Geotechnical engineering and protection of environment and sustainable development

Engineering géotechnique, protection de l'environnement et développement durable

Vaníček M., Jirásko D., Vaníček I.
Czech Technical University in Prague

ABSTRACT: The paper highlights the positive role of geotechnical engineering for protection of environment and sustainable development, first of all from the view of sustainable construction. The main attention is therefore focused on the problems which are sensitive to society in general as the construction on brownfields, utilization of waste and recycled materials for new construction and rehabilitation of territory affected by open pit mining process which is proposed as new development area. The first point is connected with the protection of greenfields and is defining basic phases of process of rehabilitation as the significance of first phase of geo-environmental investigation, remediation of contaminated subsoil and utilization of old foundation. The second point describes practical experiences with utilization of large volume waste as construction and demolition waste or ash in earth structures– not only from the view of mechanical behaviour but also from the view of potential impact on environment. The last point describes the utilization of the surface of the mining spoil heaps for new construction together with control of long term stability of slopes even for future expected ground water table and heavy rainfalls.

RÉSUMÉ : L'intervention souligne le rôle positif de l'engineering géotechnique dans la protection de l'environnement et le développement durable, et ceci essentiellement du point de vue de la construction durable. Elle se concentre surtout aux problèmes généralement perçus par la société comme sensibles : la construction sur les friches industrielles, l'utilisation de déchets et de matériaux recyclés dans la nouvelle construction, ainsi que le réaménagement du territoire affecté par l'exploitation minière à ciel ouvert. Le premier point est lié à la protection des greenfields et définit les phases principales du processus du réaménagement, comme la première phase de la prospection géo-environnementale, l'assainissement du sous-sol contaminé et l'utilisation des bases anciennes. Le deuxième point décrit des expériences pratiques avec l'utilisation des déchets volumineux comme p.ex. des déchets de construction et de démolition ou bien des cendres dans les ouvrages en terre, non seulement du point de vue des caractéristiques mécaniques, mais aussi de celui de l'impact potentiel sur l'environnement. Le dernier point décrit l'utilisation de la surface du terril pour les nouvelles constructions, tout en assurant le contrôle de stabilité de long terme des pentes, même pour la nappe d'eau souterraine attendue et les précipitations fortes.

KEYWORDS: brownfield, remediation, contaminant, waste, spoil heap, soil improvement

1 INTRODUCTION

Geotechnical Engineering is falling under the limited group of professions, which to the high extent are able to react not only on classical construction problems but also to new society demands, namely with respect to:

- Protection against natural hazards – first of all against floods, landslides and earthquakes;
- Energy savings – especially with respect of Geothermal energy, as with high potential energy (from large depth) or with low potential energy in the forms of earth aerial heat exchanger, systems utilizing heat pumps or systems utilizing heat reversible pumps either for heating or for cooling with help of energy piles or diaphragm walls;
- Raw materials savings – with high potential for waste and recycled material utilization, especially for large volume waste as e.g. ash, slag, construction and demolition waste etc;
- Protection of greenfields – as GE is playing significant role in the field of "Construction on brownfields";
- Environmental protection in general – e.g. from the view of safe deposition of waste (landfills, tailing dams, spoil heaps, underground repositories) or with respect to remediation of old ecological burdens – decontamination of subsoil.

However in a matter of fact all above mentioned problems can fall under the umbrella of Environmental geotechnics and are parts of the geotechnical engineering benefit to Sustainable Construction, (Vaníček I. 2012).

The branch of Environmental Geotechnics is now very well established, falling under the important part of Geotechnical Engineering which can be called Geotechnics, Geo-Technology and represents the third column by which Geotechnical Engineering is supported, (Vaníček, I. and Vaníček, M. 2008). Remaining three columns are Theoretical background, Geomechanics and Feeling for ground response, whereas the first column Theoretical background relies on the understanding of natural sciences such as geology, engineering geology and hydrogeology on the one hand, and on the understanding of mechanics, theory of elasticity on the other. The second column relies on the application of existing findings to the behaviour of soils and rocks under different stress - strain states – we are speaking about support from soil and rock mechanics and finally the fourth column relies on a certain feeling of geological environment which Terzaghi (1959) denotes as "capacity for judgment", and he says that "this capacity can be gained only by years of contact with field conditions", (see Figure 1), (Vaníček, I. 2010).

