INTEGRATED METHODOLOGY FOR GEOTECHNICAL RISK IDENTIFICATION IN BUILDING CONSTRUCTION PROJECTS.

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Resumen
A pesar de la disponibilidad de los códigos de diseño, es necesario acentuar en que la seguridad no puede ser totalmente garantizada, incluso si las directrices propuestas en los códigos de diseño son estrictamente cumplidas. A mediados de los años 90, expertos de la industria de construcción comenzaron a proponer la integración de metodologías de Gestión de Riesgos (GR) a los procesos de diseño y construcción. En muchos países, la sociedad evolucionó a considerar la filosofía de la prevención como la base para sus reglamentos nacionales. Los estudios recientes indican que, 80-85 por ciento de todos los fallos en proyectos de edificación están relacionados con problemas en el terreno. Esto significa que hasta ahora problemas relacionados con el suelo siguen siendo la principal causa de los retrasos y sobrecostes en proyectos, lo que sugiere que los ingenieros aún necesitan un mejor entendimiento de la naturaleza del riesgo geotécnico. Antes de analizar el riesgo geotécnico, el ingeniero tiene que entender y definir los escenarios de aquel riesgo para cada proyecto en particular. Esta fue la razón básica para el desarrollo de una metodología concisa de identificación sistemática de los riesgos geotécnicos.

Abstract
Despite the availability of design codes, it has to be emphasized that security cannot be totally assured; even if guidelines proposed in design codes are strictly followed. Therefore, from the midst of 90s, many construction industry experts began to propose the integration of Risk Management (RM) methodologies to construction development processes. In many countries, the society evolved to consider the philosophy of prevention as the base for its national standards and regulations. The recent studies indicate that, according to European statistics, about 80-85 per cent of all building failures and damages are related to problems in the ground. It means that until now, ground-related problems remain the biggest cause of delays and cost overruns in civil engineering projects, suggesting that engineers still need a better understanding of the nature of geotechnical risk. Before analyzing the geotechnical risk, the engineer needs to understand and define the geotechnical risk scenarios for each project in particular that he or she has to face. This was the basic reason for the development of a concise and consistent methodology for systematical identification of risks related to geotechnical problems of building construction projects.
1. Introduction

Despite the fact that the construction industry belongs to one of the most important engines of the developed countries economies, it still has to advance in many of its particular problems. According to VanStaveren (2006), there are three main challenges in the construction industry that are searching for the solutions in order to get back the initiative:

- Increasing complexity of the technological systems.
- Growing aversion of many people in a lot of countries feel towards corruption and fraud.
- High failure costs represented to a large degree by the problems related to the ground conditions.

Brandl (2004) indicates that, according to European statistics, about 80-85 per cent of all building failures and damages are related to problems in the ground. It means that until now, ground-related problems remain the biggest cause of delays and cost overruns in civil engineering projects, suggesting that engineers still need a better understanding of the nature of geotechnical risk. Despite the availability of design codes and construction process and material recommendations, it has to be emphasized that security cannot be totally assured; even if the design codes and guidelines are strictly followed (Rodríguez el al, 2006).

Therefore, from the midst of 90s, many construction industry experts began to propose the integration of Risk Management (RM) methodologies to construction development processes. In recent years, a great progress has been made mainly in the areas of tunnelling, coastal or overseas structures, and dam construction projects. RM methodology recognizes the value of the risk as a mathematical equation and defines it basically as a multiplication of two variables, probability of occurrence of determined risk event, and the value of possible impact in case of its materialization (PRAM, 2004).

Within the construction project, the geotechnical engineering is familiarized to work with uncertainties. As the soil characteristics are “predetermined” and largely not known at the beginning of the project, which is not the case, for example, of a concrete as artificial material, the geotechnical engineer has to assume the role of the risk manager from the beginning. This being the case, a new strategy is required (Whitman, 2000; Clayton, 2001; Rozsypal, 2001; Rodríguez, 2006). Those involved in geotechnical engineering should among other things:

- Accept that ground conditions will always be, to a greater or lesser extent, uncertain.
- Introduce geotechnical factors into Risk Management (RM) systems.
- Identify geotechnical hazards in the early stages of project planning.

