IOP Conf. Series: Materials Science and Engineering **236** (2017) 012072 doi:10.1088/1757-899X/236/1/012072

Geotechnical risk and earth structures

Ivan Vaníček[1], Daniel Jirásko[1] and Martin Vaníček[2]

[1]Czech Technical University in Prague, Faculty of Civil Engineering, Geotechnical Dept. Thákurova 7, 166 29 Prague 6, Czech Republic
[2]SGeosyntetika Ltd, Nikoly Tesly 3, 160 00 Prague 6, Czech Republic

E-mail: daniel.jirasko@fsv.cvut.cz

Abstract. There is a general acceptance that the complexity of each geotechnical design should correspond to the expected risk. The attention of the paper is therefore focused on the closer specification of the geotechnical risk – risk with which the design and realization of geotechnical structure is connected. The special attention with respect to this geotechnical risk is devoted to the earth structures.

1. Introduction

There is a general feeling that the geotechnical structures design is connected with higher risk than other civil engineering structures, especially when the concrete or steel are the main construction materials. Steel and concrete are typical man-made construction materials and the designer of concrete or steel structures has a great chance that the defined properties in the phase of the design will be very close to the properties in the realized structure. On the other hand the geotechnical structures are connected with natural material, soil, rock, properties of which are strongly variable and our opportunity to check their properties are limited on extremely small volume of the real volume which is part of the realized structure. From the three main types of geotechnical structures – foundation structures, underground structures and earth structures, the last one are more sensitive to the discussed problem as natural environment is not only in the interaction with the realized structure but this material is also the main construction material. There is a general acceptance that the complexity of each geotechnical design should correspond with expected risk. This fact is explicitly expressed also in Eurocode 7 Geotechnical design, however the closer specification is indirect via classification of the geotechnical structures into three Geotechnical Categories. Therefore the paper is focused on the closer specification of the geotechnical risk – the risk with which the design and realization of geotechnical structure is connected. Special attention is devoted to the geotechnical risk for earth structures, as the problem is there even more problematic.

2. Risk generally

All human activities are facing many different factors and influences, both internal and external that make it uncertain as to whether, when and the extent to which they will achieve their objectives. The effect of this uncertainty is called risk. To make it more likely that their objectives are achieved, the detection and understanding to this risk is needed and, if it seems prudent, necessary or beneficial, to modify those risks. With respect to the organization these principles are defined by ISO/CD 31000

"Risk management – Principles and guidelines" where are also specified such terms as "risk management process", "risk assessment", "risk identification" or "risk analysis".

In geotechnical engineering, for cases connected with natural hazards, closer specification in this direction was proposed e.g. by [1], [2] or [3]. They are working with specifications as probability of natural hazards occurrence, with expected cost of the total loss of the element, respectively with vulnerability of the element in risk, as under some circumstance not total loss of the element at risk can occurred.

It is obvious that most problematic in this expression is specification of H – probability that a particular danger (threat) occurs within a given period of time. For natural hazards, as floods, slope stability of natural slopes, there are many historical, statistical evaluations, so that the estimation can be roughly specified. However the similar approach for the geotechnical structures design cannot be used as the estimation of all negative factors including their frequency is practically impossible. In this case the geotechnical risk evaluation can be done first of all in more general level, however with the utilization of terms (processes) specified in ISO/CD 31000.

3. Risk according to EC 7

Problems with EC 7 design in general are described e.g. by [4] or [5]. EC 7 in section 2 Basis of geotechnical design recommends as the first step to distinguish between light and simple structures and other geotechnical structures. For these light and simple structures it is possible to ensure that the minimum requirements will be satisfied by experience and qualitative geotechnical investigations, with negligible risk.

This statement is very important as allows the design on the base of up to date experiences – know how – without necessity to calculate limit states.

On the other side EC 7 distinguishes very large or unusual structures, the design of which should follows the basic principles of EC 7 however often needs alternative provisions and rules to these in EC 7.

EC 7 is using terms Geotechnical categories and simple structures are falling into 1st GC, very large or unusual structures into 3rd GC. However not only character of structure but also character of ground conditions (geological and geotechnical conditions) have to be evaluated, when terms as "straightforward" for 1st GC or "unusual or exceptionally difficult" for 3rd GC are used.