However with the respect of the limited range of the paper only three problems will be discussed further.

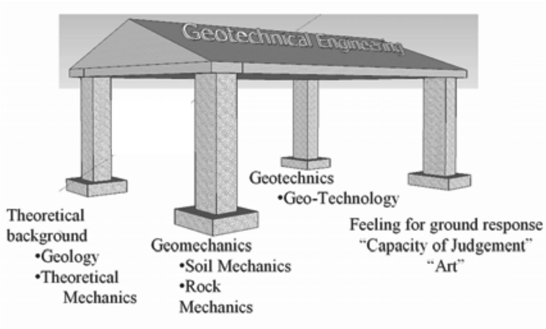

Figure 1. Four columns of Geotechnical Engineering

1 ROLE OF ENVIRONMENTAL GEOTECHNICS IN THE BROWNFIELDS REDEVELOPMENT

Very often the whole process of the brownfields redevelopment can be divided into the following individual steps, (e.g. Vaníček and Valenta 2009):

- site location identification,
- First phase of investigation,
- preliminary economic analysis,
- Second phase of investigation – detailed site analysis
- project of site development and methods of financing – feasibility study
- project and completion of site remediation
- project and completion of construction of new development (including foundation engineering, reuse of old foundations).

From these basic 7 steps, it is obvious that environmental geotechnics is strongly involved in the whole process. But typical for geotechnical engineers are four parts – 1st phase of investigation, 2nd phase of investigation – detailed site analysis, project and completion of site remediation and the problem of foundation engineering, respectively reuse of old foundations. These parts will be discussed further in more detail, (Vaníček 2010).

The first two steps are labelled as the first phase which can be also called the desk study, which is only supplemented by visual inspection. So this first phase mostly uses existing materials, where the study of archive materials and different maps composes the most important part of this phase.

The 2nd phase of the investigation encompasses site investigation, usually starting with borings, field tests, collection of samples and laboratory tests. Classical geotechnical data are useful from the foundation design perspective, geoenvironmental data from the view of site contamination.

The properties of the brownfields ground is usually affected by previous man made activity. These changes have character of physical, chemical or biological change. Owing to biological degradation some problems with gas (mostly with methane) are expected. However in most cases the subsoil remediation is connected with

- Physical improvement of the subsoil quality, with porosity decrease;
- Chemical improvement.

The main principle of physical improvement is to create top layer with much better quality than subsoil to be able to eliminate differential settlement of the subsoil and to guarantee the possibility to create good footing bottom for new foundations, see more in chapt. 4.

As the depth of the affected subsoil is usually deeper than the depth for which classical compaction rollers can be used it is necessary to apply other methods. The dynamic consolidation method was for example used for the subsoil improvement of old toxic landfill in Neratovice, (see Figure 2), where on the compacted material a new landfill was constructed, (e.g. Vaníček et al 2003).

Figure 2. Compaction of deposited waste by dynamic consolidation

In the north part of Bohemia, where there are many inner spoil heaps composed of uncompacted clay clods, a new method called "clay piles" was successfully applied.

A pre-driven profile is backfilled by clay of similar properties as is the surrounding material and subsequently compacted there, (see Figure 3).

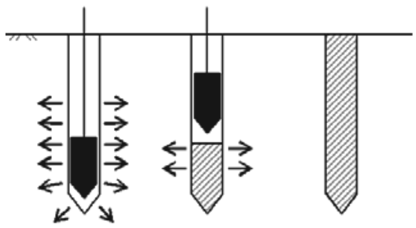

Figure 3. Ground improvement by "clay" piles

- The main aim of chemical improvement is to decrease the degree of subsoil chemical contamination on accepted level.

