UDK 624.042.7

THE IMPLEMENTATION OF EC 7 TO THE EARTH STRUCTURES

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АНОТАЦІЯ: Грунтові конструкції, що підпадають під дію Єврокоду 7 «Геотехнічне поектування», зазвичай пов’язані з високим ризиком. Тому визначення цього ризику, уточнення геотехнічних категорій, визначення характеристичних геотехнічних величин, граничних станів, проектних ситуацій, покращення грунту та підходи до екологічної безпеки обговорююься в статті.

АННОТАЦИЯ: Грунтовые конструкции, которые подпадают под действие Еврокода 7 «Геотехническое проектирование», обычно связаны с высоким риском. Поэтому определение этого риска, уточнение геотехнических категорий, определение характеристических геотехнических величин, предельных состояний, проектных ситуаций, улучшение грунта и подходы к экологической безопасности обсуждаются в статье.

ABSTRACT: Earth structures, which are falling under EC 7 Geotechnical design, are generally connected with high risk. Therefore the determination of this risk, specification of Geotechnical categories, the determination of characteristic geotechnical values, limit states, design situations, soil improvements and sustainability approach are discussed in the paper.

KEY WORDS: Earth structures, geotechnical risk, limit states, sustainability approach.

INTRODUCTION

Process of the geotechnical design a realization is generally passing via 4 main well known and recognized phases (steps), which are also specified in EC 7:

- Geological model – represents a geometrical model of the geological environment;

- **Geotechnical model** – specifies for geological model the geotechnical data, firstly obtained during field and lab tests, secondly and subsequently after the evaluation the geotechnical data which are used for the design;

- **Calculation model** – specifies the basic approach to the geotechnical structure design;

- **Execution** (building-up) of the geotechnical structure – specifies the construction technology.

It is very important to take this process into consideration from the first moment – from the step of intention of the design and construction of the geotechnical structure.

The main difference between the geotechnical structures and other structures is the fact that our geotechnical profession is dealing with natural material – with soil and rock – while other structural engineers are dealing with man-made materials.

The properties of man-made materials can be specified by the designer in advance and he/she can count that the properties of structural elements (from steel, concrete, timber…) will really have demanded properties when installed in the structure. Certainly with small deviations. Therefore for steel, concrete, timber and other structures there are only 2 main phases: calculation model and structure execution.

The situation for natural materials is more complicated as properties of nature are always complex and can be tested only on limited numbers of samples either in lab or during field investigation. These samples represent only limited volume (let say 1: 1 000 000) of the natural – geological – environment, which is affected (is in interaction) with constructed structure.

The Eurocode 7 "Geotechnical design" is also based on the accepted principle that the complexity of each geotechnical design shall be performed in agreement with associated risk, Frank et al (2005). And this risk (often called as geotechnical risk) is strongly connected with above mentioned 4 main phases, as each of these phases is connected with some uncertainties. Therefore after the evaluation of these uncertainties for all stages the overall judgement of risk can be specified. 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.

EC 7 recommends to divide the geotechnical structure according to the risk into 3 Geotechnical categories. However the overall risk evaluation appropriate for Geotechnical categories specification can be also based on:

- Complicacy of ground conditions – encompassing above mentioned first two phases.
- Demandingness of structure – encompassing last two phases.
- Impact of failure of the proposed structure on human lives and environment generally (so called consequence classes mentioned in EC 0).

SPECIFIC POSITION OF EARTH STRUCTURES BETWEEN GEOTECHNICAL STRUCTURES

Practically all structures are in the interaction with ground – with geological environment. The same is valid for geotechnical structures, which can be divided into three main categories:

- Foundation structures – construction **on** ground.
- Earth structures – construction **with** ground – where soil is the main construction material.
- Underground structures – construction **in** ground.