Therefore the EC 7 concentrates on conventional structures. However for such conventional structures the risk can be in very wide range and so closer specification is needed, which are presented further. If to the above mentioned character of structures and character of geological and geotechnical conditions the impact of failure of the proposed structure on human lives and environment generally is included, we are obtaining three characterizations with three different degrees:

- Demandingness of the structure – simple, middle, very demanding
- Complicacy of ground conditions – simple, modest, very complicated
- Impact of failure of the proposed structure on human lives and environment generally - practically negligible, moderate (conventional), very high.

With respect to the above mentioned segmentation, into 1st GC are falling structures for which all characterizations are simple and into 3rd GC structures for which at least one characterization is very complicated, e.g. [5]. After that we recommend to divide the 2nd GC into three subgroups, whether one, two or all three characterizations are falling into middle range – 2nd GC with low risk, with middle risk and with high risk.

This closer characterization is very important from the view of selection of characteristic values of geotechnical parameters, values, which are used during the design with the help of calculation model. EC 7 states that either standard tables of characteristic values, related to soil investigation parameters, or characteristic values evaluated from the measured results via statistical interpretation can be used, always as very cautions estimate. These two possibilities strongly affect the demands on geotechnical investigation as for the first case the index properties are sufficient for the classification, on which standard tables are based, [6]. Utilization of standard tables we recommend for 2nd GC with low risk, respectively the statistical evaluation for 2nd GC with high risk (and of course for 3rd GC as well). In ordinary praxis very often the number of measured results is deficient for good statistical evaluation, and therefore the final cautious estimate is based on both, measured and table values - this case can be recommended for 2nd GC with middle risk.

4. Risk based on the uncertainties of the main steps of the geotechnical structure design and performance

Another risk evaluation can be based on the uncertainties associated with four main phases of the design and performance, as is briefly shown in Figure 1 [7]. Here the “geological model“ represents a geometrical model of the geological environment; “geotechnical model“ specifies for geological model geotechnical data obtained during field and lab tests and subsequently, after cautious estimation, the characteristic values used for the structure design; “calculation model“ specifies the basic approach to the geotechnical structure design and “execution“ (construction) of the geotechnical structure – specifies the construction technology.

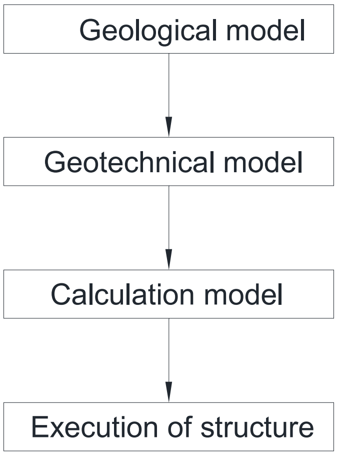

Figure 1. Main phases of the design and performance of the geotechnical structure.

Any uncertainties are connected with each of this phase and risk assessment can be based on credibility of each ones. For example – the credibility of the geological model depends on:

- Seriousness of the geological environment; its anisotropy, non-homogeneity, irregularity of discontinuities; generally speaking, the more problematic this geological environment, the greater the risk connected with the design and performance is;
- Actual state of exploration of this geological environment; e.g. during earlier steps of site investigation and construction implementation;
- Extend of the ground investigation and its quality;
- Skill of the persons responsible for the site investigation interpretation.

5. Specificity of earth structures

The designer of earth structures does not need to know only the properties of natural ground, on which the fill is situated, but also properties of fill alone. As far as the specification of ground properties is more complicated process than for man-made construction materials as steel, concrete, the specification of fill properties is even more complicated. Therefore we can speak about specific risk connected with earth structures. In this case, the designer has specified in advance the properties of fill material, which are used during the design, [8], [9]. This specification is based on the laboratory compaction tests, for fine grained material mostly on Proctor test, for coarser material with index of density. For samples compacted in laboratory, for the consequently defined range, the tests of strength, deformation and permeability are performed and after that from this received set of results the characteristic values of the geotechnical parameters for fill are selected as cautious estimate. The specification of demanded properties for the contractor is in most cases indirect, not with the help of mechanical-physical properties, but via dry density and moisture content, which are subsequently controlled on the site. Therefore, only in limited cases the designer is receiving a feedback that the properties are as demanded, e.g. permeability for sealing layer of dams or sanitary landfills.

Logical scheme of the Geotechnical Design Report (GDR), as specified in EC 7, is for earth structures shown on Figure 2. Geological model have to be presented not only for the ground but also for borrow pit. GIR – is Ground (Geotechnical) Investigation Report. Geotechnical model is divided into two parts:

- Geotechnical site (ground) model - representing really obtained results of the individual tests (measured or derived values) and the executor of GIR is responsible for it;
- Geotechnical design model – representing characteristic values used during the design and designer is responsible for it.