There is a very wide range of different methods which are used for site remediation. It is not the intention of this lecture to present the overview of these methods, because they are covered elsewhere, (e.g. Suthersan 1997), are summarized by US EPA or are a part of activities of ICEG – International Congresses on Environmental Geotechnics. Most of the methods utilize some geotechnical approaches, as drilling, pumping, hydraulic fracturing, and monitoring.

Nevertheless there are 3 methods preferably utilizing classical geotechnical methods as:

- Encapsulation – with the help of the underground sealing wall (Different types of cut-off walls) and the horizontal sealing system (CCL – compacted clay liner, GCL – geosynthetic clay liner, GL – geomembrane liner or composite liner), (Vaníček et al 1997),
- Permeable reactive barrier, e.g. (Jirasko and Vaniček 2009), where the vertical sealing wall regulates the contaminant plume to the permeable window –where contaminated water is cleaned – with the help of sorption, precipitation or degradation, (see Figure 4).
- Stabilization, solidification, - these methods are based on the principle of mixing waste with a bonding agent to create a stiff matrix where the contaminant is bonded. As a bonding agent the different combinations of cement, ash, lime and slag are usually applied.

Question about utilization of old foundations is the last geotechnical problem connected with brownfields redevelopment. This problem is especially sensitive for large cities as the average design life of office buildings is about fifty years.

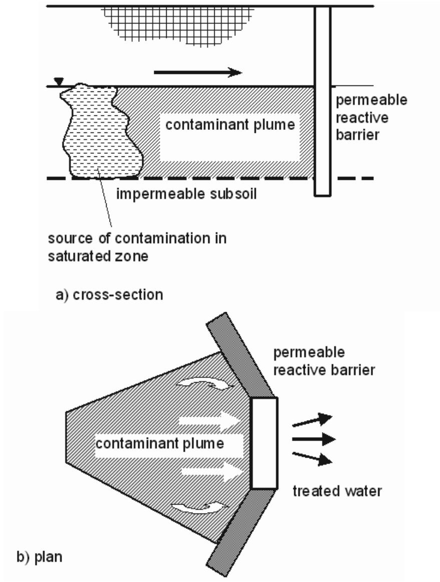

Figure 4. Remediation by in situ reactive barriers

So it means that buildings constructed in the 1950´s- 1960´s are now often demolished and reconstructed. Many of these large modern buildings have been designed with wide column spacing necessitating the use of deep piles or piled raft foundations, as was the case e.g. for London, (Chow 2003). Therefore the discussion is about three options – avoid, remove, reuse. The last option is now preferred as reuse of old foundations has many positive aspects from the environmental point of view, (e.g. Butcher, Powell and Skinner 2006).

Nevertheless we can reuse also spread foundations, which were used for old dwellings, e.g. prefab panel buildings; for farm buildings as well as for old industrial structures. Although the price for removal is not as problematic there as for pile foundations, the version of reuse is very attractive. Here the bearing capacity for subsoil composed of clays increased with time as the result of consolidation. Also the foundation settlement induced by new loading can be rather low, as some additional structural strength had chance to develop there with time for particle arrangement given by stresses from the old foundations.

Direction of the new research activity is therefore connected with observation of changes with time not only in subsoil surrounding existing foundations but also at the contact with this foundation. For bearing capacity and for settlement stress and strain paths are more complicated. Schematic drawing what is going on for selected layer below spread foundation is shown in Figure 5 and new laboratory and filed investigation should to prove some expected assumptions.

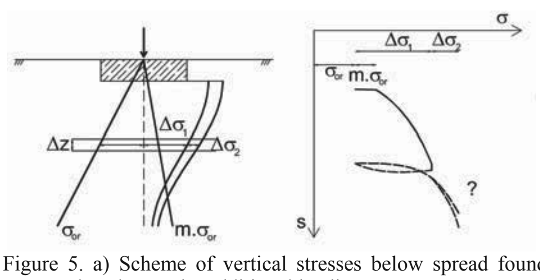

Figure 5. a) Scheme of vertical stresses below spread foundation; b) Expected settlement by additional loading $\Delta\sigma_2$

