled. The accepted risk level must be established in an early phase of the project in order to make the most suitable decisions from the initial phases of the project. The accepted risk level should be established in the risk policy for the project (Hintze 1994 & 2001).

The willingness of a decision-maker to accept a specific risk governs the risk acceptance. The risk acceptance depends on several factors, e.g. the risk perception of the individual or organisation facing a risk, the decision criteria, and the existing knowledge and experience of similar decision situations. The actual handling of an individual or an organisation facing a risk reveals the risk acceptance which can be divided into three categories; risk averse, risk neutral or risk taking, see figure 2.25. These can be defined by the certainty equivalent which is the expected value or the guaranteed amount of resources that is equally worth as a risky situation.

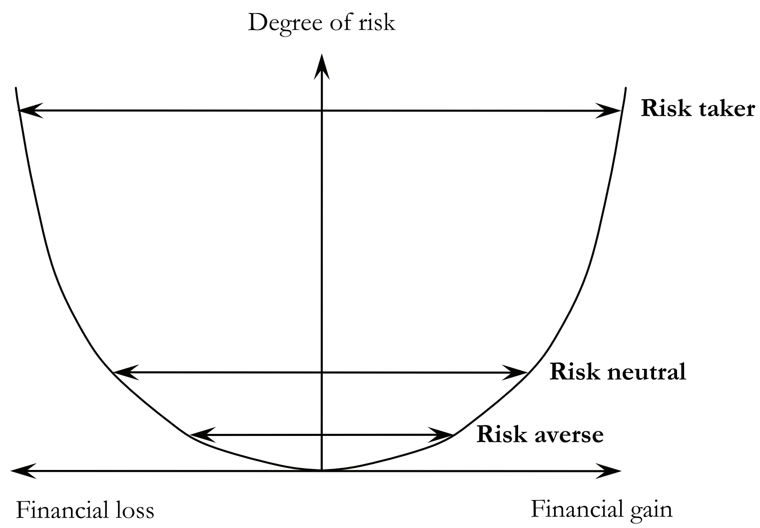

Figure 2.25 Risk acceptance for different types of decision-makers (after CIRIA 2002).

The decision-makers attitude towards the risk can in a similar way be evaluated by an estimation of the risk premium. The risk premium is the decision-makers willingness to pay an amount over the expected monetary value to avoid the risk (Edlund & Högberg 1986). A risk avoiding decision-maker will then have a negative risk premium and a risk taking decision-maker a positive risk premium. A risk neutral decision-maker will usually use the maximum expected monetary outcome as a decision criterion.

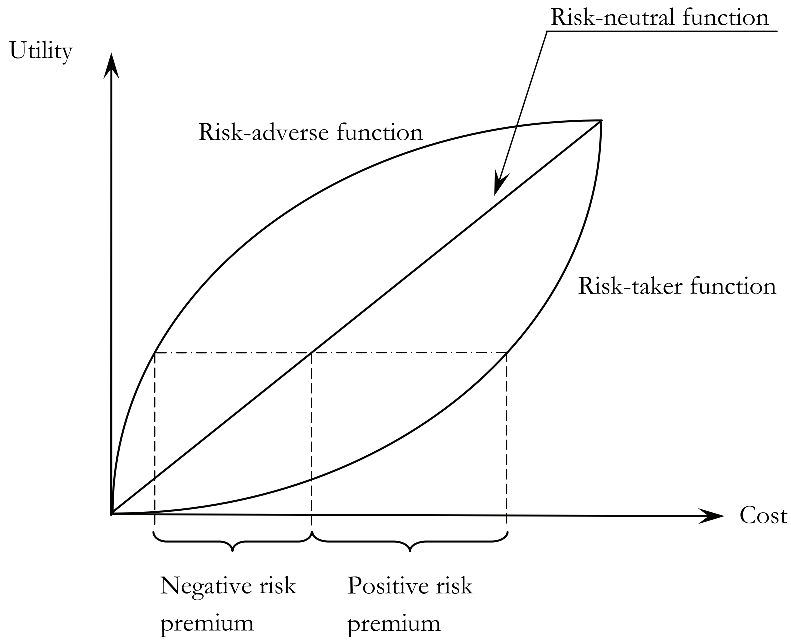

Figure 2.26 Risk acceptance of a risk-taker, risk neutral and risk adverse decision-maker on the basis of the risk premium (Edlund &Högberg 1986).

The risk acceptance is determined by many factors, some inherited and some acquired. Furthermore, the accepted risk level is different among different individuals, groups and societies and is dependent not only on personal factors, but also on technical, economical, social and psychological factors. The risk acceptance is, for examples, influenced by experiences of similar risk situation, public focus, familiarity with the working methods at hand etc. (Rowe 1977 and Persson 1991). An organisation generally accepts a higher risk level than the individuals in the organisation. The risk acceptance of individuals is thus often risk averse, while risk neutral or even risk taking characterise organisations. Generally, there seems to be a trend that the risk perception of individuals has a Gaussians distribution with skewness towards a lower willingness to accept risks, i.e. the human being seems to be risk avoiding in nature. Though, risk neutrality can be presumed when the sacrifice or expected loss is small (Rowe 1977).

However, in most situations it is almost impossible to decide the risk acceptance of individuals and organisations. Therefore, the accepted risk levels have to be based on more simplified methods. Melchers (2002) describes two ways of determining acceptance criteria in engineering projects. The first way to decide project specific acceptance criteria is to compare the estimated risks with other acceptable risks in the society. This is applicable for consequences including loss of lives, but seldom for economical loss. Some accepted risks associated with engineering projects are illustrated in figure 2.27.

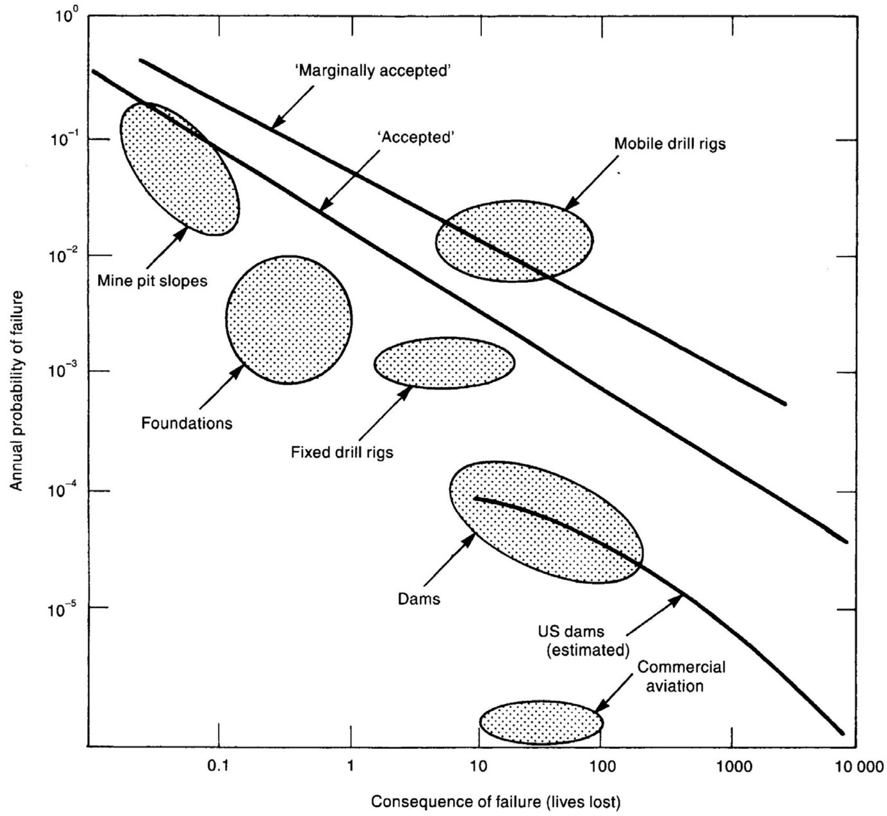

Figure 2.27 Accepted risk levels in some types of engineering projects (Wyllie 1999 after Whitman 1984).

The second way is to use cost-benefit analysis to decide the accepted risk level. The aim is to maximise the difference between the total benefit of the project and the total cost of the project. The probability and consequence of failure is then one parameter of the total cost. The cost-benefit equation can then be written (Melchers 2002):

$$\max(B - C_T) = \max(B - C_I - C_{QA} - C_C - C_{INS} - C_M - p_f \cdot C_F)$$

where B is the total benefit of the project, C_T is the total cost of the project, C_I is the initial cost of the project, C_{QA} is the coast for quality assurance, C_C is the cost of corrective actions in responsive to quality assurance, C_{INS} is the cost of insurance, p_f is the probability of failure and C_F is the consequence of failure. This equation can be used to find the "optimal" probability of failure given a certain level of quality assurance. Assuming a constant benefit B and minimising the total cost C_T a minimum will exist, i.e. $dC_T/dp_f = 0$ as illustrated as in figure 2.28.

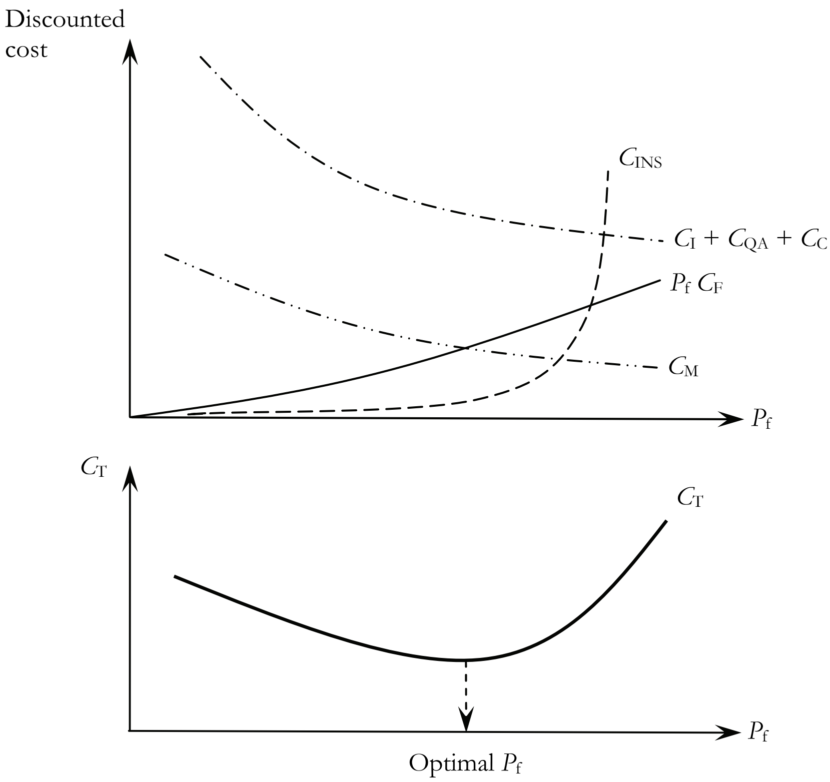

Figure 2.28 (a) Component cost and (b) total cost as a function of p_f (after Melchers 2002).

Due to the large uncertainties involved in the risk management process it is seldom possible to determine the risks exactly. As a consequence, the acceptance criteria are, to a great extent, based on experiences of similar risks.

2.6 Risk Communication

All the risk management activities, e.g. problem formulation, risk identification and risk mitigation actions, are worthless unless they are properly communicated to the actors involved in the project. However, risk management is in itself a way of passing information to other actors in a project, whether they are clients, designers, contractors, subcontractors, suppliers or the public, through the systematic approach requiring information from many different actors. Nonetheless, the communication of risks should be considered as a hazard in the project since the awareness and knowledge of potential risks and the communication of these among the participants in a project is essential for the result of the risk management process. In fact, the biggest hazard in many projects is the lack of communication according to CIRIA (2002). The importance of quality-assured communication and flow of information within projects has been considered by e.g. Muir Wood (1994), Rollenhagen (1995) and Sturk (1998).

In general, information flow both horizontally between the actors in a specific phase and vertically between different project phases, see figure 2.29. The aim and content of the information is usually different in different phases. In order to ensure a proper communication in the project, part of the problem assessment should be designated to the communication between the different actors involved. This includes, for example, the understanding of the objectives of the study and the different actors' frames of reference, and the assessment of the actors' concern. Successful communication rests, among others, on the characteristics of the sender and receiver of the information, the decision situation and the environment. A prerequisite for successful communication is an understanding of the obstacles that can prevent the intention of the communication. These can be divided into general, organisational and personal obstacles, see Stille et al. 2003.

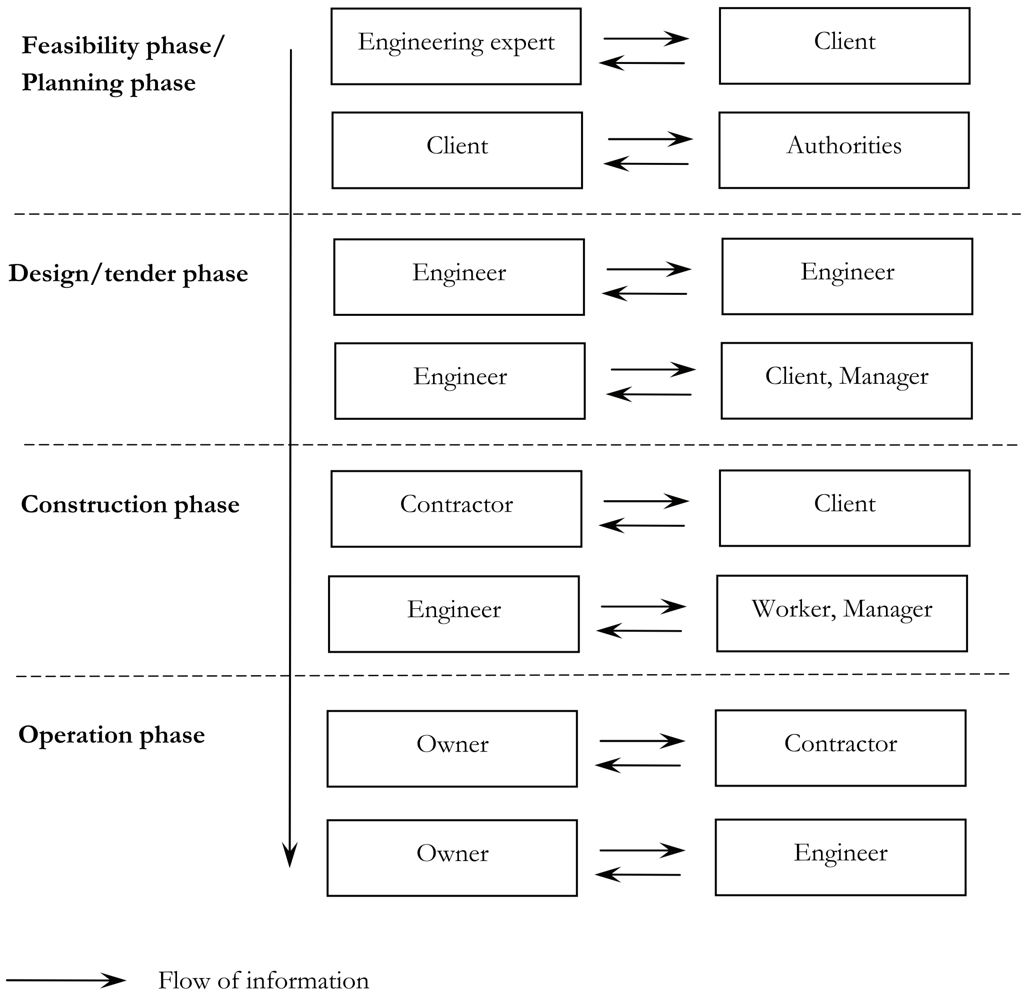

Figure 2.29 Some important information paths in an infrastructure project (modified after Sturk 1998).

The rate of information flow within the organisation is governed by the distribution of responsibilities and the authorisation for making decisions in the project organisation. To minimise the time required from an indication, e.g. of a mitigation action, to authorisation of making decisions regarding these issues, the responsibility should be given to those closest to the actual work and, thus, the best suited for the decision-making.

Since the aim and contents of the information generally are different in different phases, the requirements of the information also change during the project progress. For example, the requirement for details generally increases as the project proceeds from pre-planning to actual construction. The contents of the information regarding the risk management also changes during the project progress, se figure 2.30.

Flow of information →

Pre-Planning	**Planning**	**Construction**	**Operation**
Risk Management: Design alternatives Political decisions Financing Public opinion Public demands Organisation	**Risk Management:** Technical solutions Costs Time schedule Environmental impact Work environment Organisation	**Risk Management:** Costs Time schedule New risks Operation Organisation **Measure:** Review and follow-up	**Risk Management:** Operation New risks Function **Measure:** Review and follow-up

Figure 2.30 The content of the information of risks in different phases of a project.

The quality and the suitability to the purpose of the communication and flow of information between the actors and between the different phases in a project are important for the success of the risk management strategy. Through adequate information and communication the possibility to avoid risks and hazards is increasing. Though, if the amount of information becomes too large or too diverse problems with the general view and the interpretation of the information may arise. Furthermore, the information should be clear regarding the uncertainty involved, related to the current situation (e.g. representation, extent and quality), understandable and quality-assured (Stille & Sturk 2001).

The information of risks must be adapted to the receiver so that the receiver has the possibility to understand and exploit the information (Sturk 1998). The characteristics of the information between, for example, two engineers can not reasonably be the same as the information between an engineer and a worker or between an engineer and a client. There are, of course, differences in the use and meaning of words and language, knowledge and experiences which affect the way to communicate.

In order to achieve successful flow of information, Rollenhagen (1995) proposes that the following criteria regarding the characteristics of the information shall be fulfilled:

- High (sufficient) quality information, i.e. the information shall be adapted to its purpose, understandable, correspond to the expectations and transparent.
- The amount of information must be adapted to the decision situation.
- The time for arrival of the information and the speed of the presentation of the information must be adequate.

Muir Wood (1994) points out the importance to distinguish between information based on knowledge and information based on assumptions. Otherwise problems may arise in the interpretation and the utilisation of the information. However, this is not trivial in many situations in an infrastructure project due to the rather heavy reliance upon empirical relationships and subjective judgements.

The transferring of information usually arouses associations among the people involved in the process. This has been pointed out by Nørrestranders (1991) and is discussed in Sturk (1998). Information implicitly based on associations is here called exformation. If the sender of the information succeeds to trigger the intended associations in the receiver's mind, the information can include limited explicit information but still be comprehensive due to the implicit information involved. On the other side, if undesired associations arise, the receiver's interpretation of the information can be totally different from what the sender's intentions. Thus, it is important that both information and exformation is taken into consideration when transferring risk information between the actors involved in a project (Nørrestranders 1991).

CIRIA describes a way to ensure that the relevant information regarding the risks in a project is distributed to all the relevant actors in a project. First, at least one member of the staff from each organisation is appointed to be part of the project risk management team during the entire project. Verification must be obtained that these persons have received the risk information and understood it and that those concerned are committed to undertaking the required risk mitigation action. Second, a project wide risk register is then used to pass details of each identified risk, its impact on the project, who is responsible for the management of the risk and how this is to be achieved (CIRIA 2002). A similar way of working is described by Melvin (1998) where a designated risk engineer is responsible for the communication and handling of the risks through the entire project process.

2.7 Quality Assurance of Risk Management

The risk management process is a process with a degree of subjectivity involved and different risk analysts may, of course, come to different results. It is therefore necessary that the process is documented in a proper way. Furthermore, it is important that the result is reviewed critically as for all other studies and investigations.

A basic prerequisite of the quality assurance of the risk management process is that the entire process is documented in a logic and systematic manner. This documentation is the final verification that the analysis has been performed in a satisfactory manner. The documentation should include the objective of the analyses, methods and data sources used in the analyses, the recommended risk handling actions and the main results. It is also important that the uncertainties in the models used and the underlying assumptions regarding estimation of probabilities and consequences are identified and quantified. These uncertainties should be made clear so that there are not hidden for the decision-makers (Clayton 2001b).

The quality of the data used in the analysis can be improved by the use of historical data from similar projects. If no historical data exist, well compounded teams of highly skilled individuals with different topics of interest and experiences can be used. By the use of teams of individuals with diverged knowledge and experience it is believed that a synergy effect is obtained.

In many situations and among many individuals, and especially engineers, there is a strong belief in quantitative data (Hansson 2004). There are certainly great advantages in expressing the estimations of probability and consequences with the accuracy that follows a quantitative analysis. Though, if there are discrepancies in the data quality and data sources a quantitative analysis is not always to prefer. In these situations, a well-performed qualitative analysis can be used with the same level of detailness. Regardless of what kind of method that is used, the documentation should include a discussion of the quality of the data and data sources that are used in the analysis. Moreover, a description and discussion of the system and problem definition, identified risk sources and hazards, initiation events etc. should also be included (Sturk 1998).

2.8 Conclusions

The risk management process is influenced by many factors, for example the meaning and interpretation of the word risk, the risk management methodology, individuals' perception of different types of risks, the accepted risk levels and the communication of risks. This chapter included a literature review of the concept of risk and uncertainty and risk management at a fundamental level as well as a study of risk perception, risk acceptance, risk communication and quality assurance of the risk management process.

Risk management developed as a discipline in the United States in the 1960's due to increasing costs for business insurances which resulted in a demand for preventive measures to reduce business risks. In the construction industry, the interest in risk management started to grow in the 1990´s due to an increasing number of complex projects including large risks and uncertainties, e.g. the expansion of the infrastructure in urban areas. The risk management in future infrastructure projects will probably become a more complicated process than before due to increasing dependence on advanced technology and location of complex infrastructure systems in urban areas in combination with tight time schedules and rigid cost limits. Additionally, an increasing consideration has to be taken to public interests and relations as well as environmental issues. Therefore, there will be a greater range of risks to be considered and the management of the risks will become more diverse.

Risk management is currently used in many businesses to control risks and uncertainties, e.g. health and safety, finance and the nuclear industry. A convenient way of managing geotechnical risks should be to add geotechnical risk factors to the existing systems of risk management in these businesses. There are however conflicts of interests in all projects and the management of geotechnical risks will not be the most critical issues in many projects. Though, for some types of projects the risk management of geotechnical risks will result in significant improvements in costs and quality.

The word risk is an ambiguous and a multidimensional word having different meanings to different individuals and is used with different meaning in different businesses and in everyday language. In addition, research has shown large discrepancies between the public and experts when it comes to the definition and meaning of the word risk and the perception of risks. In order to make an effective risk management possible the word risk must be defined with a strict meaning depending on the context. In a technical context, the standard meaning of the word risk is the statistical expectation value of an unwanted event which may occur. An expectation value is a probability-weighted value which has the benefit of being is additive. This definition is often used in risk-benefit analysis in the systematic comparison of risks with benefits. There are however several drawbacks in this definition. Furthermore, the concept of risk is a value-laden word which has a negative meaning to most people and often takes a "threat perspective". However, risk has a positive side as well, opportunity, which is often ignored. As a consequence, today risk management is often about managing risks rather than opportunity management.

The risk management process generally consists of three parts; risk analysis, risk evaluation and, risk reduction and control. The risk analysis and the risk evaluation is sometimes called risk assessment. Risk analysis consists of three phases; scope and system definition, risk and hazard identification, and risk estimation. The aim of the risk analysis is to provide a basis for the decisions that have to be made in a project.

The scope definition defines the scope of the project as well as the fundamental requirements from the client, society etc. The system definition defines the projects in terms of conceptual system, e.g. series, parallel or combined systems, in order to understand the origin and the characteristics of the risks. The risk and hazard identification aims at identifying all significant types and sources of risk and uncertainty associated with each of the investment objectives and the key parameters relating to these objectives, determine the causes and the initiating events of each risk, and to decide how different risks are related to each other and how risks should be classified and grouped for evaluation. Risk estimation is a problem definition phase in the risk management process which quantifies potential risks in terms of probability and consequences. The aim of the risk estimation is to estimate the total expected damage cost (the total risk) of a project in economic terms and to classify and prioritise the risks.

The second part of the risk management process, i.e. the risk evaluation, consists of risk tolerability decisions and analysis of options. The risk evaluation is the process in which judgements are made on the tolerability of the risk on the basis of the risk analysis, taking factors such as socio-economic and environmental aspects into account. The aim of this part is to decide the risk level that can be accepted in the project and analyse the different handling options to deal with the risks. The accepted risk level is dependent on the risk perception of the decision-makers. The risk perception depends for example of the nature of the risk, the familiarity of the risk and personal, cultural and social factors. Depending on the risk perception and risk acceptance decision-makers can be divided into risk averts, risk neutrals and risk takers. Most individuals seem to be risk averts while most organisation can be characterised as risk neutrals.

The third part of the risk management process, i.e. risk reduction and control, comprises decision-making regarding the handling of identified risks and implementation and monitoring of risk handling actions. Risk handling can be defined as the risk management phase that includes specific methods and techniques to deal with risks that can not be accepted without further attention. The aim of this part is to separate those risks that can be accepted with or without any further attention from those that can not as well as to decide, plan and implement appropriate handling actions for those risks that need further attention. If the risks can not be accepted they risk can be avoided, left untreated, transferred, shared or mitigated. The communication of risks has a major influence on the result of the decided handling actions.

Due to the special characteristics of an infrastructure project it is not enough with one person's subjective and informal assessment and management of risks for the success of the project. The risk management must be structured and systematic and involve all individuals in the project. Personal and financial resources for the risk management process must exist as well as knowledge and experience of geotechnical engineering and risk management. The success of the risk management process depends, for example, on:

- An unambiguous definition of the word risks which is known by all involved in the project.
- An understanding of the actual problem and the system at hand as well as the fundamental demand and prerequisites of the project.
- A focus on both risks and opportunities.
- Involvement of the entire project team and, often, assistance from external experts who are knowledgeable in existing risk areas.
- An early implementation of a risk management system which will give the most benefit as there will be more options to handle the risks if they are identified in an early phase of the project.
- A thorough search for existing information as well as sufficient experience is brought to identify hazards and risks as well as estimation of probabilities and consequences.
- An understanding of the hazards themselves and the process from the initiating event to the actual damage.
- An understanding of factors that determines the risk perception and the risk acceptance.
- High-quality communication and transferring of correct information.
- Adequate quality assurance of the risk management process.

3 Project Risk Management in Geotechnical Engineering

Project risk management is a growing area with applications in all engineering areas. Due to the large risks and uncertainties generally involved in geotechnical engineering it has become more and more common to apply risk management techniques in infrastructure projects with the aim of acquiring knowledge of the principle sources of the uncertainty influencing cost and/or time.

Project risk management is about how to deal with risks in a project environment and during the execution of the project. The overall aim of the project risk management is to identify and avoid or exploit the risks before they occur. The success of a project will rest on an understanding of the risk, hazards and uncertainties involved in a project. The project performance will also be significantly influenced by the distribution of the risk between the actors involved in the project. Therefore, the chapter includes a literature review dealing with risks, hazards and uncertainties in geotechnical engineering, risk sharing and methods for management of project risks in geotechnical engineering.

The aim of the chapter is to review some of the risks usually present in geotechnical engineering and to point out the most critical risks in infrastructure projects in general. The examples of methods for project risk management are presented in order to illustrate some useful examples of these methods, not to be a complete presentation of all existing methods.

3.1 Introduction

Project risks can be defined in similarity with the previous definitions of risk with the addition that the risk affects the objectives of the project. Thus, project risk can be defined as a *"combination of the probability of an event occurring and its consequences for project objectives"* (IEC 2001).

On a fundamental level, the threats associated with the construction process can be divided into four categories:

- The completed project is a threat against its surroundings.
- The completed project is a threat against its expected function.
- The environment is a threat against the completed project.
- The building process is a threat.

The first category is usually regulated through laws, norms and standards which state that the completed structure shall have satisfactory load-bearing capacity, stability, durability etc. In addition, it is the responsibility of the building proprietor to secure that the completed structure is not a threat against its surroundings. The threats against the expected function and the environmental impact are usually handled in the design. The threat against damage on property or personal damage of third party is normally the responsibility of the building proprietor. The safety of the people involved in the project execution is the concern of the contractor.

There are many different ways of classifying project risks presented in the literature. According to Mattsson (2000) project risks can be divided into technical and social risks depending on their source and characteristics. In geotechnical engineering, technical risks are often related to the insufficient or adequate knowledge of the geotechnical conditions at the site. Other technical risks are risks with the design, the contract between the parts involved, the equipment and the construction method used for the project. Social risks are those risks that affect people outside the project and the environment. Examples of these risks are risks of contamination, settlements, vibrations and noise as well as risks for bad publicity and loss of goodwill or reputation.

Another classification of project risks presented by Leung et al. (1998) divides the risks into risks related to internal risk factors, e.g. design, construction, and management, and external risk factors, e.g. factors related to time schedule, economical, political, environmental and financial issues.

Project risks can affect many aspects of a project, for example costs, time schedules, quality, health and safety of the workers and the public, and environment. These risks can have direct or indirect consequences. Risks with direct consequences are for example risks related to design, construction, environment, working safety and guarantee engagements. Risks with indirect consequences are risks that affect the reputation or goodwill, the public opinion or the market value of the company. Examples of these risks are risks related to working safety, environment, client relations and quality.

According to Clayton (2001b) construction work can result in at least five different types of risks:

(i) Risks related to the health and safety of the workers and the public.

(ii) Risks related to the environment.

(iii) Risks related to the quality.

(iv) Risks related to the time schedule.

(v) Risks related to the financial budget of a project.

