The education of geotechnical engineers should incorporate risk management

L'education des ingénieurs géotechnique demande inclusion de management des risques

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ABSTRACT

The authors analysed about 50 deep excavations in the Netherlands, with failures in different degrees, ranging from very severe with large impact on the structure it self or on the surrounding, to only relatively small damage to the work or the built environment. The analyses show that in more than 60% the failures were not caused by lack of knowledge but simply by not (correctly) applying existing knowledge. Therefore, the challenge for the education of geotechnical engineering is to not only teach a good theoretical base, but also to learn the students to apply risk management during the entire design process. The paper shows how geotechnical risk management is taught at the Section of Geo-Engineering of the Delft University of Technology.

RÉSUMÉ

Les auteurs ont analysé environ de 50 puits de construction profonde aux Pays Bas, avec des échecs dans différents degrés, avec effet très grave sur la structure ou sur l'entourage, ou effets relativement petits au travail ou à l'environnement établi. Les analyses montrent que plus de 60% des échecs n'ont pas été provoqués par manque de la connaissance mais simplement par ne pas appliquer la connaissance existante (correctement). Par conséquence, le défi pour l'éducation de la technologie géotechnique est d'enseigner non seulement une bonne base théorique, mais d'enseigner également les étudiants pour appliquer le management des risques pendant le procès de conception entier. Ce papier montre comment on enseigne le management des risques géotechnique à la section de la Geo-Technologie de l'université de technologie de Delft.

Keywords : Risk management, education, deep excavations

1 INTRODUCTION

In deltaic areas world wide urbanisation increases resulting in densely populated metropolitans in which the use of the sub soil is becoming more and more intensive. Therefore, the number of underground constructions for infrastructure, parking facilities and other functional purposes such as storage or theatres increases. It leads to the construction of deep excavations in city centres of our metropolitans and even in medium-sized cities.

This of course benefits the foundation industry leading to an increasing demand for geotechnical professionals. A serious drawback of this positive development is the fact that in relatively many cases the implementation of these underground constructions faces considerable problems. Over the last years several deep excavations in the Netherlands encountered severe technical problems during construction resulting in months, sometimes years of delay and in some cases even the suspension of the whole project. Such cases make politicians and clients reluctant in planning underground constructions. Moreover, due to the fear and lack of trust neighbouring citizens strongly oppose such plans. This has adverse effects for the foundation industry and more general for the development of our cities because the use of the underground is not a luxury but a need to keep the centres inhabitable.

Van Tol (2007) analysed about 50 building pits in the Netherlands, with failures in different degrees, ranging from very severe with large impact on the structure it self or on the surrounding to only relatively small damage to the work or the built environment. In this paper, the main conclusions of the analyses regarding the type of failures and the causes of failures are described. Next, the authors focus on the possible role of risk management to counteract the ongoing stream of failing building pits and in particular on the role of education of geotechnical professionals.

2 ANALYSES OF GEOTECHNICAL FAILURES

The excavations that were analyzed cover a period of about 10 years (Van Tol, 2007). The failures analysed caused in many cases damage to the neighbouring buildings or to work itself. In other cases real damage could be avoided by more or less drastic measures leading to additional costs and delays. Also these cases were taken into account.

The analyses showed that in more than 40% of the analysed problematic cases, the failures are due to the installation (e.g. vibratory sheet piling) or performance (e.g. leakage trough secant pile walls) of the earth retaining structures. In about 30% of the analysed pits, the problems arose at the adjacent building when limiting values for the deformations or the vibrations were exceeded. As, for a part of this last category also the (installation of the) retaining wall is (partly) to be blamed it is obvious that a proper choice and design of the retaining structures is of paramount importance. Figure 1 shows the full decomposition of the cases analysed.

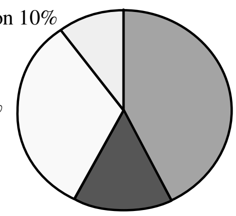

Figure 1. Decomposition of deep excavation failures

Bea (2006) analysed hundreds of construction projects with mayor problems in the field of geotechnical engineering. He concluded that failures that occurred were in many cases

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directly related to lack of knowledge. He distinguished in these cases between "Unknown knowables" and "Unknown unknowables". With the first category Bea mend that the knowledge did exist but was ignored, not used or incorrectly applied. In Van Tol (2007) the same method of interpretation was used. He came to the conclusion as depicted in figure 2.