2 UTILIZATION OF LARGE VOLUME WASTE

Human activities produce a huge amount of different waste. Therefore the most important aim is to decrease the volume of such waste. Nevertheless for remaining waste the strategy should be defined and more efficient way is connected with reutilization of this waste. Civil engineering and first of all geotechnical engineering has a great chance to reuse large volume waste as:

- Construction – demolition waste – old bricks, concrete, ceramics, old asphalt pavement, gravel ballast.
- Industrial waste – ash, dross, slag;
- Mining waste – overlaying soils, waste rock, quarry waste, residues after washing china clay…

During last period the orientation is also on other relatively large volume materials as tyres, glass, polystyrene…

Only one example will be shown, which is combining the utilization of waste for the production of new construction material which can be used for better protection against floods. This new construction material is called brick – fibre – concrete which is composed from old bricks and concrete crushed particles together with classical additives for concrete – cement and water and with new additives – with synthetic fibres, (Vodička et al 2009).

After mixing together the final product looks like on the Figure 6a, where interconnection of individual components is visible. The degree of compaction can significantly determine the final result – what is for example very important from the view of permeability, as this property can be guaranteed in relatively wide range. The impact of the fibers can be seen from the Figure 6b, representing the result of bending test of prepared beam.

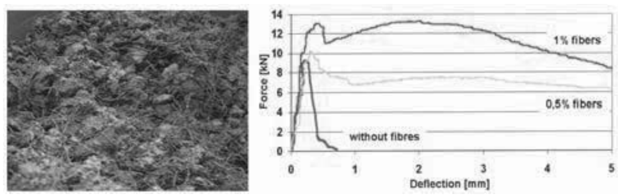

Figure 6. a) Mixture of brick – fibre – concrete; b) Influence of synthetic fibres on the strength parameters and behaviour after failure

After heavy floods there is usually huge amount of the construction and demolition waste and the new product can be applied for the reinforcement of reconstructed part of dikes. Laboratory models up to the scale 1:1 (see Figure 7) proved extremely high resistivity against surface erosion and such reinforced dikes can be applied not only for reconstructed parts but also in selected sections of dikes, where the crest is little bit lower than other part and overflowing can start there as higher resistivity is guaranteed.

Figure 7. Model of reinforced dike before and after the test

3 THE UTILIZATION OF THE SURFACE OF THE MINING SPOIL HEAPS FOR NEW CONSTRUCTION

Roughly 200 mil. m^3 of clayey material which overlay brown coal seam are removed and backfilled during open pit mining activity in the Czech Republic each year.

As extremely large part of the country in this area is affected by mining activity the construction of new structures on the surfaces of these spoil heaps is nearly necessity. The first condition is connected with long term slope stability as material properties are changing with time as well ground water level, (Vaníček and Chamra 2008). Second condition is connected with settlement, first of all with differential settlement, as this uncompacted clay fill has sometimes extreme elevation – more than 100 m. Typical example is Ervenice corridor, (Dykast et al 2003), with cross section shown in Figure 8. Only for top layer about 5 m little bit better material was applied and partly compacted. Nevertheless this layer significantly eliminated differential settlement, so that motorway on the top can be used without special limitation (see Figure 9) even when the total settlement exceeded 2 meters.

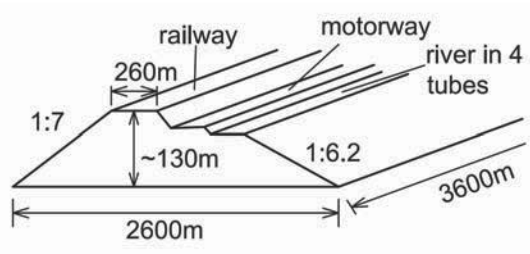

Figure 8. Schematic cross-section of Ervenice corridor

Figure 9. Photo of the top of Ervenice corridor

For classical objects founded on the spoil heaps surface the following approaches are applied:

Among passive measures we can count:

- postponing the new construction – however sometimes this condition is unacceptable;
- using some methods of deep foundations like piles – but solution can be limited by height of fill, by economical reasons and a negative skin friction should be taken into account;
- preconsolidation with additional load, which has to be removed after a certain time – very problematic as it is connected with huge volume of additional fill and with time needed for which this additional loading have to be applied.

