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Risk in geotechnical engineering and profession prestige

I. Vaníček
Czech Technical University in Prague, Czech Republic

ABSTRACT: A great deal of attention has been devoted to the risk connected with construction design during the last period. The design principle connected with potential risks was also included in Eurocode 7 – Geotechnical Design. At the same time, we very often speak about the prestige of geotechnical engineering both on the level of engineering professions and in society in general. In most cases, this evaluation is not so good, the prestige of our profession, in agreement with the opinion of most of us, does not correspond to the significance, importance, generally, to the risk with which geotechnical structures are designed, or to the significance which geotechnical engineering entails.

The paper describes some aspects influencing the degree of this risk. It is, first of all, the risk associated with the range and complexity of geotechnical investigation. To what degree this investigation can give precise figures about the geological environment. How great is the potential risk associated with the numerical model which simplifies this geological environment and up to what degree this numerical model, based on different assumptions between changes of stresses and changes of deformations, is really authentic. And, finally, how great is the risk which a new geotechnical structure brings to its environment, first of all in terms of the interaction of this new structure with a nearby older historical structure.

The relationship between the main partners of the building process is also the subject of discussion, whether they all have or do not have the same interest in lowering this risk. Broadly speaking, geotechnical engineers generally deal with a high risk, they take over a high responsibility for this risk and sometimes under increased public pressure (maybe even as a result of a competition) they get to the edge of this risk which in the case of a failure can have a negative impact on the position of our profession, especially on a long-term basis. However, geotechnical engineering has a significant influence on the living standard of population as it reacts to its demands per saltum. At the end, the status of two different professions is compared; the status of geotechnical engineering and medicine, as both work with high risks, and our profession comes out of this comparison as strongly undervalued. Therefore, geotechnical engineers should speak and discuss about this reality on different levels to help to improve the professional prestige. Some recommendations in this direction are summarized in the end.

Keywords: Risk management, site investigation, geological and geotechnical models, profession prestige, foundation –subsoil interaction

1 GEOLOGICAL ENVIRONMENT INVESTIGATION, GEOLOGICAL AND GEOTECHNICAL MODELS

Practically each construction is in a direct interaction with the geological environment, therefore, the correct evaluation of this mutual interaction is the basic presumption of a safe and economic design of such a construction. This interaction is connected with the problem of the structure foundation or with loading of this structure from the geological environment respectively, which are typical challenges of geotechnical engineering.

In addition, specific geotechnical structures also solve the design of these structures. It may be an earth structure, where soil is the fundamental structural material or the structure is constructed in an earth environment and the design fully employs the achievements of soil mechanics or it is an underground structure constructed in a rock environment where the achievements of rock mechanics are fully employed.

Optimal interaction design or the design of a geotechnical structure is strongly influenced by a correct evaluation of the geological environment. In principle, two basic steps play an important role there:

- Creation of the **geological model,** which, on the one hand, represents a geometrical model of this environment specifying the thickness and bedding of individual geological layers, their regularity, dislocation by different discontinuities, etc., and, on the other hand, gives them geological specification, however, not only for the area which is directly affected by new construction, but for a much larger area. As ground water is a natural part of the geological environment, the geological model must be supplemented by detailed information about ground water fully employing the achievements of hydrogeology.
- Creation of the **geotechnical model** which specifies the mechanical and physical properties for individual parts of the geological model, including discontinuities. In doing so these properties are obtained either from field investigation methods or from laboratory tests performed on samples obtained during site (ground) investigation.

In the phase of bonding these two models, engineering geology plays a very important role as it is able to evaluate the reaction of the investigated geological environment to different changes as changes in loading, to technology used in the phase of construction etc. The role of engineering geology is very important in this phase and has its unsubstitutable role.

Although the credibility of the geotechnical model is of cardinal importance for further steps, its correctness depends on many factors like:

- 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 during earlier steps of site investigation and construction implementation;

  Extend of ground investigation and its credibility. This question is very sensitive; the possibility to investigate the entire rock massif influenced by new constructions is not realistic. In most cases, closer information can be obtained roughly from one millionth of this massif and from this fact it is evident that the risk connected with the interpretation of the obtained results on the whole affected rock massif is really very high.