The actor that takes on the risks changes with time. In the early planning phase and in the operating phase of a project, the building proprietor (or the client) takes on a large part of the project risks until the funding is established or a contract is signed. The risks in this phase of a project can however be changed by different measures, e.g. insurances, joint ventures, concessions and financial agreements. For the contractor, the risks are often considered to be most severe after the contract is signed as the contractor's responsibilities and engagements then are fixed.

Infrastructure projects are in general considered to include large risks due to the nature of these projects, e.g. varying and difficult conditions and demands, long project time schedules, complex contracts, high technical level, complex organisations and political, public and environmental focus. Severe cost overruns, time delays, quality problems and environmental impact have been reported in many projects recent years (see e.g. Kastbjerg 1994 & Nylén 1999). The risks in infrastructure projects are typically related to the geotechnical conditions, technical solutions, political decisions, financing, time scheduling, organisation, operation, and cost and time estimations (Jaafari 2001).

According to Tengborg (1998), the major risks are related to the contract, the organisation, the geotechnical conditions, the construction method and the financial arrangements. Risks related to technical issues, such as the soil and rock mass, are in general quite obvious and is therefore managed in some way in most projects, whilst risks associated with the organisation and contract are not that obvious and as a consequence often neglected (Tengborg 1998). Risks related to the contract, organisation and construction methods are only consider on a fundamental basis in this thesis but have been discussed extensively by Tengborg (1998). Additionally, risks related to the financial aspects of a project, e.g. currency changes, inflation and rates of interest, are not considered herein.

Project risks result from the combination of a *hazard* and *vulnerability* (Clayton 2001b). A *hazard* is here something with the potential to do harm, such as a substance, geometry, a person or a contract. The meaning of *vulnerability* is those factors that determine the likelihood that a hazard will have unfavourable consequences. The process from a hazard to an actual damage can be illustrated as in figure 3.1. Central concepts in this process are *risk object*, *hazard*, *initiating event*, *warning bell*, *damage event* and *damage object*.

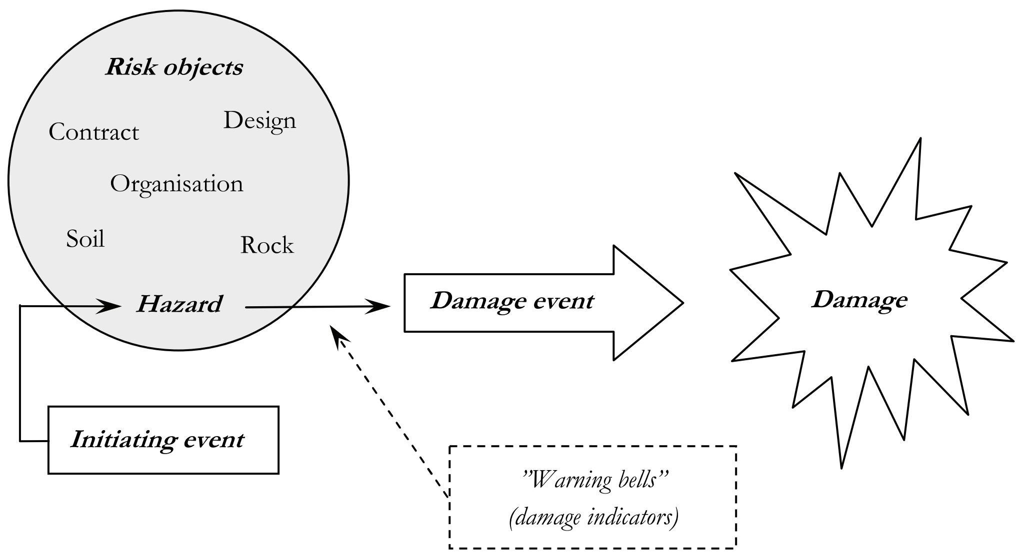

Figure 3.1 The process from initiating event to damage (after Sturk 1998).

These concepts can be defined as (Sturk 1998):

- A *risk object* is an object which includes hazards that can cause damage, e.g. the organisation, the contract, the design, and the soil and rock mass.
- A *hazard* is an inherent property of the risk object and is defined as a threat of a possible damage event. Examples of hazards are water, unclear responsibilities and authorities in a contract, and insufficient competence in an organisation.

- An *initiating event* is the event that triggers a damage event, e.g. excavation, a decision and an approval of some sort.
- A *warning bell* is an indication that a damage event is about to occur or already have occurred, e.g. soil movement, vibrations and flow of water. Warning bells almost always exist for the different types of hazards and it is important to notice them in due time.
- A *damage event* is an event that causes damage, e.g. a collapse of a sheet pile wall, a over-dimensioned structure and water in a tunnel.
- The resulting *damage* is often expressed as economical loss or loss of resources for the project since the risk usually is expressed in monetary terms.
- The part in the project that is subjected to the damage is here called the *damage object*, e.g. the client, the contractor or the society.

These concepts, or definitions, are often used with different meanings in everyday language, but it is recommended that a stringent nomenclature is used in the context of risk management in order to avoid misunderstandings. Furthermore, all these concepts are not appropriate in all situations. Some types of damage are relatively easy to express in monetary terms, e.g. time delays and reconstruction, while other is practically impossible, e.g. costs for negative opinion and the loss of goodwill or co-workers.

In table 3.1 some examples risks in infrastructure projects are presented in these concepts. For a more comprehensive description of these concepts and general risks in infrastructure projects and geotechnical engineering, the reader is referred to e.g. Hintze (1994), Sturk (1996 & 1998) and Tengborg (1998).

Table 3.1 Examples of risks in infrastructure projects (Tengborg 1998).

Risk object	The rock mass	The contract	The organisation	The design
Hazard	Flowing ground	Responsibility of discrepancies	Description of authorities	Insufficient competence
Initiating event	Excavation	Shortcomings in the site investigation	Inadequate decision	The approval of the design
Damage event	Tunnel collapse	Unjustified demands from the contractor are approved	Collapse in a tunnel	Inadequate design
Damage	Economical loss	Economical loss	Economical loss	Economical loss
Damage object	The contractor	The client	The client or the contractor	The client

3.2 Risks and Hazards in Geotechnical Engineering

Geotechnical risks can be defined as the risks to building and construction due to the geotechnical conditions. There are several reasons why geotechnical risks affect the outcome of a construction project in a severe way. These are mainly because the special nature of the ground (Clayton 2001b):

- The properties and distribution of the geotechnical properties are predetermined and basically outside the control of the designer, the client and the contractor.
- In contrast with man-made materials, e.g. steel or concrete, the geotechnical conditions generally are highly variable from place to place and with the depth.
- The accuracy of many geotechnical design methods is poor despite the developments in recent decades.
- There are many ways in which difficult or unforeseen geotechnical conditions can cause problems in a construction project.
- Different methods of construction and different technical solutions will be affected by changes in the geotechnical conditions in different extents.
- Civil engineering works are in general executed early in the project life-cycle and problem will affect all subsequent phases in the project.

Risks and hazards in geotechnical engineering generally have three components of impact; technical, contractual and project management (Clayton 2001b). These risks can adversely influence the cost and time schedule, health and safety, quality and the environment. There are many types of risks and hazards in geotechnical engineering and the consequence of failing to manage these risks can be severe in many projects. Some examples of risks in geotechnical engineering are given in table 3.2.

Table 3.2 Examples of risks in geotechnical engineering (after Sturk 1998 and Hintze 2001).

Risk object	The soil mass	The rock mass	A sheet pile wall	The rock mass
Hazard	Water	Water	Large move-ments	Running ground
Initiating event	Excavation	Insufficient grouting	Excavation	Excavation
Damage event	Settlements	Large water inflow	Settlements	Tunnel collapse
Damage	Economical loss	Economical loss	Economical loss	Economical loss
Damage object	Contractor or client	Contractor or client	Contractor or client	Contractor or client

Many work activities in geotechnical engineering projects, e.g. excavations, foundation work and tunnelling, can be characterised as series systems. This means that a work activity is dependent on the previous work activities and affects the subsequent work activities. The construction process is therefore very sensitive for changes. For example, the installation of anchors for supporting a sheet pile wall is dependent on the installation of the sheet pile wall and the excavation to the anchor level. This implies that the risks and hazards also are connected to each other in a similar way (Isaksson 2002).

Consequently, geotechnical risks often have disproportional effects on the cost and the time schedule of a project, since problems occurring in one phase affect the subsequent phases. This will often lead to irrecoverable time delays which lead to extra costs in addition to the costs for changing the design, re-construction etc. The costs in a geotechnical engineering project can be divided into normal and exceptional costs which could be represented both as deterministic and stochastic variables. Normal cost is here the cost for construction if no undesirable events occur. Exceptional costs are the construction cost if undesirable events occur, e.g. due to unexpected geotechnical conditions. The exceptional cost is a function of the probability and consequence of an undesirable event (Isaksson 2002).

In a study of construction projects in Sweden, Nylén (1996 & 1999) found that limitations in geotechnical design, ground investigations and the interpretation of these are the reasons for approximately one third of the total cost of errors. According to Clayton (2001b), the majority of delays and cost overruns in the British construction industry are caused by ground related events. Minor changes in design due to unforeseen geotechnical conditions can easily add 5% to the total cost and figures as high as 30–50 % are not uncommon (Tyrell et al. 1983). If extensive unforeseen geotechnical conditions arise, extra costs up to 100 % have been reported (Mott MacDonald 1994). According to Clayton (2001b), the most frequent sources to geotechnical risks are due to uncertainties in soil boundaries, soil properties and the groundwater situation, see table 3.3.

Table 3.3 Sources to ground-related risks in construction (Clayton 2001b).

Risks related to	**[%]**
Soil boundaries	22
Soil properties	20
Groundwater	13
Contamination	11
Obstructions	10
Site investigation	9
Services	6
Detailed design	5
Other	4

Even though the methods for site and laboratory investigations in geotechnical engineering have continuously improved during the years, the pre-knowledge of the geotechnical conditions at a site have generally not improved in the same extent. This is in partly because a trend that a minor part of total project budget is spent on geotechnical site investigations. The fact that many ground investigations tend to be procured according to the lowest bid does not make the geotechnical risks less severe and less common (Clayton 2001b).

In a survey of around forty British highway projects conducted by Mott MacDonald (1994), a correlation between the cost overruns and the expenditure on site investigations was found, see figure 3.2. In the British construction industry, generally around 1 % of the total construction budget is spent on site investigations and cost overruns up to 100 % have then been reported. Facts suggest that the cost overruns are reduced as the expenditure on site investigations is increased.

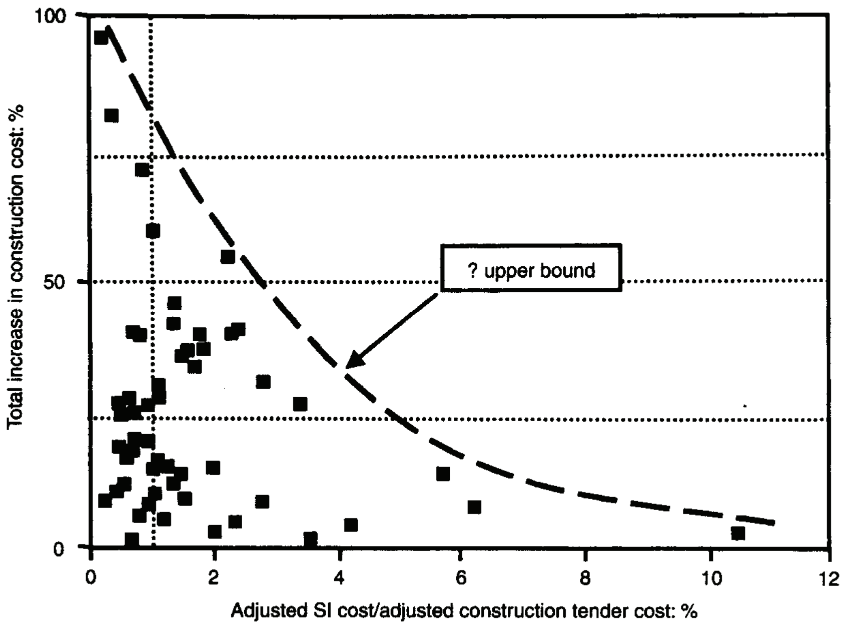

Figure 3.2 Increase in construction cost as a function of expenditure on site investigation (Mott MacDonald 1994).

Geotechnical risks have to be managed systematically if significant problems are to be avoided. As been mentioned before, geotechnical risks influence both the technical and contractual parts of a project as well as the project management. Evidently, there are many types of construction risks besides geotechnical risks. Nevertheless, construction management should attempt to integrate the risk approach so that all risks are handled in a total risk management system. According Clayton (2001b) a successful management of geotechnical risks can be performed through the following steps:

(i) creation of a team of geotechnical and geological experts,

(ii) collection data on the geotechnical conditions at the site,

(iii) identification of the likely range of forms of construction that might be used,

(iv) identification of hazards and risks to different forms of construction,

(v) ranking risk according to impact by group experience,

(vi) establishment of a risk register,

(vii) associate various risks to different stages of construction, and finally

(viii) estimation of consequences and likelihood by group experience.

3.3 Uncertainties in Geotechnical Engineering

Uncertainty arises due to a lack of knowledge and there are generally many types of uncertainty in geotechnical engineering. These are caused by, for example, insufficient or adequate information of included parameters or models, unfamiliar techniques or locations, lack of experience or competence and, unforeseen changes in scope and prerequisites. Some of these types of uncertainties are in some situations quantifiable and some are not.

Furthermore, many phenomena, processes and events in geotechnical engineering include some form of inherent randomness and heterogeneity, i.e. the outcome of an event is to some extent unpredictable (Ang & Tang 1975). These phenomena are characterised by experimental observations that are different from one experiment to another, even though the experiments are carried out in the same way. Therefore, there is usually a range of measured or observed values which shall be used in the design or in other applications.

Engineering uncertainties are not limited to the variability in the basic variables. First, the estimated values of a variable are not free from errors. If the there are limited data, the estimate will be nothing more than an educated guess based on past experience and the judgements of the engineer. Second, both mathematical and laboratory models are just a representation of the reality and will include uncertainties due the difficulty in the model interpretation. As a consequence, the predictions and calculations made on the basis will include uncertainties (Ang & Tang 1975).

According to NEA (1997) the uncertainties can be categorised into scenario uncertainty, conceptual model uncertainty and data uncertainty. The scenario uncertainty concerns uncertainties in the evolution of a studied system due to initial internal conditions or by future external conditions. Conceptual model uncertainty deals with the uncertainty due to the fact that the fundamental knowledge of a system or a process and the connections between these are not inclusive. Data uncertainty concerns the uncertainty in the parameter values of a specific model.

In order to estimate the impact of the uncertainties it is necessary to quantify them. Both the uncertainty due to the inherent variability and the model inaccuracies may be assessed in statistical terms. The evaluation of their significance on engineering design can be accomplished by using concepts and methods embodied in the theory of probability. The range of values can be described in a histogram, also called a frequency diagram, or as a probability density function. The histogram presents a graphical picture of the relative frequencies of the observations. In many situations certain aggregate quantities, such as mean value and variance, are more useful than a complete histogram. These can be evaluated from the histogram, but is usually calculated as the sample mean and the sample standard deviation (Johnson 2000). If the observed data show some form of randomness, the value can only be predicted with an associated probability.

If two or more random variables are involved the degree of dependence between them must be estimated, i.e. how the value of one variable depend on the value of another value. When dealing with systems, e.g. series and parallel systems, the correlation between the parameters has a major impact on the result. Thus, it is essential to estimate the statistical dependence between the parameters that are included. Furthermore, the uncertainty of one parameter may affect the uncertainty of another parameter.

In addition, many properties, such as geological properties, show spatial variability, i.e. the properties vary in space. Spatial variability is not really an uncertainty, but is related to uncertainty. Even though there is no uncertainty in the spatial variability, the spatial variability may magnify the consequences of other uncertainties. The uncertainty should then be represented by a function and not a single value. Uncertainty in a function may be described by the concept of stochastic processes, where the difference between different outcomes of these functions represents the uncertainty in the spatial variability. The uncertainty caused by the spatial variability depends on the scale of the problem. Generally, the uncertainty of the spatial variability will decrease as the scale increases. Thus, when dealing with spatial variability it is crucial to understand the difference between variability and uncertainty and how the scale of the problem affects these (Andersson 1999).

The uncertainty of a single parameter can be described by a probability distribution or a probability density function. The probability distribution can be discrete or continuous or a combination depending on the nature of the uncertainty. However, when dealing with uncertainties in geotechnical engineering traditional statistical methods are not always appropriate due to the fact there rarely is adequate data series to base the analysis on. Then other methods must be applied. Often it is possible to fix the parameter values within some boundaries, e.g. the quartiles and the mode, and then assign a distribution, e.g. a triangular distribution. It is also possible to use subjective assessments by expert opinions and judgements based on experience and knowledge in a specific area and the available information (Andersson 1999).

However, there is a need for caution when using subjectively assigned probability distributions. According to Andersson (1999) a minimum requirement is that the assessment results are not critically dependent on the selected functional form of the density function. Even though the available data are scarce there are often enough data to make some kind of estimation. Without any uncertainty estimate at all the quality of the assessment can not be judged. Even a rough estimation, e.g. in the form of intervals, can be sufficient in many times.

The input parameters can be chosen in many ways depending on the purpose of the analysis. Andersson (1999) describes three types of uncertainty estimates; “reasonable”, “pessimistic” and “probalistic” estimates. The purpose of choosing “reasonable” is to explore how the system functions under normal circumstances. A “reasonable” value is not necessary the statistical mean or median. In general, these values do not represent the most likely outcome. The “reasonable” value can be estimated be based on available data or on a model analysis. A “pessimistic” estimate is an estimate of a parameter value or conceptual model within the uncertainty range which will maximise the consequences. The main advantage of choosing a “pessimistic” value is to avoid a detailed description of a model or phenomenon which in many cases is difficult. Therefore, a “pessimistic” value can be chosen to handle to conceptual model uncertainty. If looking at system performance or safety this approach may be suitable. However, the decision alternative could be too costly. If all parameters are given a “pessimistic” value the result will be even unrealistic. Thus, the selection of “pessimistic” values should be considered carefully and be motivated.

If the result from the analyses with "reasonable" and "pessimistic" values shows large deviations it is necessary to use "probalistic" estimates, i.e. probalistic distributions which considers the variability in the properties. When there is little knowledge, experience or few data present of the underlying stochastic parameters there is of course difficult to make an estimation of the probability distribution. In these situations, the existing information can be used to identify intervals.

As a result of these uncertainties, decisions must be based on trade-off between different factors, e.g. cost, utility, safety, probability of failure and uncertainty. The optimal decision is the decision that minimises and/or maximises some or all of these factors. The cost-benefit analysis should include the effect of the uncertainties on a given decision.

3.4 Risk Sharing

In any project, the risk sharing between the actors involved in the project will have significant influence on the project performance. The distribution of the risks is usually governed by the contract between the parts involved. Thus, the contract is a significant element in the risk management process. In addition, procurement methods have important implications for the risk management. Regardless the method of procurement and the form of contract, risks will be best managed when risk analysts representing all the actors concerned are brought together as early as possible in the project (Clayton 2001b & Hintze 2001).

Despite the form of contract, there are certain risks and obligations that the actors always are responsible for regardless of the type of contract. The building proprietor is always responsible for the geotechnical conditions and to specify the demands regarding the function and quality. Though, there are some forms of contract in which the contractor takes over the responsibility for the soil and rock media, e.g. when the client only specifies a certain function of the planned facility and it is the choice of the contractor how to create this function. The contractor is, however, always responsible for the working safety and the actual execution of the project (Tengborg 1998).

It should be in all actors' best interest to make an estimate of the risks and uncertainties involved as good as possible before the contracts is signed. An understanding of the uncertainties regarding the cost and time schedule of the project is especially important both for the contractor in the procurement and execution process and the client in the project developing process (Elms 2003).

Methods of procurement in the construction industry have changed during the last decades. The traditional arrangement with a single consultant, engaged for design and supervision of the work is used less frequently today. Instead, more competitive and time-restricted conditions have lead to new types of contracts which has created new prerequisites and demands for construction managers, designers and contractors. The shift to contractor and subcontractor design in combination with shorter time schedules implies that the traditional approach of dealing with risks must change (Clayton 2001b).

According to a survey conducted by Clayton (2001b) there has also been an apparent shift in contract arrangements in the construction industry. Traditional pre-design contracts have been replaced by methods such as "design-and-build" and other arrangements decided by the client. This means that a great part of the design probably will be subcontracted in the future which implies that the final design will not be decided until late in the design process. As a consequence, the following factors are required in order to provide a more certain outcome in a fragmented construction environment:

- High-quality communication.
- A team approach to problem-solving.
- An integrated total project process.
- A risk-based approach to construction management and design.

How the contracting method affects the allocation of the responsibility for risk factors between the actors have been discussed in the literature by for example Gordon (1994) and Kveldsvik & Aas (1998), Tengborg (1998), Clayton (2001b) and Isaksson (2002). Gordon (1994) describes four aspects that characterise the construction-contracting method. These are scope, organisation, contract and award. The scope is the portion of the project tasks that are assigned to the contractor, which are design, construction and/or finance. The part with whom the client enters a contract is the organisation, e.g. a general contractor, design-build team or turnkey team. The contract is the arrangement of payment between the client and the contractor, such as lump sum, unit price or cost plus. The award is the method used to choose the contractor and/or the price, for example by competitive bidding, negotiation and price proposal.

Tengborg (1998) discusses the distribution of the risks regarding the type of contract and compensation. Different forms of contract lead to more or less risk, responsibilities and commitment for the client and the contractor, see figure 3.3. Two extremes of the distribution of the risk are illustrated; a general building contract where the client takes on a large part of the risks and a design-and-build contract where the contractor takes on the major part of the risks. The distribution of risks is somewhere between these in other types of contracts.

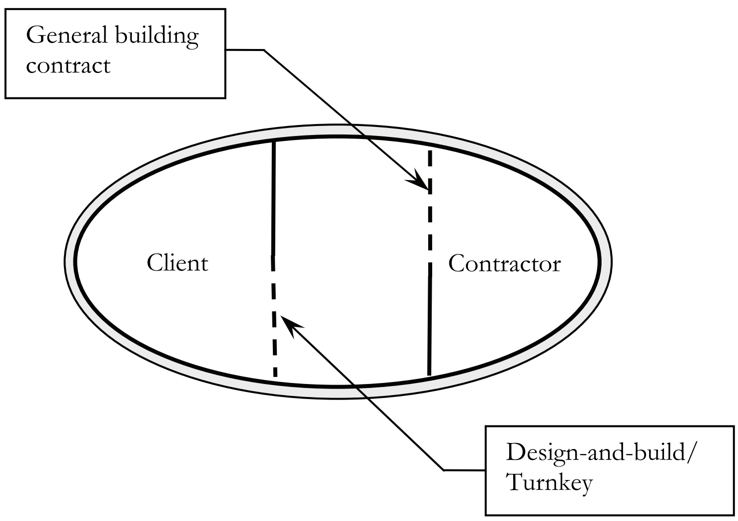

Figure 3.3 Distribution of risks due to the contractual arrangements (after Tengborg 1998).

The distribution of risks involved in the construction process for some commonly used types of contracts are illustrated in figure 3.4.

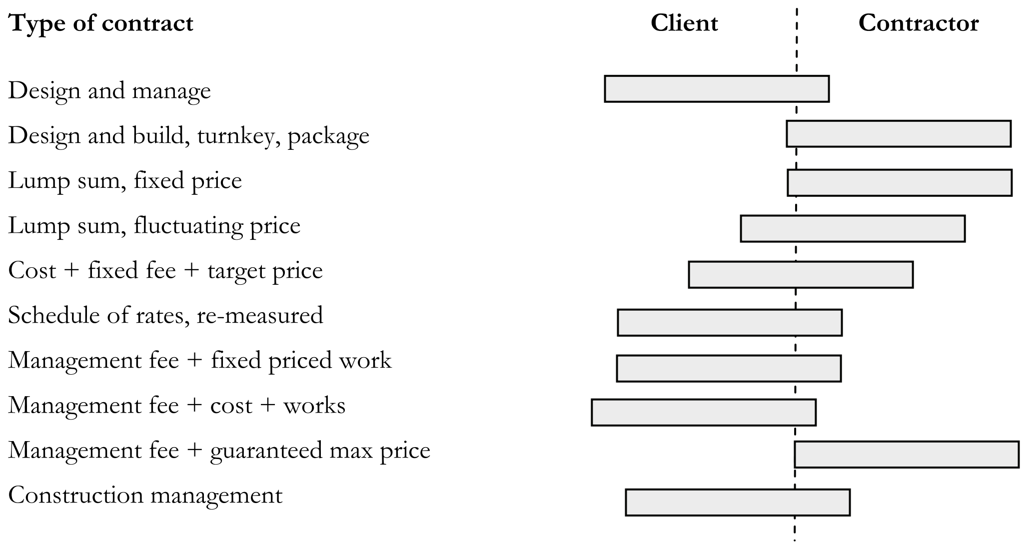

Figure 3.4 Risk sharing between the client and the contractor depending on the type of contract (Flanagan & Norman 1993).

Kveldsvik & Aas (1998) have described how the project cost is influenced by the risk distribution between the client and the contractor, se figure 3.5. The minimum project cost is then obtained when "the Norwegian practice" of risk sharing is used. Though, this is highly subjective statement with no proof available.

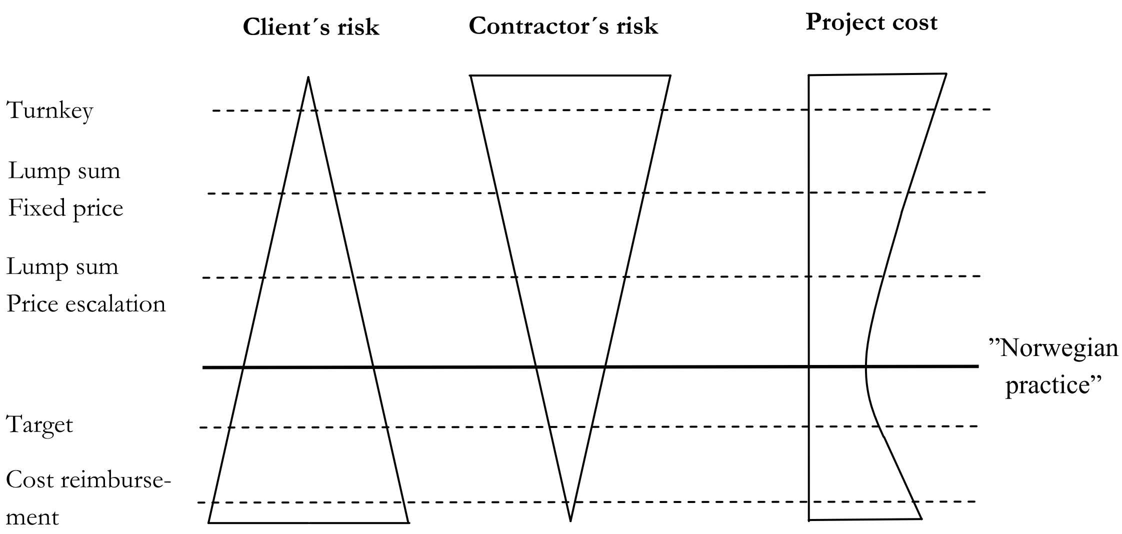

Figure 3.5 Risk sharing influencing project cost (Kveldsvik & Aas 1998).

The contract should distribute the risks, responsibilities and engagements in a fair way and with a direct connection between work and compensation. In order to design the contract in a proper way, it is important to identify all the risks and hazards before the contract is established. The contract should regulate all imaginable deviations and changes which can arise during the project execution, especially deviations from the geotechnical conditions which often are disputable (Tengborg 1998).

If the risks are not adequately distributed in the contract, claims and disputes may be some of the consequences during construction (Reilly et al. 1996). The contractors may also add high contingencies to their tenders to cover the costs of identified hazards and risks. Furthermore, it is important that all parties have an identical understanding of the risks, as risk contingencies in a tender generally increase the tender price or extend the time schedule, or both. The contract should aim at foreseeing and answering any contingency arising from the original prerequisites eliminating any future discussion over regulation of construction time or costs (Charoenngam & Yeh 1999).

However, there is always a conflict of interest involved in a project. For the contractor, the general goal is to execute a project which maximises the profit over a long time period. The risks for the contractor are often considered to be severe after the contract is signed as the contractor's responsibilities and engagements then are fixed. On the other hand, the general goal for the client (or building proprietor) is to get a specified product or function with a given quality to the lowest price possible, "maximum value for money". The risks for the client are largest in the early planning phase, before the funding is set and a contractor is contracted, and in the operation phase of the project. This conflict of interest will normally make the risk distribution difficult and in combination with the fact that no actor will take on risks for free.

Traditionally, disputes concerning geotechnical matters have been settled either by litigation or by arbitration. According to Turner et al. (1999), there are signs that these methods, nor those involving adjudication, mediation or expert determination, are particularly satisfactory. Negotiation is perceived to be the best method of dispute resolution, but it is of course better to avoid disputes if possible. Using an agreed model of the geotechnical conditions can provide a sound basis for negotiation when separate contracts are used for design and for construction. The joint appointment by all actors to a contract of a "disputes review board" or a "geotechnical advisory panel" to advise independently on the technical merits of a dispute may also help to speed up dispute resolution, thus saving considerable time and money (ASCE 1989).