Mentioning the risk identification process, it is considered the most often used RM element in construction projects (Lyons, Skitmore, 2004). It is essential for the geotechnical engineer to identify all possible mechanisms of damage (limit state) to prevent (Whitman, 2000; Clayton, 2001; VanStaveren, 2008). Only after doing that correctly, also describing the relationships between the risk events would be then possible to estimate effectively the probability of risk occurrence and the value of its impact. After that, the risk scenario is prioritized and effective risk treatment actions could be taken. The registered risks, together with the probability of failure and
impact statistics, provide valuable information for the risk manager who then is able to prepare optimum risk mitigation measures. This result in a “better and cheaper” project effect, and importantly, lowers the price of insurance policy premium. Although RM guidelines for Geotechnical Project (GP) exist, there is insufficient information about how to provide correct and concise risk identification process when working on a real GP. Normally, risk manager has to decide which from the selected RM techniques and tools to apply, how many times and when to repeat the process, to who distribute the risk information, and so on.

The above mentioned affairs were the basic reasons of establishing an investigation project whose general objectives were the following:

Develop and test a concise and consistent methodology for systematic identification of risks related to geotechnical problems of building construction projects.

Register geotechnical problems related risks that may directly or indirectly affect the structural safety of the building using selected identification techniques. The concern was focused on operational risks of the GP in the pre-design phase.

And finally, give recommendations on the use of the determined Risk Identification (RI) techniques applied on geotechnical issues.

2. Applied methodology for risk identification process creation

At the beginning of the investigation project, a methodological process to achieve the established goals was designed as displayed in detail on Figure 1. First, it was necessary to analyze the existing RM standards and guidelines (Rodríguez et al, 2008) to take a look of the advantages and disadvantages of selected standardized RI techniques and tools been on the use until now. Several activities have been executed before the Integrated Methodology for Geotechnical Risk Identification (IMRIG) was finally presented. For the IMRIG, the RI process, RI techniques and tools, risk register structure for all GP phases, RI team, and management and risk communication activities were established. The new Risk Breakdown Structure (RBS) (Rodríguez, Hruškovič, 2007) (Figure 2) forms a part of a new methodology. The main function of RBS is to control the scope of RI process. For test the IMRIG, it was decided to apply several RI techniques, based on the same initial conditions to be able to compare them and give recommendations on its use. Initial conditions were referred to simulate the RI in pre-design phase of the GP focusing on the human factor operational risks resulting from the GP activities and operations that could materialize during the different phases of building construction project development and finally affect the security of the building and/or other adjacent structures.

When finished the Risk Identification (RI) process of IMRIG, using all selected techniques, as a practical result, the identified and registered risk scenarios are expected. These scenarios can be then used as a database for real building construction projects when it comes to take a look on the risks inherent to the activities and operations in the geotechnical prospection, geotechnical analysis and design, foundation and soil stability works execution and maintenance programs. It is typically found that actual failure rates exceed predicted failure rates, perhaps by as much as two orders of magnitude. Further examination reveals that most of the failures are the result of human error, e.g., structures not built according to plans, materials not meeting the specification, some loading not considered in the reliability analysis, etc (Whitman, 2000).
This was one of the main reasons why the operational risks area was chosen as the case study for first IMRIG application. Testing the IMRIG also gives us the possibility of its own upgrade, which means that recommendations on the application of RI techniques could be upgraded as well. This article treats the right side of the diagram activities seen on Figure 1, i.e. the activities which conducted to the cyclic RI process creation. Also preliminary recommendations have been made on the use of RI techniques displayed in this article. The variety of techniques was selected under the hypothesis, saying that when several techniques are systematically applied, then there is a major probability to cover all the expected geotechnical risk scenarios and to deliver a reliable risk register.
When giving recommendations on the use of the RI techniques in Geotechnical Project (GP), the PUMA methodology (Del Caño, De la Cruz, 2002) served as a principal example together with the PRAM (APM, 2004). The PUMA states that the RM techniques has to be applied taking in account the complexity and absolute or relative size of the project, and also considering the maturity of RM processes within the organization in charge.

