Examples of the use of environmental urban geotechnics for brownfield redevelopment.

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Abstract: Environmental geotechnics has a very important role in brownfield redevelopment. This is demonstrated through the basic phases of the redevelopment process. Practical examples of the evaluation and characterisation of the locality including the preliminary phase of the investigation, based on the study of historical documents, geoenvironmental maps and site visits, are presented. The results of this evaluation form a very useful tool to use in the decision making process. It can help with the preliminary feasibility study and help define the successive stages of investigation from the municipality perspective, to define urban plans. The second group of examples will examine the situation where the subsoil is physically affected and often comprising made ground containing artificial deposits resulting from of open pit mining. In the made ground the main focus is devoted to the reduction of total and differential settlement and therefore the different methods for subsoil settlement prediction and improvement are presented.

Résumé: La géotechnique de l'environnement joue un rôle très important dans le réaménagement des « brownfields » (localités abimées par une construction) : ceci sera montré sur toutes les phases essentielles du processus de réaménagement. On présente des exemples pratiques de l'évaluation, de l'identification de la localité et de la première phase de l'investigation, basés sur l'étude de documents historiques, de même que sur l'usage de cartes géo-environnementales et sur l'observation personnelle de la localité. Les résultats de cette évaluation représentent un outil très important dans le processus décisionnaire et peuvent être très utiles pour la première étude de faisabilité, notamment du point de vue d'une municipalité, pour réaliser des plans d'aménagements du territoire. L'autre groupe des exemples pratiques est orienté sur les cas des sous-sols présentant une influence physique – sous-sols composés de dépôts artificiels résultant d'une exploitation à ciel ouvert de charbon. Dans ces exemples, on s'oriente notamment sur l'abaissement de la déformation totale et inégale, c'est pourquoi de différentes méthodes de prédiction du tassement du sous-sol et de son amélioration sont présentées.

Keywords: environmental urban geotechnics, environmental geology maps, reclamation, surface mining, spoils, settlements

INTRODUCTION

The significance of new construction on derelict land, referred to as brownfield redevelopment, is similar in practice in the Czech Republic as in many other industrialized countries, where huge effort has been devoted to urban restructure over the last few decades (Vaníček, 2003). An example of a well documented case is the remediation of London Docklands (Berry, 2003). In recent years there has been a decline in many traditional industries particularly mining, heavy industry, textile industry and the decrease of military bases etc. This has been replaced with a growing pressure for new land for development and implementation of new opportunities connected with new industries such as light engineering, IT, business, marketing, warehousing activities, etc. In most cases new investors strongly prefer the construction on Greenfield sites. The research activities in this area is considered to be very progressive and environmental geotechnics plays a very significant role. The main aim of these investigations is to provide data and technical solutions in order to enable reuse of locations affected by former anthropological activities.

Basically we can distinguish between redevelopment of urban areas, and areas affected by mining. For example the extraction of brown coal by open cast techniques in the north part of Bohemia imposed on historical urban centres, which were in some cases partly destroyed. Only a few buildings were protected, for example the transfer of a gothic church in Most over a distance of about 862 m (Herle & Škopek, 2003). Huge amounts of overburden mine waste have been deposited partly at surface and partly as backfill into pits with new construction unavoidably located over these spoil heaps in this area. Urban areas can be divided into two basic groups; relatively large cities, with significant historical past and industrial legacy; and where a strong demand exists for new development land in smaller cities, where affected areas are not so prevalent, but nevertheless form a the paper concerns industrial activities and concentrates on smaller cities. The second part is connected with new construction on spoil heaps created by former mining activity.

PHASES OF THE REDEVELOPMENT PROCESS FOR URBAN BROWNFIELDS

Very often the whole process of brownfield redevelopment can be divided into the following steps:

- site selection,
- 1st phase of investigation,
- preliminary economic analysis,
- 2nd phase of investigation – detailed site analysis
- planning including site development and methods of finance – feasibility study
- identification and selection of appropriate site remediation
- identification and selection of construction techniques

From these basic 7 steps, it can be seen that environmental geotechnics is prominently impacts through the whole process, starting from the site selection and 1st phase of investigation, through the 2nd phase of investigation, remediation process and finishing with recommendation for foundation design, which can include the option for utilization of old foundations.