Partnering and term contracting are also finding favour with major client bodies, who are also increasingly restricting their tender lists in order to make their supply chain management more effective. Such arrangements make rapid and effective dispute resolutions more likely in the event that unforeseen problems occur, since construction companies are likely to take a longer business view (Nyström 2005). However, these arrangements do not offer a totally effective geotechnical risk control, since clients may pay an unreasonable high price for asking construction companies to take an unquantifiable or uncontrollable risk.

3.5 Methods for Project Risk Management

As been stated before, infrastructure projects generally involve major risks and uncertainties due the geotechnical conditions, high technical level, long planning and execution times, complex distribution of responsibilities etc. Furthermore, these projects often involve innovative, but uncertain, technologies. Risk analysis and management of risks in the construction industry is still mainly dependent on intuition, judgement and experience. Formal techniques for analysis and management of risks are seldom used due to a lack of knowledge and to doubts on the suitability of these techniques for the construction industry (Akintoye & MacLeod 1997). However, because of the risks and uncertainties involved in many projects the use project management with a risk perspective, i.e. project risk management, has grown in the construction industry in recent years. The main objective of these methods is to gain insight into the principal sources of uncertainty in cost and time (Bedford & Cook 2003).

The risk management process should start prior to the start of a project and should be repeated throughout the lifetime of the project (Hintze 2001). This allows incorporation of experiences and acquired knowledge into the project and keeps the risk profile updated. A project risk analysis can be a helpful aid already in the bidding process as it identifies and quantifies the hazards, uncertainties and risks in a project. The analysis gives the management knowledge of the risks that need to be considered in the contract or in insurance and financial arrangements. A well-performed risk analysis in the bidding phase is also a valuable for a company in deciding a bid. As been mentioned before, all risks can not be foreseen but when a risk analysis has been performed the odds are at least known.

The aim of this section is to review some of the different methods that can be used in project risk management in geotechnical engineering. The reviewed methods were selected with the aim of showing some different types of methods which have the potential of managing geotechnical risks in infrastructure projects. Some of the methods are though more widely applicable. There are, however, several more methods of project management that incorporate, more or less, risk management than those presented here. These are described elsewhere in the literature, see e.g. Cooper & Chapman (1987), Thompson & Perry (1992), Bedford & Cook (2003) and Chapman & Ward (2004b).

3.5.1 The Risman Method

The Risman method was developed for infrastructure projects in the Netherlands, such as railway and road projects. The method is a typical example of the way in which risk management is applied in these kinds of projects (Rijke 1997 and Bedford & Cook 2003). The method includes one or several of the following steps:

- Identification of uncertainties and countermeasures.
- Quantification of uncertainties and countermeasures.
- Calculation of project risk.
- Calculation of the effect of countermeasures.
- Decision-making and risk handling.

The first step, identification of uncertainties and countermeasures, is usually performed in qualitative terms and can be separated from the rest of the steps. The uncertainty is generally divided into normal uncertainties (i.e. uncertainties with natural variability), special events (i.e. events with small probability and large consequence) and plan uncertainties (uncertainties due to the fact that the project will be affected by decisions in the future).

For the uncertainty identification a so called "project uncertainty matrix" is used. This matrix is divided into different sections which correspond to different phases of the project and has four columns; aspect, cause, consequence and countermeasures. By aspect is meant the area in which the uncertainty is located, e.g. the technical, organisational or financial area. The cause indicates the characteristics of the uncertainty and how it appears. The consequence specifies the possible effect of the uncertainty, e.g. in time and cost. The countermeasures are the actions that can be performed in order to reduce the probability that an adverse event will occur and/or mitigate the consequences of that event. These activities commonly include technical, organisational, financial and legal measures.

The quantification of uncertainties and countermeasures is often based on expert judgements as adequate data often is missing since most projects are unique. For normal uncertainties a continuous distribution is often determined using expert judgement. The triangular distribution is frequently used an approximation. For special events and plan uncertainties it is generally more difficult to quantify the uncertainty but some estimation of the risk can be done in most situations, e.g. by the use of expert judgements.

The time for completion and the costs of an infrastructure project are largely determined by the so called critical path of the project. Therefore, the risks that are associated with the activities on the critical path are considered to be especially important. The calculation of the project risk can then be calculated by a combination of the critical path method and simulation techniques, e.g. Monte Carlo simulation, if the different work activities are described in statistical terms. In the critical path method the project is simulated as a series system since the various parts of the project are interdependent as one part can not start before the earlier parts are finished. The interdependence is usually illustrated in a network diagram, see figure 3.6 where A, B, C, etc. are work activities and S is the start of the project.

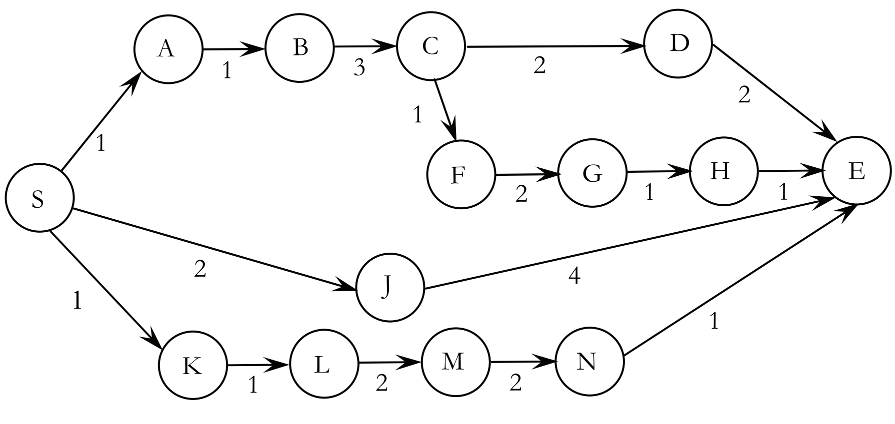

Figure 3.6 A simple network diagram with required times for completing the work activities (Bedford & Cook 2003).

The critical path is the sequence of work activities through the network with the longest times required to complete the project. The critical path is a set of activities determining the completion time and can be determined by a so called roll-forward-roll-back algorithm. Each node in the network is here described by a set of times $\{c_n, l_n\}$ where c_n is the time required for completing activity n and l_n is the latest time at which activity n can be completed. If activity m directly precedes activity n, i.e. $m \rightarrow n$, and f_n is the first time at which activity n can be completed then the relationship between c_n and f_n is:

$$f_n = c_n + \max\{ f_m | m \rightarrow n \}$$

Thus, f_n is calculated by taking the maximum of the first completion times for the nodes before it in the net and the add the completion time of the current activity. This iterative process starts at the first node and is called the roll-forward algorithm.

The roll-back algorithm calculates l_n which is the minimum of the latest completion times for the nodes after it in the net having first subtracted the completion times of those activities, as:

$$l_n = \min\{ l_m - c_m | n \rightarrow m \}$$

Obviously, $f_n \le l_n$ for all n. Figure 3.7 shows the result of the roll-forward-roll-back algorithm for the example in figure 3.6.

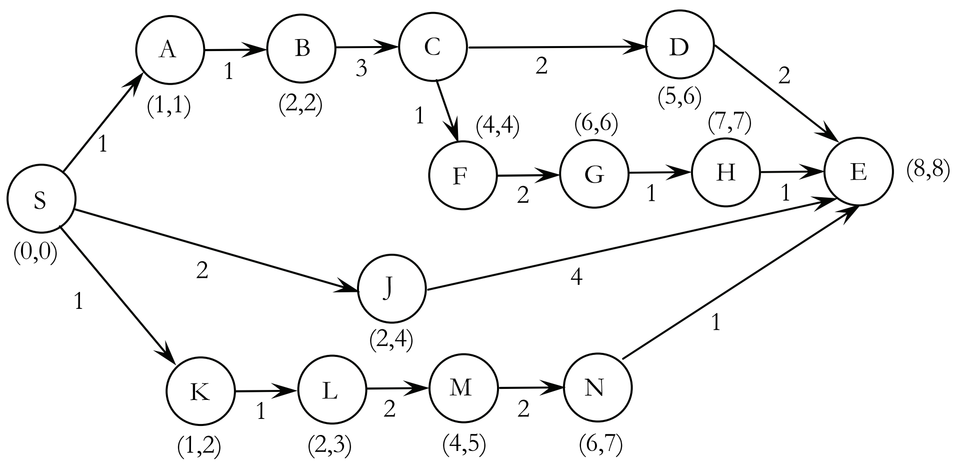

Figure 3.7 Critical path resulting from the roll-forward-roll-back algorithm (Bedford & Cook 2003).

As can be seen from figure 3.7, there is only one path through the network in which $f_n = l_n$. This is the critical path and determines the total completion time of the project. Of course, there can be several critical paths.

The times and cost required for completing an activity are generally not known by certain, but can be modelled as probability distributions assigned by e.g. expert judgement. Then the critical path will also be a distribution. A useful risk management method to rank the activities is the critical index, which is the probability that an activity will be in the critical path. When the correlations between the activities are modelled, a Monte Carlo simulation can be used to simulate the distribution of completion times and project cost.

3.5.2 Risk Budget Management in Progressing Underground Works

Risk budget management in progressing underground works and is a way to manage project risks in a structured manner presented by Arends et al. (2004). As construction works in general, and civil engineering works in particular, require a long planning phase linked with extensive public coordination, several risks can be addressed in the planning phase. In order to minimise the time and cost of the project it is important to have identified points, so called milestones, at which decisions shall be checked by independent experts. The works can reasonably be expected to be completed on time schedule and at an economical and acceptable cost only when the risks involved are exposed and when a plan to manage them exists.

The risk budget management process divides the construction process in five different risk phases. The risk phases include different portions of the total risk with a heavy bias of risk towards the early phase, see figure 3.8. The figure also shows at which times the project shall be reviewed by independent project auditors working equally for the client and the contractor. In this way, the risks can be controlled and managed. The same auditor can perform the review in phase 1-3 and 4-5.

In the model of risk budget management, the costs that affect the decision-making are divided into direct costs and indirect costs. Direct costs are defined as those costs that are incurred directly for the execution of the project. These costs are largely determined by the construction cost and are dependent on the task at hand, the construction method, the prerequisites and the risks associated with these. Costs for tendering, planning, design, project management, financing and insurance are examples of direct costs.

Indirect costs are those costs that are incurred by those affected by the project and not usually the client. These costs are generally difficult to quantify and can not always be expressed in financial terms. Examples of indirect costs are costs due to changes in geotechnical conditions, the impairment of traffic flow and the impact on the environment.

To ensure a clear distinction between the risk borne by the client and the contractor, Arends et al (2004) suggests that every bidder should be required to submit a risk analysis including a risk evaluation and a risk allocation with the bid. Furthermore, the bidders should price their actions to manage the risks as well as the quality-assurance of the project. Examples of details that need to be agreed on are the quality, the quality guarantee, definition of force majeure and the responsibility for the construction geotechnical risk. A transparent presentation and discussion of the risks is considered to avoid subsequent disputes and the possibility of overprices subsequent quotations.

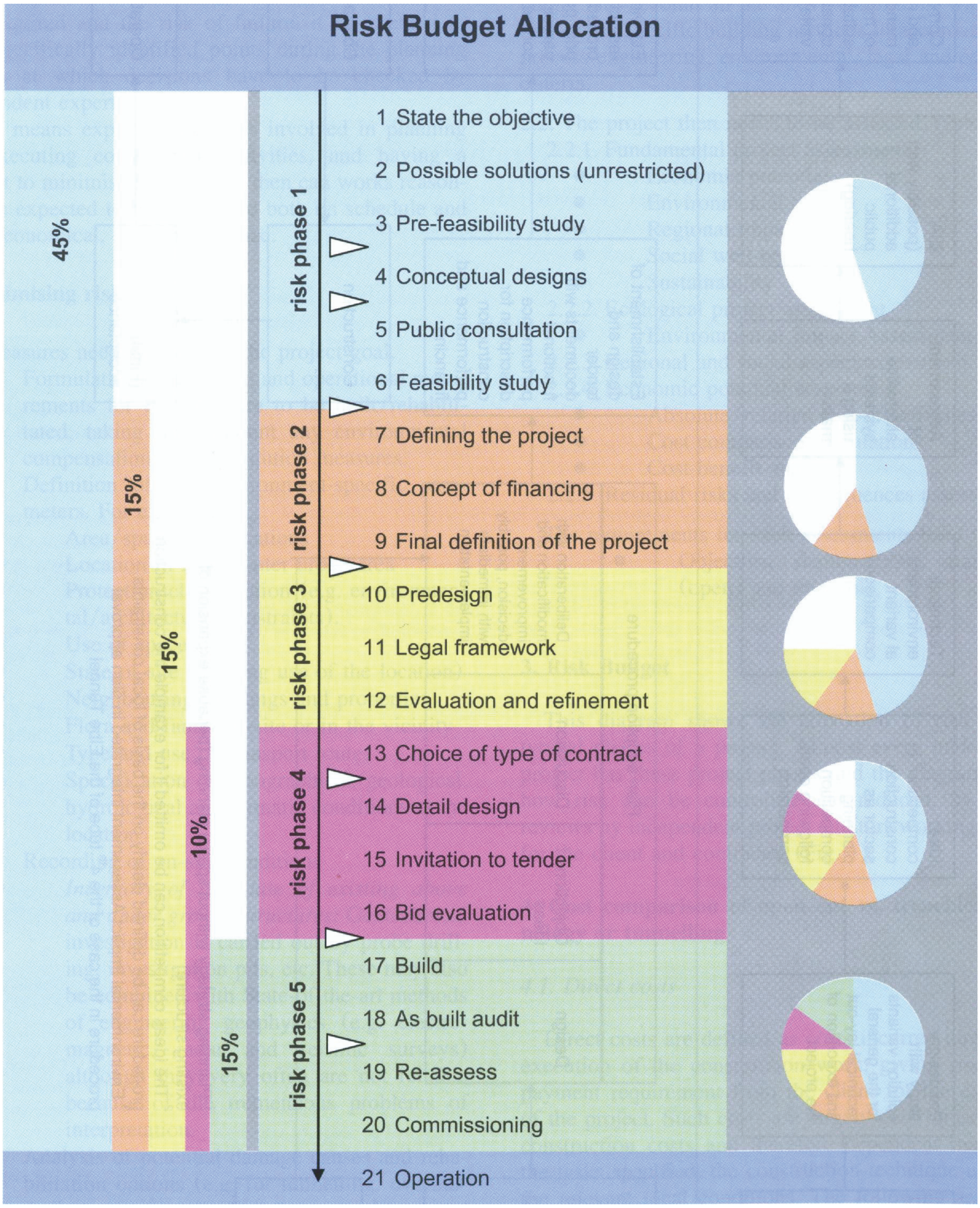

Figure 3.8 *The process of risk budget management (Arends et al. 2004).*

3.5.3 Risk Analysis and Management of Projects (RAMP)

RAMP provides a method to enable a structured and consistent analysis of risk within projects to be carried out effectively (Lewin 1998). RAMP is basically similar as PRAM (Project Risk Analysis and Management) which was published in the year of 1997 by the Association of Project Management. However, while PRAM describes a number of techniques for risk identification, risk analysis and risk management and the practical use of these, RAMP has a more strategic view of risk management and focuses on financial implications.

RAMP can be applied either at a strategic level or as a detailed analytical and control process. The process covers the entire life of a project from initiation to closedown. The method emphasises the overall picture of the project rather on the physical asset alone. The components of the RAMP approach are shown in figure 3.9.

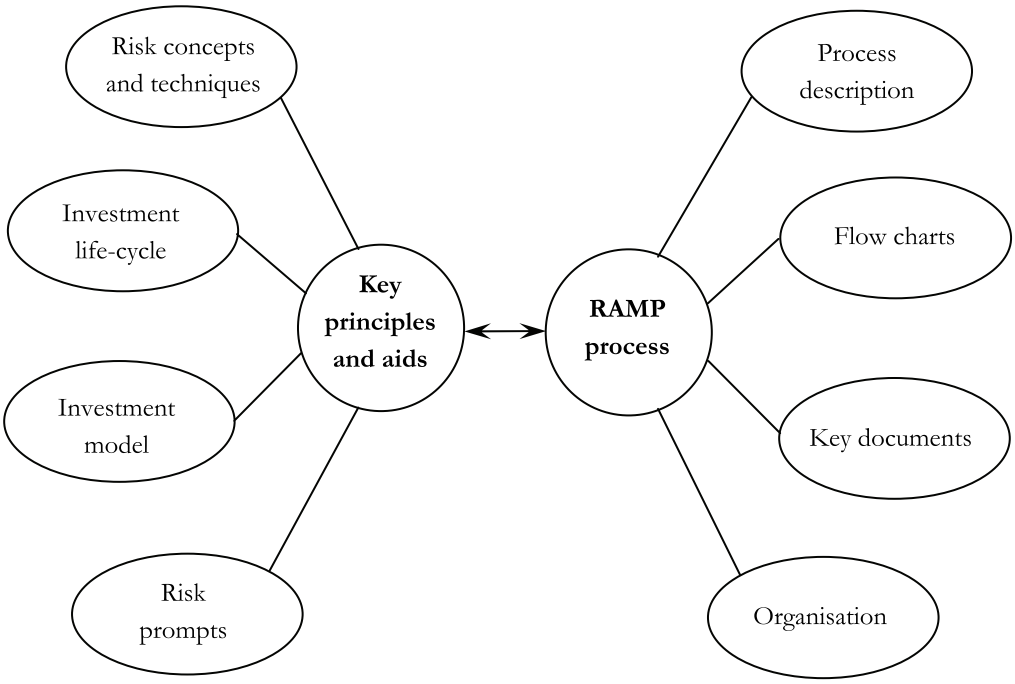

Figure 3.9 Components of the RAMP approach (Lewin 1998).

The main activities in the method are *process launch, risk review, risk management* and *process closedown.*

In the *process launch* step the risk management process is implemented, fundamental objectives, scope and plans for the project are defined as well as the underlying assumptions on which these are based. The process launch phase consists of:

(i) Plan, organise and launch the risk management process including
   - confirm perspective,
   - appoint risk process manager and team,
   - define investment brief,
   - determine timing of risk reviews,
   - decide level and scope of the risk management, and
   - establish a budget for the process.

(ii) Establish baseline, covering
   - objectives and key parameters of investment,
   - baseline plan, and
   - underlying assumptions.

In the *risk review*, key stages or decision points are defined in order to systematically identify the risks. The risks are typically entered into a risk register. Subsequently, the likelihood and consequences of the identified risks are evaluated and the relationships between them are identified. Finally, risk handling actions are identified to avoid, mitigate or transfer risk. These actions are incorporated into a risk handling strategy. An investment model is the used to estimate the overall risk and viability of the project. Assuming the project is not aborted, a risk response plan is then prepared. The risk review phase consists of:

(i) Plan and initiate risk review.
(ii) Identify risks.
(iii) Estimate risks.
(iv) Devise measures for handling risks.
(v) Assess residual risks and decide whether to continue.
(vi) Plan response to residual risks.
(vii) Communicate risk handling strategy and response plan.

The *risk management* phase incorporates the risk review into the ordinary management of each phase in the life of the project by implementing the risk handling strategy and the risk response plan. The work activities and other events are monitored to identify new or changing risks. Designated individuals are charged with managing the risks. The risk management phase consists of:

(i) Implement strategies and plans, including

- Integrate with the ordinary project management.
- Manage the agreed risk handling initiatives.
- Report changes.

(ii) Control risks, including

- Ensure effective re-sourcing and implementation.
- Monitor progress.
- Continually review and categories trends.
- Identify and evaluate risks and changes.
- If necessary, initiate full risk review again.

The *process closedown* is a retrospective review of the investment in terms of its success in meeting its objectives and the effectiveness of risk management process in contributing to the outcome. The process closedown phase consists of:

(i) Assess investment outturn, covering

- Results against original objectives.
- Risk impacts with those anticipated.

(ii) Review the process, including

- Effectiveness of process and implementation.
- Experiences for the future.
- Possible improvements.
- Communication of results.

As can be seen, the structure of the RAMP process is on a fundamental level similar to the risk management process presented in figure 2.3 in chapter 2. The RAMP process is also an iterative process consisting of continual risk review and risk handling.

3.5.4 The Observational Method

The observational method or the active design method has been proposed for a cost effective and safe working practice in geotechnical engineering and especially in complex projects including risks and uncertainties, see e.g. Terzaghi (1961), Terzaghi & Peck (1967), Peck (1969), Baecher (1981), Bredenberg, Stille & Olsson (1981), Ladd (1991) and Powderham (2002a & 2002b). According to Eurocode part 7, the use of the observational method can be appropriate in complex projects when it is difficult to predict the geotechnical behaviour.

The method has its origin in a program for a cost-effective and safe execution of geotechnical works which was formulated for the first time by Terzaghi in 1961. This program consisted of eight parts (Terzaghi 1961):

(i) The extent of the site investigations should be enough to obtain a general overview of the geological and hydrological conditions.

(ii) Assessment of the most probable geotechnical conditions and the most negative deviations from these that can be expected.

(iii) Design on the basis of the most probable geotechnical conditions.

(iv) Determination of the parameters and phenomena which should be measured during the project execution and the expected values of these.

(v) As in point (iv) but on the basis of the most negative deviations from the most expected geotechnical conditions.

(vi) Establishment of a plan of action for every imaginable deviation from the expected ground conditions and behaviour of the structures.

(vii) Continuous measurements of the identified parameters or phenomena during the execution of the project.

(viii) Modification or re-design on the basis of the measurements.

Thirty years later Ladd formulated the observational method in three parts in a similar way as Terzaghi (Ladd 1991):

(i) Choice of design parameters:

- The designer chooses key parameters that should be measured continually during the execution and predict expected values of these on the basis of performed investigations. Appropriate action programmes are established which is used if the measured values is different from the predicted.

(ii) Monitoring:

- The monitoring shall be performed in right time so reliable measurements of the key parameters are obtained.

(iii) Evaluation of measurements:

- The designer evaluates the results from the monitoring in order to assure that the actual conditions are not different from the expected.
- If the actual conditions are different from the expected, the planned actions are carried out.

The observational method includes a continuous process of prognosis of acceptable limits and range of behaviour, observations of key quantities, analysis of observed quantities and actual conditions and corrective actions that have been decided in advance. By the use of simulation methods, e.g. Monte Carlo simulation, the probability that the actual behaviour will be within the acceptable limits can be calculated (see e.g. Olsson & Stille 2002). A simulation can also give the probability distribution of an observed quantity, which can be used as a basis for design of a monitoring system and for updating the predicted behaviour. The working procedure includes in general the following steps (Olsson & Stille 2002):

(i) Find those damage objects that are to be protected.

(ii) Determine the target values, alarm thresholds and critical limits for those functions.

(iii) Identify the damage events and the initiating events that can disturb the functions.

(iv) Design a plan of corrective actions before the work starts.

(v) Monitor the key parameters, i.e. warning bells, in order to recognise the identified damage mechanisms and initiating events.

(vi) Take corrective actions if necessary.

(vii) Re-evaluate the design in the light of the monitored key parameters.

The corrective actions generally take some time to be implemented and to be effective. It is therefore necessary that some time, "lead time", elapse between the time when the alarm threshold and the critical limit is reached. Different stress-strain relationships, e.g. ductile or brittle failures, lead to different lead times as shown in figure 3.10. The time required for corrective actions to be set up influence the design of the monitoring system. The alarm threshold can therefore be defined from the time necessary for implementing the corrective actions and the time for the corrective actions to prevent the critical limit from being exceeded. The target value should be based on the prognosis of the actual behaviour and reflect the expected value of the measured quantity. It is important that the target value, the alarm threshold and the critical limit are set under careful considerations and are clearly distinguished between. Arbitrary set values tend to undermine the monitoring system and the perception of the risk.

The extent of a monitoring system is influenced by several factors, e.g. the probability and consequence of the potential damage events and the cost of the system components and measurements. The appropriate and cost-effective extent of a monitoring system can be decided by the use of decision tree analysis, see Stille et al. 2003.

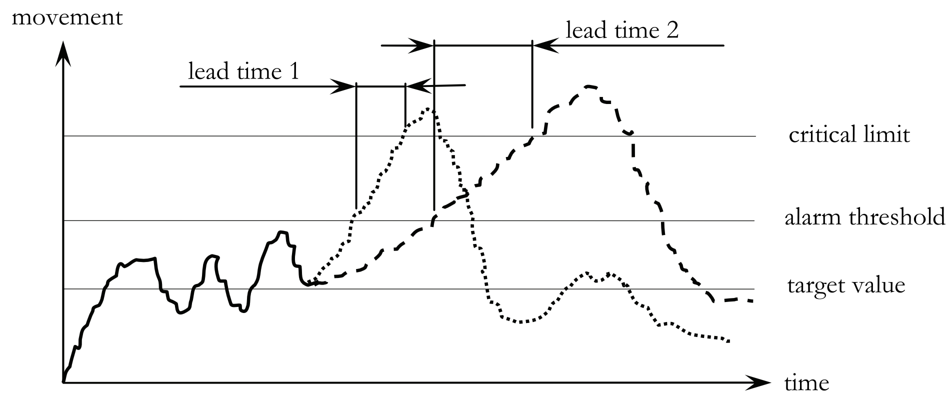

Figure 3.10 Alarm thresholds and lead times for two different stress-strain relationships A and B (after Paté-Cornell & Benito-Claudio 1987).

In order to make a prediction of potential events and phenomena, estimate lead times and to determine appropriate corrective actions and to design the monitoring system, a model of the systems and problems involved must be established (see figure 3.11). Different types of systems, e.g. series or parallel systems, loading situations and stress strain relationships lead to different lead times, damage events and corrective actions. Furthermore, the measured values are often affected by errors and/or bias in the measurements or the interpretation of the measurements. The relationship between the measured values and the alarm thresholds must therefore be established.

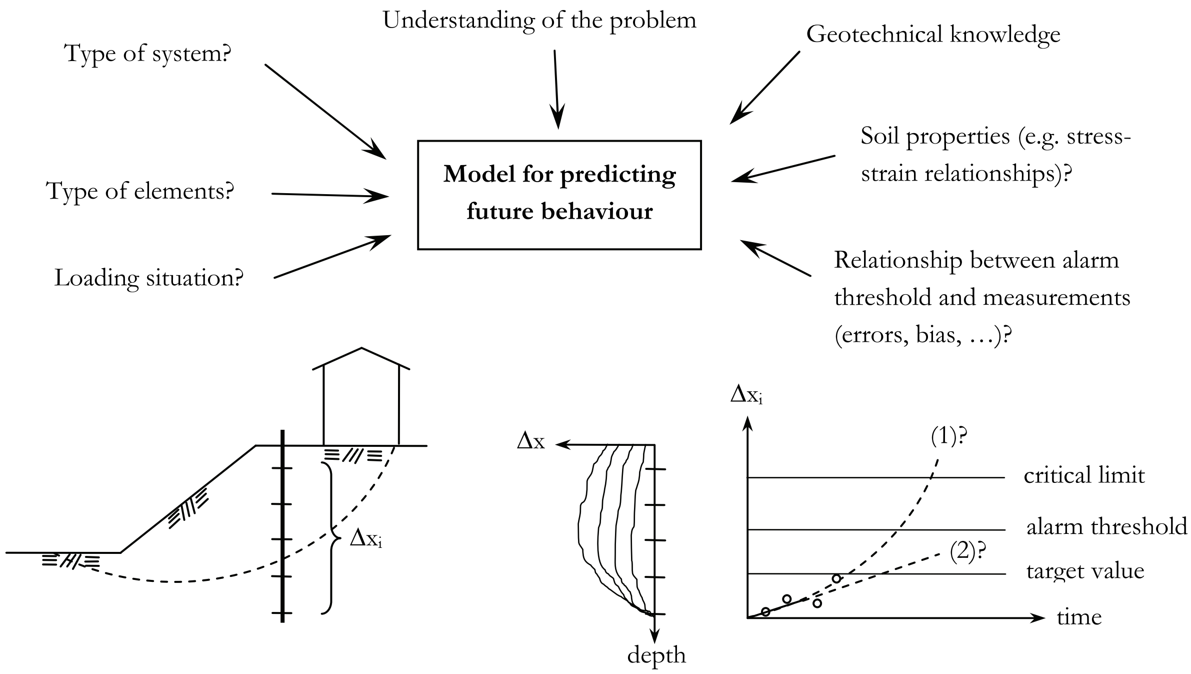

Figure 3.11 Model for predicting future behaviour in order to decide corrective actions and alarm values (modified after Olsson & Stille 2002).

3.5.5 PROPS

One way of making the project work, the quality work and the risk management in a stringent and structured way is to use a well-defined project model. PROPS is a project model developed and used by the Ericsson Company Group since 1994 and described by Stille et al. (1998). The project is here considered as a process with a continuous flow of work activities. When every significant work activity is completed and a pre-defined milestone is reached, a toll gate is stopping the work. The toll gate is working as a control point aiming at ensuring that the latest activity has been performed appropriately and that adequate information and experience have been passed on to the next work activity. The control can be performed by individuals within the project or by an independent review team.

A distinction is made between the general project model, the project work model valid for a specific object and the actual project work. The quality work and the risk management should be a part of the project work and not a control function parallel with the actual work. The quality work and the risk management are connected to the work activities within the project. The use of toll gates and milestones are important, see figure 3.12.