  Note 1. For planar structures, as foundation slab, there is a certain chance that for small differences the final results can be averaged, however, this possibility is much lower when one dimension prevails, as it is for tunnels, dykes, motorway and railway earth structures etc. In many cases, one bore hole is implemented there in a distance of 100 meters or even more. However, for tunnels, dykes there is another negative factor; they are built in areas where previous investigation was limited and where the variability of subsoil, mostly for dykes along 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 the geological, but also for the geotechnical model is extremely important.

  Note 2. A specificity of earth structures is that the design of these structures utilizes mechanical and physical properties of soils; however, the prescript for implementation generally uses indirect values (mostly moisture content and dry density determined from compaction tests as Proctor test). These indirect values are also used for the structure quality control and, again, only roughly one millionth of compacted soil is controlled.
- Skill of the person responsible for the site investigation interpretation, this skill is connected with a certain feeling for a geological environment, experience, which Terzaghi (1959) denotes as ”capacity for judgment“ and he specifies that ”this capacity can be gained only by years of contact with field conditions“.

2 ABILITY OF THE NUMERICAL MODEL TO DESCRIBE THE GEOTECHNICAL STRUCTURE BEHAVIOUR OR INTERACTION OF SUBSOIL WITH THE NEW STRUCTURE

The combination of seriousness of the geological environment and complexity of the structure significantly influences the manner in which the design and implementation of this structure will be verified. It is not only the difference between different geotechnical structures, but, first of all, the above mentioned combination. The difference between the design of a low earth dam on homogeneous subsoil with low permeability under which there is no built-up area and a large rock-fill dam with a clay core in a steep valley and with non homogeneous subsoil under which there is a highly populated area can be mentioned as an example. A similar difference is between the approach to the foundation design of a single-floor small house and the foundation design for a high rise building where the groundwater level is high and there are existing buildings in the vicinity.

Therefore, it is obvious that the calculation model can and must be different. For a simple geological and geotechnical model and for modest structures the experience gained up to now from previous applications can be used. The present-day approach, which is also recommended by Eurocode 7 Geotechnical Design, strongly distinguishes these combinations and the risk associated with them and defines 3 Geotechnical Categories. The design of very complicated structures and a complicated geological model according to EC 7 falls under the 3rd Geotechnical Category which is connected with the highest risk and in this case it is necessary to utilize all findings, firstly from soil and rock mechanics, and to utilize the numerical model which is able to represent the geotechnical model as precisely as possible.

The finite element method which can relatively easily come out from the previous models offers a great opportunity in this direction. However, FEM can be applied in many versions, which differ both in the precision of the subdivision of the solved environment into individual elements, and in the definition of the function expressing the changes of properties between individual elements, or which differ between different used relations, between changes of stresses and changes of deformations for stress strain problems or for changes of filtration properties for hydraulic problems.

However, it is necessary to mention that only constitutive models expressing the dependence of deformation changes on stress changes can have many different variants from classical linear elastic models up to very complicated models expressing nonlinearity of this dependence. This great variability in this direction is a significant distinction from other structural materials, such as steel, concrete and timber. This difference is intensified by the presence of ground water, as the properties of soil and rock are influenced by water pressure in pores and this water pressure is strongly dependent on the time effect. Therefore, time plays a very important role for the design of geotechnical structures.

In spite of this, the possibilities of numerical models to describe the behaviour of geological environments improve with time; nevertheless, there is always some simplification. But this problem is not only connected with the numerical model, it is also our ability to measure the above mentioned relation between stress changes and strain changes with the help of field or laboratory methods. Therefore, more sophisticated devices are needed for the performance of such tests, more time for their implementation, which also means higher financial inputs. The last question is whether the laboratory tested sample exactly describes the properties which the in-situ obtained sample had.

3 INTERACTION

In principle, two different interactions can be distinguished:

- interaction of new foundations with subsoil or interaction of a new earth structure or underground structure with the surrounding geological environment;
- interaction of a new structure with an older existing neighbouring one.