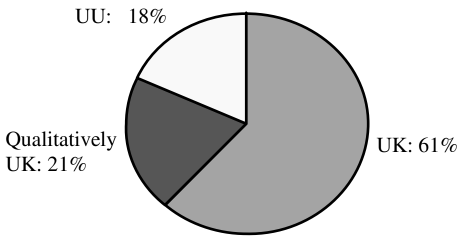

Figure 2. Subdivision in known and unknown knowledge

In more then 60 % of the cases the failure was due to not (correctly) applying existing knowledge. This is amazing but confirms Bea's findings. Moreover in 20% of the cases the cause of the failure is qualitatively known, meaning that this kind of failures are known, but it cannot be predicted exactly where and when they occur. An example of this category is: it is known that the interlocking of sheet pile walls may fail during installation (declutching). This is known, but it is hard to predict where and when this will occur. But by using clutch indicators this effect can be monitored and corrected during installation. Only in less than 20% unknown knowledge was the main reason, all the others were "predictable surprises" as called by Bazerman and Watkins (2004).

The findings above are important because they can subsequently be used to answer the question how to improve the performance of geotechnical engineering.

In figure 3 another subdivision is shown explaining that 60% of the failure cases could have been avoided with a proper training and education of the geotechnical staff. In 20% of the cases lack of information (e.g. the length of piles, the depth of a shallow foundation, etcetera) regarding the neighboring foundations was the main reason of failure. Often such information is extremely hard to obtain, in particular in the design stage of a project. The related risk of failure due to the lacking of such data can however be managed by carefully analyzing all possible consequences. This involves identifying possible events, assessing the importance of the event and defining the necessary countermeasures (and related costs) that eventually should be taken. The same applies for the lack of ground information. In many cases, it is impossible to carry out a proper soil investigation because existing buildings are still present on the jobsite. Then just for the start of the project the existing building are demolished and CPT's and borings are performed often leading to surprises and additional costs. Also these surprises can be avoided with a proper risk assessment during the design process of the project.

Therefore it can be concluded that in 88% of the cases failures could have been avoided if proper risk management would have been applied during the preparation of the projects, because such management also identifies the lack of knowledge of the staff working on the project.

Therefore the challenge for the education of geotechnical engineering is to not only teach a good theoretical base but also to learn the students to apply risk management during the entire design process. Especially the inexperienced geotechnical engineers should be familiar with a risk based approach for the field of geotechnical engineering in which practice and experience play a major role.

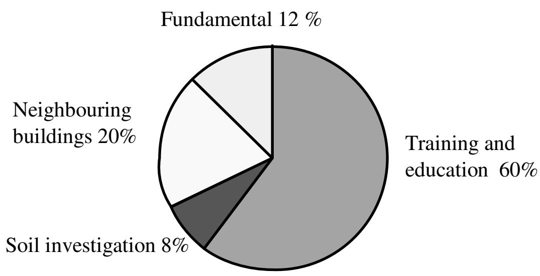

Figure 3. Focus of possible measures to improve performance

3 RISK BASED EDUCATION OF GEOTECHNICAL ENGINEERS AT DELFT UNIVERSITY

3.1 *The need for risk management education*

The preceding introduction and analysis of geotechnical failures raises one major question:

How to improve the current geotechnical practice?

In many parts of the world, there are already promising responses to today's demanding construction challenges. In Europe, national change initiatives to strengthen the construction industry have been started over the last years in countries such as the UK, Denmark, Finland, Norway and The Netherlands. Outside Europe similar initiatives are running in for instance Australia, Hong Kong, and Singapore.

One of the answers to today's and tomorrow's challenges is the well-structured application of risk management in general and of geotechnical risk management in particular. For becoming really effective, risk management should be embedded and consistently applied in *all* phases of a construction project. Within the construction industry, and in its education as well, attention to continuous risk *management*, rather than a few moments of risk *analysis* is still rather new. Starting to educate this *awareness*, followed by *how* to apply risk management during all phases of a construction project, is of paramount importance. Professional practitioners, but in particular the near-future practitioners, which are today's students, should become well-educated and trained in basic risk management principles and practices. Only then, the next generation of engineering and construction professionals will be able to effectively answer the ever increasing demands of the construction industry and society .

3.2 *GeoEngineering and Geo Risk Management*

In September 2006, the faculty of Civil Engineering and Applied Earth Sciences of the Delft University of Technology started their new Masters course in GeoEngineering. A Geo Risk Management course is part of the core curriculum of the MSc in GeoEngineering, which means that it is compulsory for any student aiming to complete a MSc in Geo Engineering. The course, based on extensive professional experience from The Netherlands and abroad and based on Van Staveren (2006), is taught by Martin van Staveren (Deltares), Martin van der Meer (Fugro) and several guest lecturers.

3.3 *Objectives of Geo Risk Management*

Geo Risk Management aims to teach the student in particular *why* and *how* to apply structured management of ground-related risk during the entire process of any construction project. After following the course, any student should be aware of the inherent risk of ground within civil engineering and construction, including the impact and difficulties of the people factor. Furthermore, the student should be able to apply principles of ground-related risk management during the entire project management process for a variety of civil engineering constructions. Such course objectives align and support the recommendations for developing the academic education for the construction industry towards more generic expertise. For instance, the Regieraad Bouw, a major Dutch construction industry committee, advocates to educate all-round civil engineers, with knowledge of less in-depth yet critical topics like project management. Fostering risk management competencies, including the awareness of the inherent complexity of the people factor, fits well within these industry needs.