The first two steps are referred to as the 'first phase' in the following discussion and described in more detail. Preliminary economic analysis plays a key role in defining the suitability of a site for new construction, determining how the site can attract new investors, especially after comparison of financial inputs for redevelopment and the economic return. This preliminary economic analysis is supported by architectural study (which identifies structures of historical importance for protection), and social study, which determines how the redevelopment can improve the quality of life in the affected area. The 2nd phase of the investigation includes site investigation including borings, field tests, collection of samples and laboratory testing. Routine geotechnical analysis is useful from the foundation design point of view and geoenvironmental data for investigating the potential for site contamination. Feasibility studies evaluate the workability from the financial point of view and define the financial plan for remediation and realization of construction. Site remediation can be very expensive if the level of contamination is high, and includes the whole process of remediation (starting from the evaluation of temporal and spatial contaminant distribution, comparison of the test data against regulatory limits, the selection an implementation of the most appropriate remedial methods, and monitoring to determine whether the proposed level of clean was achieved, the impact on the existing community and the final validation report for the administrative bodies (Vaníček, 2002).

Significant decisions can be taken after individual steps, for example:

- after the first phase (first two steps), the local authority can realistically evaluate and advise on future requirements, having sufficient information on the nature and extent of contamination,
- after the feasibility study the potential financial risk for investors can be defined,
- many investors prefer to purchase the site at the end of remediation process, after the validation statement (from administrative body) that the site will not pose any potential environmental risk for future evelopment.

First phase

The first phase involves desk study, which is supplemented by a visual site inspection. This first phase relies mostly on existing and available data, principally the study of archival materials and various maps.

Site identification is connected with investigation of the site using real-estate registers, where preliminary information regarding the site area, ownership, and other pertinent data can be obtained. Typical problem with ownership exist as the land ownership has often changed over the last 65 years – as is the case at the beginning and at the end of the Second World War or as the political environment changed after the years 1948 and 1989. In this case other historical documents can be used. The type of landownership can have some influence on different types of available grants, which can be obtained from different agencies. Supplemented influences include prices for parcels across a wider area, potential interest, and advertising, all of them can help to define the potential attractiveness of the site.

The 1st phase of investigation tends to allow the preliminary assessment of the potential chemical, biological or physical nature of the subsoil.

Visual inspection

The main aim of the visual inspection is to evaluate the site, particularly geomorphology of the wider area, surface water, groundwater (from monitoring old wells), discussion with owners, information about vegetation, inspection of existing buildings with assessment of their condition, with particular reference to any unusual symptoms, including as colour, odour, anecdotal information, discussion with former employees. All visual inspections should be accompanied with photographs, videos, etc.

Archive and contemporary data collection

At this stage useful information is collated for structures, but also about former industrial processes, and associated materials and the sort of waste material produced. From archival and other historical documents information can be obtained on potential problems or past incidents and from these data a judgement can be made on the probability of soil and water contamination and hydrogeological consideration can be made.

General information about buildings includes:

- Details about building construction
- Observation of old projects, with special respect to geotechnical engineering,
- Materials used for the construction,
- Engineering networks,
- Services
- Transport infrastructure
- Reports, surveys

History of the buildings utilization:

- Manner of utilization, type of production, selected technologies, manufacturing programme.
- Volumes, quantities, frequencies,
- Substances used
- Changes with time, final closure of production,
- Accidents, incident, failures, fires, lost of lives

Information from archive and other historical documents:

- Municipal records,
- Old ground plans
- Previous site utilization
- Old cadastre maps.