The first type of interaction is strongly connected with site investigation as this investigation should give as much information as possible about all geological environments which are affected by this interaction. Therefore, it is not possible to propose and perform this investigation without a closer specification of the proposed construction. For a wider spread foundation the area affected by the stress increase in the footing bottom is larger (and deeper) than for a narrower spread foundation. On the other hand, a wider foundation is much easily able to equilibrate small differences in subsoil properties. Therefore, for a pile foundation, mainly for individual piles, small differences in subsoil can play a significant role in terms of settlement. This factor can have an impact on a safe design and performance of pile foundations below bridge piers or for the foundation of individual pylons as are e.g. pylons for wind power plants.

However, technological aspects also play a significant role, especially for underground structures, such as the manner of rock breaking (excavation). The selected technology can differently react to unexpected responses of the rock massif during the process of mining (excavation) and can have a different impact on the change of properties in the vicinity of the excavation perimeter. For example, the question connected with property changes in a good quality near field zone, especially in terms of permeability, is very sensitive for proposed underground nuclear waste repositories. For a rock massif which is not so strong this interaction directly influences the design and construction of lining of tunnels, galleries etc.

The second interaction – with existing objects – has different levels, from a purely technical up to legislative, juridical level. Engineers, firstly geotechnical engineers, know very well that each change in stresses originates changes in deformations. Therefore, when changes of stresses induced under new structures also influence the area under existing older structures, these stress changes induce changes in deformation as well. The problem is especially sensitive when the owner of the older structure agrees with the new structure only under the condition that "the new structure will not have any impact on the older one". It is an obvious contradiction, however, it is very often accepted as this condition can be explained as a new one – the change does not cause "visible" deformations e.g. in the form of micro cracks on the façade of the older structure. Very often all partners agree with this new, but unarticulated condition, and the design and structure construction is adapted to it. Therefore, this form of interaction is very sensitive for older historical structures which are more sensitive to small changes than new modern structures. Therefore, the passportization of an existing older structure before starting a new one is extremely important to be able to distinguish between older existing cracks and new cracks developed in the phase of the new structure construction.

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

4 ACCEPTABLE RISK

The question connected with the risk of faults and accidents of a constructed geotechnical structure is generally very sensitive. The general effort of generations of our predecessors was always and still is to understand to the geological environment as much as possible so that the final numerical calculation model will represent its behaviour most authentically. Subsequent design after that was a little bit on the conservative side. This design used the global factor of safety (stability) to cover most of the risks with which the description of the geological environment, the methods of investigation and calculations were connected. The optimal global factor of safety was selected in such a way that, on the one hand, it was able to cover most of the uncertainties and, on the other one, most design was not so conservative, structures not so much overdesigned, which is naturally connected with higher financial inputs.

The present-day limit state approach applies different partial factors of safety as our ability to describe partial parameters used in the calculation model is different. EC 7 Geotechnical Design gives individual countries a possibility of independently selecting the values of these partial factors according to their previous experience.

In disregard of the above it is very useful to search the frequency of faults and accidents for individual types of structures. The limit state approach was accepted in the Czech Republic roughly 40 years ago and at that time the discussion was also connected with the accepted frequency of accidents. The frequency of roughly 0.01 % was accepted (1 failure from 10 000 cases) for the design of spread foundations and partial factors recommended for this frequency. However, for the last roughly 20 years (as the last code for the spread foundation design was changed in 1987) the author has only been informed about 2 examples where the problem of a structure was connected with the foundation unacceptable behaviour. From this fact we can deduce that partial factors are still on the conservative side.

For larger civil engineering structures the situation is rather different. For large dams the frequency of faults and accidents is much higher than for spread foundations. The study of ICOLD (International Commission on Large Dams) roughly in the seventies devoted great attention to this problem and summarized information about dams constructed after 1900. The frequency of accidents is a little bit over 1%

and the frequency of faults is 3-4 times higher –see also Vaníček, I. and Vaníček, M. (2008). This frequency decreases with time as our knowledge is improving; however, it is still significantly high.