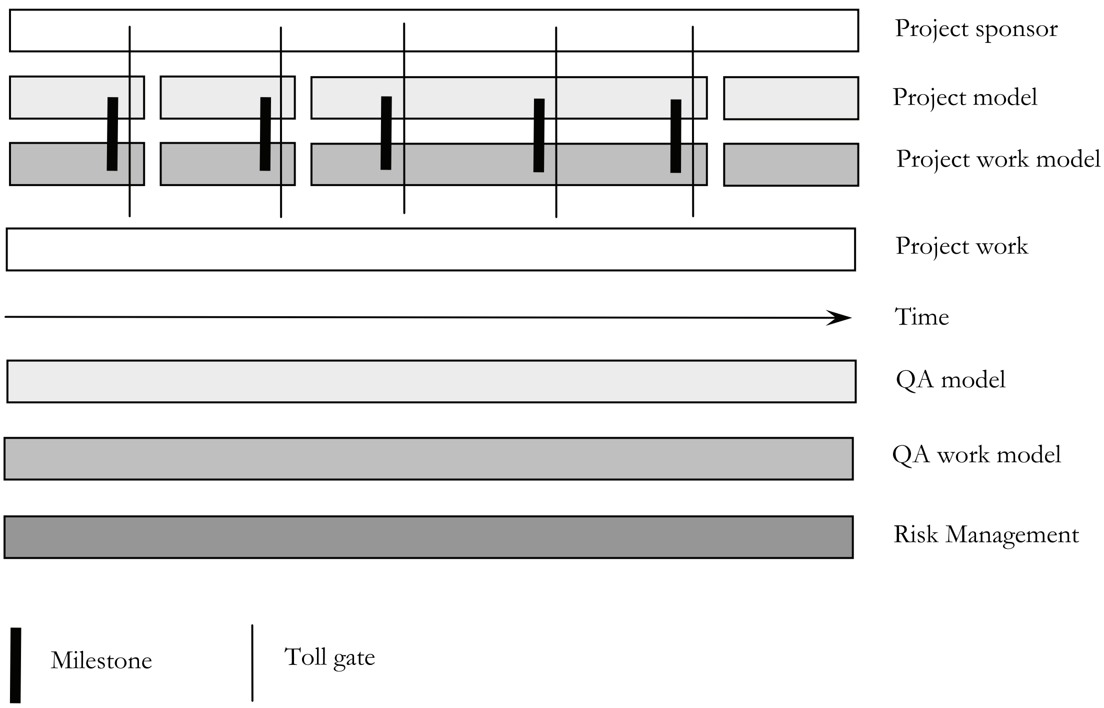

Figure 3.12 Project model, based on PROPS, and QA-model (Stille et al. 1998).

The risk management process and the quality work should be closely linked to the project organisation with the aim of creating a continuous control of quality and environmental impact throughout the entire project, see figure 3.13. The management tools in this process are the risk management process and the quality system. This requires that the responsibilities and authorities in the organisation are clear, well-defined and known in the organisation (Hintze 2001).

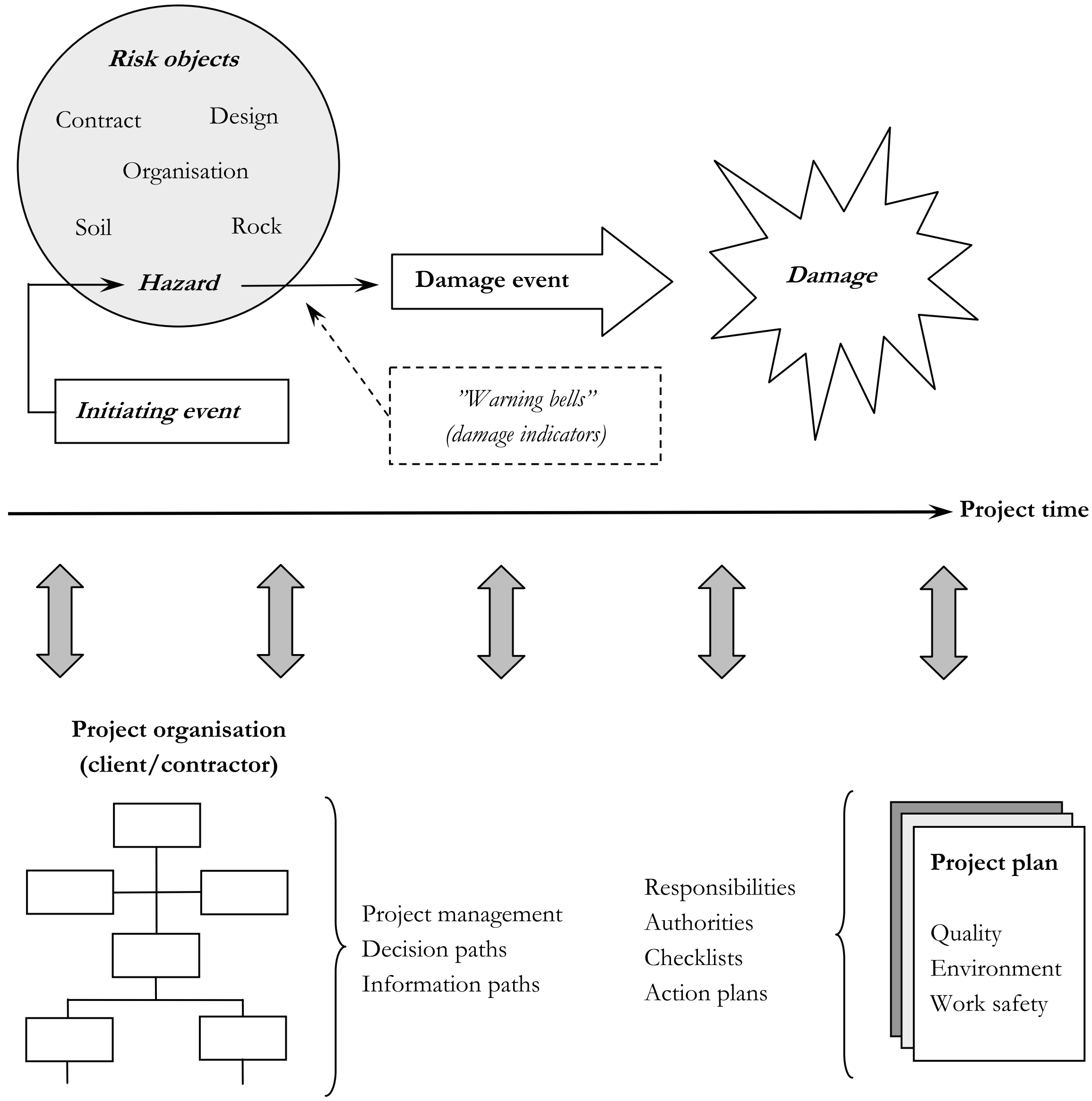

Figure 3.13 The link between the risk management and quality control (Hintze 2001).

3.5.6 Management of Innovation Projects

For a successful execution of complex high-technological civil engineering projects Engwall recommends that the project should be executed as an innovation project and not as, traditionally, an implementation project (Engwall 2002).

The traditional idea of project management emphasises control and is based on a belief that all necessary knowledge can be obtained before the projects starts and that this knowledge can be incorporated into a specification of or goal description for the project (Tjäder 2000). This is generally possible in an implementation project which is defined as a well-known and stable project where the pre-knowledge and the goal description are complete (Obeng 1995). In an implementation project the main task is to exploit existing knowledge in an effective way as all the knowledge of the project content is obtained during the preparations. The extent of the project is on the other hand fixed during the execution of the project. The only additional knowledge that is obtained during the execution is the knowledge of different methods of production (Engwall 2002).

However, if the pre-knowledge is incomplete, as in most civil engineering projects, the specification and the goal description of the project only have limited signification for the actors involved. Experience and knowledge obtained during the project execution are then required to make the specification and goal description meaningful and complete. The knowledge of the meaning of the project management evolves during the project even if the original formulation of the project is unchanged (Obeng 1995). The main differences between an innovation project and an implementation project are summarised in table 3.4.

Table 3.4 Characteristics of an implementation and an innovation project (Engwall 2002).

	Implementation project	**Innovation project**
Pre-knowledge	Complete	Incomplete
Project goal	Exogenous the project work	Endogenous the project work
Acquisition of knowledge	During planning	During planning and execution
Main result	Final product	Final product, knowledge of the goal and the process of reaching the goal
Rationality	Effective project execution	Adequate knowledge for the project

In an innovation project, the distinction between the preparations and the execution is not distinct. On the contrary, the knowledge of the extent of and the conditions for the project gradually increase during the execution. Therefore it is important to have contingency plans in order to handle the genuine uncertainty that arise due to changing prerequisites of the project. Additionally, an important issue is to create opportunities for a learning environment to create appropriate knowledge and experience during the project work (March 1991).

This implies that the knowledge about the identified hazards and risks involved increases during the project as well. This increased knowledge can be used to reduce the risks, either by reducing the probability or the consequence of the unwanted event or by transferring them to a part outside the project. There are at least two fundamental types of innovation projects. These are projects that include knowledge growth of the outcome of the project and projects that develop knowledge of the realisation process through their execution.

Additionally, Engwall (2002) argues that the characteristics of different types of projects are often not recognised today due to the traditional rhetoric of projects as implementation projects. In addition, the function of traditional project management tools as the financial budget and the time schedule require that the goal and scope of the project do not change too much during the project execution. As an example the authors discuss the tunnel project through the Hallandsås ridge in Sweden, which has experienced severe time delays and cost increases, in these terms. This project is considered to be a mixture of the two fundamental types of projects mentioned above due to the well-known construction method in combination with the difficult and unique geotechnical conditions, e.g. high water pressures in combination with soft and fractured bedrock.

However, like the tunnel project through the Hallandsås ridge, most projects probably have parts that can be characterised as innovation project and parts which can be described by implementation projects. Furthermore, a project can be an innovation project for one individual and an implementation project for another depending on the knowledge and experiences of that individual.

Nonetheless, in both cases it is important that the organisation is flexible enough to utilise the new information that evolve in the project in order to handle the uncertainties and the risks and that working procedures for this exists. It is also important that the information paths, responsibilities and authorities are comprehensible, definite and familiar in the entire project organisation.

3.6 Conclusions

Project risks management is about how to deal with risks and uncertainties in a project environment during execution of a project. The fundamental objective of project risk management is to identify and avoid or exploit risks and hazards before they are realised since these will undoubtedly affect the execution and success of the project. The project performance will also be significantly influenced by the distribution of the risk between the actors involved in the project. In order to study these topics, the chapter included a literature review dealing with risks, hazards and uncertainties in geotechnical engineering, risk sharing and methods for project risk management in geotechnical engineering.

Project risks can be defined in similarity with the definition of the word risk in chapter 2 with the addition that the risk affects the objectives of the project. Project risk can therefore be defined as a combination of the probability of an event and its consequences for project objectives. Project risks can affect many aspects of a project, for example cost, time schedule, quality, health and safety of the workers, the public and the environment. Project risks result from the combination of a hazard and vulnerability. A hazard is here something with the potential to do harm and vulnerability is those factors that determine the likelihood that a hazard will have unfavourable consequences. Central concepts in the process from hazard to damage are risk object, hazard, initiating event, warning bell, damage event and damage object. These concepts and the meaning of these are, however, often used with different meanings in different situations, but it is recommended that a stringent nomenclature is used in the context of risk management in order to avoid misunderstandings. The result of a project is dependent on an understanding of the risks, hazards and uncertainties involved in the project.

Geotechnical risks can be defined as the risks to building and construction due to the geotechnical conditions. Geotechnical risks have influence on, for example, the technical, financial and contractual parts of a project as well as the project management. There are several reasons why geotechnical risks often affect the outcome of an infrastructure in a severe way. These are both due to the special nature of the ground, e.g. pre-determined properties with large variability, and the characteristics of many geotechnical works, e.g. work activities connected as a series system. Geotechnical risks have to be managed systematically if significant problems are to be avoided.

Uncertainty arises due to the lack of knowledge and experience and there are many types of uncertainty in a large infrastructure project. These are caused by, for example, insufficient or adequate information of included parameters or models, unfamiliar techniques or locations, lack of experience or competence and unforeseen changes in scope and prerequisites. Furthermore, many phenomena, processes and events in geotechnical engineering include some form of inherent randomness and heterogeneity, i.e. the outcome is to some extent unpredictable. The uncertainties in geotechnical engineering can on a fundamental basis be categorised into scenario uncertainty, conceptual model uncertainty and data uncertainty.

In order to estimate the impact of the uncertainties it is necessary to quantify them. Both the model and data uncertainty may be expressed in statistical terms. However, when dealing with uncertainties in an infrastructure project traditional statistical methods are not always appropriate due to the fact there rarely are adequate data series to base the analysis on. Then other methods must be applied. Often it is possible to fix the parameter within some boundaries, e.g. the quartiles and the mode, and then assign a distribution, e.g. a triangular distribution. It is also possible to use subjective assessments by expert opinions as well as judgements based on experience and knowledge in a specific area and the available information.

The distribution of the risk between the actors involved in a project will have significant influence on the project performance. The distribution of the risks is usually governed by the contract between the parts involved. In addition, procurement methods have important implications for the risk management. Regardless the method of procurement and the form of contract, risks will be best managed when risk analysts representing all the actors concerned are brought together as early as possible in the project.

Methods of procurement in the building industry have changed during the last decades. The traditional arrangement with a single consultant engaged for design and supervision of the work is used less frequently today. Instead, more competitive and time-restricted conditions have lead to new prerequisites and demands for construction clients, designers and contractors. There has also been a shift in contract arrangements in the construction industry. Traditional pre-design contracts have been replaced by methods such as “design-and-build” and other arrangements decided by the client. Consequently, the traditional approach to construction and risk management should be modified.

The contract should aim at distributing the risks, responsibilities and engagements in a fair way and with an obvious connection between work and compensation. The part that takes on a risk should be given reasonable compensation for it. In order to design the contract in a proper way, it is important to identify as many hazards and risks as possible before the contract is established. The contract should regulate all imaginable deviations and changes which can arise during the project execution. If the risks are not adequately shared in the contract, claims and disputes may be some of the consequences. However, there is always a conflict of interest involved in a project which will make the distribution of risks difficult.

Civil engineering projects generally include large risks and uncertainties. Furthermore, these projects often involve innovative, but uncertain, technologies. Because of the risks and uncertainties involved in many projects, the use of a project management with a risk perspective, i.e. project risk management, has grown in the construction industry in recent years. Several methods of project risk management are presented in the literature. In the thesis some of these are illustrated. These are the Risman Method, Risk Budget Management, RAMP, Observational Method, PROPS and Management of Innovative Projects.

The fundamental objective of these methods is to gain insight into the principal sources of uncertainty in cost and time and to create opportunities to manage the risk in a systematic and effective way in order to ensure a cost-effective product with the adequate quality. The risk management process should start prior to the start of a project and should be updated throughout the life-time of the project. This gives an updated risk profile which allows the incorporation of experience into the project, new opinions of experts and new technical developments.

4 Case Studies

In this chapter case studies of the management of geotechnical risks in three recently executed infrastructure projects are presented. The review of the case studies is essentially based on a literature review of the projects. The case study consists of:

- The South Link Road Construction, contract SL10, in Sweden.
- The Delhi Metro System, contract MC1A, in India.
- The road tunnel under the fjord Hvalfjörður on Iceland.

The chapter reviews some examples of methods for management of geotechnical risks used in executed projects today and some decision situations which illustrate the complexness of infrastructure projects. The aim of the chapter is to distinguish deficiencies and areas for improvements in the employed methods of risk management as well as identifying the key tasks of the actors which governs a successful management of geotechnical risks. These shortcomings and factors of success are discussed in the next chapter. The experiences and conclusions regarding the risk management process made in each project are summarised in each section. The chapter is ended with some general conclusions from the case studies.

The case studies were selected since they are projects including different types of civil engineering works and, thus, different types of geotechnical risks and decision situations. Furthermore, they manage the geotechnical risks in slightly different ways.

4.1 The South Link Road Construction, contract SL10, Sweden

4.1.1 Project Description

The South Link Road Construction (Södra Länken) is a part of the ring road around Stockholm consisting of an extensive system of urban tunnels in the south part of Stockholm, the capital of Sweden. The road construction is approximately six kilometres long, whereof 4.5 kilometres in tunnels. The length of the tunnels including access and exit ramps is 17 kilometres. It connects the two busy approach roads into Stockholm, the Essinge Link in the west and the Värmdö Link in the east, see figure 3.1. The construction work began in 1997 and was concluded in 2004.

The site of SL10 was located in Årsta and included a 460 meter long underground structure including approximately 40 metres of rock tunnel and a cut and cover concrete tunnel. Parts of the tunnel were supported by piles and other parts were founded on soil or bedrock. Therefore, extensive excavation has to be carried out before the tunnel was built in some parts. Distinguishing work activities in the project were the temporary structures including steel sheet piling, deep excavations, blasting, water infiltration systems and stability measures for temporary roads and the monitoring. The works at SL10 started in 1997 and was concluded in 2001. The client was the Swedish Road Administration (Vägverket) and the contract was a design-and-build contract.

Figure 4.1 The South Link Road Construction project in Stockholm (Hintze et al. 2000).

An important part of the project was the temporary structures required for the excavation for the tunnel. In the tender documents the excavation was proposed to be carried out inside supported diaphragm walls due to the restrictions regarding movements of adjacent buildings and the ground water condition. However, the contractor chose to use supported steel sheet pile walls instead of diaphragm walls. The requirements from the client to minimise any lowering of the groundwater level and the settlements in the surroundings in combination with the soft clay, required watertight structures with high stiffness in combination with an extensive monitoring program. For the design, a methodology based on the observational method with predictions of deformations using a finite element program together with a comprehensive monitoring system was used.

The temporary structure for the housing of a fourteen-storied residential block called Asplången was a special challenge to the designers. The excavation was here around 16 metres deep and the distance between the sheet pile wall and the buildings was 2.5 metres at the minimum. The client had specified a total allowable settlement of maximum 50 millimetres of the buildings. Moreover, anchors were not allowed to penetrate the piled foundation of the existing buildings and the allowed vertical pressure from the sheet piles on the bedrock was limited. In order to reduce the ground water flow under the sheet pile walls and in the bedrock, the soil and bedrock under the walls was grouted with cement. Several design alternatives for the sheet pile walls were evaluated.

For these reasons, struts were judged to be the best way of supporting this part of the retaining wall and a jack was inserted at every strut to measure and/or adjust the force in the struts in order to influence the deformation scenario. The concrete tunnel was built in two halves so that the tunnel walls could be used as supports, see figure 4.2. Before the installation of the sheet pile walls started the existing building was underpinned as a first preventive step to avoid damage.

Figure 4.2 The sheet pile wall with supporting system of struts and anchors at the residential block Asplången (Carlsson et al. 2004).

Some aspects of the project have earlier been presented by Hintze (2001), Hintze (2002a), Nordström (2002) and Carlsson et al. (2004). Experiences from design, monitoring system and geotechnical measurements during the construction have been reported by Hintze et al. (2000).

4.1.2 Geotechnical and hydrological conditions

The soil strata mainly consisted of fill material above a thick layer of soft clay on top of a thin layer of granular soil or dense moraine above the bedrock. The soil strata reached its maximum depth in the central part of the working area and had there a total thickness of approximately 25 metres. At greater depths, the soil shifted from clay to silt and sand close to the bedrock. The bedrock, in this area, consists of gneiss with a surface layer mainly of hard unweathered granite. The groundwater table was close to the ground level.

4.1.3 Risk Management

Before the South Link Road Construction project started, the client was aware of that the whole project should be considered as high-risk project due to the complicated nature of the project, e.g. the difficult soil and rock conditions and the ground water situation in the area, the deep excavations in soft clay and the tunnelling, the location in an urban area, heavy traffic inside the working area, busy adjacent roads and the public, political and environmental focus. Therefore, risk management and safety issues had a distinguishing feature in the entire project. The risk management process in the project was mainly executed with a similar methodology as been presented in chapter 2, according to figure 4.3.

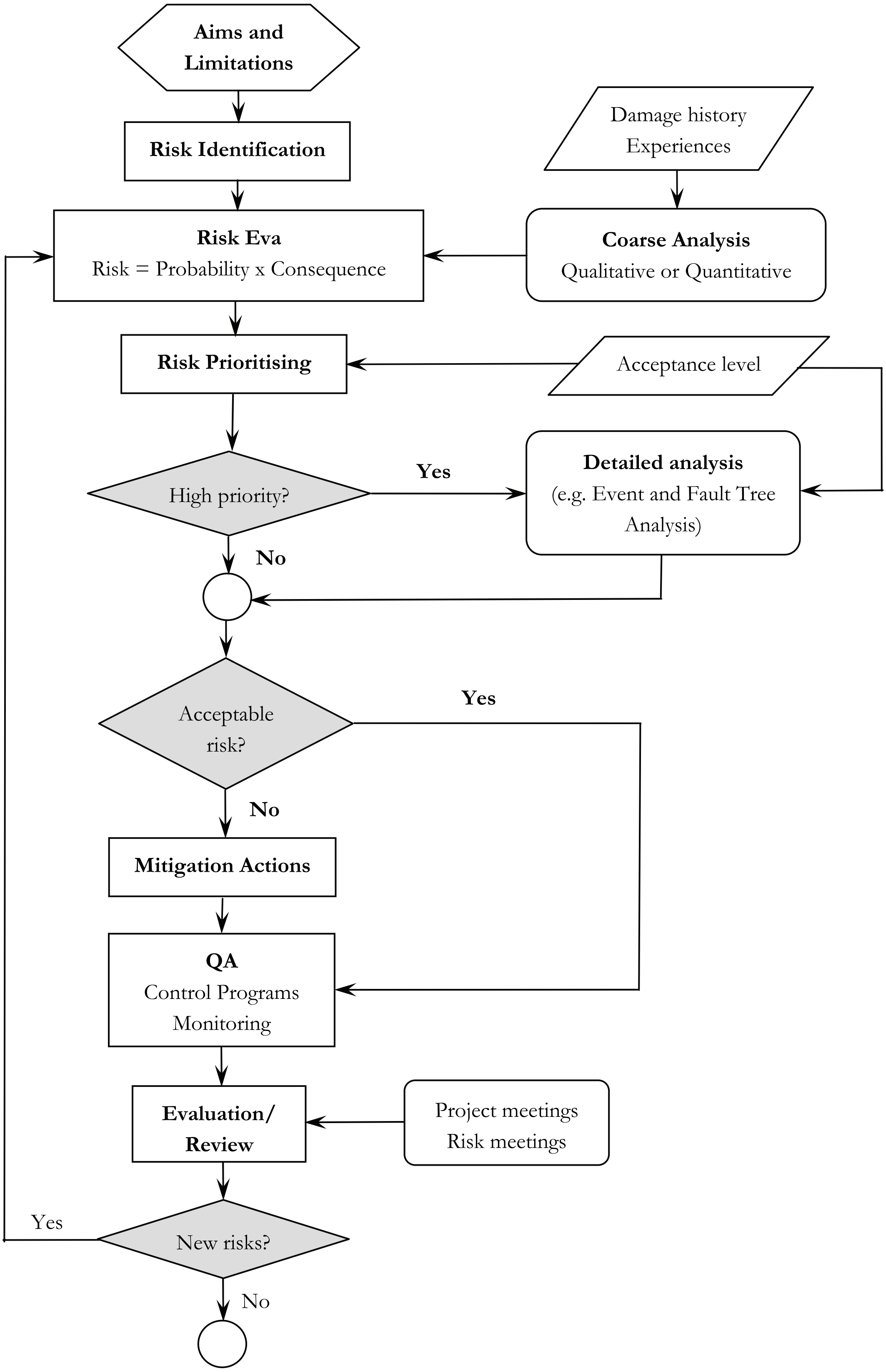

Figure 4.3 *The risk management process in the South Link Road Construction (Swedish Road Administration 2002).*

The tender and design phase

In the tender phase, a project plan according to SS-EN ISO 9000 was established by the contractor. The plan included a description of responsibilities and authorities for the identified key roles in the project. Furthermore, the plan described chains of decisions and information in the project.

Furthermore, a risk analysis was performed in an early phase of the project. The risk analysis was performed with the aim of being an effective tool for identifying and handling risks, as it should help the project staff not only to handle risks but also to consciously address the actual handling of risks. The underlying thought was that a better understanding of the hazards and the process from the hazards to the actual damage was going to lead to a more cost-effective execution of the project.

The risk management process started by reading the tender documents and specifications of the project. Thereafter, site visits and meetings with the client were conducted. Risks related to geotechnical and environmental issues were then studied. Risks related to traffic in the site area, the temporary structures and adjacent buildings were studied on site and in an extended study.

The risk analysis provided the framework and the tools in order to understand the risks in the project through a description of the process of events which could lead to some kind of damage. Furthermore, the risk analysis described the initiating events that could trigger a realisation of a hazard, see figure 4.4. This process has earlier been discussed in section 3.1.

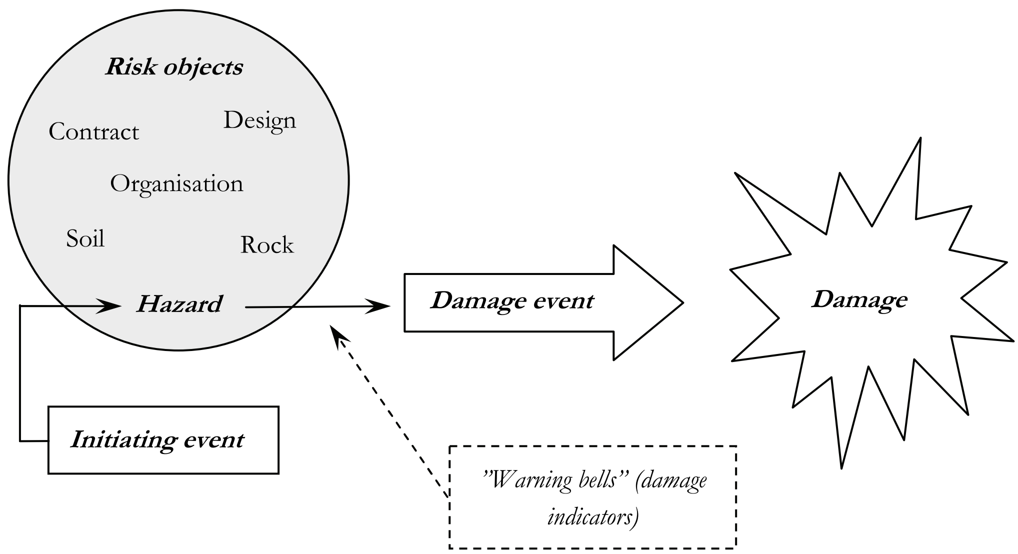

Figure 4.4 The process from initiating event to damage (after Sturk 1998).

In the design phase, the risk analysis focused on geotechnical and environmental risks as well as the management of the project organisation in relation to the design commitment. Well-planned communication and the transfer of adequate quality-assured information were identified to be the key factors to carry out the project successfully.

In the design phase, the risk management process included the following factors:

- Identification and prioritisation of hazards and risk objects.
- Identification of damage events.
- Identification of initiating events for the most crucial hazards.
- Estimation of the associated risk.
- Identification of warning bells with the aim of detecting initiating events and damage events.
- Identification of risk handling actions, i.e. preventive and/or mitigation actions.
- Planning and preparation of critical decisions.
- Description of critical work activities.
- Preparations for the assessment of damage events.
- Planning for a separate inspection of the critical activities by an independent review team.

The nine most crucial hazards that were identified in the design phase were:

(i) The groundwater level in the surroundings outside the sheet pile walls.

(ii) The groundwater level inside the sheet pile walls.

(iii) The sheet pile wall close to the residential block "Asplången".

(iv) The sheet pile wall close to the railway line "Snabbspårvägen".

(v) The struts between the sheet pile wall and the tunnel at "Asplången".

(vi) The sheet pile wall in an area where the piles could not be driven down to the bedrock.

(vii) A water pipe crossing the excavation pit close to "Asplången".

(viii) A large sewer pipe crossing the excavation pit.

(ix) The blasting works close to the adjacent buildings.

These hazards were gathered in risk registers depending on their characteristics and origin. The risk registers included information of the damage event, the observations and initiating events, the risk handling actions and the risk owners that should be contacted in the event of an alarm.

The risk register for the hazard "the groundwater level in the surroundings outside the sheet pile walls" is illustrated in table 4.1.

Table 4.1 Risk register for the hazard "The groundwater level in the surroundings outside the sheet pile walls" (after Hintze 2001).

Damage event	Observation	Initiating events	Mitigation action	Contact persons
1. Settlements in the soil strata due to lowering of the groundwater level.	1.A.1 Alarm via the piezometers in the monitoring system.	1.B.1 Water leakage through the sheet pile wall.	1.C.1 Contact the geotechnical engineer in charge.	Geotechnical engineer, phone no:
	1.A.2 Alarm via the settlements gauges in the monitoring system.	1.B.2 Leakage through old bore-holes, via piles etc.	1.C.2 Stop the flow of water through the sheet pile wall.	Project manager, phone no:
		1.B.3 Leakage through the blasted rock surface.	1.C.3 Increase the infiltration of water.	Client, phone no:
		1.B.4 Leakage through the jet grouted soil under the sheet pile walls.		
		1.B.5 Interruption in the infiltration system		
2. Flooding in the basements due to rising groundwater level.	2.A.1 Alarm via the piezometers in the monitoring system.	2.B.1 Too much infiltration of water.	2.C.1 Reduce the infiltration of water.	
	2.A.2 Alarm via the settlements gauges in the monitoring system.			
	2.A.3 Local heave of the foundation base.			