3.4 *Two parts – theory serves practice*

The Geo Risk Management course consists of two main elements: theory and practice, which are blended together rather than presented separately. The theoretical part of geotechnical risk management explains the concepts of uncertainty, risk and risk management. This first part presents a flexible framework for geotechnical risk *management,* rather than more conventional risk *analysis*. The tried and tested GeoQ approach for ground-related risk management in construction projects serves as framework (Van Staveren, 2006).

Furthermore, the theoretical lectures give a lot of attention to an often undervalued aspect of geotechnical engineering and construction: the *people factor*. Therefore, the role of individual professional engineers and their functioning in mono- and multidisciplinary teams are identified and explored during the lectures.

The practical part covers a number of specific topics, merely based on certain types of geotechnical constructions. Examples are underground constructions, such as tunnels, water retaining structures, and infrastructural constructions, such as roads and railroads. Moreover, the application of existing risk management tools, such as risk classification approaches and the definition of risk-driven site investigations, is demonstrated. This second part delivers a lot of geotechnical content for the risk management framework. The focus is on *how* to apply geotechnical risk management in our day-to-day practices. A lot of examples and cases demonstrate the pitfalls and the opportunities of ground-related risk management. In total, the course contains 14 two-hour lectures.

4 GEO RISK MANAGEMENT LECTURES

The theoretical basis of the Geo Risk Management course seems worldwide quite new. Therefore, particularly these lectures will be introduced in the remaining part of this paper. They proved to be the most deviating from other courses of the MSc GeoEngineering at Delft University of Technology.

4.1 *Introduction*

This first lecture aims to provide an overview of the new course on geotechnical risk management. After presenting the lecturers and the structure of the course, the first hour gives an introduction to the challenges and opportunities in the global construction industry. Major challenges presented are increasing complexity, the often still underdeveloped integrity and high failure costs, in which unexpected ground conditions have a serious stake.

The second hour serves as some kind of appetizer for the lectures to follow. It presents a variety of problems, indicated as GeoBloopers, in a variety of projects world-wide, with one common element: the unexpected behavior of ground. The main message is: ground is a (very) complicated foundation and construction material. Its inherent uncertainties and associated risks will never become completely eliminated. Therefore, we have to deal with these ground risks, which serves as the rationale and motivation for the remaining lectures.

4.2 *From uncertainty via risk to risk management*

Lecture 2 starts with presenting and discussing a number of relevant concepts: uncertainty, risk, risk management, ground, and finally ground risk management.

For instance, as set out by Blockley and Godfrey (2000), we should acknowledge three types of ground uncertainty: *randomness*, *fuzziness* and *incompleteness*. These terms are explained and related to the ground sampling and ground engineering practices. Three main different types of risk are introduced and explained. Having the ability to distinguish between these risks sets of pure and speculative risk, foreseen and unforeseen risk, and information and interpretation risk, will help any ground-related engineer a great deal with effectively managing these risks during the entire construction process.

Regarding risk management, two of the main schools are explained: the *scientific* school and the *heuristic* or *rule of thumb* school of risk management. The latter has a more qualitative approach than the first one. Heuristic or rule of thumb risk management involves acknowledgement of experiences, engineering judgement, and a certain degree of subjectivity. This paper does not allow to further explain and discuss such terminology. For instance, Van Staveren (2006) gives more detailed information.

Within this lecture, ground conditions are considered beyond solely ground. Also ground water, any type of possible pollution, and man-made structures are incorporated. Examples of the latter type are old foundation piles or buried pipelines.

Combining these concepts brings us to four main types of ground-related risk: geotechnical risks, geohydrological risks, geo-environmental risks and man-made obstruction risks. Consequently, ground risk management or geo risk management has been defined as the overall application of policies, processes and practices dealing with ground-related risk.

The second hour presents the so-called GeoQ concept. With the Q of quality, GeoQ is a risk-driven approach to manage ground conditions and behaviour in a structured way for successfully completing any civil engineering project, during all project phases and for all stakeholders involved. GeoQ presents a flexible framework with six generic project phases and six generic risk management steps. Each of these steps should be taken in every distinct project phase. GeoQ matches easily with other risk management approaches, such as MARIUN in the UK and RISMAN in The Netherlands. Finally, this lecture positions ground risk management in the landscape with ground engineering, natural hazard management, project management, quality management, and knowledge management.