Materials from hydro- and meteorological institutes:

- Precipitation
- Evaporation
- Flow rates on streams, information about floods

Materials from aerial observation – military and civic photographs

Geonvironmental maps used in the Czech Republic

Different sources can be used for obtaining information relating to a locality:

- City maps with surroundings, contour plans
- Land-use plans, Orthophotomap, GIS system
- Infrastructure and underground service plans
- Geofond – state office where all boreholes data are archived for the whole Czech republic comprising borehole geology description, geotechnical data, ground water level etc.
- Set of Geoenvironmental maps

For the purpose of this paper, only geoenvironmental maps will be discussed in more detail. This set of Geoenvironmental Maps is at 1:50 000 scale. There is different information about selected area presented on separate layers. The whole Czech Republic territory is continuously mapped. At the moment it is possible to obtain this geoenvironmental data at 1:50 000 scale for an area from the Czech Geological Survey web site free of charge. A collection of geoenvironmental maps consist of 17 maps. This paper describes the most widely available of these:

Table 1. Collection of geoenvironmental maps (scale 1:50 000)

Type of map	Covering of the Czech Republic
Geological map	100 %
Hydrogeological map	100%
Engineering-geology map	60%
Mineral deposits map	100%
Rock geochemical reactivity map	35%
Soil map	35%
Map of surface water geochemistry	90%
Geophysical map	100%
Map of geofactors of environment	45%

Geological map is a fundamental map, which is necessary for the construction of the other layers. This map includes rock and soil type in the ground, their age, stratigraphy, tectonical setting and so on.

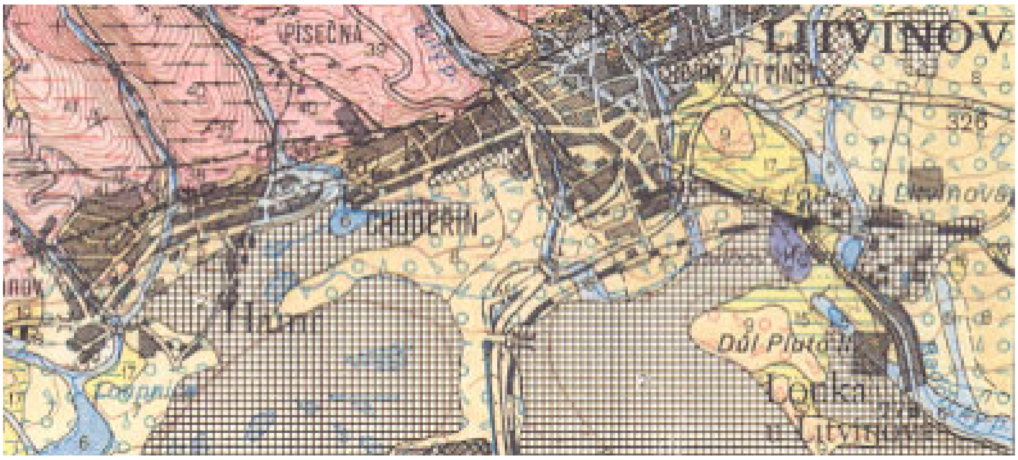

Figure 1. Example of the Geological map (1:50 000)

Engineering-geology map defines land areas with similar geotechnical characteristics, geodynamics phenomenon (landslides, rockfalls, creep) and natural hazard.

Mineral deposit map shows total range of currently extracted deposits and locality of commercial deposits. These are differentiated into ore, solid fuel, economics minerals, building materials. This map enables urban planning and shows all technical buildings related to mineral extraction (mines, old shafts, quarries etc).

Soil map shows type of substratum and type of soil horizon. This map serves for land resources protection.

Environmental geofactor map displays features that may be jeopardised in the environment – in lithosphere (mining), pedosphere (sheet water erosion), hydrosphere (important water sources), biosphere (forests), atmosphere (air pollution) and anthropogenic land influence (damp).

Hydrogeological map describes types of hydrogeological aquifers and their quantitative characteristics. A colour index on a map classes ground water discharge (m^3/s). Different symbols indicate ground water quality from serviceability point of view, ground water flow direction and important boreholes with water yield and mineralization data.