Roughly the same can be stated for tunnels constructed in soils, where even now the frequency is significantly higher. Three faults which have occurred during the construction of the city road Blanka Tunnel in Prague had a very negative impact on the credibility of civil engineering profession in general.

The group of specialists in pile foundations working on the modification of the National Annex to EC 7-1 also started to discuss this fact. The fact that the design of bored piles in the Czech Republic is the most optimistic in Europe is generally known. It means that the specialists in this field are working with a much higher risk than in other countries in Europe. The question is whether to continue this tendency or to recommend such steps to be included in the National Annex which can slightly reduce this potential risk and in such a way prevent possible problems with negative impacts on our profession as mentioned above in relation to tunnels.

Generally, this situation has raised some questions:

- Who should define the risk – only engineers or also governments (politicians) or potentially affected population respectively. With respect to EC 7 there prevails the opinion that only engineers should. However, there is a discrepancy as engineers know that even when respecting all recommended principles and standards (as e.g. EC 7-1) in limited cases (for an acceptable frequency of failures) a failure can occur. The problem is that politicians and the public are of a different opinion, practically always demanding 100 % safety. This fact is obvious for example for anti flood protection systems (dykes). Up to the 100-year flood (for which these dykes are commonly designed) they require 100 % safety, for higher floods they are able to accept a failure as an objective impact. Hence, for structures which are connected with protection against natural hazards politicians (government, local municipality) and even potentially affected population also play an important role. In the Czech Republic after heavy floods in 2002 some local municipalities approved the construction of supplemented measures for higher floods, 200, 500 even 1000-year floods, whereas paradoxically for the protection of towns mobile barriers, whose life time expectancy is only a few decades, are also used.
- How to utilize the politician's interest to our profit. Mainly during natural hazards the probability of a failure is higher and in many cases these natural hazards are connected with lost of human lives and with great material damages. And this is the case where the validity of the limit state approach should be verified. The government (politicians) should not have only an interest to quickly reconstruct the affected area but also with the help of specialists to collect as much as possible information about factors leading to these failures. The subsequent back calculation of these failures can be very important for the verification whether our design methods are correct and safe. With the help of this back analysis of real limit states our design approaches can be improved in the future. However, the government should be prepared for such situations in advance to guarantee that specialists will be on the spot immediately after the structure failure and their competences had been defined in advance.
- What the interrelationship between the main partners of the construction process should be like – namely between the investor, the designer and the contractor. The highest potential risk is connected first of all with the exaggerated importance of the total price. The designer under such an influence can propose a design connected with a higher risk and as the price for the project design often also covers the price for the site investigation, this site investigation is limited as much as possible, but with a lower predicative value. The contractor under the same pressure of the price can select construction technologies connected with a higher risk. The designer together with the contractor (which in principle represent the civil engineering profession) in that way take over the responsibility for this higher risk; from which the investor can get out very easily with the help of signed contract agreements in the framework of the first steps of the bidding process.
- What positive role the contractor can play – the role of the contractor is very sensitive as potential problems connected with repairs, corrections, sanctions for construction delays etc. are first and foremost on their side. Before signing any contract a competent contractor should carry out the evaluation of the risk management process, during which all risks connected with existing uncertainties should be evaluated. The result of this risk management process should be appropriate bidding price or the pressure on the investor to share risk or to improve the geotechnical model with supplemented investigation. The coverage mostly via the insurance company is more likely the manifestation of their own disbelief. In the case of a failure the contractor is financially covered, but their professional credibility is strongly affected.

5 PRESTIGE OF GEOTECHNICAL ENGINEERING PROFESSION

The high position of the geotechnical engineering profession is obvious from the previous chapters as it is the profession dealing with a much higher risk than other structural engineers such as designers of steel, concrete, timber structures. Simultaneously, geotechnical engineers fall under the groups of professions which to the highest extent react to society demands. Providing that the care of good quality drinking water and safe disposal of waste water had an extremely positive impact on the prolongation of the life expectancy of the population in European cities in the second half of the nineteenth century this process is still alive and brings the extension of life expectancy also in the other parts of the world.

