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Risk associated with geotechnical engineering

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ABSTRACT: The paper is focussing on the problem of the risk with which the design of geotechnical structures is associated with. Closer specification of this risk is defined, especially with respect to the individual steps of the geotechnical structure design, as are specification of geological model, geotechnical model, calculation model, first of all numerical one and finally with the execution of the geotechnical structures. Attention is also devoted to the recognition of this risk in the society generally as this fact has a great impact on the recognition of the geotechnical engineering profession.

1 INTRODUCTION

Risk in geotechnical engineering is directly connected with the main phases of the design and performance of the geotechnical structures:

a) Specification of the Geological model – whereas the credibility of 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.

This skill, according to Terzaghi (1959), is connected with a certain feeling for a geological environment and he called it as “capacity of judgment” and stated that “this capacity can be gained only by years of contact with field conditions”.

b) Specification of the Geotechnical model – whereas the credibility of geotechnical model depends not only on items mentioned for previous geological model, but also on other aspects as the number and precisions of field and laboratory tests, their evaluation and interpretation.
For planar structures, generally 3 D, there is a certain chance that for small differences in the quality of subsoil can be averaged, however this possibility is much lower when one dimension prevail, as it is for tunnels, dykes, generally for 2 D structures. In many cases one bore hole is realized there in distance of 100 meters even more. However for tunnels, dykes there is another negative factor; they

are realized in areas where previous investigation was limited and where the variability of subsoil, mostly for dykes along the rivers, is very high. Here it is noteworthy that the interconnection of investigative methods in such a way that they will be able to give data not only for geological but also for geotechnical model is extremely important.

c) Specification of the Calculation model – selection of the most appropriate calculation model is also very sensitive problem, which may consist of any of the following:

- An analytical model;
- A semi-empirical model;
- A numerical model.

As young engineers often prefer numerical model based on FEM, few notes to this method and thereby to its credibility are mentioned:

- Precision of the subdivision of the solved environment (geotechnical model) into individual elements;
- Function expressing the change of properties within individual elements;
- Constitutive model – expressing the dependence of the deformation changes on stress changes;
- Final elements to model structural components;
- Finite elements to model interfaces;
- Boundary conditions.

Only few problems with constitutive models will be mentioned, expressing relation between strain changes on stress changes:

$$\Delta \varepsilon = E(\varepsilon, \sigma)\, \Delta\sigma$$

d) Execution of the geotechnical structure

Construction of geotechnical structures is in principle connected with high risk, which is in most cases evaluated by contractors with approach, which is now called – risk management.

2 DESIGN APPROACH WITH RESPECT TO THE POTENTIAL RISK

Each structure including geotechnical structure is in interaction with ground. Therefore the design approach is firstly coming out from this interaction and the risk associated with respective design is taking into account not only the complexity of ground (geological environment which is affected by this interaction) but also the complexity of the structure. This approach is also included into Eurocode 7 – Geotechnical Design. EC 7 distinguishes 3 Geotechnical Categories. Geotechnical Category 2 which is typical for EC 7 should include conventional types of structure and foundation with no exceptional risk or difficult soil or loading conditions. Eurocode 7 also recommends taking into account neighbouring structures, therefore in some countries the resolution between different Geotechnical Categories depends on:

- Complexity of the ground;

- Complexity of the structure;

- Impact of new structure on the surrounding area.

The last point is well known for earth structures in water engineering, as complexity of the approach depends also on the potential impact of the dam failure on area below the dam, Vanicek,I. and Vanicek,M.(2008). The interaction with existing objects in the vicinity of a new one has different levels, from purely technical up to legislative, juridical, level, Vanicek (2011). Engineers, firstly geotechnical engineers, know very well that each change in stresses originate changes in deformations. Therefore when changes of stresses induced under new structures are also attaching the area under existing elder structures, these stress changes induce there the changes in deformation as well. Merits of problem consist in reality when the owner of the elder structure agrees with the new structure only under the condition that “new structure will not have impact on elder one”. It is obvious contradiction however is very often accepted as this condition can be explained as a new one – that on the elder object changes does not cause “visible” deformations e.g. in the form of micro cracks on the façade. Very often all partners with this new, however unarticulated condition, agree and the design and structure construction is adapted on it. Therefore this form of interaction is very sensitive for elder historical structures which are on small changes more sensitive than new modern structures. Therefore the documentation of existing elder structure before starting with new one is extremely important to be able to distinguish between elder existing cracks and new cracks developed in the phase of new object construction.

To protect “visible” changes the modern methods of foundation engineering are utilizing different approaches how to limit horizontal deformations of the vertical walls of the excavation pits as with the help of anchors which are ending under neighbouring structures. With respects to the ownership right the agreement with these anchors is very often connected with supplemented condition about deactivation of these anchors when horizontal deformations are limited by inside structural elements as new floors. What problems of this deactivation can cause was manifested in the case of towers of the World Trade Centre in New York after their collapse, Cermak (2003). The excavation of ruins was significantly decelerated as long as the stability of external walls was restored.