For all geotechnical structures (as well for practically all other structures) the ground properties are needed, at least for the volume of ground which is affected by proposed structure. However, for earth structures specification of properties of the ground (fill), from which earth structures are constructed, are needed as well. So it means that geotechnical investigation should be concentrated not only on ground (subsoil) but also on ground of the place (borrow pit) from which material (soil, rock) will be used as construction material. Therefore, the Geotechnical (Ground) Investigation Report (GIR) according to the demands of EC 7 should specify two geological models. Subsequently for the ground (subsoil) typical physical-mechanical properties should be determined as compressibility, shear strength and filtration characteristics, with the help of lab or field tests (so called measured or derived values according to EC 7). For the borrow pit classification properties (properties needed for soil (rock) classification) are firstly performed to distinguish geological profile of the borrow pit – just to receive first information about homogeneity of the borrow pit and about first judgement about applicability of the material for proposed earth structure. Subsequently the samples from the borrow pit are compacted in laboratory (e.g. by Proctor test). Firstly, the obtained optimal moisture content is compared with moisture content in borrow pit and subsequently tests for physical-mechanical properties are performed on compacted samples.

The tests specification should respond to the type of earth structures, as they can be divided into following groups:

- Earth structures for transport engineering as roads, motorways, railways, airports.
- Earth structures for water engineering as different fill dams (high, small), dykes, canals.
- Earth structures for environmental engineering as sanitary landfills, tailing dams and spoil heaps, firstly from mining activity.

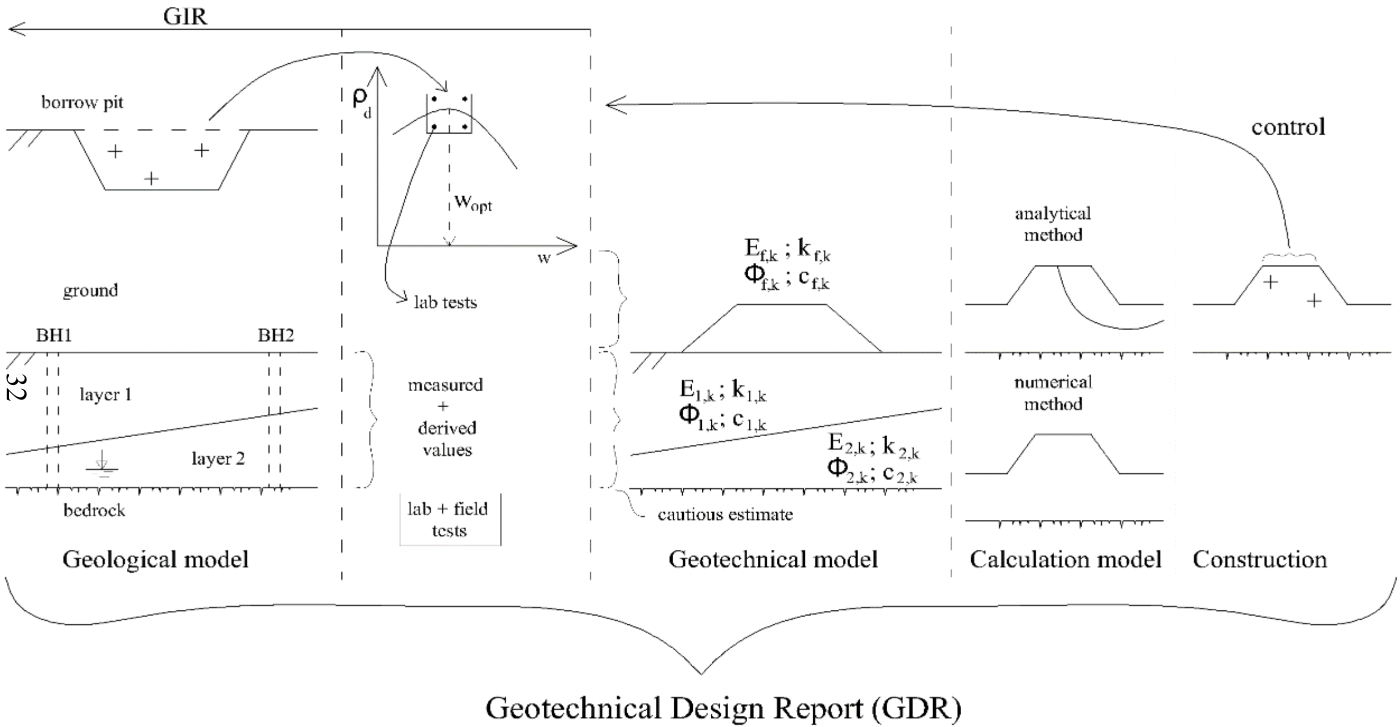
All the results are part of GIR as it is shown on enclosed figure, specifying "Logical scheme of the Geotechnical Design Report (GDR) for Earth Structures".