Another hazard that was identified was the sheet pile wall close to the residential block Asplången. A failure of the sheet pile wall was judged to be disastrous even though the building has been underpinned before the work started as a preventive action.

The risk register for this hazard "The sheet pile wall close to the residential block Asplången" is shown in table 4.2.

Table 4.2 Risk register for the hazard "The sheet pile wall close to the residential block Asplången" (after Hintze 2001).

Damage event	**Observation**	**Initiating events**	**Mitigation action**	**Contact persons**
1. Failure of the sheet pile wall.	1.A.1 Visible deformation of the wall. 1.A.2 Measurements of the sheet piles show deformation. 1.A.3 Alarm via the settlements gauges in the monitoring system. 1.A.4 Alarm via the inclinometers in the monitoring system. 1.A.5 The anchor jacks show an increase in the anchor forces. 1.A.6 Settlements in adjacent buildings.	1.B.1 Excavation for the wale beams. 1.B.2 Installation of anchors or struts. 1.B.3 The surface load outside the wall is too large.	1.C.1 Stop the excavation and fill back the soil. 1.C.2 Install an extra anchor or strut. 1.C.3 Unload the sheet pile wall.	Geotechnical engineer, phone no: Project manager, phone no: Client, phone no:
2. One or more anchors/struts fail.	2.A.1 The anchor jacks show an increase in the anchor/strut forces.	2.B.1 Excavation for the wale beams. 2.B.2 Installation of anchors or struts. 2.B.3 The surface load outside the wall is too large.	2.C.1 Stop the excavation and fill back the soil. 2.C.2 Install an extra anchor or strut. 2.C.3 Unload the sheet pile wall.	
3. Failure of the bracing of the footing of the sheet pile wall due to water leakage and subsequent erosion.	3.A.1 Local heave of the foundation base. 3.A.2 Lowering of the ground water level.	3.B.1 Excavation for the wale beams.	3.C.1 Stop the excavation and fill back impermeable soil material. 3.C.2 Install hoses for subsequent grouting. 3.C.3 Reduce the water infiltration.	
4. Anchor/strut failure due to ground frost.	4.A.1 Alarm via the inclinometers in the monitoring system.	4.B.1 Water leakage between the sheet pile wall and the soil.	4.C.1 Heating of the wall.	

The risks were not quantified in monetary terms. The risk estimation was done qualitatively and the risks were grouped into different categories. The categories regarding the probability were denoted 1-3 and the classes regarding the consequences 0-3. The categories for the consequences were different for different groups of consequences, e.g. personal damage, environmental damage, damage on property, claims and interruptions and time delays. The total risk was then calculated according to a formula which calculated the different risks with different weights for the consequences depending on the priority of the risks. This approach made it difficult to compare different types of risks. Furthermore, this way of risk estimation made it not possible to estimate the total cost for all the risks involved in the project.

The preparation and planning of critical decisions and work activities were sometimes performed rather arbitrary and not in a systematic and well thought-out way. The different decision alternatives were not identified and examined in some situations and the expected consequence of each decision alternative was not evaluated. The risk analysis aimed at being the basis for the risk decisions and the risk handling actions, but in reality it never was (Hintze 2001).

A decision situation which was especially challenging was the decisions regarding the type of support for the sheet pile wall close to the residential block Asplången. Here, the application system and reliability analyses were an important tool in the decision situation regarding the choice of the type of supporting system, see Olsson (1998) and Carlsson et al. (2004). Struts or anchors could support the wall and the choice between these was judged to lead to different risks.

In the decision analysis, two damage events were identified; wall failure and damage on the pile foundation of the adjacent building due to installation of the wall. The consequence for the first event was considered to be severe, as it would result in major damage on the adjacent building. The consequence of the second event was considered to be less severe, as it would result in settlements of the building. A separate risk analysis was performed in order to evaluate the probability of damage for the different methods of supporting the wall. The aim of the risk analysis was to make a comparison between the two alternatives and not to calculate the exact probability of failure for them. The identified initiating events for the damage event "sheet pile wall failure at Asplången" were (Olsson 1998):

- Collapse of the temporary sheet pile wall due to damage on struts or anchors.
- Incorrect construction.
- Incorrect blasting.
- Incorrect excavation.
- Fire.
- Collision, e.g. by an excavator.
- Damage caused by human actions.

The probability of damage on struts and anchors was estimated by the use of a quantitative fault tree with roughly estimated probabilities of failure for each initiating events. The result for the alternative with a supporting system of struts is shown in figure 4.5.

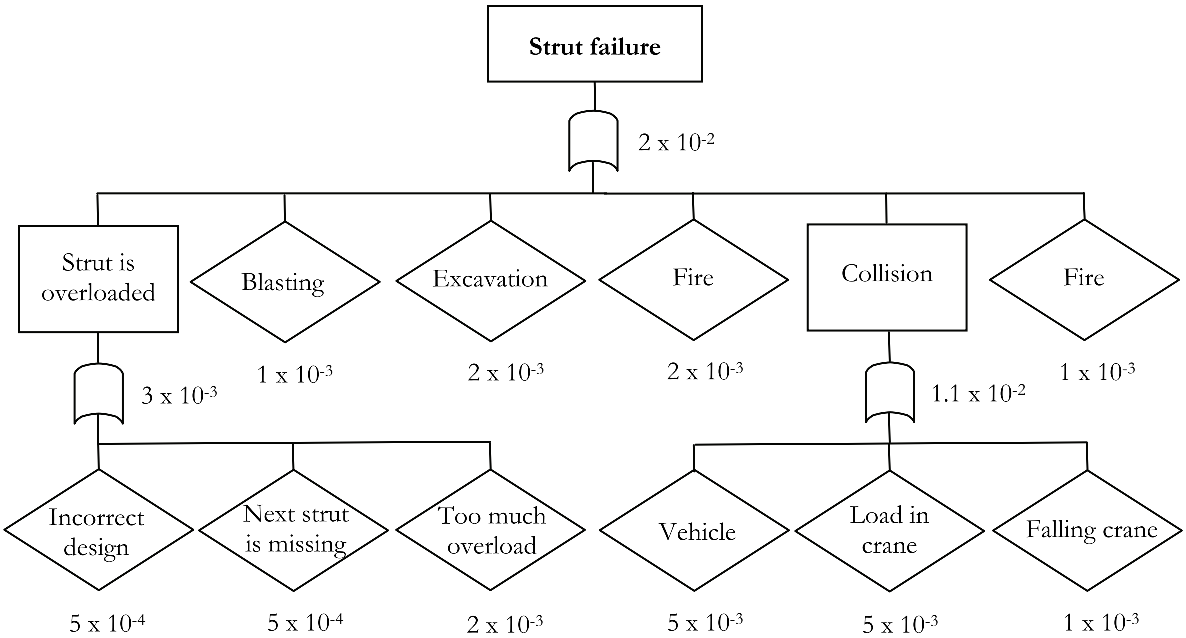

Figure 4.5 Fault tree for the damage event "Strut failure" (after Olsson 1998).

Thereafter, an event tree was established assuming that one strut or anchor has failed in order to get a connection between the estimated probabilities in the fault tree and the probability of different degrees of damage on the adjacent building. The event tree for the alternative with strut failure is shown in figure 4.6 assuming that strut failure has occurred.

The concluding result of the analyses was that the probability of sheet pile wall failure was three times higher with struts than with anchors. This is mainly due to the fact that the struts are exposed to impact in a larger degree than the anchors. Furthermore, the probability of a limited damage on the adjacent building was almost equal for the two alternatives. The probability of major damage or total collapse of the building was around ten and five times higher for the strut alternative respectively. This is partly because the wale beam and the anchors are designed to be able to withstand a loading case where one anchor has lost its capacity according to Swedish practice. When using struts, the wale beam and the struts are not designed for this load situation. This means that the two systems are different and that the system with anchors is more robust. See section 2.3.1 in this thesis and Carlsson et al. (2004) for a discussion about system analysis of these two supporting systems.

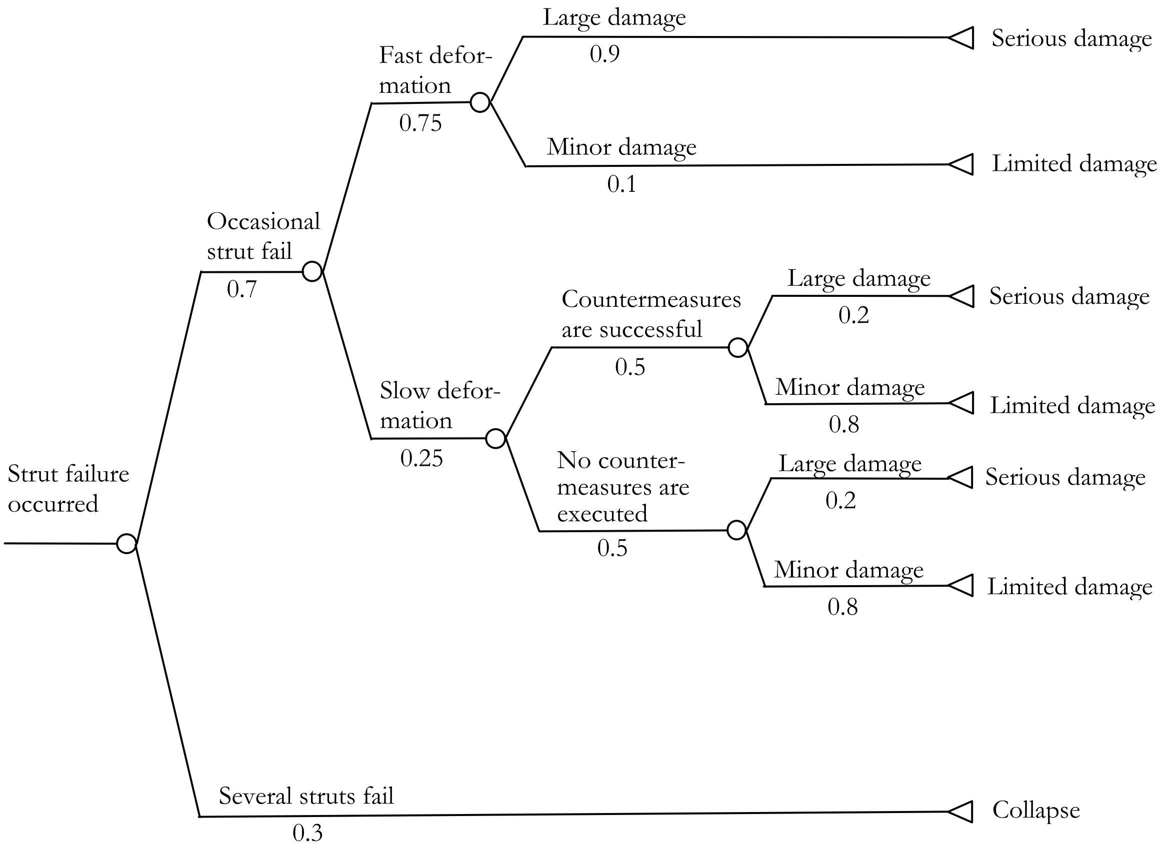

Figure 4.6 Event tree for damage on residential block "Asplången" assuming that strut failure has occurred (after Olsson 1998).

In order to handle some of the identified risk some mitigation actions were performed before the actual work began. As been mentioned before, underpinning of the adjacent building Asplången was performed as a preventive action in order to reduce the consequence of the risk for damaging the building. Furthermore, a jack was inserted at every strut to make an adjustment of the deformation scenario possible. This could be used both as a preventive action and to reduce the consequence.

During the design phase, the project plan was updated with information that was included in the contract, e.g. extent of and points of time for important meetings such as technical meetings and risk meetings.

The construction phase

The results from the previous phases in the risk management process were implemented in working procedures and control programs in the beginning of the construction phase. This was considered to be especially important for all the activities that had been identified as critical for the success of the project, such as risk communication, risk handling actions, monitoring and the follow-up of the risks.

The risks and the future work activities were communicated to the residents close to the working area on regular meetings every second week. These meetings were considered to be a success since few complaints were received and the public opinion of the project remained good along the entire project. Here it was important to adapt the characteristics of the information so that the receivers, i.e. the public, could understand and exploit the information as have been discussed in section 2.6. Furthermore, since the transferring of information generally arouses associations among the people involved, it was clear that the information of the risks and forthcoming work activities had to be unambiguous and easy to understand.

Pre-planning of the work activities was considered to be of great importance in order to manage the risks. A meeting was held between the responsible geotechnical engineer, the project manager and the workers involved before the start of any critical activity. At these meetings the geotechnical engineer and the project manager informed of the hazards, the initiating events and the associated warning bells which had been identified in the activity at hand. A project model similar to PROPS, discussed in section 3.5, was used for the project management and quality-assurance in the project. Furthermore, a review team of independent experts in different areas was assigned to audit the project performance and the risk management in a procedure similar to the procedure illustrated in figure 2.4. Toll gates were placed on the drawings and in the working procedures as well as in the project plan together with the corresponding milestones.

However, some decisions had to be taken in a rush when they came into question due to arbitrary preparation and planning of some critical decisions. Therefore, the optimal decision alternative could not be chosen in some situations (Hintze 2001). Furthermore, due to the limited knowledge of the decision alternatives and system analysis in some situations there were disagreements on the most appropriate decision alternatives occasionally, e.g. regarding the type of supporting system for the sheet pile wall close the residential block Asplången discussed in the previous section. Here, the client was hesitant about the installation of anchors under the adjacent building due to the risk for settlements and damage on the pile foundation. On the contrary, the contractor wanted to install anchors instead of struts, since anchors were judged to involve less risk for damage on the building according to the previous discussion. These differences in opinion were probably due to different views of the system analysis and resulted in decision problems.

Calculations of expected deformations for different excavation stages in the soil were undertaken with a finite element program based on a statistical analysis for different cross sections of the tunnel. Deformation curves with upper and lower limits for the deformations in the retaining wall as well as for the forces in anchors and struts were generated, see figure 4.7. The calculated upper and lower value was used as target values and the maximum estimated magnitude for the deformations was set to be the critical value and the alarm value.

Observations of warning bells and initiating events were performed continuously during the entire construction phase. Observations of the behaviour of the soil and the structures according to the control program were performed with the aim of verifying the design and the construction material properties. The monitoring system was based on the risk analysis and the design specifications and measured the identified warning bells and initiating events. There were different levels of control and measurement issues in the control program. However, the warning bells and the identification of initiating events were considered to be the most important factors for a safe and efficient execution of the project.

The monitoring system was used during the construction phase in order to measure settlements, anchor and strut forces, deformations of the sheet pile walls and the pore pressures in the soil within the working area. The monitoring system was an automatic system which registered data from the gauges, piezometers, inclinometers etc. continuously.

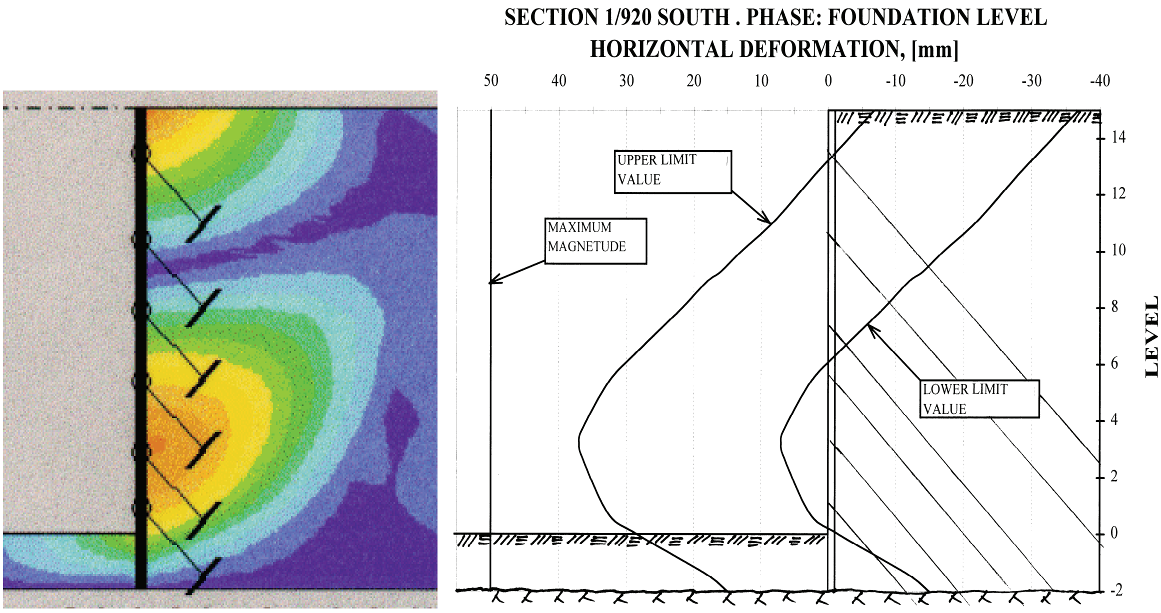

Figure 4.7 Alarm thresholds and critical limits for the horizontal deformation of the sheet pile wall in section 1/920 south (Hintze 2001).

The result of the measurements from the monitoring system were continuously compared with expected values as well as with the upper and lower limit values in order to control if any corrective actions were necessary. The data were discussed with the client on geotechnical meetings every second week. If the observations did not correspond to the prognosis an analysis of the reasons was conducted and in advance prepared corrective actions were undertaken so that the deformations would not exceed the maximum levels stated in the contract. A special meeting with the client was also set up. The working procedure was similar to the observational method which has been discussed in section 3.5.4. The results from the monitoring were however not used in order to update the risk profile of the project and the project plan.

In the evaluation of the measurements, no distinction was made between alarm thresholds and critical values and the focus was principally on individual values and not on trends. As a consequence, it was difficult to decide the right time for the corrective actions to be undertaken, see figure 4.8. Depending on the stress-strain relationship, it could be too late to undertake the corrective actions when the alarm threshold was exceeded, see curve (1) with a short lead time, or the corrective actions could be unnecessary, see curve (2) which have a decreasing trend and never exceeds the alarm threshold.

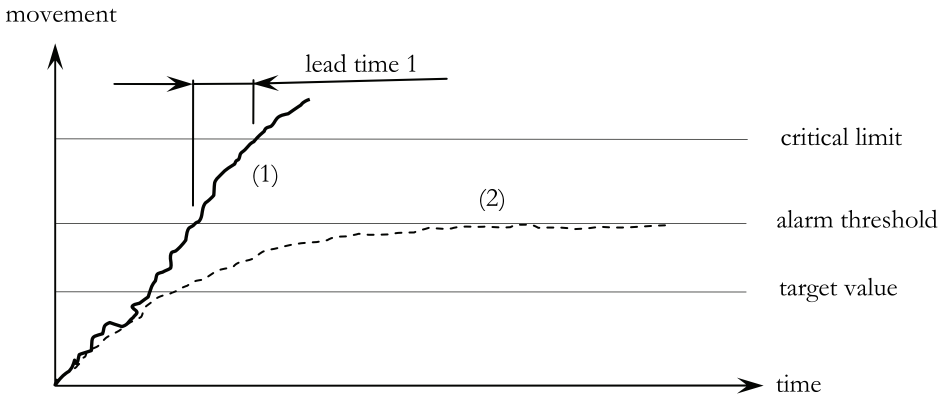

Figure 4.8 Definition of target values, alarm thresholds and critical limits (modified after Paté-Cornell & Benito-Claudio 1987).

In some situations there were problems with fixing the boundaries of responsibilities between different areas in combination with shortcomings in the system analysis. For example, the bridge for the water pipe crossing the excavation pit was fixed to the sheet pile wall in one end and had a span of allowed movement of 20 millimetres in the other end. However, the calculated lateral movement of the sheet pile wall was between 10 and 40 millimetres and when the actual movement exceeded 20 mm the sheet pile wall was stuck to the bridge. Due to the monitoring of the lateral movement of the sheet pile wall this problem was discovered and appropriate countermeasures could be carried out before any damage was occurred.

4.1.4 Conclusions

Before the work started, the client and the contractor were aware of that the project should be a high-risk project due to the characteristics of the project, e.g. the geotechnical conditions, the deep excavations in soft soils and the high public, political and environmental focus. The risk management process was considered to be vital for the success of the project, both for the client and the contractor, and should therefore have had the full commitment from the client and the contractor.

However, a comprehensive risk analysis including technical, environmental, organisational and economical risks was not established in the early phases of the project. A quite detailed list of technical damage events and identified hazards, initiating events and warning bells as well as planned countermeasures was however established. As a consequence, a consensus of some of the risks involved was not obtained among the actors involved in the project. A mutual fundamental view of the risks in the project as a basis for risk handling, risk sharing etc. was therefore not obtained. In addition, some decision alternatives could not be completely explored. As a result, non-optimal decisions sometimes had to be made and disagreements when choosing among decision alternatives appeared in some situations. The causes to these problems were probably different views of the risks, the risk management process and the systems analysis as well as the communication of risks. An establishment of a complete risk analysis in an early phase of the project would probably create opportunities to execute to project in a better way.

Pre-planning of the work activities was considered to be of great importance in order to manage the risks. Before the project started the contractor had to describe how the identified hazards should be handled in the daily work. The contractor established a risk analysis including identification and prioritisation of hazards, identification of initiating events and warning bells, and preparation of countermeasures. A review team of independent experts was used in order to audit the project performance and the risk management process. This way of working was successful in the project.

The working procedure according to figure 4.4 with identification of risk objects, hazards, initiating events, warning bells and damage events together with the monitoring system and pre-defined countermeasures worked well in the construction phase. The project could consequently be managed by the use of the observational method to some extent. However, the observational method could not be used with its full potential in the project. The monitoring system fulfilled its aim of observing warning bells and initiating events. Though, the observations were not used in order to optimise the design since there was some resistance to carry out changes.

The risks were not quantified in monetary terms which made it impossible to estimate the total cost for all the risks involved in the project. Furthermore, no prioritisation of the risks according to some established method, e.g. the analytical hierarchy method, was made. This had probably improved the risk management process.

The project succeeded in the distribution of authorities and responsibilities specified and described in the project plan and fixing the boundaries of responsibilities between the actors involved. The work activities in the project plan were established on the basis of the identified hazards and risks. Revisions were conducted in order to ensure that the working procedures in the project plan were followed. However, the project plan was not updated during the construction phase, e.g. with the results from the monitoring, in an extent that is desirable in order to make it a governing document in the project.

The flow of information in the project was considered to be successful in the project. The information was communicated regularly to all individuals involved in the project. The risks and the future work activities were also communicated to the public on regular meetings every second week. This resulted in few complaints from the neighbouring residents and a positive opinion of the project.

4.2 Delhi Metro, contract MC1A, India

4.2.1 Project Description

The Delhi Metro project consists of a new underground railway with stations in the capital of India, New Delhi. Some parts of the railway are planned to go in rock tunnels and some parts in concrete tunnels.

The contract of MC1A included 4.3 kilometres railway and four new stations located approximately 10–15 metres under ground level and around 10 metres under the groundwater level. The contract of MC1A was a design-and-build contract with a fixed price. The contractor was a joint-venture between contractors from Sweden (40%), Japan (40%) and India (20%). The design was carried out by a consultant in Australia. The work started in 2001 and was concluded in 2005. The client was the Delhi Metro Rail Corporation Ltd.

The contract was divided into four areas of responsibility located around the stations (A1–A4), see figure 4.8. Each of these had a designated project manager, two from the Swedish contractor and two from the Japanese contractor.

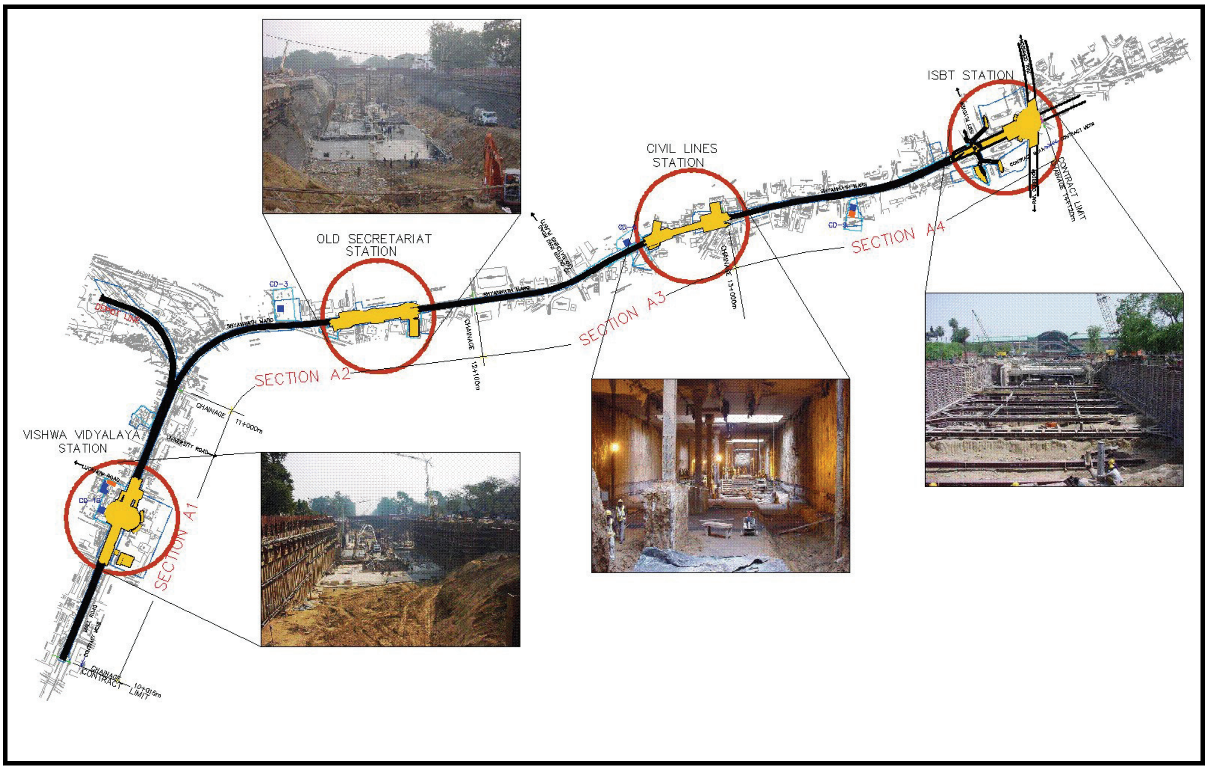

Figure 4.8 Dehli Metro, contract MC1A (Hintze et al. 2004).

In the contract MC1A, all the tunnel sections were concrete tunnels built with a cut-and-cover technique, i.e. the stations and the tunnel sections were built from the foundation level after excavation inside sheet pile walls or diaphragm walls. Two of the stations were built with the similar bottom-up technique and the other two with a top-down technique, i.e. the stations are built from the roof and down with successive excavation inside sheet pile walls or diaphragm walls.

For a more detailed project description see Hintze et al. (2004).

4.2.2 Geotechnical and hydrological conditions

The geology in the area is characterised of the "Delhi ridge" which is an anticline with steep layers of quartzite. The quartzite has layers of sandstone and shale which are less resistance against weathering. The soil in the area consists of silt which has weathered from these layers of sandstone and shale. The thickness of the soil strata varies between 3 and 30 metres. The groundwater level is located approximately 2–4 metres below the ground level. The bedrock is composed of quartzite which is partly weathered and fractured, especially close to the surface.

4.2.3 Risk Management

The tender and design phase

The risk management process started in the tender phase with a general risk analysis, including general risks such as risks with the contract, the form of compensation and the organisation, and a technical risk assessment, including technical risks such as risks with the soil and rock conditions, the design and the planned constructions. The following hazards were identified in the tender phase of the project (Hintze 2002b & Hintze et al. 2004):

- the location and client,
- the soil and rock conditions,
- the precipitation and ground water,
- the type of contract and form of compensation,
- the temporary structures and impact on the environment, and
- the installation of the diaphragm walls.

The location was identified as a hazard since the project was situated in a densely populated area in the middle of the city of Delhi. A major challenge during the construction time was the rearrangement of the traffic as well as the transportation of building material and excavated soil and rock material. The client was considered to be a hazard since the client was unknown to the main contractors in the joint-venture.

The pre investigation of the soil and rock properties was limited. Around twenty standard penetration tests and a few core samples of the bedrock were presented in the tender documents. Therefore, the uncertainties regarding the actual soil and rock conditions were judged to be severe.

During the rain period it can rain 200 millimetres in twenty four hours in the area. As a consequence, the ground water level shows large deviations which could affect the execution of the excavations and the design of the structures. The heavy rain could also influence the stability of slopes and the work in general, with changes of work procedures and time delays as a result.

The contract was a design-and-build contract which implies that the contractor is responsibility for both the design and execution of the project. In the contract there was a clause stating that the client should review and approve all documents, e.g. method statements and work procedures, before the related activity could start. Therefore, all work procedures and methods had to be described carefully. In order to succeed with the project there had to be a consensus about risks, costs and work procedures, both with the client as well as between the contractors in the joint-venture.

The possible impact on the adjacent buildings was considered to be an apparent hazard in the project. Many buildings close to the excavations were in bad condition when the works began, see figure 4.9. The contract stated that no additional damage on these buildings was allowed. As a consequence of this, extensive design work was performed with finite element programs in order to estimate the deformation of the temporary structures and the settlements in the surroundings.

Figure 4.9 Buildings in bad condition close to the working site (Hintze 2002b).