4.3 *The GeoQ risk management process*

After the first two lectures, the GeoQ risk management process is explained step-by-step in the remaining lectures by presenting theory and practical examples. These lectures connect *thinking* about the GeoQ *concept* of the previous lectures with actual *doing* by applying the GeoQ *process* in the remaining lectures. The six generic GeoQ steps of (1) setting project objectives and gathering project information, (2) identifying risks, (3) classifying risks, (4) remediating risks, (5) evaluating risks and finally (6) mobilizing all relevant risk information to the next project phase by a risk register are introduced, explained by abundant examples, supported by tools, and discussed by the students.

For each step several tools are available and many of them are briefly introduced in this lecture. Here the students recognize some risk analysis tools from other MSc lectures as well, such as Fault Tree Analysis (FTA) and Failure Mode Effect and Criticality Analysis (FMECA). Now they may become aware of the very fundamental difference between risk *analysis* and risk *management*. The first is basically just a *tool*, however a very important one, in the entire risk management *process* that ideally continues from the early beginning to the end of the project's lifetime.

Three cases are incorporated in the course. The first is a risk identification and classification exercise, based on a real case, in the so-called Electronic Board Room (EBR). Here the student experiences the inherent differences in risk perception between people, even when all people have the same factual geotechnical information. The EBR provides groupware that allows risk identification, classification and remediation in a structured way, in which each participant can bring in his own experiences and build forward on those of other participants (Van Staveren, 2006). Laptop computers and easy to use risk management software allows each participant to brainstorm anonymously on risk identification, classification, and remediation. One can build forward on the results of other participants, while unfavourable effects of group dynamics are reduced, because any input remains unidentified by the participants. Two other cases are provided by guest lecturers from the professional practice about the remediation of deep excavation risks and risk-based design of underground constructions by using the observational method.

4.4 *The human factor in geo risk management*

Directly after the risk identification and classification exercise in the Electronic Board Room, a slightly different type of lecture is provided to the students: the role of the human factor in geotechnical risk management. Giving detailed attention to the human factor in lectures on geotechnical risk management at a civil engineering department seems a rather innovative approach. The need for it has already become clear by the research of Bea (2006) and Sowers (1993. For those readers not yet convinced, there is the following citation of Brandl (2004):

"There are no insurmountable weak soils or rock,
there are only weak engineers".

This possible weakness of engineers starts if there is no awareness of the role of the people factor in engineering in general and in ground risk management in particular. Therefore, the concept of the individual professional, his or her inherent differences in risk perceptions, and how these may contribute to geotechnical risk management, are explained. Some exercises with the students demonstrate how sound facts easily result into totally different interpretations. Table 1 is retrieved from Van Staveren (2006) and based on work performed by Clayton (2001), Kort (2002), and Koelewijn (2002). This table illustrates the effects of differing engineering opinions in geotechnical analyses. Table 1 shows that differences between geotechnical calculations, performed by different professionals, may vary a factor 5 to 10. The actual measured values are positioned in-between the margins.

Table 1. Margins within geotechnical engineering (Van Staveren, 2006).

Geotechnical analysis	Calculated		Measured
	minimum	maximum	
Pile bearing capacity (Clayton, 2001)	1000 kN	5400 kN	2850 kN
Horizontal sheet pile deformation (Kort, 2002)	50 mm	500 mm	100 mm
Slope stability safety factor (Koelewijn, 2002)	0.36	1.65	-

Next, the concept of the *team* is introduced, with special attention to the differences between groups and teams, hurdles to overcome before real teams perform, culture and risk communication in teams, and the danger of groupthink. Three important types of teams are discussed: *expert* teams, *multi-disciplinary* teams and teams as *change agents*. The latter are required for implementing risk management practices.

During the first Geo Risk Management lectures, most of the MSc students showed difficulty with acknowledging the inherently different risk perceptions between people. To some of them it is some sort of shock that these differences in risk perception even occur between apparently rational human beings, such as engineering students. It was therefore very rewarding to notice a change in student awareness and attitude during the lectures. Their understanding of the inherent differences of the client's, the engineer's and the contractor's risk perceptions increased, as was demonstrated by the questions, discussions, and exam results.

5 CONCLUSIONS

Based on analyses of about 50 deep excavations in the Netherlands, this paper shows that in more than 60% the failures were not caused by lack of knowledge but simply by not (correctly) applying existing knowledge. Therefore, the challenge for the education of geotechnical engineering is to not only teach a good theoretical base, but also to learn the students to apply risk management during the entire design process.

One main conclusion can be drawn from the GeoRisk Management course taught at Delft University of Technology: the rather innovative combination of geotechnical risk *management*, the *people factor*, examples of geotechnical risk *analysis* tools and many *cases* from practice, all blended in one new course, has been enthusiastically welcomed by the students. They showed serious motivation to apply this mixture in their professional practice. The future will teach us how our construction industries, and thus our societies, will benefit from this new and integrated approach of geotechnical risk management education.

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