3. Risk identification process for geotechnical issues of the construction project.

Part of the IMRIG creation was the establishment of risk identification process and selection of suitable techniques and tools within it. Qualitative analysis of selected RM standards belonged to one of the first activities of the investigation project. The objective was to select a suitable standardized documentation for IMRIG creation. During the document search, large number of the RM standards and guidelines were encountered. Among them, the selected ones have been subjected to detailed comparative analysis. Table 1 displays the results of comparative (advantage and disadvantage) analysis resume of the most important RM standards from geotechnical RM point of view. First the content of the standards (scope, objectives, techniques, tools, and examples) was revised, then the advantages and disadvantages of their possible use on new methodology creation were identified, and finally they were compared between each other.

Based on the Table 1 the final conclusions states the following most important:

GeoQ Process which considers all of the GP phases was chosen as the most suitable for IMRIG integration. IMRIG has to be fully compatible with the above mentioned standard.

PRAM 2004 was chosen to serve as a support standard for risk identification techniques execution as it provides comprehensive information about the use of the selected ones. None of the analyzed standards describe how to execute these techniques in the case of geotechnical project considering its phases, time, cost, size and complexity.

IEC 0812 together with IEC 1025 were chosen as the baseline standards for risk scenario description (failure mode, causes and effects) identifying geotechnical problems related in design phase (also with possible use in pre-design phase) of GP.
Table 1: Comparative qualitative analysis of selected RM standards and guidelines for geotechnical RI method creation.

<table>
<thead>
<tr>
<th>TITLE OF STANDARD (CONTENT)</th>
<th>ADVANTAGES AND DISADVANTAGES</th>
</tr>
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<tbody>
<tr>
<td>IEC 0812 Failure Mode and Effect Analysis (FMEA) (RM process, Risk Analysis method description, Risk register structure)</td>
<td>ADVANTAGES: Detailed picture about system hierarchy and how to define and register technological risks. Describes how to apply other technological risk identification tools within the FMEA (RM) process. DISADVANTAGES: Lack of Risk Identification tools and techniques description. Process applicable only for design phase of geotechnical project.</td>
</tr>
</tbody>
</table>

Other findings followed related most of them to the application of Risk Management (RM) standards in a real GP. Among them it was concluded that there is no recommendation about which Risk Identification (RI) technique is the most effective for geotechnical RM and in which circumstances is considered adequate its application. Also, there is no methodology proposed for structured documentation search for risk identification and no recommendations for geotechnical risk identification personnel selection exist. No case study of geotechnical RI was found in existence within the scope of analyzed standards. These above mentioned findings permitted to encounter the possible future contributions in improving the current situation.

The standards neither describe whether to integrate the RM/RI activities within the activities of the existing and recognized project parties or if they have to be in charge of an independent geotechnical consultant or inspection service. Leaving the discussion at hand, the main geotechnical risk management activities (risk identification activities included) within the GP phases are as described in Table 2. Following the recommendation of the several authors such as
Rozsypal (2001) and Rodríguez (2006), it is better to commission this work to experienced and independent geotechnical consultant, rather then share it between the project parties.

Table 2: Integration of Geotechnical Risk Management (GRM) activities within the Geotechnical Project (GP) phases.