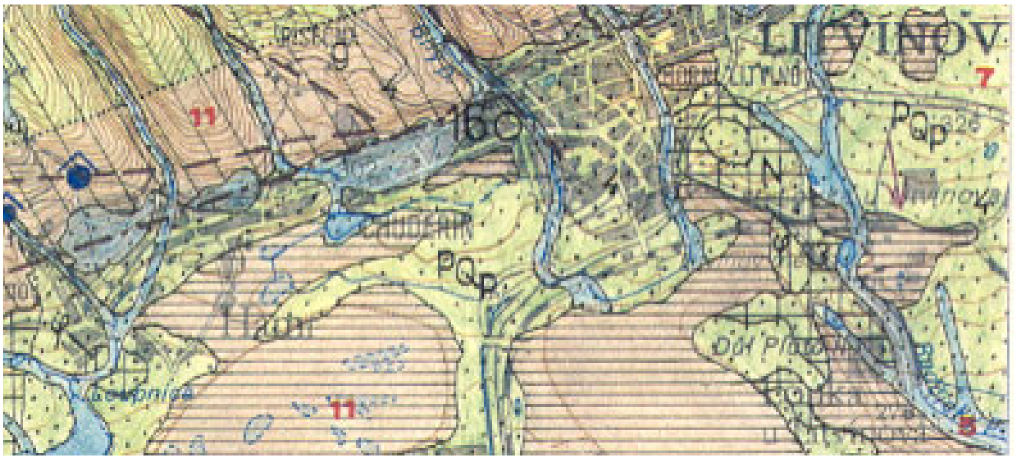

Figure 2. Example of the Hydrogeological map (1:50 000)

Surface water geochemistry map includes catchment areas for water features such as streams and their pH value. Water sampling locations and trace elements content (As, Pb, Be, Zn, Li) are marked on the map. The map of water surface geochemistry displays the level of pollution of surface water.

Figure 3. Example of the Map of surface water geochemistry (1:50 000)

Other maps

The area of large cities in the Czech Republic is mapped at a scale of 1:5 000. These maps contain detailed environmental information for the areas, including material transport over a large area and how the environment is impacted. This map shows both type of underlying solid rock and thickness of quaternary soil layer with strength and deformation characteristics, man-made earth cuts, waste bank with thickness values. Hydrogeological data includes ground water depth and ground water flow direction. The documentation data locates and describes all boreholes sunk in the area with ground water chemical analysis. At the moment the coverage is for around 3% of the Czech Republic. Maps 1:5 000 consist of:

- Geological map
- Hydrogeological map
- Map of superficial deposits
- Map of documentation points

Data evaluation from the preliminary phase

The main aim of this phase is to collate all available pertinent information with minimum financial expenditure. It is considered that all archival data are very useful for decision making on the municipality level and should be requested by all municipalities dealing with brownfield problem, because it provides reliable answers on the following three aspects:

- *Potential site contamination* – the preliminary phase of investigation involves collating all relevant available information, from which it can be determined whether contamination may be present, at what level and to what extent. Also based on appropriated data an estimate can be made of the possibility of contamination movement within the subsoil (e.g. direction, velocity) and what impact on the surrounding environment it will have.
- *Evaluation of the potential of the site* – information which make the best account of this includes the size of the site, disposition, quality of buildings, halls, technical equipments, quality and density of engineering networks, what can be used in the future, what is recommended for demolition etc.
- *Site attractiveness* – in which part of the city is situated, what is traffic accessibility, what is concurrency in near surroundings. What restrictions exist (from the owners point of view), whether there are existing liabilities. Comparison with similar localities or similar projects, why they were successful or only partly successful and details. What is the impact of the remediation process with respect to humans and what benefits society and the local authority can be made (higher prices of the surrounding areas, lower unemployment etc).

We consider that this first phase of site evaluation should be a compulsory condition for preparation of new development plans. Also as part of the preliminary stage an economical, architectural, environmental and sociological evaluation, time and technical heftiness of the remediation realization can be made. Roughly distinction can be made between:

- *Sites with high attractiveness* – which are situated in very attractive locations, such as town centres or where existing development does not exist. New construction is fully financed by private investors and the local authority from the financial point of view is not involved. Ratio between private and public capital is 1:0.
- *Interesting sites* – for such sites the method of financing PPP – Private Public Partnership is appropriate, because of collaboration between private and public sectors. From the local authority perspective these projects are still very attractive, ratio between private and public capital is 10:1 – 10:3.