The execution of the tunnel inside the diaphragm walls was planned to be done according to a top-down method. Furthermore, blasting works had to be performed very close to the walls. A blasting test was carried out outside the city as there was little experience of blasting works in the area. The bedrock was found to be both very hard and very weathered and fractured, see figure 4.10. As a consequence, the working procedure according to the top-down method was identified as a hazard because the available equipment was not designed to install in this type of conditions.

The identified risks were gathered in a risk register together with the initiating events and a qualitative estimation of the probability and consequence of the damage events.

Figure 4.10 The site for the blasting test (Hintze 2002b).

During the design phase, additional hazards related to the design were identified mainly due to the insufficient ground investigation and the limited knowledge of the local conditions. In the tender phase some of the excavations for the tunnels were assumed to be performed without any retaining structures. An excavation test executed in the design phase showed however that the maximum excavation depth was around five metres without any earth supporting structure. Signs of liquefaction around two metres under the ground water level were also apparent in the test. Therefore, the original plan of building the stations has to be changed. An extensive ground water pumping system was planned to be installed in order to lower the ground water level inside the excavation pit. To maintain the ground water level outside the excavation, a water infiltration system was designed.

As a consequence, additional risks and hazards were identified and more risk handling actions had to be planned. All the identified risks and hazards were gathered in the risk registers together with initiating event and warning bells.

The limited knowledge of the soil and rock conditions made it clear that a careful follow-up, e.g. by the use of the observational method, of the prerequisites used in the design had to be conducted in the construction phase. This was considered to be essential for a cost-effective design and to secure the reliability of the structures and the safety of the workers.

The need for a suitable contract with the external designer which specified the scope of the design commitment and the client's prerequisites was identified to be important for the success of the project together with an appropriate management of the designer. A cost-effective design which was delivered in the right time was considered to be crucial to the project success (Hintze et al. 2004).

A particular decision problem originated from the blasting test. Since the bedrock was found to be both very weathered and fractured, the installation of the diaphragm walls was considered to include large risks because the equipment was judged not to be able to install the walls into the hard weathered bedrock. The identified alternative to the diaphragm walls was steel sheet pile walls. The sheet pile wall was considered to be more flexible and robust but less rigid than the diaphragm walls. As a consequence, supported sheet pile walls were decided to be used up to 18 metres of excavation and supported diaphragm walls when the excavations were deeper.

Another problem that became apparent in the design phase was the differences in design philosophy between the different actors involved in the project, e.g. when interpreting the site investigations and designing the temporary structures. From the Swedish contractor's point of view, the design consultant was conservative and risk-avert. For example, the consultant designed the retaining structures for a groundwater level close to the ground surface although it was around 2-4 metres or more below the surface. This resulted in a large water pressure against the structure and, consequently, several levels of wale beams and struts which complicated the excavation.

The construction phase

Important work processes to manage the risks and hazards which had been identified and analysed in the design phase were technical support, design management, design optimisation and monitoring. An important issue for the engineers involved in the project was to ensure that the identified hazards were handled in an optimal way through the use of monitoring systems and by the use of an external review team of experts. Technical reviews were carried at the site at three times during the project. The aim of the use of the review team was to obtain objective feed-back of the design and the construction methods as well as a review of the risks, both identified and unidentified. Information of the progress of the project was continuously sent to the review team.

The observational method was used in the construction phase in order to manage the identified risks and ensure a safe and cost-effective execution of the project. Through the use of a monitoring system the knowledge of the soil and rock conditions increased during the progress of the project. The monitoring system was designed to observe the warning bells that had been identified in the tender and design phase, e.g. vibrations, groundwater levels, settlements and movements of the retaining structures. A complementary site investigation was carried out during this phase of the project. The results from the monitoring and the site investigation could be used to a re-evaluation of the design of the structures and to update the risk registers. Some risks could therefore be abandoned and new risks were added in the register. The increased knowledge could also be used to re-design the temporary retaining structures in order to make them more cost-effective.

However, there were obstacles to use the observational method in the project. The client requested some of the savings when the measurements from the monitoring were used to optimise the temporary structures and required extensive documentation before any changes could be approved. Furthermore, the internal project organisation did not see all the benefits of optimising the design because the changes were considered to be too difficult to carry out. In the view of the Swedish contractor, the client and the design consultant were considered to be quite conservative as they considered the design to be stationary and tried to obtain a secure project execution without any major changes. Furthermore, the client was considered to have a relatively conservative view of the risks hazards and was risk-avert. There were also different views of the project management and the risk management inside the joint-venture, mainly due to social and cultural differences.

In spite of these obstacles the result from the measurements could be used in order to optimise the design regarding time and cost in some extent. For example, the amount of anchors, struts and prop levels was reduced, some of the temporary struts for the diaphragm walls could be removed and the amount of reinforcement in the diaphragm walls could be reduced. Additional risks were also identified and handled during the construction phases. For example, the limited knowledge of the risk for future seismic impact and the local laws were identified and handled. This resulted in re-design of the tunnels and stations. Furthermore, the client changed the type of power supply in the middle of the project. The difficulties regarding the distribution of responsibilities with the contractor for the other contract became obvious when the tunnel boring machine arrived at the adjacent station A4 which lowered the ground water level and affected the temporary structures in the surroundings.

4.2.4 Conclusions

The complex nature of the project, e.g. design-and-build contract and the organisation as a joint-venture, required an extensive risk management process throughout the entire project. The limited knowledge of the local conditions at the site, e.g. soil, rock and water conditions as well as the client created large risks and uncertainties which needed to be addressed in the risk management process. The large uncertainties of many of the key factors involved, e.g. the geotechnical conditions due to limited site investigations, required a systematic approach to risk management and the use of the observational method. In addition, a review team was used in order to obtain an objective review of the management of the project as well as the construction methods and the work processes. Monitoring of key parameters and the utilisation of information obtained during the execution phase had a central importance in the project.

The social and cultural differences between the actors in the project created some problems in the risk management process and the execution of the project. The client, contractor and the designer had, to some extent, different views of risks, risk management and the design of temporary structures. For example, the client and the designer were considered to be quite risk averse from the contractor's point of view since they were quite reluctant to take on more risks than necessary even if the benefits were large. There were also different views of the project management and the risk management inside the joint-venture.

There were some problems in using the observational method in the execution phase of the project. The client and the design consultant considered the design to be stationary to some extent and the client was unenthusiastic of approving changes in the design. Moreover, the individuals on site were sometimes unwilling to carry through changes, probably because they could not identify the benefits with these. Another problem that became apparent in the design phase was the differences in design philosophy between the different actors involved in the project, e.g. when interpreting the site investigations and designing the temporary structures.

The first phases of the risk management process, i.e. risk identification, risk estimation and risk evaluation, worked well in the project due to systematic approach and the use of an independent expert group. The later phases of the risk management process, i.e. the handling and control of the risks, did not work well due to difficulties in the implementation of these in the corporate culture and to get them accepted among the workers in the project.

4.3 Road tunnel under Hvalfjör∂ur, Iceland

4.3.1 Project Description

The road tunnel under the fjord Hvalfjörður is located approximately 20 kilometres north of Reykjavik, the capital of Iceland. At the location of the tunnel the fjord is roughly 3-4 km wide. The tunnel under the fjord was built with the purpose of connecting the northern parts of Iceland with Reykjavik and reducing the distance by road with around 50 kilometres, see figure 4.11. The tunnel length is around 5.8 kilometres and stretches approximately 170 metres beneath the water surface of Hvalfjörður at the deepest point. In the tender documents, the project time was about 36 months and completion date was set to the beginning of 1999.

The planning of the project started in 1987 when the Icelandic Public Road Administration published a preliminary study which presented the benefits of building a tunnel under the fjord Hvalfjörður. After several studies regarding the location of the tunnel and site investigations the excavation of the tunnel commenced in 1996. The tunnel was entirely excavated in the beginning of 1998 and opened for traffic in the end of 1998 approximately four months before the original completion date. Before the project started there was limited experience of sub sea tunnelling on Iceland in the project group. In other similar tunnel projects there had been problems related to the geological formations significant for the area as well as intrusion of gas and water.

The client was the Icelandic Public Road Administration and an Icelandic private company obtained the concession to build, own and operate the tunnel for a predetermined period of time. A joint-venture, consisting of contractors from Iceland, Denmark and Sweden, was contracted with a turnkey contract for the design and construction. The tunnel was paid at a fixed price when the tunnel was completed, tested and had been operated for three months. The joint-venture had to arrange financing for the design and construction costs to the day the client took over the project.

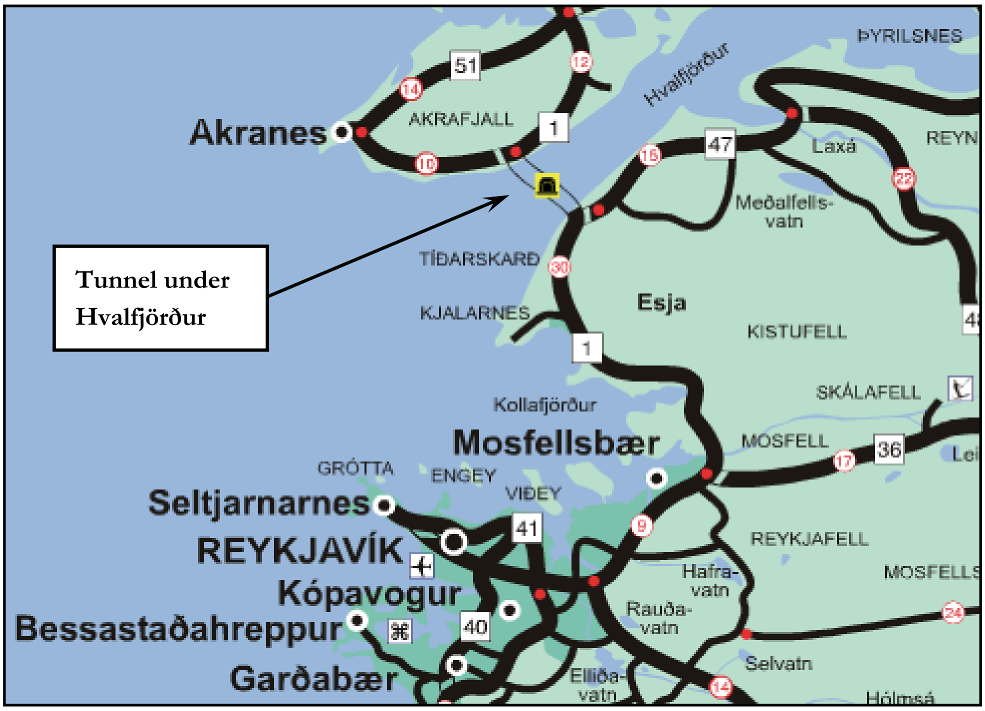

Figure 4.11 The location of the tunnel under Hvalfjörður, Iceland.

The joint-venture decided to perform a system analysis of the project before the work started with the aim of ensuring a safe and cost-effective execution of the project. The analysis was conducted by an independent group of engineers. Their task was to identify and describe the risks and hazards in the project and, with these as a basis, propose appropriate design and construction methods and the extent of the supplementary site investigation. Their work should also result in guidelines for the handling of information and the decision-making in the project.

For a more detailed description of the project see Olsson et al. (1996) and Tengborg et al. (1998).

4.3.2 Geotechnical and hydrological conditions

The geology in the area is characterised by the location of Iceland in the middle of the Mid Atlantic Ridge and the previous volcanic activities. The bedrock in the area consists of layers of stiffened magma, in places with sediment layers in between. The magma layers often have an impermeable central layer of basalt with good quality but with vertical fractures due to the cooling process. The outer layers, called scoria, usually have lower strength and higher permeability. Due to earlier magma flows there are basalt dikes, which cut through the general sequence of horizontal layers. The contact zone between the dikes and the original basalt layer has high conductivity occasionally. The bedrock is also crossed by faults and dykes due to tectonic movements.

The water depth is generally around 10 to 30 metres at the location of the tunnel. The thickness of the layers of sediments on the bottom of the fjord varies between 10 to almost 80 metres. The rock cover is approximately 40 metres at the deepest point of the tunnel. The temperature along the tunnel was estimated to rise from 5°C to 25°C at the deepest part, see figure 4.12.

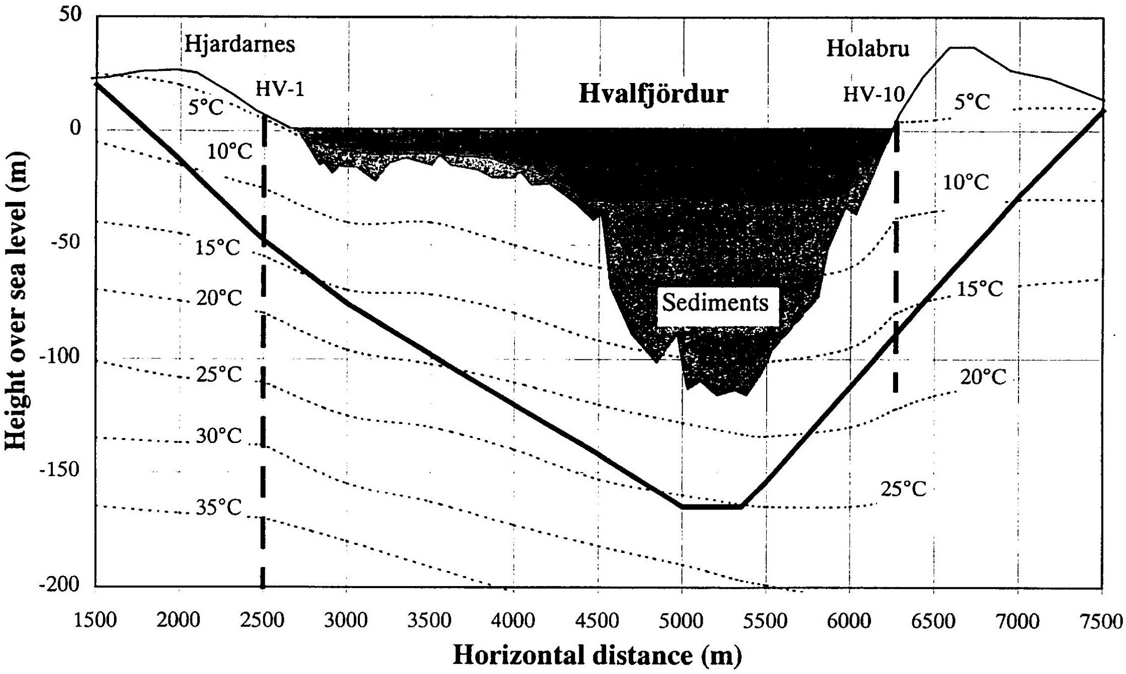

Figure 4.12 Longitudinal cross section of the tunnel with expected temperature conditions (Tengborg et al. 1998).

4.3.3 Risk Management

The tender and design phase

Due to the project team's limited knowledge and experience of sub sea tunnelling on Iceland, the severe consequences of many of the possible hazards and the failures in other similar tunnel projects, the risk management process had a distinguishing role in the early phases of the project. The risk analysis, or system analysis as it was called, was conducted by an independent group of engineers on the commission of the concession owner. Their main task was to identify and describe probable and serious hazards and their associated initiating events and warning bells and with these as a basis propose necessary site investigations as well as appropriate design and construction methods. The risk management process was mainly based on the view of the process from hazard to damage discussed in section 3.1 and illustrated in figure 4.13. The warning bells are further discussed below.

The risk analysis was divided into three phases:

(i) Information gathering, establishment of a preliminary geological model and identification of possible hazards.

(ii) Further information gathering, review of the geological model and identification of probable hazards.

(iii) Identification of warning bells, study of pre-probing methods and establishment of guidelines for information flow within the organisation.

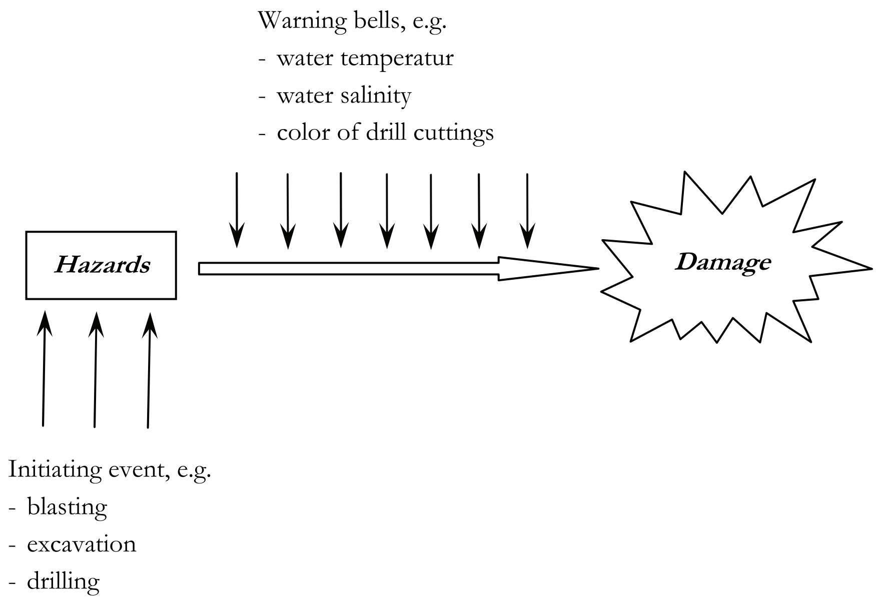

Figure 4.13 The process from hazard to damage (modified after Sturk 1998).

The first phase consisted of collecting written information regarding the geological conditions at the site and other prerequisites that could affect the design and execution of the project. None of the engineers in the analysis group had any experience of tunnelling on Iceland so an extensive literature review was performed as well as contacts with several experts of the type of project at hand. A qualitative fault tree analysis was used in this phase in order to identify the chains of events which could lead to technical failure, e.g. collapse of the tunnel. The aim of the fault tree analysis was not to quantify the risk, but to identify so many possible damage events as possible. Only damage events that were obviously not present were excluded in the analysis. Six possible damage events that were crucial to the technical success of the project were identified:

(i) Large water flow that could not be controlled

(ii) Stability problems.

(iii) Heat inflow of hot water or heat rock formations.

(iv) Injurious gases in the tunnel.

(v) Seismic damage.

(vi) Unacceptable tunnel durability.

This first phase of the risk analysis resulted in a preliminary model of the geology and a register with the characteristics of the identified hazards.

The second phase of the analysis comprised a further discussion and re-evaluation of the geological model and the identified hazards with the assistance of Icelandic experts. Several geological experts from Iceland and the contractor were consulted in order to re-evaluate the geology, hydrology and the geothermal conditions at the site. Methods for site investigations, pre-probing and excavation were also discussed. The Icelandic experts also served as a review group during the risk management process.

The damage event “large water inflow can not be handled” was judged to be the most crucial event to the achievement of the project. This was due to the fact that the tunnel was going to be excavated under a fjord with almost unlimited access to water in combination with the limited rock coverage at some places. The fault tree for the top event “large water inflow can not be handled” is shown in figure 4.14. Each of the four events at the bottom of the tree was further analysed in separate fault trees. This second phase of the risk analysis resulted in a revised geological model and a list of probable and serious geological hazards.

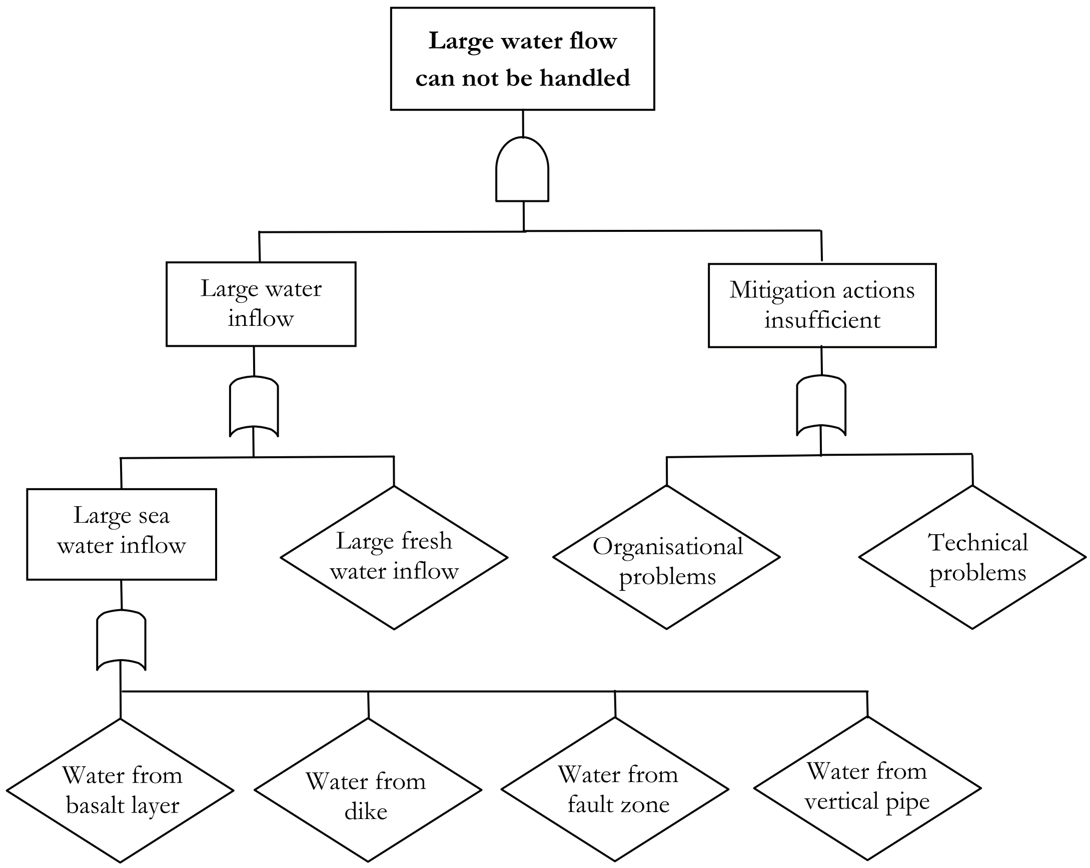

Figure 4.14 Fault tree for the most crucial damage event (after Olsson et al. 1996).

The third and last phases of the risk analysis included an identification of measurable warning bells of geological hazards as well as methods of observing and measuring these during the execution. It was made clear which of the identified warning bells that was significant for the different hazards. Examples of identified warning bells are:

- The occurrence of vertical geological formations - may indicate water flow in the contact zones.
- Water temperature – deviations from expected values may indicate connections with deeper (high temperature) or shallower layers (low temperature).
- Water salinity – high values may indicate connection with salt water from the fjord.
- Water pH value - deviations from expected values may indicate connections with deeper (high pH) or shallower layers (low pH).
- Colour of drill water and drill cuttings – may indicate presence of sediments which can affect the stability of the tunnel.
- Drill penetration – may indicate changes in the properties of the bedrock.

As a next step, methods for exploration were studied with the identified hazards as a basis. The aim of the exploration was to increase the amount of data available in the decision-making process by investigating the rock mass and to enable an implementation of risk mitigation actions when necessary. The methods of exploration to be performed in the project were chosen by the contractor in consideration of the recommendations from the analysis group. The methods for exploration were chosen so that they should give obvious and exclusive indications of the hazards that were easy to understand and interpret. The exploration was divided into a routine part and a part that should handle unexpected events. The routine part were performed along the entire tunnel length and aimed to identify indications of hazards. The other part of the exploration was conducted intermittently. Examples of methods used in the exploration were the probe drilling, core sampling, radar and geophysical methods.

Issues related to organisational hazards, e.g. the distribution of responsibilities, the communication of risks and the flow of information, were also studied. The gathering, documentation, interpretation and distribution of the data from the exploration were identified to be very important, as these should be the basis for decision-making and the decisions regarding the executions of the mitigation actions. Event trees were used in order to evaluate the strengths and weaknesses of the organisation, see figure 4.15 which shows the event tree for the chain of events from indication of a hazard to the execution of a pre-determined mitigation action. The underlying reasons for the unwanted events were further analysed with fault trees analysis.

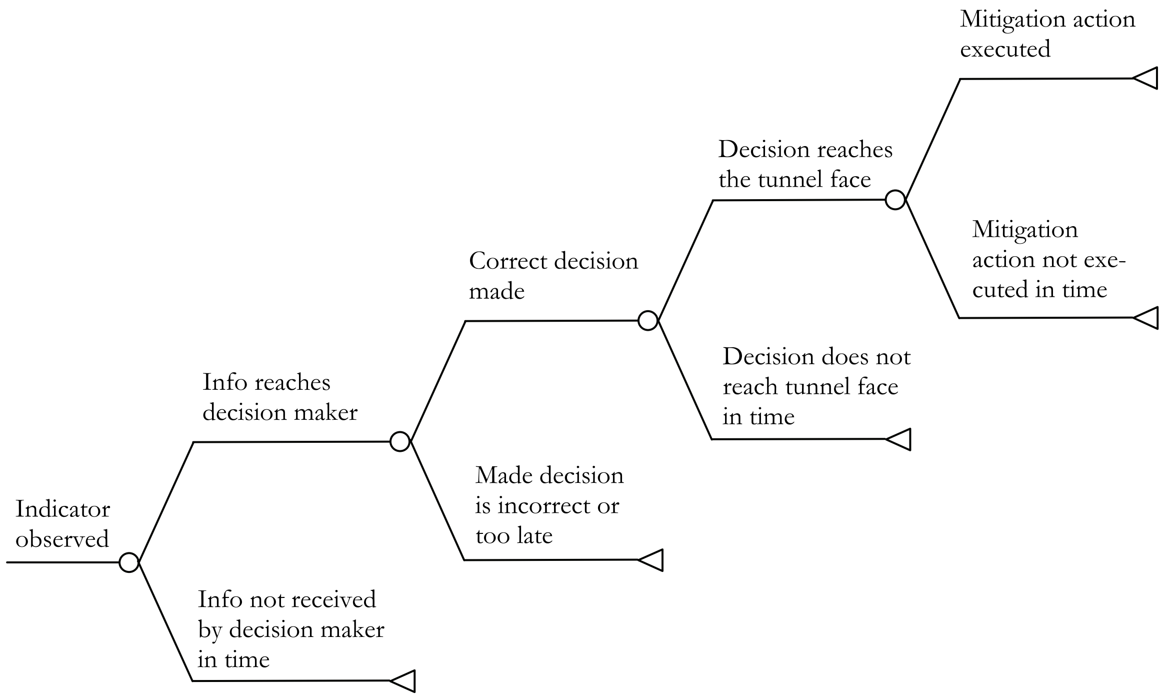

Figure 4.15 Event tree for the chain of events from indication of a hazard to the execution of a pre-determined mitigation action (after Olsson et al. 1996)

The key factors for the flow of information were judged to be:

- The time elapsed from the time for an indication to the time for execution of mitigation actions - several mitigation actions should be performed and several individuals should be involved in order to minimise the time.
- The control system - guidelines and routines for the exploration methods should be introduced in order to ensure an adequate extent of the explorations.
- The amount of information - the amount should be reduced to a minimum without losing any important information in order to make an analysis of the large amount of data possible.
- The feedback - the possibility of learning by experience should be facilitated by sending the information to the relevant personnel in order to create a learning organisation.

The construction phase

In the construction phase the risk management was conducted by the contractors in the joint-venture as the independent expert group was separated from the project. The risk management methodology and the monitoring outlined in the risk analysis were mainly adopted as the contractor implemented some parts of the risk analysis in the work procedures. Some parts were however excluded. Furthermore, the risk analysis was also used as a tool for the quality control in the project.

Monitoring of the identified warning bells were conducted in the construction phase. These were considered to play a crucial role in the ensuring of a safe and cost-effective execution of the project. In figure 4.16 the measurements of the water temperature and the salinity in the tunnel are presented.

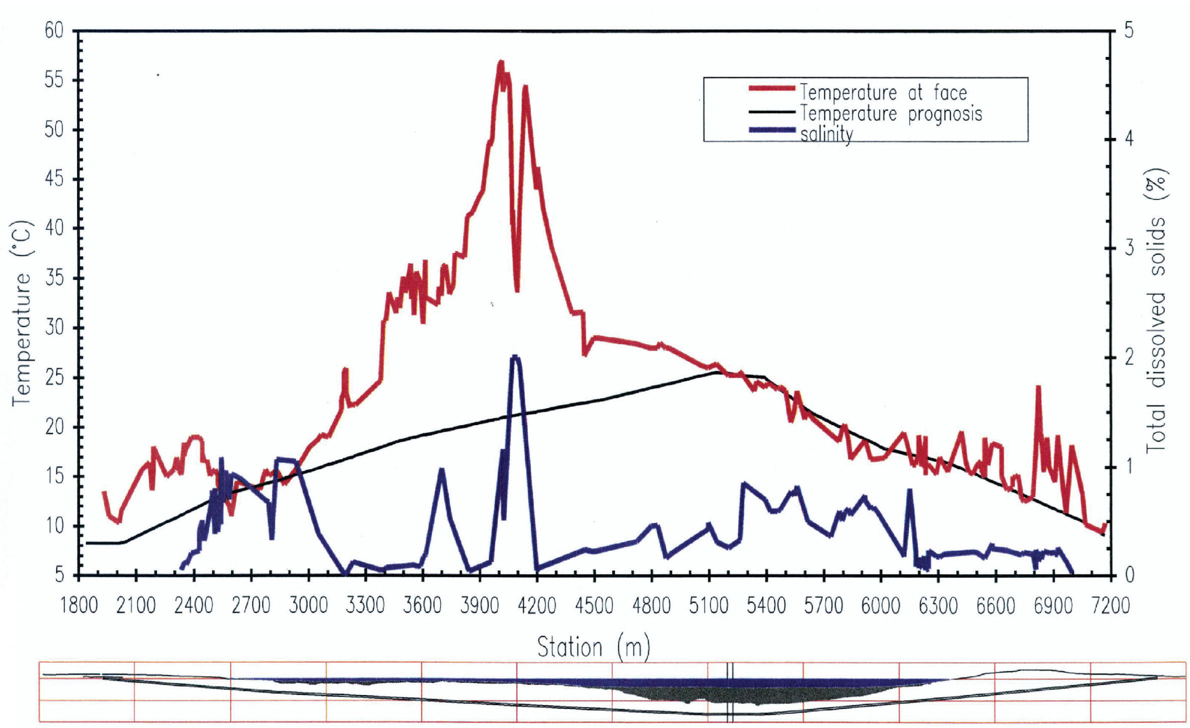

Figure 4.16 Result of the measurement of water temperature in the tunnel (Taute 1998).