Among active measures the different approach is usually chosen for total and for differential settlements. Higher value of total settlement can be accepted if:

- special technical solution is applied for engineering services as electricity, gas, sewage…,
- rectification can be applied e.g. for railway tracks, pipelines etc.

But most sensitive questions are connected with differential settlements with direct impact on damages to the structural elements and to the manner of the practical use of the structures. There we cannot so easily accept little bit higher values as for total settlement. Therefore if the probability that the expected different settlements will be higher than the accepted ones this situation has to be solved with the help of the following steps:

- to select such construction system which is not so sensitive to the differential settlements; or
- to improve the subsoil beneath foundations as was mentioned at the beginning of this chapter.

4 CONCLUSION

Short overview is stressing a significant role of the geotechnical engineering for environment protection, especially from the view of Sustainable construction, from the view which is very sensitive for all society. Three practical examples supported this general aspect from which new problems which our profession has to deal with are clearly visible.

5 REFERENCES

Dykast et al 2003 Ervěnice corridor – 130m high spoil heap from clayey material – with transport infrastructure on its surface. XIIIth European Conference on Soil Mechanics and Geotechnical Engineering, Volume 4. Praha: ČGtS ČSSI, p. 57–76. ISBN 80-86769-03-8.

Jirásko D. and Vaníček I. 2009. The Interaction of Groundwater With Permeable Reactive Barrier (PRB). *The Academia and Practice of Geotechnical Engineering*. Cairo: IFOS, p. 2473-2478. ISBN 978-1-60750-031-5.

Suthersan S.S. 1997. *Remediation Engineering. Design Concepts*. CRC. Lewis publishers, New York

Vaníček I. 2010. Urban Environmental Geotechnics Construction on Brownfields. *Geotechnical Challenges in Megacities*. St. Petersburg: GRF,. p. 218-235. ISBN 978-5-9902005-2-4.

Vaníček I. and Chamra S. 2008. The Influence of Extreme Raiinfall on the Stability of Spoil Heaps. *10th Int. Symp. on Landslides and Engineering Slopes.* London: Taylor and Francis, p. 1653-1658. ISBN 978-0-415-41196-7.

Vaníček I. and Valenta J. 2009. Examples of the use of environmental urban geotechnics for brownfield redevelopment. *Engineering Geology for Tomorrow's Cities*. London: The Geological Society of London. ISBN 978-1-86239-290-8.

Vaníček I. and Vaníček M. 2008.*Earth Structures in Transport, Water and Enviromental Engineering*. 1. ed. Berlin: Springer Science+Business Media. 637 p. ISBN 978-1-4020-3963-8.

Vaníček I.et al 2003. Remediation of Chemical Landfills in Neratovice and Chabarovice. *Geotechnical Problems with Man-Made and Man Influenced Grounds* - XIIIth European Conference on Soil Mechanics and Geotechnical Engineering, Volume 4. Praha: ČGtS ČSSI, p. 279-294. ISBN 80-86769-03-8.

Vodička et al 2009. Utilization of fibre-concrete in earth structures. *Sustainable construction 5*. CTU press, Prague, pp. 107-112.

Vaníček et al 2012. Sustainable Consruction. *Sustainable construction* CTU press, Prague ISBN 978-80-01-04873-3.

Vaníček et al 1997 Remedy of a chemical waste dump with foundation of a new dump on its surface. In Proc. 14th IC SMGE, Hamburg, vol 3, pp 1857–1860.

Chow 2003. Geotechnical aspects of tunnelling reuse of foundations and building on landfill in brownfield development. *Geotechnical Problems with Man-Made and Man Influenced Grounds* - XIIIth European Conference on Soil Mechanics and Geotechnical Engineering, Volume 3. Praha: ČGtS ČSSI, p. 343-348.

Butcher, Powell and Skinner 2006. *Reuse of foundations for urban sites.* A best practice handbook. IHS BRE Press. Bracknell.