Risk analyses in excavation and foundation work

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ABSTRACT
BegrensSkade was a Norwegian research project finished in 2015 with the aim of developing methods and processes that will help reduce the risk of damages and unexpected settlements as a result of excavation and foundation work. One subproject in BegrensSkade was related to risk assessment and management. The use of risk assessment and management aims at answering some fundamental questions:

- *What can happen?*
- *How likely is it?*
- *If it happens, what are the consequences?*
- *Is the risk level acceptable?*
- *If not, what can be done to reduce the risk?*

A method for assessing and managing the risk in construction acitivities was developed in BegrensSkade, having the above questions in mind. The proposed method is based conceptually on ISO 31000 's Risk Management framework, in that the methodology proposed is divided into five phases; Phase 1: Establish basis; Phase 2: Risk identification; Phase 3: Semi - quantitative risk analysis; Phase 4: Risk Assessment; Phase 5: Risk reduction measures. The method is implemented in a separate spreadsheet.

The risk sub project in BegrensSkade also included a workshop that aimed for constructing a fault tree for a given construction pit. The starting point was an undesirable event, a so-called top event, which in this case was larger settlements than predicted. The event was then decomposed down to a level of detail where the causes of the top event were detected. In the use of fault trees, the probability of the top event can be assessed qualitatively or quantitatively. In this case, a semi-quantitative method was used, as the causes of the undesirable event was ranked according to the expected probability rather than giving exact numbers.

Keywords: Risk, foundation, excavation, settlements, methodologies.

1 INTRODUCTION

1.1 Risk assessment in BegrensSkade

Risk assessment is increasingly used in many different activities over the recent years. For the construction industry, risk can be said to be implicitly included in the dimensioning principles, but risk assessments in the form of a systematic method is only marginally been applied. In the BegrensSkade project, risk was therefore included as a separate subproject (DP5) in order to examine how to incorporate risk assessments in the planning and execution of construction works in general, and for ground and foundation work especially.

The project includes a preparation of a guide for risk assessments for specific building projects. A test example using a fault tree method for risk assessment for a specific construction pit was also a key part of the project.

1.2 What is risk?

From literature we can find countless different definitions of risk. Aven and Renn (2010) divides the definitions into two categories:
(1) risk is expressed by means of probabilities and expected values,
and (2) risk is expressed through events/consequences and uncertainties.
As an expression of these two main categories, definitions of NS5814 and ISO 31000 states: "Risk expresses a combination of the likelihood and consequences of an incident" (NS5814); "Risk is effect of uncertainty on objectives" (ISO 31000).

Risk management is a term for coordinated activities to assess, control and cope with risks a community is exposed to. The risk management objective is therefore to review and possibly reduce the risk if necessary. When the context of risk management is established, the following steps are important in the risk management process in accordance with ISO 31000:
Step 1: Risk Identification: Potential threats and hazards are identified. What can happen?
Step 2: Risk analysis: Probabilities, potential consequences and risks are combined. How likely is it and if an unwanted event happens, what are the consequences?
Step 3: Risk Assessment: The risk is assessed in relation to the criteria for acceptable or tolerable risk. Are the risks acceptable?
Step 4: Risk reduction measures: What can be done to get the risk down to an acceptable level?

2 METHODOLOGY

2.1 General

There are a large amount of tools that can be used in the risk assessment process. The methods can be purely qualitative, a combination of qualitative and quantitative, or purely quantitative. Some methods may be used by personnel without special expertise in risk assessment, whereas such specialization is needed for other methods. The various methods can be effective tools in various stages of a project. When choosing the method to be used, one should also consider various aspects such as data access, available expertise, complexity of the problem, the purpose of the analysis, and who will use the results. The choice of methods should be justified in terms of relevance and applicability. When it is decided to carry out a risk assessment, and the goal and scope is defined, the following should be considered when choosing the methodology:

(1) The purpose of the study. The purpose of the risk assessment will have a direct impact on the methodology to be used. For example, if the purpose of the study is a comparison between different options, it may be appropriate to use less detailed impact models for the parts of the system where there are small differences between the options.
(2) The need for information to decision-makers. In some cases a high level of detail is required to make good decisions, while in other cases a more general understanding is sufficient.
(3) The type and range of risks to be analysed.
(4) The potential magnitude of the consequences. The character of the analysis should reflect the initial perception of the consequences (although this modification may be required beyond the evaluation process).
(5) Availability of resources both related to expertise, time and other required resources. A simple method applied in a good way can give more useful results than a more sophisticated method, as long as the former satisfies the purpose and scope of the assessment.
(6) Availability of data. In the early stages of the project, simple methods can be used, for example based on a qualitative or semi-quantitative approach. Later in the project, when larger amounts of data are available, more sophisticated methods should be

used, probabilistic methods if possible.

(7) Risk acceptance criteria and risk management procedures defined in the project.

2.2 Overview of methods

Quantitative methods aim to estimate both the probability and consequences of adverse events, while semi-quantitative methods aim for ranking of risk by use of relative numbers. Examples of qualitative methods in construction projects are brainstorming among experts, checklists, rough analysis, hazard and operability studies (HAZOP) and "What happens if" analyses (swift). Common quantitative methods are fault tree and event tree analysis, FMEA (Failure Modes and Effect Analysis), MORT (Management Oversight and Risk Tree), SMORT (Safety Management and Organization Review Technique), THERP (Technique for Human Error Rate Prediction), SLIM (Success Likelihood Index Method), Multi Risk, risk matrix and Markov analysis. An overview of the most applied methods and applications is given in Table 1.

3 RISK METHODOLOGY DEVELOPED IN BEGRENSSKADE

3.1 Overview

The BegrensSkade project developed its own method for risk management. The proposed method is based conceptually on ISO 31000's framework, in that the methodology is divided into five phases similar to the ISO 31000 framework; Phase 1: Establish basis. Phase 2: Risk identification; Phase 3: Semi-quantitative risk analysis; Phase 4: Risk Assessment; Phase 5: Risk reduction measures. The method is implemented in the spreadsheet *BegrensSkadeRisikohandtering.xlsm.*
The spreadsheet consists of a total of three sheets:

- 01-Basis
- 02-Risk identification
- 03-Risk

, in which all the 5 phases of the risk management process are addressed.

It is recommended that the analysis (using the method and the spreadsheet) is performed by a group of technical experts at various levels and relevant for different phases of the project. As the project progresses and new information becomes available, the spreadsheet should be revised.

3.2 Establish basis

Initially the purpose of the analysis must be clarified, which means that one defines what types of consequence to consider, as well as structuring the project into phases so that one can easily identify sources of uncertainty and potential causes of adverse events. Requested input include the determination of the types of uncertainties and which impact types to be included in the spreadsheet. The example included in the worksheet contains five types of uncertainties and four consequence types, but the user is free to remove and add it's own types. For example, the NS 5815 "Risk assessment of construction work" follows four types of consequence: Life and health, Environment, Economy / tangible assets and Reputation. Consequence types should be of such a nature that they could be subdivided into specific severity classes. Two important criteria for selecting severity classes are (a) that they are the most tangible and (b) that it later in the risk analysis is possible for the user to assess the severity class for the consequence. Specific class boundaries make risk analysis more repeatable and less subjective. Classes must be adapted to the project, i.e. the class limits set are relevant to the project. NS 5815 "Risk assessment of construction work" suggests using the following general classes: K1 = hazardous, K2 = Harmful, K3 = Critical, K4 = Very critical, K5 = Catastrophic. These adjectives can be used as a guideline when more specific class boundaries should be defined.

Probability ranges for the various events also need to be defined. As for consequence classes, the criteria are (a) that they are the most tangible and (b) that it later in the risk analysis is impracticable for the user to assess the probability class an incident ports. The following adjectives may be used as guidance for the user: S1 = Extremely unlikely, S2 = Very unlikely, S3 = Very unlikely, S4 = Unlikely, S5 = Somewhat likely. This may range from less than 0.1% per annum on Class S1 to more than 10% per annum for Class S5.