The obtained information could be used in order to reduce the risk, either by reducing the probability function or by reducing the consequence function, or to decide the time for countermeasures as have been discussed in section 2.3.5 and illustrated in figure 4.17. The mean value of the probability function could be reduced by the use of an appropriate excavation technique regarding to the geological conditions which were measured with pre-probing etc. The standard deviation of the probability function could be reduced by the use of pre-probing, radar, core sampling and geophysics. The consequence function was reduced by the use actions that limited the possible consequences, e.g. measures to prevent a submersion of the entire tunnel in case of penetration of sea water.

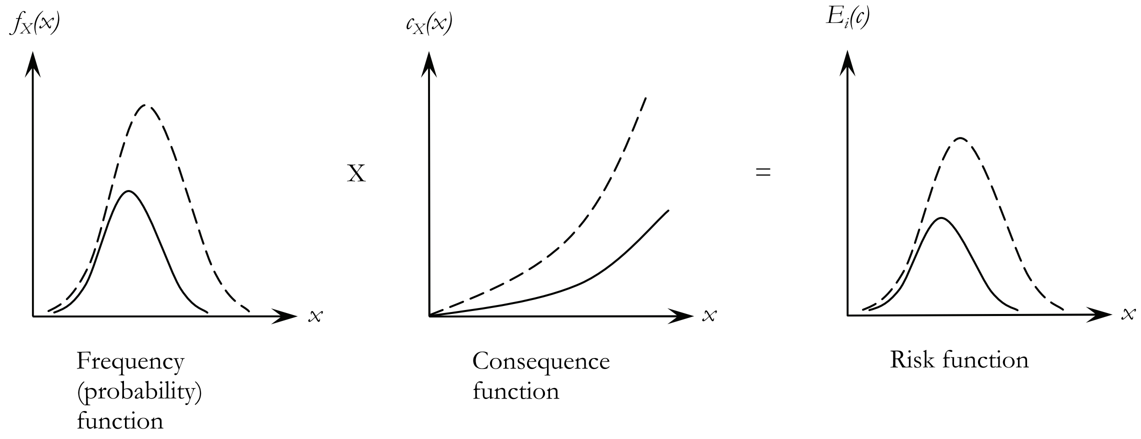

Figure 4.17 Risk mitigation using information acquired during the project.

4.3.4 Conclusions

Due to the characteristics of the project, e.g. the contract, the organisation and the financial arrangement, the limited knowledge and experience of sub sea tunnelling and the recorded failures in similar tunnel projects, both the client and the joint-venture that was assigned to build the tunnel under Hvalfjörður were aware of the potential risks in the project. As a consequence, a lot of effort was put into the risk management process in an early phase of the project. In the early phases of the project the main focus was on the identification of hazards, initiating events and warning bells and on the monitoring of warning bells in the execution of the project.

The dialog between the risk analysis group, the joint-venture, the client and the geological/ geothermal Icelandic experts increased the awareness of both geological and organisational hazards in the project. This resulted in a common view of the risks and hazards as well as of the risk management in the project. Fault and event trees were used for identifying hazards and the chain of events leading to actual damage. The use of an independent analysis group and the combination of traditional risk analysis methods and engineering judgement was considered to be successful.

The risk management in the construction phase was performed by the design department of one of the contractors since the independent expert group was separated from the project. The risk management methodology and the monitoring outlined in the early phases of the risk management process were mainly adopted as the contractors implemented some parts of the risk analysis in the work procedures and excluded some parts.

The monitoring of the identified warning bells and the use of pre-defined mitigation actions in order to handle the risks had a distinguishing role in the construction phase. Several preventive methods were used, e.g. pre-probing, radar and geophysics, and several countermeasures were undertaken. These were considered to play a crucial role in ensuring a safe and cost-effective execution of the project.

4.4 General Conclusions from the Case Studies

This chapter has presented some aspects of the risk management process and decision situations in three infrastructure projects executed in recent years. The review of the projects has revealed similarities and shortcomings as well as some factors of success of the methods of risk management used in the projects.

The similarities can be summarised as:

- The risk management process had a distinguishing role in the execution of the projects due to the complex characteristics of the projects which were recognized before the project started.
- The risk management process started with an identification of risk objects, hazards, initiating events, warning bells and damage events.
- Pre-defined risk handling actions were incorporated into the project plan with a clear definition of responsibilities and authorities.
- A monitoring system was used to monitor warning bells in the construction phase and the observational method was used to manage the risks and ensuring a cost-effective execution of the project.
- A team of independent experts was used to improve the risk management process in the tender, design and construction phase.

The main shortcomings that have been identified can be summarised as:

- A comprehensive risk analysis is not always established in the early phases of projects.
- The risk analysis is not always used as a basis for risk distribution.
- Obstacles to use the observational method sometimes exist.
- The risks are seldom quantified in monetary terms.
- Cultural and social factors have great influence on the general view of risks, risk management process and the attitudes towards risks and these are not always understood and considered.
- A weak connection between the risk analysis in the design phase and the management of risks in the execution phase sometimes exist.

The factors of success in these projects can be summarised as:

- A mutual fundamental view of risks and risk management between the actors involved.
- A transparent, objective and systematic identification of hazards and estimation of risks in an early phase of the project which are performed continuously throughout the entire project.
- The risk management process has to be integrated into the existing management systems and the corporate culture.
- Early planning of risk handling actions and implementation of these into the project plan.

- Preparation and planning before critical decisions.
- The use of an independent review team throughout the entire risk management process.
- The use of a monitoring system in order to monitor the identified warning bells.
- The risks must be communicated to all actors involved in the project in an unambiguous and stringent manner that is easy to understand and interpret.
- Responsibility for the risk management should exist in all levels in the organisation.

5 Discussion

In the previous chapters a literature review including the underlying concepts of risk management and project risk management in geotechnical engineering has been presented together with three case studies of executed infrastructure projects. This chapter discusses the shortcomings of the methods for risk management used today that have been revealed in the literature review and the case studies. Furthermore, the distribution of risk between the different actors involved in an infrastructure project and the key issues for these actors will be considered with the intention of improving the management of geotechnical risks. The chapter ends with some conclusions from the chapter. This aim of the chapter is to outline some factors of success in order to overcome the identified weaknesses and to identify areas which need further research.

5.1 Introduction

The geotechnical risks and uncertainties can never be characterised completely due to the natural variability in the ground. Consequently, the risk analysis can not identify all risks and uncertainties and there will always be risks and uncertainties that have to be discovered and managed in the execution phase. One type of problem that must be handled is that the assumed characteristics of the identified risks are generally not equal to those of the actual outcome. The discovery and management of unidentified risk is another type of problem that must be considered.

These risks and uncertainties can affect both the cost and time schedule for the project as well as the environment and third party. Recent studies suggest that the traditional methods of construction and risk management can not manage risks and uncertainties effectively, see e.g. Jaafari (1998) and Clayton (2001a & 2001b). Given the increasing use of “new” contractual agreements, e.g. design-and-build, BOT (build-own-transfer) and BOOT (build-own-operate-transfer), which tend to disperse the design responsibilities and to shift the risk to the contractor, a new way of dealing with geotechnical risks needs to be adopted. Additionally, due to the increasing location of infrastructure projects in urban areas it will be more and more important to identify those projects which include large risks and that will need a more sophisticated approach to manage the risks.

The management of geotechnical risks today seems to be performed on different basis in different projects depending on tradition, knowledge and experience of the risk analyst team and the team’s perceived ability to manage the identified risks. An incomplete or rudimentary risk management process may have severe implications in many projects. Untreated risks and uncertainties can lead to a product with unsatisfactory functions for the client, i.e. low quality, and to large costs in the end of the project in the form of insurance costs, costs for guarantee commitments and/or maintenance costs. A successful project risk management is dependent on an honest and obvious commitment from all the actors involved in all project phases in questions regarding allocation of resources, co-operation, communication and documentation. This is a necessary but an insufficient condition.

5.2 Shortcomings in the Management of Geotechnical Risks Today

The construction industry in general suffers from an "illusion of certainty" when developing projects and cost and time estimates. Risk management is often portrayed as the answer to all problems, but it is not. There seems to be a belief that all risks can be foreseen but the risk management process can not hope to identify all risks. Unforeseen risks will almost always exist and procedures for managing these risks are often missing today (Hansson 1993 and Hillson 2001).

Another deficiency in the risk management in many projects today is the absence of an appropriate risk analysis before the construction works begin. Though, it can be argued that an informal or unconscious risk analysis is always performed in the head of the actors. However, for the success of a complex infrastructure project including major risks it is not enough with one or several persons' subjective and informal analysis and management of risks which is not communicated to the rest in the project. Therefore, resources, knowledge and experience of the risk management process must exist.

As been stated in earlier chapters, the risk management process should start with an early identification of hazards and potential damage events in order to identify as many risks as possible. Decisions regarding the observations or measurements of these damage events and the response actions that should be carried out if the damage events are initialised should also be made in an early phase of the project. Furthermore, the risk analysis should be a continuous process during the entire project in order to be able to manage unforeseen risks and to utilise acquired information during excavation and should be used as a governing document in the project management (Hintze 2001).

This is seldom the situation today. For example, the risk analysis is sometimes established in the planning or design phase by individuals who do not participate in the following phases. In other words, the link between the design and risk management is sometimes weak. The decided risk handling actions are though almost invariably incorporated into the control plan but important geotechnical prerequisites are often not included. In these situations, important information regarding the geotechnical risks uncertainties is lost. In addition, responsibilities and authorities are often vaguely described in the project plan and not clearly explained and rooted in the project organisation. Systems for the flow of documents are often missing which can lead to that documents out of dates are used in the construction. The follow up and control in the construction phase is also often insufficient (Clayton 2001a & 2001b and Hintze 2001).

In many infrastructure projects today, the client, designer, contractor and insurer perform their own separate risk analysis and these are established under no or slight collaboration between the actors. As a consequence, a consensus of the risks is sometimes not established. This can affect the decision-making and co-operation in the project. Furthermore, the risk analysis can not be the basis for risk sharing in these projects.

Furthermore, in many projects there seems to be a tendency that the contract is unclear and ambiguous, responsibilities and authorities are not established and the risks are not shared in a best possible way. This often leads to an unfair risk distribution and results in disputes in case of damage and problems with the collaboration in the project. If the risk analysis was used a basis for risk distributions things would probable be better. In some projects, there have been an unwillingness to solve disputes during the construction phase and the dispute solution is therefore postponed to after the construction phase is completed. This contributes to the development of further disputes and a non-productive working climate. There are examples of projects where the work has stopped completely and all actors have been busy with legal matters and negotiations (Hintze 2001).

The risk communication and the knowledge of psychological factors affecting risk decisions are seldom given enough attention in the risk management process. Sometimes, the designer and the contractor choose not to discuss risks and divergences with the client during the design and construction stage. In addition, the client is sometimes reluctant to consider risks since this can jeopardize the whole project (Hintze 1994).

Another shortcoming is the fact that the traditional approach of dealing with geotechnical risks in infrastructure projects is based on a scientific method in a deterministic framework (Clayton 2001a). Desk studies are used to hypothesise about geotechnical conditions, possible problems and options for different types of the geotechnical design. Then a comprehensive program for geotechnical investigations is planned and executed with the aim of determining the actual conditions at site in order to decide the final design.

According to Clayton (2001a) there are several limitations and problems with this approach. First, with an increasing trend that the design is subcontracted to a contractor or a specialist subcontractor, the geotechnical investigations can not be planned as long as the design is undecided. Second, since the geotechnical conditions beneath a construction site is fixed and the variability in the properties of the ground, the design can not all alone be based on deterministic values from the geotechnical investigations. Furthermore, adequate methods of construction must be identified to secure a safe, cost-effective and environmental sound construction. Third, since many of the deterministic design methods used are inaccurate and provide different results, the design can not all alone be based on these methods. In addition, Clayton (2001a) argues that under recent years there has been growing emphasis on numerical modeling and more sophisticated models than before and less attention to sound design principles. Thus, in a risk perspective, the design process has in a sense become less effective in recent years due to less attention to engineering judgements based on knowledge and experiences.

Adequate and effective engineering design has the potential of providing one of the most effective ways of managing geotechnical risks. Though, a major part of the geotechnical design is presently based on an over simplistic approach (Clayton 2001b). Geotechnical investigations are carried out using boreholes and exploratory pits. Best practice requires that the investigation is planned on the basis of existing information on the geotechnical conditions, collected during a desk study. This is rare for building and small scale construction. Then, a conceptual ground model is created, based either on the most likely ground conditions that are imagined or on a pessimistic but generalised interpretation. Such a model is however seldom geologically representative. Finally, perceived limit states are analysed and components dimensioned to give a margin against failure.

This process may be adequate for construction projects including little geotechnical work or where the geotechnical conditions are simple or well known. But it can be totally inadequate when geotechnical conditions are more important, either because the structure is particular sensitive or because the ground is unusually variable or poor. Additionally, to often there is too little thought put into the design of geotechnical investigations, which may result in that critical conditions go undiscovered, all the ground affected by the construction is not investigated or the determined parameters are not relevant or too inaccurate.

According to Lewin (1998) there are a number of additional weaknesses in current methods of dealing with geotechnical risks. Some of these are:

- Existing methods for risk management often fail to manage many risks.
- Inadequate follow through from the analysis phase to the control of risks once the project starts to be implemented.
- A concentration of risks in asset creation rather than on the potentially higher risks in other stages of the investment life-cycle (especially the construction phase).
- A tendency towards to focus on risks which can be most easily quantified, without the exercise of proper judgement to get a good feel for the other risks involved.
- Too little attention to changing risk exposures during the investment life-cycle.
- No satisfactory method for combining risks, especially where, as often is the case, the separate risks are dependent.
- A lack of consistency in analysing and dealing with risks for different projects.

As a consequence of this (Lewin 1998),

- Projects are not consistently analysed even for the same sponsoring organisation and different standards of analysis are applied.
- Clients, investors and other actors can not rely on the results of risk analysis.
- Risks, which were identified for mitigation, can remain unmitigated.
- No satisfactory framework exists for developing a record of experiences concerning specific categories of risk and the associated outcomes.
- There is no reliable basis for auditing risk analysis and management.
- Research and expertise is largely fragmented and dispersed instead of contributing cumulatively to improve the state of art.

In addition, most individuals and organisations seem, for some reason, well able to identify and manage risks, and to devise appropriate responses (Lewin 1998). The problem arises with putting the plans into action, and actually doing the agreed responses. A common problem is lack of time or effort for the implementation of decided mitigation actions. Many individuals are so busy doing the normal tasks that there is no time to do the extra work involved with risk management. Many project teams identify and assess risks, develop mitigation plans and write a risk report, then "file and forget". As a consequence, mitigations actions are not implemented and the risk exposure remains the same.

The risk analysis is in some situations confused with method statements and working procedures. While the risk analysis shall provide information for decision-making in order to do the right things, the method statements and working procedures focus at do things right according to the international codes SS-EN ISO 9001 and SS-EN ISO 14001. On a fundamental basis, these systems focus of "doing things right" instead of "doing the right things" (Stille et al. 1998). This results in that important issues sometimes are not given enough attendance and even forgotten and left unattended due to limitations in time when many things shall be handled. A risk analysis should therefore not be replaced by these documents.

5.3 The Distribution of Risk

Geotechnical risks have most impact on clients and contractors but it is important to consider the impact on other actors as well, e.g. on the third party and the environment. To a client, geotechnical risks are likely to be considered as a largely negative factor. However, the geotechnical risk management process can represent a considerable opportunity to the project since it expose the risks involved and creates information for decisions regarding design, execution etc. Cost-effective alternatives can therefore, be revealed which otherwise have never been explored. Risk management systems that incorporate geotechnical risks and ensure an effective use of resources consequently offer considerable opportunities.

The distribution of the risks is governed by the contract between the actors involved. Thus, the contract is an important element in the risk management process. In addition, procurement methods have important implications for the risk management process. It should be in all actors' best interest to make an estimate of the risks and uncertainties involved as good as possible before the contract is signed (Lewin 1998).

Traditionally, in civil engineering contractors have been responsible for many of the risks with temporary works, but increasingly clients are adopting methods of contracting by which clients seek to transfer other types of risks to the contractor. Since the conditions of contract for design-and-build, build-operate-transfer, etc., are increasing, major clients are using partnering, term contracting and independent dispute solution boards to promote effective dispute resolution (Clayton 2001b).

The part with the best opportunity to manage a risk should in general be responsible for the risk, i.e. should be the risk owner, and should be given reasonable compensation for it. It can of course be tempting for clients to shift the risks on to the contractors in order to "get rid of them". However, this is seldom the most optimal way to distribute the risks since there can exist risks which the contractor can not control, e.g. public, political and societal risks. Shifting the risk over to a contractor will also cause a financial cost for the client since no contractor is willing to take on a risk for free. If the contractor can not control the risk this cost is a waste of money.

As been stated before, the contract between the client and the contractor should distribute the risks, responsibilities and engagements in a fair way and with an obvious relation between risk and compensation. However, what is fair is difficult to say. Nevertheless, if one actor is forced to take a large part of the risks without being compensated for it, disputes, bad working climate and bad overall performance tend to arise. In order to design the contract in a proper way it is important to identify as many hazards and risks as possible before the contract is established.

The contract should aim at regulating all imaginable deviations and changes which can possibly arise during the project execution. In order to distinguish these deviations it is essential to identify key indicators of these and agree on how these indicators shall be measured and interpreted. These indicators should be inclusive and mutual exclusive. Variations in geotechnical conditions that might have effect on the project need to be addressed at the earliest opportunity so that re-design or different methods of construction can be considered.

5.4 The Role of the Client

The fundamental aim for all clients is, of course, to gain value for their money or maximise expected monetary outcome in the cost-benefit analysis. However, in many construction projects it is almost equally important for the clients to have a certain outcome of their projects in terms of time, cost and quality since it is often important not to exceed the budget or time schedule for the project. As a consequence, the client is generally not too eager to take on risks in order to reduce the costs in relation to the budget. On the contrary, the client can be much more willing to take on risks in order to prevent budget overdrawings. As geotechnical risks can cause time delays and additional costs for e.g. re-design and change of working methods, it is in the client's interest that the geotechnical risks are managed appropriately (Lewin 1998 and Tengborg 1998).

The risk acceptance and the attitude towards risks of the client will affect the way in which risks are managed in a project since the client generally sets the standard or level for the risk management process. If the client is not emphasising the importance of the risk management it is not likely that the other actors will do so. Therefore, the client's attitudes towards risk management have major influence on the risk management in the entire project. A sound attitude should be to adopt a comprehensive view of the risks and to focus on the most important issues and risks which had been found in the problem and system definition phase and in the risk identification. A successful risk management process is also dependent on the client's full and true commitment to the management of the geotechnical risks.

The risk management process is not only influenced by the attitude of the client but also by the client's ability to analyse and establish its needs and requirements in an early phase of the project. Changes in the client's requirements are undesirable and should be avoided if possible since successful risk management requires that a set of design objectives is developed before the conceptual and the detailed design are started. Successful design results from a careful definition of needs and requirements, expressed in the simplest and most general terms, which gives the designer maximum flexibility in seeking the most robust and cost-effectives design with respect to the geotechnical risks.

For a successful management of geotechnical risks, the client should ensure that a risk management system, covering the important geotechnical risks that influence the project, is established during pre-planning of the project. Documentation and communication is especially important during the early phases of the project in order to ensure that all the risks identified during project conception are dealt with during design and construction. The identified risks and hazards should, together with the planned responses, be communicated to all actors involved throughout the entire project. Clients need to ensure that, as far as possible, their requirements are recognised by the designers and are considered in the risk management process.

The result of the early identification of geotechnical risks should include a geotechnical risk register and a short geotechnical summary which assesses the potential impact of geotechnical risks on the project (Clayton 2001b). A risk handling plan should also be included where the risk owner, mitigation actions and the time for the mitigations are presented. Additionally, the documentation should recommend whether any further work is necessary to determine the geotechnical conditions with additional accuracy in order for the project to proceed. These documents should be passed on through the entire project organisation to ensure that all actors have the relevant information and no information is lost.

Furthermore, clients need to decide the appropriate distribution of the risks in the project, i.e. who is responsible for which risks. Some of the risks may be insurable, but most geotechnical risks must be taken either by the client or the contractor. It is important that the clients select a type of contractual arrangement that reflects their wishes regarding the distribution of any residual risk that may remain after design so that the no uncertainties of this exists. If the risk distribution is not described clearly in the contract, misinterpretations and disputes are at hand. This is especially important in infrastructure projects where, due to the nature of these projects, geotechnical risks may easily lead to large cost overruns and time delays. The fundamental aim should be that the risks are distributed so that the actor that has the best opportunity to control it is the risk owner. In addition, the risk owner should be given reasonable compensation for it. How much is reasonable can however be questionable and difficult to calculate.

The additional costs resulting from geotechnical risks can lead not only to an unproductive working climate and disputes during construction, but also to expensive arbitration and litigation after the projects is completed. For large clients there may be relatively little relationship between the type of contractual arrangement used and the difficulty with which the disputes may be resolved, since they can use their purchasing power to encourage contractors to take a longer term view of losses. For such clients it should be worth investigating partnering, collaboration and the use of term contracts, since these are known to help ease the process of negotiation and settlement. For small and occasional clients, whose construction requirements are limited and infrequent, considerably more care is required in selecting suitable contracts and geotechnical advisers. The best contractual arrangements are then those where the technical resources of the client, the designer and the contractor are combined in order to overcome geotechnical difficulties as they become apparent. Formal dispute avoidance procedures should always be introduced (Lewin 1998).

Melvin (1998) suggests that the risk management process can be improved by the use of the large and wide experience of the large insurers as input in the risk management process. Furthermore, the working climate and co-operation in the project can be improved by the use of a totally dedicated risk engineer whose main task is to look after all the major contracts involved in the project and thereby anticipate any disagreement and dispute. This way of working was conducted in the construction of the new airport in Hong Kong with a satisfying result. Better construction site relationships, a deeper involvement and commitment among the actors involved and fewer claims than normal were some of the improvements that Melvin (1998) reports. The main tasks of the risk engineer in the project were to report the progress of the project and the scope of the work undertaken, to assess the risk factors and to make recommendations regarding loss prevention. The tasks of the risk engineer did not include the handling of possible claims, but to make sure that actions were undertaken in order to prevent the same problem. If any disputes or claims occurred, these were instead handled by an independent loss adjuster.

As a conclusion, the main tasks of the client in the risk management process are:

- Clients should take an active role to ensure that the risk management process is started during pre-project planning with an identification and estimation of risks and hazards as well as deciding methods for risk handling and establishment of a geotechnical risk register.
- Clients should take a leading role in co-ordinating the work with the management of geotechnical risks in the project and ensure that a fundamental view of the risks and risk management is established in the project.
- Clients should declare their fundamental construction objectives and requirements in an early phase of the project.
- Since construction often involves major risks, clients or their projects mangers need to establish their risk tolerance at the start of the project.
- Early investment in good geotechnical advice will allow the identification of projects that could be significantly affected by the geotechnical conditions.
- The impact of the contract between the client and the contractor on the distribution of risk should be considered thoroughly.
- The result of the client's risk management should be communicated to the designers, contractors and all other actors involved in the construction process.

5.5 The Role of the Designer

The main goal of the designer is, in general, to design a planned facility on the basis of the geotechnical conditions at a given site, a description of the desired function and quality of the facility, and societal laws and regulations. The designer generally wants to create a good relationship with the client in a long-term business view in order to have a good reputation as a serious advisor (Tengborg 1998).

As been discussed in chapter 2.5, most individuals are risk-averse, i.e. when exposed to risks most individuals prefer to be on the safe side. In geotechnical engineering, the situation is often the same. A construction is generally designed with some safety margin against failure, i.e. to be too strong than too weak. However, since safety reserves influences the cost, the question is how much stronger is enough. Avoiding failure is valuable, but not at any cost. Therefore, the opposing objectives of safety and adequate usage of resources must be balanced. In addition, reducing one risk may give rise to another countervailing risk (Lewin 1998 and Tengborg 1998).

Effective engineering design provides one of the most effective ways of minimising or eliminating geotechnical risks. For an effective design, designers need to understand that the geotechnical conditions can never be known with certainty because of the natural variability of the ground from place to place and with depth. In addition, the geotechnical properties vary much more widely than those of other construction materials and there are many different mechanisms by which the ground can cause difficulties for construction (Clayton 2001a).

An effective design results in effective risk handling strategies. Residual risks can then be focused on and suitable ownership defined. If major geotechnical risks remain after design then the project may not be able to proceed, or a further phase of more specialist design may be required. To be effective, geotechnical design should be systematic and recognise the uncertainties associated with the ground. The design process should be integrated within a risk management system to ensure that uncertainties are dealt with effectively.

Calculations in geotechnical engineering are not very accurate even when the geotechnical conditions are well known and the design is undertaken by experts using the best methods available (Clayton 2001b). Consequently, the design should be flexible and robust enough, i.e. easy to change and able to withstand possible variations in the geotechnical conditions without extensive re-design or change of working methods. Therefore, an effective design provides a robust defence against geotechnical risks. Robust geotechnical design coupled to systematic risk management can reduce uncertainty to accepted levels, but sophisticated geotechnical analyses can, for some projects, add significant value or reduce costs and construction time.

Geotechnical design should be carried out systematically by using a predefined staged approach to design in order to ensure that the client's needs are correctly identified, optimal solutions are found and that creativity is maximised. In other industries, such as the manufacturing industry, a method called systematic engineering design has evolved as an effective way of maximising the certainty of the outcome and minimising the risks, see figure 5.1. The first step in the systematic design is the expression of the needs of the client as simple and precisely as possible. This leads to a design specification which the final design can be checked against. The design specification shall not stipulate the technical solution. In order to fulfil the design specification it is necessary to understand the functions and sub-functions of the project and to satisfy the requirements (Pahl et al. 1996).

In the next step of the systematic design, the conceptual design consciously breaks down the project into these functions and sub functions and finds solutions for each function, by using a combination of practice, hazard avoidance, judgement and experience, meeting the requirements of cost, uncertainty and, environmental, health and safety impact. The conceptual design results in a number of design alternatives for each function and sub-function which shall be judged against the design specification. The best combination of solutions will then be selected on the basis of a range of qualities, such as fitness for the purpose, likely cost, simplicity, certainty of outcome and environmental, health and safety impact. In geotechnical engineering, the conceptual design phase will usually result in a geotechnical design report.

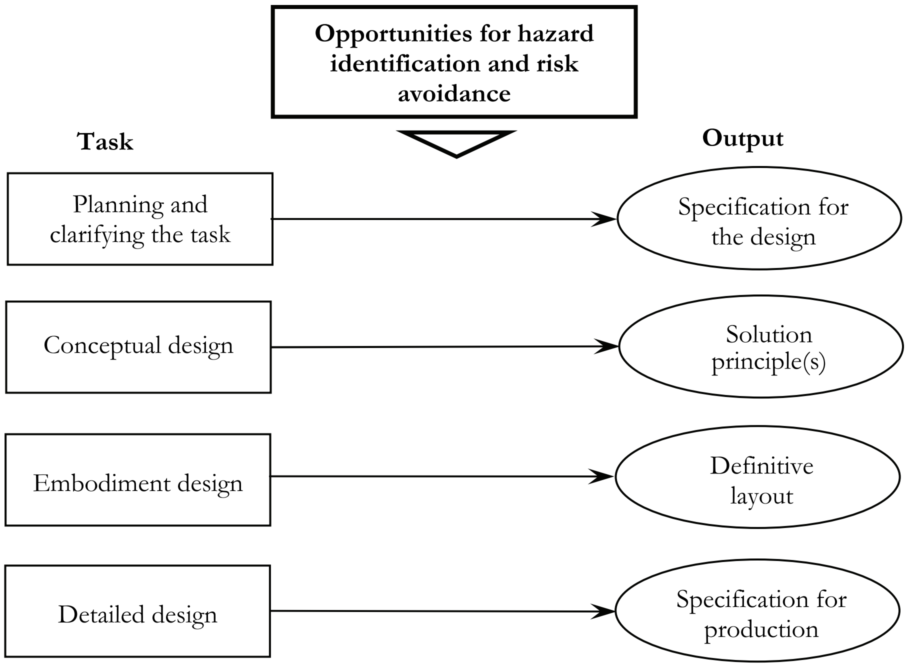

Figure 5.1 Elements of systematic engineering design (Pahl et al. 1996).