- *Less interesting sites* – are usually situated in areas where existing development exists, or are relatively complicated, support from the public sector should be higher. Ratio between private and public sector is 1:1 – 1:5
- *Very problematic sites* – usually sites significantly contaminated, where decontamination and remediation costs are fully supported by the state. Therefore the ratio is 0:1.

CONSTRUCTION ON PHYSICALLY AFFECTED GROUND (MAN-MADE GROUND)

Where disturbed made ground is only physically compromised, then the porosity is usually much higher than for its natural undisturbed equivalent ground composed of sediments or comprising residual soils. Such ground is typically composed of placed or dumped materials, which can comprise natural soils or waste material such as building waste. The main problems are connected with higher porosity – macroporosity between individual clods of deposited material due to the fact that no controlled compaction was applied. Main problems are therefore connected with higher settlement of foundations on such ground.

Physically affected ground can be found in the vicinity of old cities, where raw materials for construction were historically won from local excavation such as stone for stonework masonry, brick clay for bricks, fine sand for mortar etc. But other depressions and voids resulted from war activities such as bombing, shelters etc. All these voids were refilled using various uncontrolled materials. Basic problems of identification exist due to the irregular and sometimes relatively small areas involved, so the foundation can be partly situated on natural ground and partly on made ground, resulting in differential settlement. Different methods of ground improvement have to be adopted.

Variable ground conditions are present in ground where huge amount of material waste are deposited as in the case of spoil heaps comprising tertiary clays overlaying coal seams, because there is not only settlement in active zones under the new foundations but also settlement of the spoil heaps and settlement of the sub soil below the spoil heap. This scenario will be discussed in more detail.

Ground from spoils after open cast mining

The northern part of the Czech Republic is strongly affected by open-cast mining activity. Brown coal from these mines is used in the electric power plants also situated in this area. This has a great environmental impact on this region and poses many geotechnical problems. A typical problem is connected with spoil heaps (tips), which are mostly composed of tertiary clays that overlay the brown coal. The total amount of excavated and back-filled clay material generated per year is roughly 200 $M.m^3$. The total height of spoil heaps is now up to 150 m with an anticipated maximum final height of 300 m. A typical view on the spoil heaps is shown in Figure 4. The utilisation of uncompacted clayey soil heaps for new construction is a necessity in this region. The limit state of total and differential settlement is usually a controlling factor. Similar problems in the UK are described by Charles (2003).

Figure 4. General view on the spoil heaps

The overlaying clays are characterised as overconsolidated soils with a stiff to hard consistency. The clay content ranges from 10 to 40% and the silt content ranges from 20 to 60%. The principal clay minerals are kaolinite and illite. The plasticity index (I_p) is typically ranges between 30 and 60%, with a liquid limit reaching a maximum value of 100%.

Specific behaviour of spoil heaps from tertiary clays

From excavation to deposition in spoil heaps, the clayey material is transported mainly by conveyor belts. Prior to transportation huge clods of material are typically crushed down. During the transportation the individual clods are round-off and during wet weather their moisture content is increased. At the end of transportation the individual clods are partly compacted by free fall (the overburden conveyer bridge it is up to 20 m above ground level). Bulk density is after that approximately 1500 - 1600 kg.m^{-3} and macroporosity is around 30%. The individual macropores between individual clods are interconnected. The character of the fill resembles that of general tipped rockfill (see Figure 5).

Figure 5. Character of clay clods after deposition

Figure 6. Detail of weathered clay clods

The properties of the deposited clay soils change with time due to two basic aspects:

- process of softening of individual clay clods as a result of kneading and moisture content increase,
- process of hardening as a result of surcharging caused by new deposited layers.

Basically the character of the fill material changes from that of a rockfill to that of a plastic saturated clay with many modifications in between. The main aim is therefore to slow down a process of softening because of the detrimental effect on stability and deformation of the spoil heaps.