<table>
<thead>
<tr>
<th>PROJECT PHASE</th>
<th>GEOTECHNICAL RISK MANAGEMENT (GRM) ACTIVITIES</th>
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<tbody>
<tr>
<td>FEASIBILITY</td>
<td>Identify geotechnical RI internal team.</td>
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<td></td>
<td>Identify suitable geotechnical advisors (experts).</td>
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<tr>
<td></td>
<td>Identify project decision-makers (risk owners).</td>
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<tr>
<td></td>
<td>Start geotechnical risk register.</td>
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<tr>
<td></td>
<td>Introduce geotechnical factors to project SWOT analysis and Scenario analysis.</td>
</tr>
<tr>
<td></td>
<td>Assess vulnerability of project to geotechnical risks.</td>
</tr>
<tr>
<td>PREDESIGN</td>
<td>Identify other suitable geotechnical advisors if necessary.</td>
</tr>
<tr>
<td></td>
<td>Consider ground-related risk and project operative risk scenarios.</td>
</tr>
<tr>
<td></td>
<td>Define client needs and risk tolerance.</td>
</tr>
<tr>
<td></td>
<td>Provide semi-qualitative analysis with previous recommendations for risk reduction for different design solutions.</td>
</tr>
<tr>
<td>DESIGN</td>
<td>Provide detailed geotechnical risk analysis of final design solution.</td>
</tr>
<tr>
<td></td>
<td>Consider system and process technological risk scenarios.</td>
</tr>
<tr>
<td></td>
<td>Define risk reduction measures for potential failure mode causes and effects.</td>
</tr>
<tr>
<td></td>
<td>Provide quantitative risk analysis if necessary.</td>
</tr>
<tr>
<td></td>
<td>Assess benefits of further geotechnical studies/investigations.</td>
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<tr>
<td></td>
<td>Execute Observational Method (OM) if necessary.</td>
</tr>
</tbody>
</table>

**Note:** Risk manager has to balance risk profiles with volume and quality of GI and geotechnical observation in every phase of GP. Execute cost-benefit analysis of risk treatment measures if provided.

According to the RM standards analysis, the cyclic risk scenarios identification process was established for the IMRIG seen in the Figure 3. This generic process is executed preferably at the beginning of the project. It consists of the RI plan, uses a defined risk register, and identifies risks using different recommended risk identification techniques. The use of the techniques for each project phase as well as the scope of identification is agreed between the client and geotechnical risk consultant. Geotechnical risk consultant works as a risk manager and uses schemes that permits her or him to select an optimum portion of techniques, documentation and personnel needed to execute this exercise taking in account the time, cost and quality margins established by the client. It can be seen on the Figure 3, that except the Document Review (DR) technique
the rest of the techniques are optional. The DR technique is recommended to be used as a first and when there is insufficient or low quality information about the risk obtained, the use of rest of the techniques could proceed.

Figure 3: Cyclic risk scenarios identification process for IMRIG.

This is recommended not only for economical and reliability reasons but also for the reasons of risk categorization and subsequent group identification technique execution planning.

4. Preliminary analysis of the applicability and effectiveness of risk identification techniques on geotechnical project.

When choosing the Risk Management (RM) techniques (Figure 3) one has to consider several factors that form the function of its applicability. Techniques selected for a project should be
tailored to the information needed by that project; in addition the size and nature of the project, the time available for the study, the information available, the project culture and the experience or risk maturity of the staff should also be considered (PRAM, 2004). In PRAM 2004 and other RM standards, no mention was made on the effectiveness of those techniques for determined project situations. Additionally, studying the work of Chapman (1998) and Del Caño (2002), rest of the factors that influences the Risk Identification (RI) techniques use were determined (Figure 4). For GP no recommendations on the use have been made until now. Much of the problems that have to be resolved during GP are of technical character and so is the description of risk scenarios in the RI phase. Specialist geotechnical expert group has to be formed; optimum RI organization is required for the group sessions and DR must be organized correctly as well.

![Image](image.png)

Figure 4: Selected factors influencing the application of risk identification techniques in projects.

According to the survey made by Lyons (2004) and others, about the factors that influenced the implementation of RM techniques, the “lack of time” was the highest scored among the factors studied, followed by the “lack of information”. No wonder that the study has confirmed the risk maturity of the respondents as low to moderate. The PRAM 2004 also states that the timescales for the completion of a RM exercise also have a significant influence on the techniques used and quote that brainstorming and structured interviews are relatively quick to complete, can provide a significant amount of information and are therefore ideal when time is short. The brainstorming technique was designated as most frequently used for risk identification (Lyons, Skitmore, 2004), (Raz, Michael, 2001).