First step of the geotechnical structure designer is to select from the measured and derived values of the geotechnical parameters so called characteristic values, which are subsequently used during the design. EC 7 states that this selection is based on caution estimate, which take into account some other aspects – e.g. structure importance (geotechnical category) or the volume of ground which can be affected (e.g. length of slip surface – having impact whether to select properties closer to mean value or to be more conservative – for short slip surface), Vaníček (2015). Characteristic values (with index k) are part of geotechnical model.

As the distinction between measured (or derived) values and finally selected characteristic ones is so important, there is recommendation to use for the second generation of EC 7 (expected in 2020) for the outputs of GIR the term "geotechnical site model" and for the final version the term "geotechnical design model".

Above mentioned procedure is valid for typical case. However, with respect to the geotechnical categories the EC 7 is allowing also different procedures:

- for 1st GK – representing light and simple structures and small earthworks associated with negligible risk, the design (minimum requirements) can be satisfied by experience and qualitative geotechnical investigations. The typical example for Earth structures is the recommendation of USBR for the slope inclination of small dams for different soils compacted by standard compaction energy, Wagner (1957)
- for 3rd GK – representing structures connected with very high risk, and therefore the geotechnical investigation, design and performance control should include alternative provisions and rules to those specified in EC 7.
- for 2nd GK – representing all other structures – there the geotechnical investigation, design and performance control should follow the procedure specified in EC 7. And here EC 7 allows two possibilities how to specify characteristic values of geotechnical parameters (physical-mechanical parameters). The first possibility is based on statistical evaluation of measured and derived values. The second one is based on standard tables of characteristic values related to soil investigation parameters – mainly on parameters needed for soil (rock) classification.



Logical scheme of the GDR for Earth Structures

Simply speaking the characteristic values are based on up to date experiences. Usually this approach is selected for geotechnical structures falling into 2nd GK with lower risk and the first approach where the risk is higher. The distinction for ground investigation is obvious, for the first approach the undisturbed samples are needed, while for the second approach the partly disturbed samples are sufficient.

With respect to the calculation model the designer usually counts with analytical methods or with numerical methods. Anyhow in both cases it shall be verified that not only no relevant limit state is exceeded, but also for any possible design situation. Therefore, the first step is connected with defining the design situations and limit states. EC 7 specify ultimate limit state (ULS) and serviceability limit state (SLS), followed by selecting of all relevant actions. For earth structures the limit state ULS is usually connected with limit state of GEO (mostly bearing capacity or slope stability) or HYD (mostly internal erosion caused by hydraulic gradient) and the limit state SLS is connected with settlement, differential settlement or with basic demands on fulfilment of the structure purpose (e.g. water retention, contaminant retention etc.). From the design situation point of view at least short term and long term conditions should be compared.

The basic difference between earth structures and other geotechnical structures is connected with the phase of control. For foundation structures the quality of subsoil surface is controlled and differences between expected one (with respect to geological model, partly geotechnical one) can lead to the small correction in the design. The same is roughly valid for underground structures, as during the excavation the geological model is confronted with reality. Similar control for earth structures is possible only for cuts. The most sensitive problem is connected with control of compacted soil. The control is in most cases indirect, as usually only dry density and moisture content are controlled (and compared with recommended values based on the Proctor compaction test). New continuous compaction control (CCC) is a certain step forward in this direction, e.g. Brandl, Kopf and Adam (2005). Nevertheless, the designer has no direct control of physical-mechanical properties with which counted in the design, in calculation model. Therefore, the simple conclusion can be made: risk associated with design and performance of earth structure is one of the highest.