In order to make it easier to find sources of uncertainty and potential causes of adverse events, the spreadsheet is built up so that the main processes in the project are identified, numbered and listed. How the project is split up, is defined by the user. The processes can for example be arranged chronologically and/or according to the responsible for the process.

3.3 Risk identification

Risk identification involves going through all the main processes of the project as defined and identify risk sources and causes of adverse events. A semi-quantitative risk analysis starts by entering numerical values for probabilities and consequences for all risk sources. These data are presented as a risk matrix (Figure 1) where probability (on scale 1 to 5) is plotted against impact (on scale 1 to 5) for each of the risk sources. The user also has the opportunity to decide which risk sources should be included in the matrix.

3.4 Risk evaluation

In the risk evaluation, calculated risk is compared with risk criteria to determine if risk reduction measures are necessary. In the spreadsheet, it is built into some simple tools to assist in this process. The risk criteria to be used will be decided by the user.
In a semi-quantitative method risk is not measured explicitly. The resulting risk is subdivided into 5 levels, illustrated with 5 different colors. The colors of the matrix is related to risk by making different assumptions about how the relative scales (1 to 5) for probability and consequences are connected to physical probability and consequence, see Figure 2. The following operating for color coding is implemented in the spreadsheet:
a) Staircase: This method means that the borders between the five different colors in the array looks like a staircase. Using this method corresponds to the color boundaries of constant risk if the relative scales (1 to 5) on the two axes of the matrix corresponds to exponential scale for physical probability and consequence. b) Hyperbola: This method means that the borders between the five different colors of the matrix are hyperbolas. Using this method corresponds to the color boundaries of constant risk if the relative scales (1 to 5) on the two axes of the matrix corresponds to a linear scale for physical probability and consequence.

3.5 Risk mitigation

Risk reduction measures can be structured into two groups; (1) reducing the probability and (2) reducing the impact. For more refined structuring, measures can further be based on uncertainty types and consequence types defined in Phase 1. In the example included in the spreadsheet, the following types are defined:
1. Reduction of probability / uncertainty:
a. Material (M)
b. Design (D)
c. Execution (U)
d. Natural loading (N)
e. External factors (E)
2. Reduction of consequence. Measures to protect the vulnerable elements of injury:
a. Life and health (H)
b. Environment (M)
c. Progress (F)
d. Economy (SE)
In the spreadsheet, the ability to add description of risk reduction measures is included. It is recommended to save the version of the worksheet that contains measures part as a separate file. Various stimulus packages can be analyzed separately and each package of measures can be saved as a separate spreadsheet file. For each package of measures, numerical value of probability and consequence and risk analysis could be revised. The user may then assess whether the measures are sufficient.

4 RISK ASSESSMENT WORKSHOP

4.1 Basis

A workshop within DP5 Risk was held in spring 2015. In all, 10 people involved in the BegrensSkade project participated. The purpose of the workshop was to jointly construct a fault tree diagram for a construction pit in order to explore possible causes for unexpected settlements outside the construction pit.

The work on the preparation of a fault tree diagram was conducted for a construction pit with the following assumptions:
-Area construction pit (45m * 90m).
-Sheet pile walls anchored at 3 levels.
-Base foundation 10 m below ground.
-Foundation: Piles to rock from the molded base plate, lime-cement stabilization along parts of the pit.
- Relief wells in central pit to avoid bottom heave.
-Ground conditions: Varying depth to mountains, fill material, homogeneous clay, groundwater level 1 m below ground level.
- Neighbour building: piled, some piled into mountains, some sole-founded building, large areas of traffic on a page.

4.2 Fault tree analysis

Basically for a fault tree analysis, an undesirable event is called a top event. The incident is then decomposed successively down to the desired level of detail for the events or mistakes that have caused the top event. The method is both qualitative and quantitative in nature.

Fault tree analysis has a relatively wide range of applications and is one of the most widely used methods for risk analysis. It's purpose is to identify the reasons why adverse events occur.

A fault tree analysis consists of three steps: constructing the fault tree, identifying which combinations of events that have caused the top event, and an assessment of probabilities (or relative ranking).