Based on the factors defined in Figure 4, a preliminary analysis was executed. The results are provided in the following tables 3 and 4. In Table 3, the IMRIG RI techniques and their applicability were put to judgement considering the most important project phases from RM point of view (where the effectiveness inherent to the application of RM processes is supposed to be the highest), RM maturity of the organization in charge, and resource requirements. In Table 4, the recommendations are given for a risk manager to select the optimum configuration of the applied techniques according to the GP size (absolute or relative) and its complexity. As can be seen, the qualitative results of the preliminary evaluation in both of the tables were obtained based on selected documents review. The studies about RM maturity and culture in companies from construction sector indicate that until now, the level rounds between low to moderate (Lyons, Skitmore, 2004). To improve the current situation and justify the effectiveness of RM system there is much to do from now. If there is an independent agent in the project it could ensure progressive improvement of this state and this would then strengthen the use of some more sophisticated RI techniques, while simultaneously improving the knowledge and quality management processes.
Table 3: Applicability of RI techniques by geotechnical project phase and resource requirements (time and/or cost and risk maturity level). (PRAM, 2004) (VanStaveren, 2008) (Chapman, 1998)

<table>
<thead>
<tr>
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<tbody>
<tr>
<td></td>
<td>Feasibility</td>
<td>Pre-Design</td>
</tr>
<tr>
<td>IGB</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>NGT</td>
<td>LT</td>
<td>G</td>
</tr>
<tr>
<td>DR</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>RI (IB)</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>RQ (Delphi)</td>
<td>P</td>
<td>G</td>
</tr>
</tbody>
</table>

**Note 1:** G – Good/Strong application, P – Potential application, LT – Limited application, H – High resource requirements, M – Medium resource requirement, L – Low resource requirement

**Note 2:** IGB – Interactive Group Brainstorming, NGT – Nominal Group Technique, DR – Document Review, RI (IB) – Risk Interview (Individual Brainstorming), RQ (Delphi) – Risk Questionnaire (Delphi Technique)

Table 4: Preliminary recommendation on the employment of RI techniques by size and complexity of the geotechnical project. (PRAM, 2004) (Del Caño, De la Cruz, 2002) (Rodríguez et al, 2008) (Chapman, 1998)

<table>
<thead>
<tr>
<th>Geotechnical Project (GP) Absolute Size</th>
<th>GP Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Small</td>
<td>DR</td>
</tr>
<tr>
<td>Medium</td>
<td>DR  + IGB</td>
</tr>
<tr>
<td>Large</td>
<td>DR  + IGB/RI (IB)</td>
</tr>
</tbody>
</table>

Hence the recommendations displayed in Table 4 are considering that both the independent RM consultant and the client provide moderate to high level of RM maturity. If this is not the case, the risk manager (or project manager, if there is none) has to look out for a much more simplified configuration. The Table 4 shows an optimum model, a base line from where to begin. As it can be seen in Table 4, there are some optional modes for RI techniques selection, such as in the case of individual or interactive group brainstorming execution. The productivity rates (quality, quantity and originality of ideas) of IMRIG RI techniques are expected to be measured and compared to provide clearer vision on their use in certain phases of the GP.
5. Conclusions and future works

Based on preliminary results that following conclusion have been made:

IMRIG is fully compatible with GeoQ process. The selected RI techniques are supposed to be applicable on GP always considering its size and complexity. IMRIG is supposed to be applicable on other construction project areas.

Use Document Review (DR) RI technique always and as a first from selected ones (DR is completely applicable for every phase of GP).

Effectiveness of the RI techniques depends basically on factors such as GP phase, resources availability (time, cost), and RM maturity level of the client and organization.

It’s recommended to engage an independent RM consultant if possible. RM consultant could serve as a point of risk information interchange between the client and the contractors especially for the complex and large size building projects.

Further investigation will be based on the comparison of productivity, applicability and resource requirements of selected RI techniques given the same start conditions (expert sample, model project situation).

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Acknowledgements
The authors thank the technical audit company CPV Iberia professionals, especially to Mr. César Fernández-Yáñez. Thanks also to the staff of the Department of Geotechnical Engineering of SvF STU Bratislava, especially to Mr. Luboš Hruštinec. Thanks to them and many others involved in this research, who made their contributions with valuable experiences.

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