In the first case it is necessary to consider that unloading, as a result of excavation of the material from a great depth, causes the total stresses to drop to zero. As a result, the closed cracks in fissured overconsolidated soils are opened and the size of the individual clods is decreased due to slaking (see Figure 6). A large suction potential develops due to the negative pore pressure and so the individual clods absorb either free water flowing in the spoil heap (e.g. rain water) or water present in the fabric of the material such as macropores. The material properties can be altered (for limited access of water and large surcharge by new deposited layers) from the variable character of rockfill to a homogeneous material, with closure of macropores and improvement in consistency. Although, when macropores are filled with water, the consistency may be change through plastic consistency to occasionally liquid consistency. In reality various controlling techniques need to be implemented to slow down the process of degradation, generally with the help of following measures:

- To mitigate against the effects of free water, therefore attention is devoted to the drainage of the spoil heap basement.
- Tight control on filling to decrease the number of depressions, where rain water can collect.
- At the end of filling to level the surface and compact it to reduce water infiltration into spoil heap body.

Settlement prognosis

The settlement of spread foundation of new buildings or the settlement of new highways or rail tracks situated on the spoil heaps surface has 3 main components.

$s = s_a + s_s + s_b$

where: s_a is settlement in the active zone under the spread foundation; s_s is settlement of the spoil heap; s_b is settlement of spoil heap basement.

The last component depends on the type of spoil heap. For outer spoil heap founded on natural surface, the settlement is usually significant, as the subsoil is compressible. For the inner spoil heap formed within excavations the subsoil is more competent and so the settlement is much less of an issue. For practical reason the two last components are included into one for the purpose of monitoring the settlement of the spoil heap surface.

To be able to predict the total settlement of the spoil heap or the surface settlement as a function of time there are three basic approaches:

- apply current knowledge and experience,
- geotechnical prediction from large oedometer tests,
- to predict further settlement on the base of knowledge of measured deformation.

Results of the heavy penetration field test may also be used, but the problem exists with a prediction of the time dependent function.

Current experience is based on the surveying of the spoil heap surface. If monitoring commences at the end of filling operation the expected total settlement is between 1(2) - 3% of total height of the spoil mound. For the total height from 40 to 200 m expected total settlement of between 0.4 to 6.0 m will occur. Therefore for new construction some delay is recommended to allow significant part of the total settlement to occur. Recommendation advises that the new construction should only commence after a delay in years determined as a function of the height of the spoil heap in meters. This kind of stringent recommendation is generally unacceptable. It is known that the total settlement after one year reaches 25-50% of the total settlement, after 5 years about 70-75%, and within 10 years about 85-90%. These values based on practical experience are supported by information about bulkage of the placed material. Just after deposition with a macroporosity of about 20-40% the degree of bulkage is between 1.2 – 1.4. At the end of filling due to loading imposed by new deposited layers the average bulkage is significantly lower at around 1.10 – 1.15. After completion of the spoil heap the deformation settlement continues and can be easily monitored, the coefficient of average soil bulkage usually decreases another 2-3% after several tens of years. Therefore the coefficient of final and permanent bulkage of the spoil heap can be within 1.07 – 1.12. The aim, is to decrease this value by limiting of water ingress during the initial phase of filling.

Performance of oedometer tests for determination of the modulus of deformation is a accepted standard procedure. To simulate the behaviour of clay clods, the main problems relate to the size of clods, relatively high vertical loads, and degradation on clod contacts after wetting, etc (Vaníček, 1986). Therefore different size oedometer cells were used up to a diameter of 667 mm with the capability to apply standard dead load of up to 1 MPa and, for higher loads of up to 6 MPa a compression machine was used with the ability to maintain constant pressure for a long period. Improvements also consist of the ability to measure pressure at the upper and lower loading plates (to eliminate skin friction) and with the option to measure pore pressures at the bottom of the oedometer.