Conceptual design should include a system approach as a counterbalance to the usual bottom-up process of analysis. Systems analysis aims at identifying the key factors that affect the project and the dependence between these. System analysis questions the assumption that components of a system are the same when separated as when they are part of the system. In figure 5.2 a system approach using interaction matrices is illustrated with the aim of identifying unfavourable design interactions. In the geotechnical design it is important to search for unfavourable interactions since these can sometimes be critical. Geotechnical hazard and risk identification and hazard avoidance are fundamental parts of effective conceptual geotechnical design. Where particular critical mechanisms of failure can not be avoided, they should be prevented from occurring by using more than one defensive measure, the so called “defence in depth” (Clayton 2001b).

The next step in systematic engineering design is the embodiment design which aims at identifying the optimal design alternative. The embodiment design results in a description of the definitive layout of the construction. In geotechnical engineering, the embodiment design typically results in drawings and working procedures.

Once the optimal design alternative has been identified, a detailed geotechnical investigation should take place to provide information for the detailed design to proceed. During detailed design, little reliance should be placed on deterministic “best-shot” analysis, since these will often lack accuracy and provide only an incomplete assessment of likely construction problems. A probalistic approach should therefore always be considered. The geotechnical investigation should be planned to test the geotechnical conditions in the conceptual model. The detailed analysis generally results in technical specifications for the construction. An effective systematic design in geotechnical engineering should also include method statements and control programs.

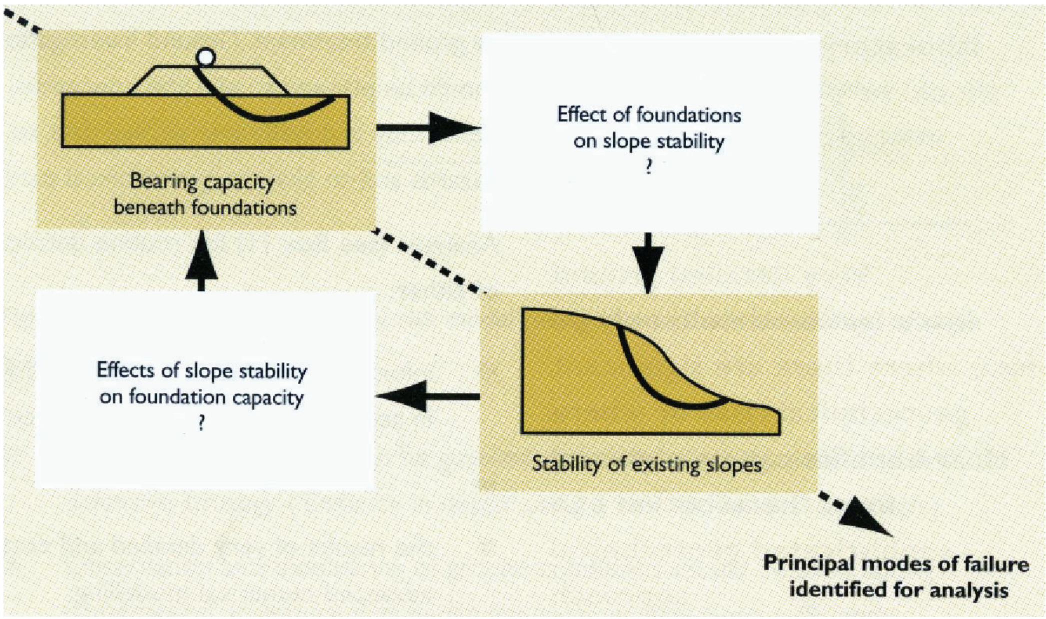

Figure 5.2 *A system approach, using interaction matrices, to identify unfavourable design interactions (Clayton 2001b).*

Detailed investigations should only be done where there are significant geotechnical risks or where clear benefits can be obtained from a sophisticated geotechnical approach. As a consequence, most designs will be based on limited investigations and the shortcomings of this most be recognised by the designer. Six approaches can be helpful in projects with limited geotechnical investigations. These are (Clayton 2001b):

- An independent team of experts can be used to review the detailed design to ensure that key mechanisms of failure are not overlooked, that realistic parameters are selected and that the design calculations are performed competently and correctly.
- The use of sensitivity analyses and/or probabilistic calculations allows the designer to understand the effects of uncertain parameters on the result of analyses, see figure 5.3.
- Especially critical failure mechanisms can be prevented from occurring by adopting more than one risk strategy.
- Observation and monitoring of the geotechnical conditions could be used during construction to ensure that the assumptions made in the design are representative for the geotechnical design to perform satisfactorily.
- Where design can be flexible, monitoring of key components can be formalised in the observational method.
- The use of an active design approach or the observational method.

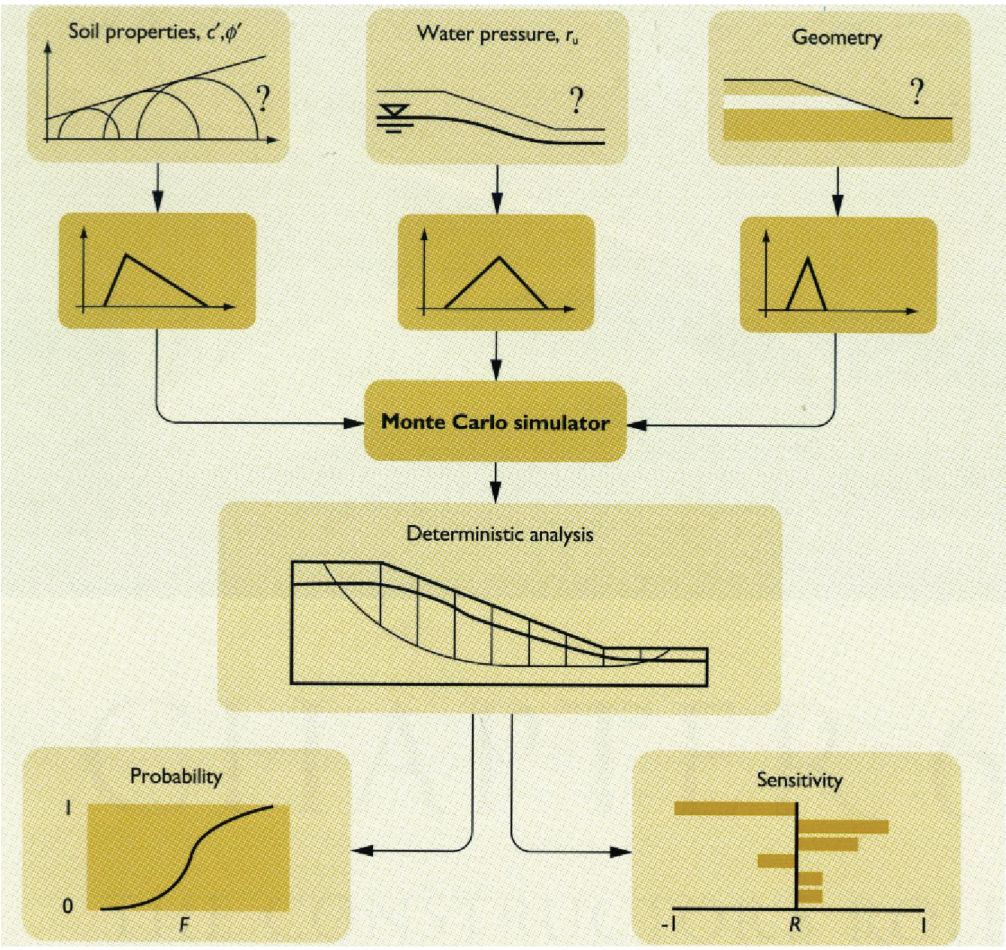

Figure 5.3 An example of sensitivity analysis of a slope (Clayton 2001b).

In the context of risk management, the result of an investigation should be reflected in the light of what can be foreseen, rather what is actually found. A geotechnical investigation can in general be divided into three phases, i.e. desk study and site reconnaissance, detailed investigation for design and, at last during construction, construction review. When using a more dispersed geotechnical design, Clayton (2001a) proposes the following changes to improve the risk management process:

- For effective hazard identification the first geotechnical investigation has to be carried in an early phase of the project and a geotechnical specialist should therefore be involved from the project start.
- Several geotechnical investigations have to be performed as the geotechnical design will generally be carried out in several phases of the project.
- The geotechnical conditions should be observed and recorded during construction. The actual conditions should be compared to those presumed in the hazard identification phase and the design.

- For low-risk projects it will be enough with a limited site investigation in combination with construction review. In high-risk and complex projects, e.g. construction of dams, tunnels and deep excavations in urban areas, it will be necessary with extensive investigations in order to manage the risks.
- Geotechnical data, including the motives for geotechnical investigations and its interpretation, should be made available to all actors in the project.

As a conclusion, the main tasks of the designer in the risk management process are:

- Designers should be systematic and identify the client's needs and risk acceptance.
- Designers should recognise that the geotechnical conditions always are uncertain and should adopt design strategies that are effective in managing uncertainties, e.g. systematic engineering design and observational method.
- Designers should always consider the opposing objectives of safety and adequate usage of resources in order to create cost-effective structures which are easy to construct.
- Designers should emphasise conceptual design and sensitivity analysis in order to understand unfavourable design interactions and the effect of uncertain parameter values.
- Decide the extent of geotechnical investigations in relation to the degree of geotechnical risks involved.
- Designers should recognise the limited accuracy of many geotechnical design calculations.
- Designers should create robust designs with redundancy which shows that damage has occurred before the system collapses.
- Gather the result of risk analysis and design responses to risk in a risk register.
- Designers should observe the geotechnical conditions during construction in an adequate manner and compare these to those presumed in the hazard identification phase and the design.
- At the end of the design process, forward the risk register and all the geotechnical information to the client and the contractor.

5.6 The Role of the Contractor

The fundamental goal for contractors is in general to maximise the profit, both in the short and long term. This means that the contractor is interesting in fast profits but also anxious to create a good relationship with client. The contractor is usually seen as the most risk-taking actor in the construction process (Tengborg 1998).

As been stated before, geotechnical risks have the most impact on clients and contractors and there are trends that clients increasingly are adopting methods of contracting by which the risks are transferred to the contractor. This means that the contractor probably have to allocate more personal and financial resources for the management of geotechnical risks in the future in order to manage the risks. However, the risks and uncertainties associated with the geotechnical conditions can represent a considerable opportunity to knowledgeable, experienced and well-organised contractors to create cost-effective projects. Therefore, it is important that the contractor's geotechnical risk management strategy recognises the impact of the contractual framework within which the work is to take place.

In all projects, a risk management system should be introduced as early as possible (see e.g. Hintze 2001). Geotechnical risks and hazards should preferably be identified and analysed during the tender or negotiation phase. Risks with temporary works should also be included. Risk modelling to include the financial implications of geotechnical risks may be helpful even in this initial phase. The contractor should also establish systems and procedures to avoid damage, e.g. method statements and working procedures. Some of the risks can be avoided by the use of these systems and procedures while other can not be foreseen before they are realised. As a consequence, the contractor should establish procedures to identify and manage unexpected risks.

When the contractor enters the project, a risk register should be received from either the client or the designer. The risk register should be reviewed and supplemented before the start of execution regarding the proposed construction methods. It should also be reviewed regularly during construction to ensure that risks have, as far as is practically possible, been reduced to an accepted level and that they are relevant to the conditions actually encountered. If a risk register is not received from the designer or client, the contractor should start to establish one as soon as possible (Clayton 2001b).

The risk register should be a living document and should be updated regularly during the design and construction, particularly regarding the proposed temporary works and specialist construction techniques. Wherever the contractor takes on design responsibilities, a geotechnical design review should be carried out to ensure that the geotechnical risks have been effectively managed. The risks associated with geotechnical construction techniques should be assessed as soon as they become known. The result of the contractor's geotechnical risk management should be communicated to all specialist subcontractors and geotechnical designers that are subsequently employed in the project.

The techniques to be used for geotechnical construction are increasingly being selected by the contractor. Cost and previous experience are typically used by the contractor as basis to select the particular methods to be used on any given site. The methods chosen and their associated specialist equipment will bring forward new geotechnical risks that must be added to the risk register and managed properly. Specialist groundwork contractors need to be included in the risk management process so that they can feed their expertise and experience into the risk register and the continuing process of geotechnical risk analysis and response (Clayton 2001b).

Often the most effective way of controlling geotechnical risk is by producing flexible designs coupled with observation, investigation and characterisation of the geotechnical conditions at the time of construction. During the project execution the contractor should then, as far as is practical, observe, monitor and record the actual geotechnical conditions and behaviour. In some projects, either for complex high-risk projects or where the permanent or temporary works design can be modified during construction to take advantage of new information, it may be worthwhile to make measurements of key indicators during construction and to use the observational method.

The use of the observational method is a powerful tool when used in the right way. The success of the method is dependent on a successful implementation of the method. It requires commitment and understanding from all the actors involved in the process, i.e. the contractor, the designer, the client and the client's associates. Otherwise it is hard to implement changes in the project as they can be considered only as a disturbing element and not as an opportunity to improve the project.

The result from the monitoring will allow an evaluation of the adequacy of the project design. A comparison of observed and expected geotechnical conditions can give early warning of possible problems, allowing changes to be made before additional costs and time delays becomes significant. Where there are significant geotechnical temporary work risks, geotechnical specialists should be brought to the site to make a risk assessment during construction. However, monitoring is often complex, expensive and requires expert geotechnical input during construction, but can be particularly worthwhile where large parameter uncertainties are thought to exist and conservative design has a major impact on construction cost. The cost and extent of the monitoring must therefore be balanced against the likely benefits of the measurements.

The result of the observation and monitoring during construction should be fed back to designers as it becomes available, to ensure any unexpected condition and behaviour is detected. Furthermore, the contractor should identify construction defects and ensure that methods of construction are changed where beneficial and re-design can be carried out if necessary. Following construction, the data collected during risk management should be reviewed by all actors concerned with the project to allow continuous improvement of the risk management system (Clayton 2001a).

In order to avoid the "file and forget" of the risk analysis in the construction phase, the agreed risk responses could be placed on equality with normal work (Lewin 1998). If the risk responses are considered only as extra work they will be given second rate status behind the ordinary work activities. However, if the risk responses are given equal importance with other project tasks people will be encouraged to implement them. Only if the risk responses are considered to be valid and important tasks which make a significant contribution to achieving the objectives of the project, the risk responses will be treated seriously and actually implemented. After all, identifying risk responses but not implementing them is a waste of resources. Only when putting the agreed risk responses into action the risk exposure can be changed and the chances of meeting the objectives be improved. The following four steps might help in this matter:

(i) Accept that the risk responses might require changes to the project cost or time schedule.

(ii) Ensure that every risk response is fully defined with a duration, cost, resource requirement, owner, completion criteria etc.

(iii) Add an extra task to the project plan for every agreed response.

(iv) Monitor the progress on the risk response tasks in exactly the same way as for all other tasks.

As a conclusion, the main tasks of the contractor in the risk management process can be summarised as:

- The contractor should allocate an adequate amount of personal and financial resources to work with the management of geotechnical risks.
- The contractor should make the risk management work equally important as the other work activities.
- The contractor should start the risk management process as early as possible, i.e. during the tender or negotiating phase.
- The contractor should review and supplement the risk register before the start of the execution regarding the planned construction methods and review the risk register regularly during construction.
- The contractor should establish method statements and working procedures to manage identified hazards and procedures which can identify and manage unexpected risks and hazards.
- The contractor should as far as is practical and possible in relation to the contract, observe, monitor and record the actual geotechnical conditions and behaviour during the project execution.
- The contractor should review the geotechnical aspects of the design and identify opportunities where re-design could make construction safer and more cost-effective.
- The contactor should, together with all other actors involved in the project, reconsider the data collected during risk management in order to allow continuous improvement of the risk management process.

5.7 Conclusions

Geotechnical risks and uncertainties in infrastructure projects can never be characterised entirely due to the inherent variability in the ground and the complex interactions between these. These risks and uncertainties can influence both the technical and financial performance of a project as well as the environment, third party etc. Recent studies suggest that the traditional methods of construction and risk management can not manage these risks effectively in all projects. Furthermore, the increasing use of "new" contractual agreements, which tend to disperse the design responsibilities and to shift the risk to the contractor, a new way of dealing with geotechnical risks needs to be adopted.

The literature study and the case studies have revealed some shortcomings and weaknesses in current methods for managing geotechnical risks. Some of these are:

- The construction industry suffers from an "illusion of certainty", i.e. there is a belief that all risks can be foreseen, and procedures for handling unexpected risks are therefore sometimes not established.
- There is a lack of consistency in analysing and managing risks for different projects and clients.
- The risk management in many projects is based on scientific method in a deterministic framework.
- Existing methods of risk management often fail to manage many of the critical risks.
- A tendency towards to focus on risks which can be most easily quantified.
- No satisfactory method for combining risks exists.
- Inadequate follow through from the analysis phase to the control of risks once the project starts to be implemented.
- There is sometimes a weak connection between the risk analysis in the design phase and the management of risks in the execution phase.
- The risk analysis is not used as a basis for risk sharing in many projects.

The risk management process is influenced by the conflict of interests that is apparent in most projects since the actors have different and, sometimes, conflicting objectives. Additionally, the actors also have different attitudes towards risk and risk management. Risk management based on a systematic use of expert opinion provides, however, an effective framework within which to identify and assess the importance of geotechnical risks. A successful project risk management is dependent on an honest and obvious commitment from the actors in all project phases in questions regarding allocation of resources, communication and documentation.

The distribution of the risks is governed by the contract between the actors involved. Consequently, the contract is an important element in the risk management process which has to be addressed properly. The contract should reflect the client's wishes regarding the risk distribution in an unambiguous way. In order to decide the distribution of risk between the actors involved, an estimate of the risks and uncertainties involved should be performed before the contracts is signed. The actor that has the best opportunity to manage the risk should in general be responsible for the risk and should be given reasonable compensation for it. There should also be an obvious relation between risk-taking and compensation. The contract should aim at regulating all imaginable deviations and changes which can possibly arise during the project execution if disputes etc. are to be avoided.

Effective design offers one of the best opportunities to manage geotechnical risks. In order to ensure an effective design the client and designer should:

- Determine the essential project requirements.
- Be systematic, so that no important design stages are missed.
- Use conceptual design in order to identify designs and construction methods that can be changed with reasonable means in order to manage potential risks.
- Use design methods that recognise that the geotechnical conditions are uncertain.
- Check the design against current and precedent practice in similar geotechnical conditions.

In the light of the increasing use of new contractual arrangements and procurement methods in combination with more complicated projects in urban areas, the current strategy of risk management should be modified. In order to ensure an effective management of geotechnical risks the actors involved in the building process should:

- Accept that there always will be geotechnical risks and uncertainties.
- Use a top-down philosophy to focus on the problem at hand.
- Allow a multipurpose and thorough investigation of the geotechnical conditions at the planning stage.
- Introduce geotechnical risk factors into existing risk management systems.
- Start the identification of geotechnical hazards and initiating events in the early phases of all projects.
- Monitor and record the actual geotechnical conditions and behaviour during the project execution and review the geotechnical aspects of the design and identify opportunities where re-design could make construction more cost-effective, e.g. by adopting the observational method.
- Emphasise appropriate design techniques, e.g. systematic engineering design or conceptual design.
- Collect data during the risk management process which at the end of the project should be used to provide feedback on the effectiveness of the procedures used.

6 General Conclusions

The literature study has showed that there have been cost overruns and time delays in many infrastructure projects around the world in recent years. There have also been problems with achieving the expected quality in many projects. Given the average level of profit in the construction industry, it is crucial for both clients and contractors that these cost overruns, time delays and quality problems are avoided in the future.

A significant part of these costs overruns, time delays and quality problems are a result of the significant risks and uncertainties involved in many infrastructure projects and there tend to exist numerous, often interrelated, risks and uncertainties. Furthermore, the risks and uncertainties are not always obvious and the relationships may be ambiguous and complex. The risks may also exist at all project levels throughout the life of a project. If the uncertainty could be transformed into a calculable risk, it is believed that around one third of the cost of failures could be avoided.

Many of the reported problems are associated with geotechnical risks and uncertainties which are not managed sufficiently in the planning, design and execution phase of the project. In order to achieve a cost-effective product and a more predictable outcome of the project to an expected cost, it is therefore essential to manage the existing geotechnical risks and uncertainties. The traditional methods of construction and risk management have showed not to be able to deal with these problems. The need for a new approach to risk management is also highlighted by the increasing trend towards a broader package of risks and the transfer or sharing of risk for capital investments between public and private sectors. The rapid evolving methods of construction procurement also require a modified approach to management of geotechnical risks.

Risk management is however not something new and is a part of our everyday lives and something we do every day, e.g. when deciding to cross a road at a specific place or not. This type of risk management is usually instinctive and subjective and is based on our knowledge and experience. However, in a complex infrastructure this is not sufficient. A successful management of risks in an infrastructure project is dependent on a structured and systematic approach involving all actors in the project during the entire life-cycle. A structured and systematic risk management describes the risks formally, focuses on major risks, makes informed decisions, minimizes potential damage and control uncertainties. A structured identification and analysis of risks should not only reduce the negative effects of the risks but also bring forward the positive aspects of risk-taking.

The fundamental nature of the risk management process is not especially difficult because it is a structured way of dealing with significant uncertainty. All that is needed is to determine which objectives are at risk and then identify hazards that might affect their achievement. The next step is to estimate and prioritise identified risks and decide how to respond, and then take action. But although this process is simple to describe, it seems hard to make it work in reality because the process involves many different actors and individuals with different knowledge and experiences, includes many different types of uncertainties and risks, and extends over relative long period of time. In addition, the risk management process is influenced by many factors, for example the meaning and interpretation of the word risk and the risk management methodology, the attitudes towards different types of risks and the communication of risks.

The literature study and the case studies have revealed some shortcomings and weaknesses in current methods for managing geotechnical risks. Some of these are:

- There is a lack of consistency in analysing and managing risks for different projects and clients.
- The different actors sometimes perform their own risk analyses and these are not co-ordinated.
- The construction industry suffers from an "illusion of certainty", i.e. there is a belief that all risks can be foreseen and procedures for handling unexpected risks are therefore sometimes not established.
- The risk management in many projects is based on scientific method in a deterministic framework.
- Existing methods of risk management often fail to manage many of the critical risks.
- There is a tendency towards to focus on risks which can be most easily quantified.
- Inadequate follow through from the analysis phase to the control of risks once the project starts to be implemented.
- The risk analysis is not used as a basis for risk sharing.
- There is sometimes a weak relationship between the risk analysis in the design phase and the management of risks in the execution phase.

The risk management in an infrastructure project rests on an understanding that risks are a natural and an unavoidable part of the project. Some of the risks may be planned or design for, but some risk will always be present in the execution phase and must be managed there. Furthermore, the risk management process can not hope to identify all risks so procedures to discover and manage unidentified risks have to be established.

The fundamental aim of the risk management is in general to discover possible hazards and damage events in due time and to handle these before they result in damage. The risk management process should identify and prioritise the hazards in the project, identify initiating events and warning bells, estimate and prioritise the risks, decide appropriate risk handling actions and create risk-based information as a basis for decision-making. An important risk characteristic is the time period before a risk is realised, because time is critical in determining risk handling actions. The objective is then to avoid crisis management and problem solving by managing risk up front. The probability and/or consequence may change as the project progresses and information becomes available. Therefore, the risks should be re-evaluated continuously throughout the project life-cycle, from initiation, during planning, design and construction, throughout the operating period, to close-down of the project.

A successful management of geotechncial risks requires that an identification of risks and hazards is performed in an early phase of the project in a transparent and objective way by geotechnical engineers with knowledge and experience of risk management. An important issue is to ensure that the identified risks and hazards are managed properly in the execution phase, e.g. through the use of monitoring, the observational method and technical reviews. The risks and hazards should be communicated to all actors involved in the project in an appropriate manner.

In the light of the shortcomings and weaknesses, the growing use of new contractual and procurement arrangements and the increasing location of infrastructure projects in urban areas, the current strategy of risk management should be modified. In order to ensure an effective management of geotechnical risks the actors involved in an infrastructure project should:

- Ensure that there is an unambiguous definition of the word risks and the risk management process which is known by all involved in the project.
- Focus on both risk management and opportunity management.
- Accept that there always will be geotechnical risks and uncertainties in infrastructure projects.
- Use a top-down philosophy to focus on the problem at hand and adopt a comprehensive view of the project.
- Allow a multipurpose and systematic investigation of the geotechnical conditions at the planning stage.
- Use design methods that recognizes that the geotechnical conditions are uncertain.
- Use conceptual design in order to identify designs and construction methods that can be changed with reasonable means in order to manage potential risks.
- Give risk management activities equal importance as other project tasks.
- Ensure that every risk handling actions are fully defined, with a duration, cost, resource requirement, owner, completion criteria etc.
- Use contracts that distribute the risks, responsibilities and engagements in a fair way and with an obvious connection between work and compensation and that regulate all imaginable deviations and changes which can arise during the project execution with mutual exclusive and extensive indicators.
- Communicate the risks to all actors involved in the project in a stringent way that is easy to understand and interpret.
- Monitor and record the actual geotechnical conditions and behaviour during the project execution, review the geotechnical aspects of the design and identify opportunities where re-design could make construction safer and/or more cost-effective.
- Collect data during the risk management process which at the end of the project should be used to provide feedback on the effectiveness of the procedures used.

7 Proposals for Further Research

Risk management in geotechnical engineering is an extensive and complex subject and due to the many risks and uncertainties generally involved in infrastructure projects there are many ways of continuing this study. Furthermore, there seem to be several problems and shortcomings in the management of geotechnical risks in many infrastructure projects today. As a consequence, the chapter presents only some of the areas that the author thinks require deeper knowledge. The proposal for further research focuses on four topics in geotechnical engineering which need more considerations:

(i) The problem of understanding and identifying critical risks.

(ii) Further studies of methods for estimation of risks.

(iii) The attitudes towards risk and the communication of risks.

(iv) The distribution of risk among the actors involved and the connection to the type of contract and compensation.

The understanding of the problem at hand and identification of critical risks seem to be an important part of the risk management process since the costs of unidentified and unmanaged geotechnical risks are large in many infrastructure projects. However, it is not always obvious which risks that have the greatest impact on the project cost and the time schedule. The system analysis is the key to the problem identification and understanding of the problem at hand. The system analysis identifies the key parameters occurring in a project and the correlation between these and almost all civil engineering projects and structures can be expressed in terms of conceptual systems. Furthermore, a system approach encourages a holistic and comprehensive view of the project. A better understanding of different types of systems and system analysis in infrastructure projects would probably improve the problem understanding and the identification of critical risks and thereby the risk management process. This can be achieved by an elaborate review of some types of civil engineering projects and structures, express these in system terms and describe the implications for the management of risks.

The estimation of risks is performed in a rather superficial level in many projects and the estimation of risks is generally carried out using qualitative methods. The risk is then described by using probability and consequence classes and the connection between the risks are generally not considered. In some projects this approach can be satisfactorily, but in some projects probably not. But in which projects is it enough with a schematic qualitative analysis and which projects require a more detailed quantitative analysis? What are the characteristics of these projects? Why do we not use quantitative analysis more often or can we develop the existing qualitative methods to satisfy our needs? What is the problem? Is it the estimation of the probability, consequence or the connection between the risks? If we had the answers to these questions the risk estimation could be improved. This can be accomplished by, for example, studying the risk estimation performed and the outcome of the risk management process in executed projects as well as conducting interviews with risk specialists.

The attitudes towards risks are different among different individuals and different organisations. This means that the risks are managed in different ways in different projects depending on the risk attitude of the individuals involved in the risk management process. In the case studies it has become obvious that personal, social and cultural factors have a major impact on the attitudes towards risks. The success of the risk management process and the execution of the project are dependent on a true commitment from all individuals involved and require that all individuals understand the risks and the risk management process and acknowledge the benefits of a systematic risk management throughout the entire project. If one link in the risk management chain breaks the risk can not be managed appropriately. Furthermore, there are many psychological factors affecting the risk estimation which need to be understood and considered. A better knowledge of the most important factors influencing the attitudes towards risks in infrastructure projects as well as how the risks shall be communicated to the individuals and actors involved in order to create understanding and commitment would certainly improve the risk management process. This could be realised by further literature studies of the personal, social and cultural factors influencing the attitudes towards risk and risk communication in infrastructure projects in combination with case studies and interviews with clients, contractors and risk analysts and, perhaps, behavioural scientists.

The risk distribution seems to be a source of disputes and poor working climate in many projects. The distribution of the risks is, in general, governed by the contract between the parts involved and the risk analysis seems not to be a basis for deciding the optimal risk distribution in many projects. Of course, no one will take on more risks than necessary and risk taking is not free. There is also a conflict of interest involved in a project since the parts involved have different objectives. A non-optimal distribution of the risk will result in an ineffective risk management process and execution of the project. A fundamental demand on the risk distribution is, as have been discussed earlier, that it should be fair and that the part that has the best opportunity to manage the risk should be the risk owner and should be reasonable compensated for it. It is rather easy to discuss these issues in qualitative terms as "fair" and "reasonable" but much more difficult to determine them in quantitative terms. What is fair and reasonable compensation in this matter? How can we in an objective way decide which part that has the best opportunity to manage a risk? These questions need more consideration. Answers to these questions may be found in other industries, e.g. in the insurance industry, by studying successful projects or by the application of optimisation methods.

It is quite easy to discuss all these topics in qualitative terms but a quantitative representation would be both desirable and valuable as it would make the risk management of geotechnical risks more incisive.

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