The identified errors and malfunctions are decomposed further down into smaller events. The last step identify the events that started the chain, also called basic events. This is followed by a survey of specific combinations of events. The probability can be assessed qualitatively or quantitatively. For quantitative assessment the probability of the top event is calculated using calculation rules for the logical operators.

The workshop was conducted by first dividing the participants into two groups, where each group had a discussion regarding the possible causes of the top event (settlements in surroundings). The results of these discussions were subsequently codified in plenary by constructing a fault tree diagram under the direction of sub-project leader for DP5.

The result of the exercise in the form of the constructed fault tree diagram is provided in Figure 3. It was indicated three possible independent causal; i) horizontal displacements of sheet piles, ii) pore pressure build-up, and consolidation settlements, iii) mass loss or stirring effect of drilling rods anchoring. These possible causal relations were so decomposed further into two levels.

5 CONCLUSIONS

The studies made in the BegrensSkade project shows that there is a large potential for reducing damages and costs in excavation and foundation works by systematic use of risk assessment methodologies. Risk based decisions can in case be used in every single step in the preparation and construction work. In this work it of special importance to identify potential risk sources, to assess the risk and to mitigate the risk if found required.

6 REFERENCES

Aven and Renn (2010). Risk management and governance. Concepts, guidelines and applications. Springer-Verlag, Berlin Heidelberg, 2010

ISO 31000 (2009). Risk management - Principles and guidelines. International Standard, 2009-11-15

NS5814 (2006). Risikovurdering av anleggsarbeid

Table 1 Overview of risk assessment methodologies

Method (Chapter)	**Purpose**	**Relevant types of projects**	**Appli-cation**	**Quali-tative**	**Semi-quanti-tative**	**Quanti-tative**
Checklists	Hazard identification	All	Conceptual phase	+	-	-
Preliminary hazard analysis	Preliminary hazard identification and risk estimate	All	Conceptual phase	+	+	-
Hazard and operability study (HAZOP)	Hazard and risk identification	Industry/ technical systems	Design phase	+	+	-
What-if analysis (Swift)	Hazard identification and mitigation	Industry/ technical systems	All project	+	-	-
Scenario analysis	Analysis of possible future events	All	Conceptual phase	+	+	-
Observational method	Perform corrective actions based on monitoring		Design and execution phase	+	-	-
Failure Mode and Effect Analysis, FMEA	Identification of failure sources and effects	Technical systems	Design phase	+	+	+
Fault trees	Identification of hazards and events	Technical systems, environ-ment	Design phase	+	+	+
Event trees	Description of events and consequences	Technical systems, accidents	Design phase	+	+	+
Decision tree	Ranking of decision alternatives		Design phase	+	+	+
Risk matrix	Risk evaluation	All	All project	+	+	-
Bayesian	Risk evaluation	All	Design phase	-	+	+
MORT	Barrier analysis	Technical systems, environ-ment	Design phase	+	+	+
Monte Carlo simulation	Calculating expressions including stochastic variables		Design phase	-	-	+
β-method	Calculating expressions including stochastic variables		Design phase	-	-	+

Figure 1 Risk matrix used in the BegrensSkade spreadsheet. Colours define relative risk (from green – very low to red – very high).