3 PROBABILITY OF FAILURE

Risk is directly connected with probability of failure. Nevertheless the reasons for a certain failure can results from the following factors:

a) Limit state design approach, as based on the theory of probability, counts with a certain risk of failure, it is its principle.

b) Risk of failure is influenced by our level of understanding, depends on our ability to describe and to understand to the very complicated geological environments.

c) Risk of failure is however also associated with our mistakes, sequent to our lack of education or lack of sufficient workmanship control.

Last point ad c) is usually under the control with the help of some regulations. In different countries these regulations can be different but in most cases are controlled by the Chamber of Civil engineers, specifying the conditions for persons examining geotechnical design and construction performance – e.g. authorization for geotechnical engineering which is usually needed for structures falling into Geotechnical Category 2 and 3. The expectation that this fact can be solved only by market cannot by fully accepted especially for problems falling under the Environmental Geotechnics, as some mistakes can be recognized with a great delay.

Second point ad b) is associated with our level of knowledge. It is the general effort of generations of our predecessors to understand to the geological environment as much as possible so that the final calculation model will represent its behaviour most authentically. Our effort in this direction should be focused on process of education, combining the theory with praxis. It is never ending process.

First point ad a) is associated with the fact that even if we will follow all recommendations of existing codes, e.g. EC 7, there is a certain risk of failure. Therefore on this place there is rightful question, what probability of failure is accepted, can be defined and if yes by whom.

Up to now there is limited information on the expected probability of failure, however roughly can be estimated as follows:

- 1:1 000 000 for the design and performance of spread foundations;

- 1:100 for large earth and rockfill dams – according to the evaluation of ICOLD for dams constructed between 1900 – 1975 – certainly this number is decreasing during last period;

- For shallow city tunnels this probability is even higher, even for last period.

From this it can be seen that there are a great differences. However e.g. probability of failure 1:10 000 (1.10^{-4}) means that in 9 999 cases the structure is safe, but can be also uneconomical – overdesigned. Therefore there is eligible question, are we for spread foundations on the conservative side? Can we change this probability with the help of partial factors of safety or with the very careful selection of the characteristic values of the geotechnical parameters?
For very complicated structures, falling into 3rd Geotechnical Category as large dams and tunnels, the approach to the design can be individual. Comparing on one side the price and time for activities which can improve our knowledge about geotechnical model or application of new technologies (very often more expensive but with higher ability to reduce the risk of failure) and on the second side with price and time connected with potential repair of a certain failure, resp. with negative image on our profession after such failure.

4 CONCLUSION

Profession of geotechnical engineering is connected with extremely high risk which is not fully accepted in society. This high risk is first of all connected with our ability to realistically model the behaviour of geological environment under changes caused by new construction activity. Natural task of the geotechnical engineers is to decrease this risk with the help of new design and construction methods utilizing all new findings is this profession. However it is also necessary to spread the responsibility for this risk between other partners of the construction activity, mostly between investors and politicians. Risk acceptance and sharing will have positive impact on the prestige of geotechnical engineering profession. Some recommendations in this field were mentioned in the paper nevertheless short summary is as follows:

- Together with other professions, working also closely with geological environment, to give publicity to the idea of shared risk, that there is the necessity to accept a certain percentage of failures during design and performance of structures. The cooperation is needed between colleagues who are members of the learned and professional societies as are ISSMGE, IAEG, ISRM, ITA, EFFC, IGS as well with societies where the problem of earth structures for transport and water engineering is covered as well;

- To use any possibility to stress the significance of site (ground) investigation – to define minimum demands on the site investigation for different geotechnical structures – probably still there is such possibility to implement it in EC 7-1 (into paragraph 2.1.(8);

- To be very cautious with respect to the risk of uncertainties when classifying the geotechnical structures into basic three geotechnical categories;

- To give priority to the observational method of design;

- During definition of partial factor of safety (respectively when selecting characteristic values of the mechanical physical properties of the ground) to be more likely on the safe side and after some experience (e.g. in cycles of 5 to 10 years) carefully evaluate recommended values and subsequently to refine them. However it is possible only as the result of well documented failures for which the back analysis was performed – in this direction to support the idea of expert's commissions prepared in advance to visit as soon as possible the structures which failed;

- For the case of interaction between older and new structures via deformation of the ground to support the fact that this deformation is always higher than zero but should be kept in acceptable limits;

- More care should be devoted to the risk management process, especially for contractors firms;

- To support the idea that the elimination of the potential risk mainly via insurance is not the right way.

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