The comparison of these two “Geotechnical models” will show very clearly what values were selected for the calculation from values obtained during the phase of investigation.

Another specificity of earth structures compared with most of other structures is so called 2D effect. For earth structures the 2D effect prevails, either for earth structures of transport engineering - motorways, railways so for earth structures of water engineering – channels, small dams, dykes along rivers etc. Two basic problems are playing more important role here:

- Distance between individual borings (investigation points), namely with respect of interpretation of the geological model between these two investigation points. It is obvious that closer spacing between investigation points will help to decrease the potential risk that some untypical changes will not be disclosed in advance.
- The potential failure in relatively small part of the whole structure will cause total collapse of the functionality of such structure, as is typical case for dykes along river. Gash of width about 10 m can cause a complete loss of functionality e.g., 10 km long dyke.
- Therefore some conservatism shall be accepted in such cases, even we will know, that about 99.9 % of such structure is safe, somewhere nearly extremely. The discussion between investor and designer is needed, as relatively small amount of money added to the geotechnical investigation can decrease the probability of missing weakest section and in such way to reduce conservative approach to the selection of characteristic geotechnical parameters. The combination of the weakest part in subsoil combined with weakest part for the fill cannot be neglected.

Last note to earth structures is connected with sustainability approach, as there are a great opportunities, [10]. Smart earth structures can safe agricultural land, natural aggregates or energy but in comparison with classical solutions they are connected with higher risk.

IOP Conf. Series: Materials Science and Engineering **236** (2017) 012072 doi:10.1088/1757-899X/236/1/012072