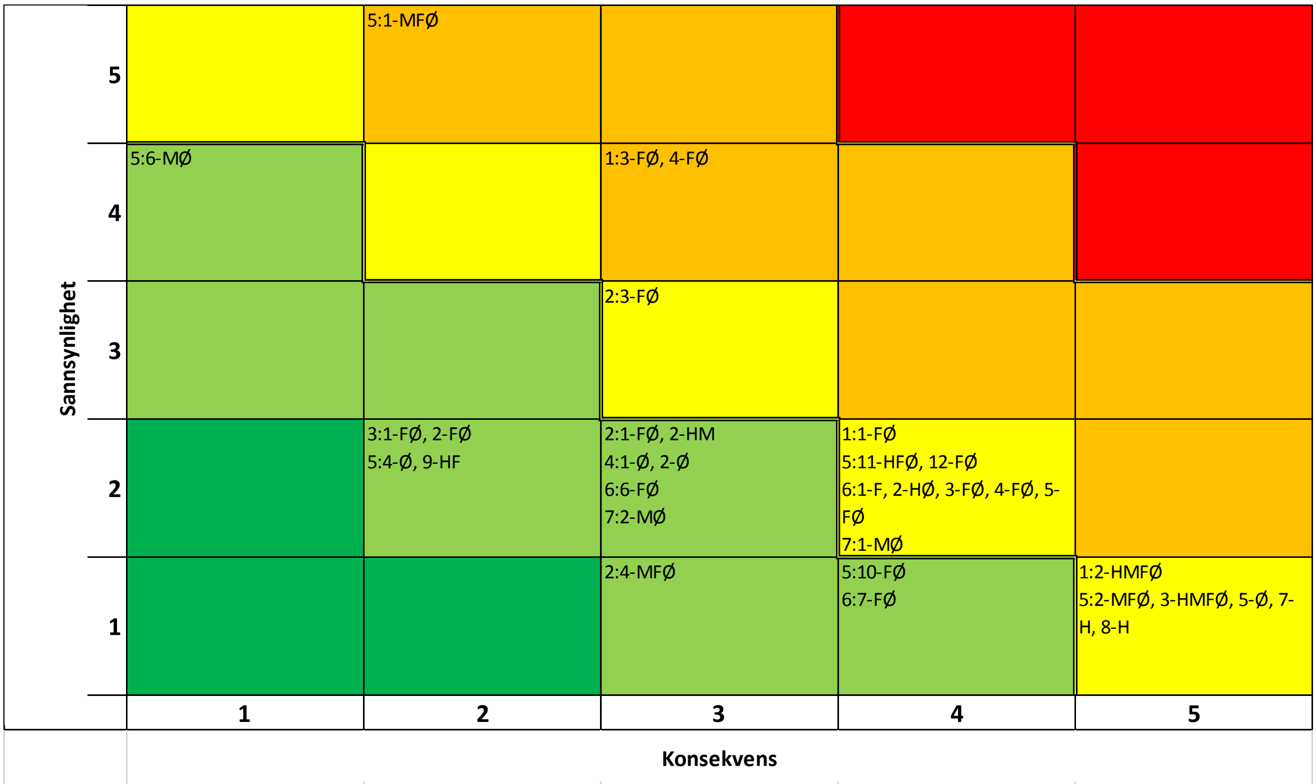

Figure 2 Example of a risk assessment study.

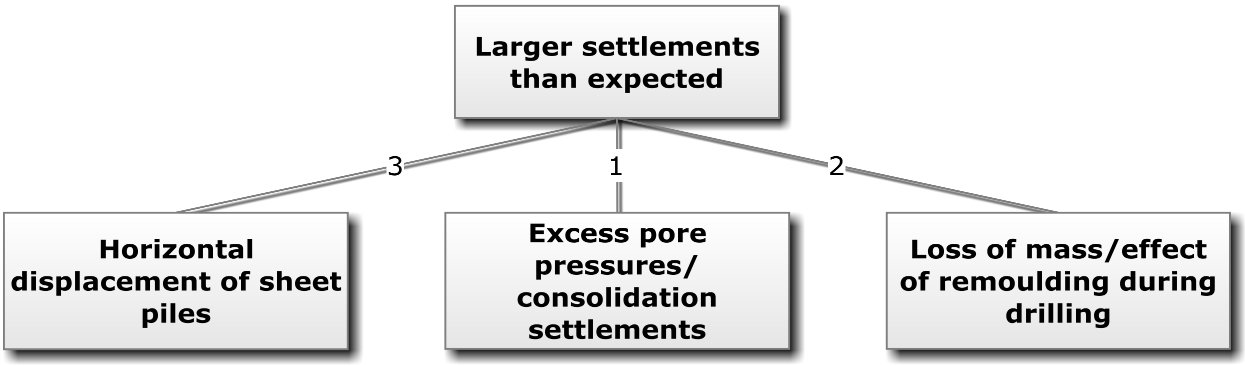

Figure 3 Results of fault tree analysis, level 1