At the same time, geotechnical engineering actively reacts not only to classical demands of the construction sector but also to the demands of society with respect to energy, raw materials demands, to natural hazards, protection of the environment in general. From these spheres, mainly the issues connected with the protection of ground water against contamination or the solution of the old ecological burdens present problems which are, on the one hand, very attractive but, on the other one, connected with high potential risks. The problems of contamination spreading and the application of remediation technologies are strongly time depending problems, not so easily controlled and some mistakes can come to light with a significant delay, when their subsequent solution can be very problematic and expensive.

A partial conclusion to this part is simple, geotechnical engineers work with a geological environment which is rather complicated, never investigated in detail. Therefore, the prognosis of the behaviour of such an environment and how this environment will react to changes, primarily caused by loading changes, can be successful only with the help of up to day existing results, with the help of personal experience and intuition.

The fact that society demands only solutions which are able to guarantee 100 % safety is in fact the basic problem. Therefore, the explanation that this way is not the way in the right direction is the main task of the geotechnical engineering profession as this way can lead to uneconomical design and applications, with negative impacts on the whole society.

It is difficult to find some comparison with other branches of human activity, however, with a certain exaggeration, the profession of geotechnical engineering can be compared with medicine. The doctor of medicine also “works” with an extremely complicated environment – with the human body. Nevertheless, already from its basic merits it is a strongly respected branch, as all of us depend on its achievements. The following reality is coming to light when these two professions are compared:

- In medicine nobody speaks about 100 % safety; on the contrary, the probability of success is often mentioned for a certain medical procedure, indirectly the percentage of failures. For geotechnical engineering 100 % safety is expected as mentioned before.
- The range of site investigation for the geological environment is more likely limited than supported; the methods of site investigation are improved by geotechnical engineers themselves. On the contrary, in medicine investigative methods are strongly supported by different financial resources either from all society tools or from the tools of different foundations and individuals (philanthropists). The investigative methods are improved by a wide spectrum of different professionals.
- The monitoring of the observed objects is much more supported in medicine than in geotechnical engineering even if the monitoring can significantly improve our activity in the future.

Not to end this comparison so pessimistically for geotechnical engineering it is suitable to mention the design method also recommended in EC 7-1 Geotechnical Design – it is the observational method. This design method is close to the methods which are applied in medicine and in principle it accepts the fact that our ability to model the geological environment is limited. The design can be modified during the construction phase when the result of the monitored response differs from the most probabilistic value, however, only in the range which was expected in the first phase of design.

6 CONCLUSION

The profession of geotechnical engineering is connected with an 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 a geological environment due to the changes caused by new construction activity. The natural task of geotechnical engineers is to decrease this risk with the help of new design and construction methods utilizing all new findings in this profession, especially the technology of construction process should be able to immediately react on the monitored geological environment responses.

Nevertheless even when all phases – starting from the site investigation up to the post-construction period of monitoring – are performed under up to date standards, still some probability of failure is remaining there, what is in fact with the basic principle of the construction approach.

Therefore, it is also necessary to spread the responsibility for this risk among other partners of construction activity, mostly among investors and politicians. Risk acceptance and sharing will have a positive impact on the prestige of the geotechnical engineering profession. Some recommendations in this field were mentioned in the paper; nevertheless, a short summary is as follows:

- Together with other professions, also working closely with a geological environment, to give publicity to the idea of shared risks, that there is a necessity to accept a certain percentage of failures during the design and performance of structures. Cooperation is needed among colleagues who are members of the learned and professional societies like ISSMGE, IAEG, ISRM, ITA, EFFC, IGS as well 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 for site investigation for different geotechnical structures – probably there is still such a 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 three basic geotechnical categories;
- To give priority to the observational method of design;
- During the definition of partial factors of safety (respectively when selecting characteristic values of 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 a result of well documented failures, what is their probability. Back analysis of well documented examples can help very much. Therefore the idea of creation of experts´ commissions prepared in advance to visit the structures which had failed as soon as possible, should be supported very strongly;
- For the case of the 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 potential risks mainly via insurance is not the right way.

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