The main observations may be summarised as follows:

- For dry clay clods with a high macroporosity the oedometer modulus is very small for low pressures (0.1 - 0.4 MPa) and significantly increases for higher stresses (from roughly 1 MPa to 6 MPa).
- For a low initial test macroporosity the oedometer modulus is high (roughly 30 MPa) and subsequently drops to 6-7 MPa for pressures of 0.6 - 1.0 MPa.

The credibility of utilising the results of oedometer modulus was approved for design along the Ervenice corridor (Dykast et al., 2003; Dykast, 1993). Prognosis derived two years before completion of the corridor in 1981 for settlement along the longitudinal axis of the corridor (length of 3600 m) after 10 years (for 1993) was in good agreement with actual settlement monitored in subsequent years of between 500 – 1500 mm. Ervenice corridor is comprises the largest earth structure, consisting of more than 400 $M.m^3$ of material.

As mentioned previously, the construction on the spoil heaps should be postponed for an appropriate number of years to reduce the total settlement following construction. During this period the measurement of the surface settlement is recommended because from the curve of surface settlement as a function of time we can estimate future settlement.

Different functions of $s_t = f(t)$ were checked, particularly those where settlement drops down logarithmically or exponentially. Currently the following simple equation is recommended:

$$s_t = a + b \cdot \ln t$$

in which a,b are parameters determined from initial measurements.

The accuracy is controlled by the "age" of the spoil heaps and the quality and duration of monitoring. For longer monitoring periods the results are noticeably superior. Usually for a period of around 8 years the prognosis becomes more reliable and accurate because the results are also influenced by different hydrological conditions. Correlation between the rainfall and velocity of deformation were observed.

Recommendation for safer construction on spoil heaps, (Vaníček, 1991):

- Total settlement will be higher than is usually acceptable (which is close to 50 mm),
- The differential settlement which occurs should be eliminated as much possible.

Possible ways to fulfil these criteria are:

- *Soil improvement in the active zone* - this improvement is generally based on a decrease of porosity (macroporosity) - e.g. by compaction or by filling up the macropores with additional material. This improvement not only has a positive impact on the settlement under the foundations in the active zone (where the macroporosity is generally still very high) but also has a positive impact on reduction of the differential settlement of two other components. Traditional compaction of the last few meters using compaction roller is the most appropriate, particularly if reinforcing geosynthetic elements are included within individual layers. But sometimes this approach may prove to be too expensive and time consuming. In certain cases more robust compaction by dynamic consolidation or Menards method has also been attempted. Relatively good results were obtained by applying soil displacement piles, where the column formed by penetration is refilled using similar clay material. Mixing of clay clods with other waste aggregates such as fly ash was also investigated.
- *New arrangement of all engineering infrastructure* – because of high total settlements, the infrastructural arrangement of different networks should be arranged in such a way that this can be partly eliminated, including siting of overhead electric line, flexible connection of water conduit, gas lines, sewage system, etc.
- *Selection of structural systems not so sensitive to differential settlement* – use of flexible construction systems such as wooden skeleton or stiff systems such as reinforced concrete boxes, where the differential settlement has a negligable effect on structural stability but can induce tilt inclination of the building.

CONCLUSION

The paper demonstrates that environmental geotechnics can play a very important role in the utilization of ground for new construction, previously affected by anthropological activity. Two scenarios are presented. The first details the need to collect and review all relevant data in the first phase of brownfield site investigation as part of the desk study supported by visual inspection. The set of 17 different geoenvironmental maps prepared for the whole Czech Republic at 1:50 000 scale has been discussed in detail. This relatively quick and cheap first phase of investigation is a very useful tool for decision-making process on the municipality level when considering problems with brownfields and with utilization of these areas for new construction. The second example describes the situation where the ground comprises physically disturbed materials, where problems of extreme total and differential settlements occur. An extreme case was selected for, an area in the north part of Bohemia, where spoil heaps formed from uncompacted Tertiary clay overburden to brown coal. These spoil heaps are extremely high and therefore generate large settlements. A prognosis of settlement is presented as well as solution for reduction of settlement or on adaptation of appropriate structures to these settlements.

The authors believe that all relevant information can be used to help slow down the existing preference for new development on greenfields.

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