EARTH STRUCTURES WITH SUBSOIL OR FILL IMPROVEMENT

The differences or specificity of earth structures are even emphasized in the case of some alternative design. In many cases the subsoil needs some improvement. There are two basic opportunities: diffusion ground improvement and discrete ground improvement. For the first case it is e.g. dynamic consolidation (Ménard method of compaction) or different methods for speeding up consolidation process as application of vertical drains, preloading. For the second case some additional elements are added, starting from classical piles, via stone columns, lime columns, geosynthetic encased columns, jet grouted columns etc.

For fill improvements two methods prevails. It is firstly geosynthetic reinforcement or soil stabilization, where soil before compaction is mixed mostly with cement or lime, e.g. Schlosser (1997). Another way is connected with application of alternative aggregates, either for fill lightening (e.g. light weight aggregates from expanded clay or expanded polystyrene) or with application of different large volume waste (as ash, construction and demolition waste etc.).

In all cases the design is even more complicated, as determination of ground or fill properties are more difficult with not so many previous experiences. The design in some cases deserve nonstandard methods, as solution counts with heterogeneous medium. Therefore, the risk associated with such solution is even higher.

EARTH STRUCTURES AND SUSTAINABILITY APPROACH

Concept of sustainable development was accepted in Rio de Janeiro International conference "Environmental Summit". After that, this concept was gradually developed in various areas of the human activities, as well as for construction sector, including geotechnical engineering, e.g. ECTP reFINE (2012), (O´Riordan, 2012). The main aim is to provide the economically competitive construction with higher utility value and at the same time with lower energy demands, the lower raw material inputs and lower need of new plots of land when the risk of the danger for human health and life during natural disasters, accidents and unwanted events is reduced.

Earth structures of transport engineering represent very good example where above mentioned principles can be applied, Vaníček,I and Vaníček,M (2013), Vaníček, Jirásko and Vaníček (2013). Some examples can be mentioned:

- saving the land (greenfields) when designing steeper slopes of embankments or cuts, usually with the help of soil geosynthetic reinforcement;

- saving natural aggregates when applying alternative materials mentioned in previous chapter, Head et al (2006). When large volume materials are applied, the physical-mechanical properties as well their environmental impacts should be checked in advance to protect non-standard behaviour (as e.g. swelling for slag) or causing subsoil contamination from waste leachate, Vaníček, M. (2006).

- saving of energy for all the life time expectancy, which can have many different aspects. Starting via application of sustainability approach, as for steeper slopes we can safe not only land but also energy needed for excavation and transport. The selection of best technology and control for the compaction effort is also important aspect from the point of view of energy savings. Utilization of geothermal energy can be added as well and finally the savings can bring the application of new smart geotechnical structures, where the demand on energy consumption is lower than for classical geotechnical structures, Heerten et al (2013). One example can be mentioned – retaining wall from reinforced soil in comparison with classical concrete gravity wall.

CONCLUSION

Earth structures belong to the oldest structures and the soil is most used structural material. However, up to the half of the last century, the design was mostly based on previous experiences and the technology of construction played most important role, designed as "Earthworks". With growing demand on large dams, high road embankment, airfields constructed on the see floor and especially during construction of structures falling under environmental engineering, the real design prevails. Therefore, paper focused on the design which is in agreement with EC 7, when the special attention is connected with selection of the geotechnical data used for the design – characteristic values. The reason of this focus is the fact that soil and rock are made by nature and not by man, and the properties of nature are always complex. To be able to overcome this problem, which is connected with higher risk, with which the design and performance are associated, some rules are stressed in the paper. Firstly, it is complexity of the geotechnical investigation, design and control, which is function of the geotechnical risk. Some rules connected with limit states, design situations are also emphasized.

To be able to construct earth structures under less convenient situations some improvement either for subsoil or for fill are mentioned, bringing another uncertainties to the design. In this direction earth structures deserve our great attention, as they are offering large opportunities for future research activities.

This opportunities are connected also with the implementation of sustainability approach to the construction sector. Smart geotechnical structures, firstly earth structures of transport engineering, can react on society demands to decrease consumption of land, energy, natural aggregates on one side and guarantee long term functionality on the other one.

ACKNOWLEDGEMENT

The paper was prepared with financial support of the research project TEO 120168 of the Technology Agency of the Czech Republic CESTI – Centre for effective and sustainable transport infrastructure.

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The article has entered in edition on 19.07.2016.