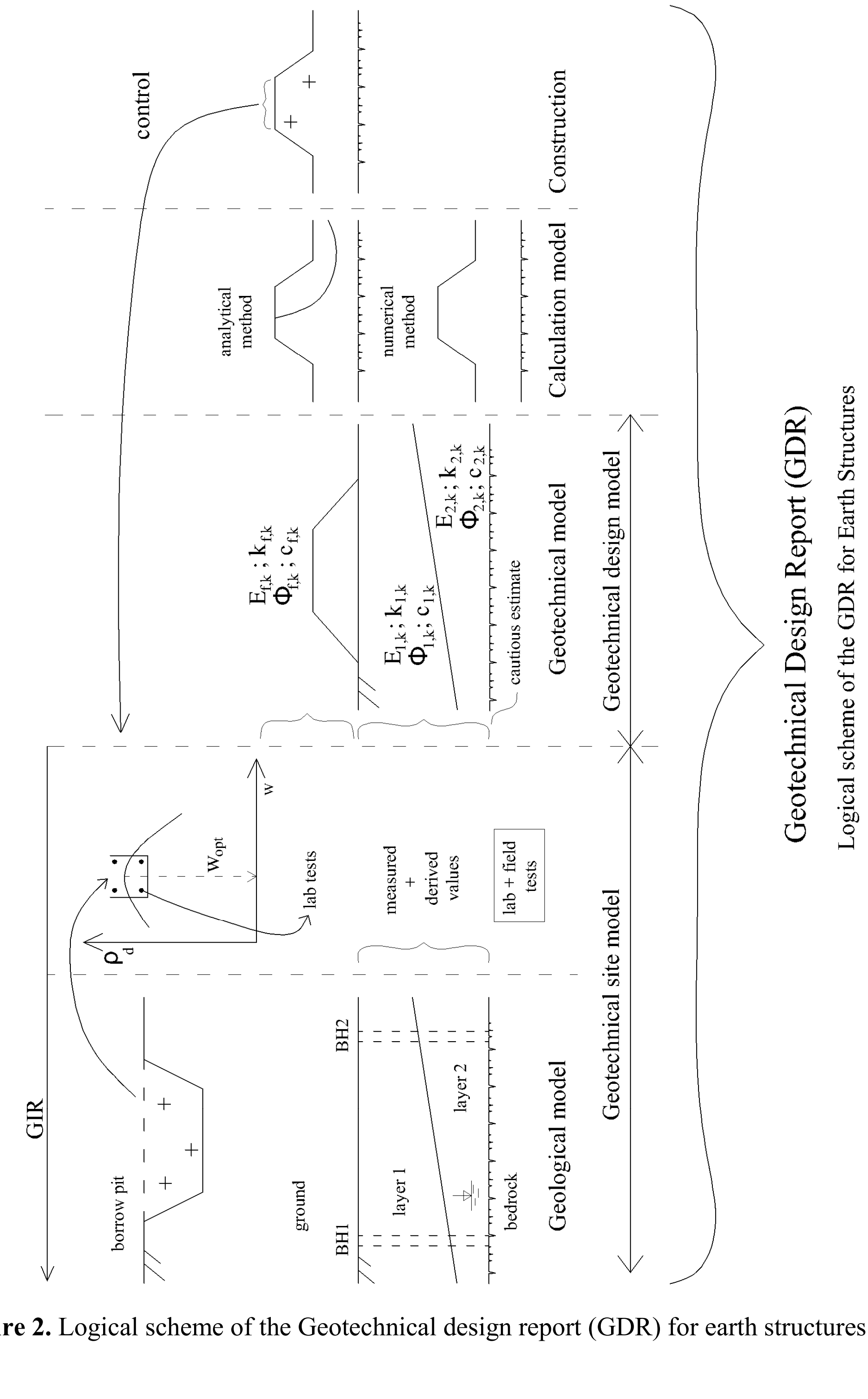

Figure 2. Logical scheme of the Geotechnical design report (GDR) for earth structures.

6. Conclusion

Word meaning "risk" is very wide and a certain guidance can be found in ISO/CD 31000 "Risk management – Principles and guidelines". Risk evaluation for structures affected by natural hazards, as e.g. landslides, floods, can be evaluated when probability of occurrence is known, however for general case it is very vague, as the estimation of all negative factors including their frequency is practically impossible. Nevertheless the closer specification of risk is needed as the complexity of each design should be strongly connected with this risk. In this case the geotechnical risk evaluation can be done first of all in more general level, with risk estimation, risk assessment, taking into account basic steps during which the geotechnical design has to pass. Two possibilities are therefore mentioned by the authors, which are however very close to each other. The first is utilizing demandingness of the structure, complicacy of ground (geological and geotechnical) conditions and the impact of failure of the proposed structure on human lives and environment generally. The second possibility is based on the evaluation of uncertainties or credibility of individual phases of the geotechnical design and performance as geological, geotechnical and calculation models plus execution of structure. Specificity of earth structures are expressed and recommended logical scheme of the Geotechnical design report presented.

Acknowledgements

The paper was prepared with financial support of the research project TE01020168 of the Technology Agency of the Czech Republic CESTI – Centre for effective and sustainable transport infrastructure.

References

[1] Lee E M and Jones D K C 2004 *Landslide risk assessment* (Thomas Telford London)
[2] Kalsnes B, Nadim F and Lacasse S 2010 Managing Geological Risk *Proc. 11th IAEG Congress (Auckland, New Zealand)* pp 111-126
[3] Vaníček I 2011 *Sustainable Construction* (CTU Press Prague) 163 p
[4] Bond A and Harris A 2008 *Decoding Eurocode 7* (London : Taylor and Francis) 598 p
[5] Frank R, Bauduin C, Driscoll R, Kavvadas M, Krebs Ovesen N, Orr T and Schuppener 2011 *Designers guide to Eurocode 7 Geotechnical Design* (Thomas Telford London) 216 p
[6] Vaníček I 2015 Earth Structures – sensitivity of the design to the characteristic geotechnical parameter values determination. Chapter in: Jubilee Volume – A. Anagnostopoulos *50 years of service at the National Technical University of Athens* ed M Kavvadas pp 543-52
[7] Vaníček I 2011 Risk in geotechnical engineering and profession prestige *Proc. 3rd Int. Symposium on Geotechnical Safety and Risk (Munich*) ed N Vogt, B Schuppener, D Straub, G Brau (BAW Bundesanstalt für Wasserbau Karlsruhe) pp 3-9
[8] Vaníček I and Vaníček M 2008 *Earth Structures in Transport, Water and Environmental Engineering* (Springer) 637 p
[9] Vaníček I and Vaníček M 2013 Modern Earth Structures of Transport Engineering *Procedia Engineering* **57** pp 77-82
[10] Vaníček I, Jirásko D and Vaníček M 2013 Geotechnical engineering and protection of environment and sustainable development *Proc. of the 18th IC SMGE Challenges and Innovations in Geotechnics (Paris)* (Presses de l'école nationale des ponts et chaussées) pp 3259-62