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Risk management in environmental geotechnical modelling

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The objective of this article is to provide an overview of the basis of risk analysis, assessment and management, accompanying problems and principles of risk management when drafting an environmental geotechnical model, enabling the analysis of an entire territory or developed region as a whole. The environmental impact will remain within the limits of the criteria specified with the standards and will be acceptable for human health and environment. An essential part of the solution of the problem is the engineering-geological model based on risk analysis and the assessment and forecast of mutual effects of the processes.

Key words: risk analysis, assessment, management, environmental geotechnics, modelling, dams

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INTRODUCTION

Risks accompany all human activities, and risk management is nowadays widely used in financial activities, agriculture, industry, logistics and other branches of economy.

The results of not accounting for risks are increased responsibility for the administrator of the territory with accompanying insurance payments, unforeseeable pollution charges and often also damage caused by accidents or unpredictable events. In order to manage risk or any other process, it should be first identified, formulated, then assessed, and a solution should be found for risk mitigation. The objective of risk management is control of risks.

The risk management process as a whole includes analysis of risks, assessment of risks and treatment of risks:

1. Risk analysis should determine what is risk.
2. Risk assessment should find the answer to the question whether the risk is acceptable.
3. Risk management should set up activities for risk mitigation.

Risk analysis determines the probability of processes, their possible development scenarios and consequences. It includes determination of undesirable cases, analysis of the probability of occurrence, and provides an assessment the consequences and effects and whether the process is manageable.

Mark Morris et al. (2001) have described why the methods of risk analysis developed for various branches of industry have not been used, e. g., in the case of dams.

It was concluded that the main reasons were:

- inadequate data
- the fact that all dams are unique
- the complex interactions involved in the behaviour of a dam
- unrealistic or meaningless results
- the fact that the risk of dam failure is perceived to be negligible
- concern about the cost of risk assessment
- scepticism
- problems with terminology (risk, hazard, etc.)
- difficulties in understanding or applying the output from any form of risk assessment
- lack of knowledge of risk assessment techniques by the dam community.

The principal conclusions and recommendations from this stage of the project were that:

- The application of risk assessment could help to improve reservoir safety in the UK and it should therefore be welcomed.
- A relatively simple and easily understood risk assessment methodology would be which is cheap to implement would be preferred.
- Full probabilistic risk assessments using fault trees, etc. were not needed, although a simplified approach may be appropriate in some cases.
- Hazard indexing would be useful in identifying the potential consequences of failure and in the classification of reservoirs.

Two radical behaviours or paradigms can be detected: an extreme confidence in dam safety, because all aspects were considered during the project (a typical specialist position) or because there is a blind faith in technological power (a typical position of a believer in absolute engineering efficacy), and a strong suspicion and fear of the uncertain consequences of a new technological environment or constraint (Betâmio de Almeida, 2001).

RISK ASSESSMENT

The objective of risk assessment is to provide an answer to the question whether or not the consequence resulting from realisation of the risk exceeds the tolerance limit of the environment. This can be assessed employing criteria and standards required by legislation, risk levels accepted by the public, and limit values established in specific conditions. A comparison may be made between the FN curve derived for the UK Dams between 1831 and 1930 and the FN curve produced in the ACDS (Advisory Committee on Dangerous Substances) report for the total national societal risk from handling dangerous substances in all UK ports, or the national societal en-route risks for transport of dangerous substances by road and rail (Fig. 1).

The data for ports, road and rail have been synthesized from representative accident scenarios, assuming dangerous goods transport rates and traffic data from the mid-1980s: they do not therefore represent historical cumulative accident data in the same way as for the dams. The ACDS data do not have a time span: they are a snapshot in time at the date of publication (1991).

An essential part of risk assessment and management is feedback – establishing a monitoring network and supervision of the processes, making the necessary corrections possible in addition to the control of the situation.

In Estonia, such monitoring is in most cases the obligation of the entrepreneur whose activities involve essential risks. Additional public monitoring has been organised in territories with a risk of accompanying cross-border effects or interference with public interests, e. g., Sillamäe WD, Port of Muuga, Narva power stations.

RISK MANAGEMENT

In risk management, risk factors are specified according to the priorities. Measures are developed for their elimination or mitigation. This requires mapping of the resources needed for risk management and determination of the level at which each risk should be managed (institution, city, or state). If there is a lack of resources, the risk cannot be managed.

On reviewing and scoring all appropriate elements for a site, the next stage is to prioritise these elements so that the risk they pose may be considered in detail. Prioritisation is undertaken through a twin approach: to consider the product of *Consequence* × *Likelihood* and also the value of *Confidence* alone. The *Confidence* value may be related to the need for investigative works while the product of *Consequence* × *Likelihood* may be related to remedial works. All of the elements scored are therefore prioritised through the following steps:

1. Initial ranking of all elements according to their *Criticality* score.

2. Rank elements, primarily according to their *Consequence* × *Likelihood* product

and secondly by their *Criticality* score.

3. Rank elements, primarily according to their *Confidence* score and secondly by their *Criticality* score.

This then identifies the high-risk elements according to their potential need for remedial works and also the need for investigative works. Combining their criticality score with the impact score also allows for a comparison of these elements against the risks posed by elements at other sites.

On prioritising and identifying the key risk elements it is then essential that the assessor reviews the scoring and justification behind each high risk element to ensure that the risk assessment is justified. Only by reviewing the score justification tables and understanding the nature of the risk posed will the assessor be in a position to manage those risks through appropriate measures (Betâmio de Almeida A., 2001).

RISK MANAGEMENT PRINCIPLES UPON DRAFTING AN ENVIRONMENTAL GEOTECHNICAL MODEL

Risk management principles can be used when drafting an environmental geotechnical model, as they enable to assess the interaction of various natural and technological processes, prioritise objectives and start developing solutions of the most essential problems in the first stage.

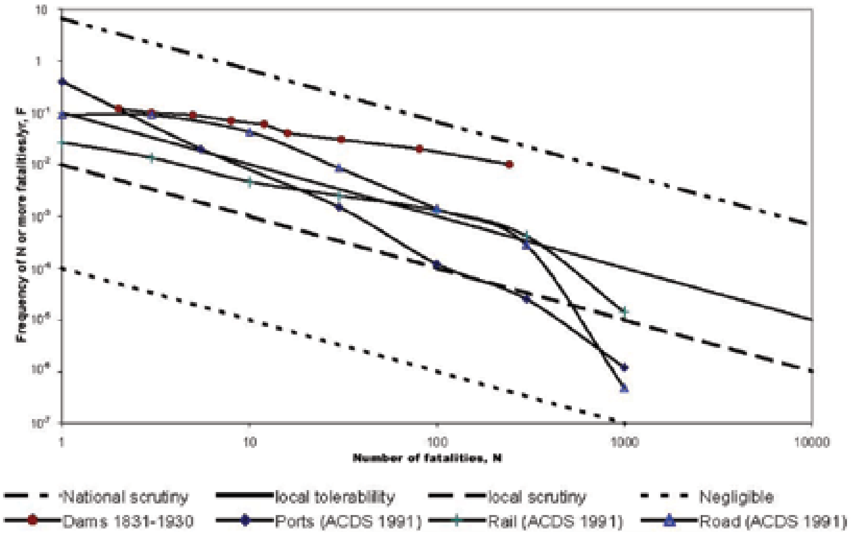

Fig. 1. Historical FN Curve for UK Dams (1831–1930) compared with ACDS National Risk from ports, road and rail transport of dangerous substances (Mark Morris et al., 2001)

1 pav. Didžiosios Britanijos (1831–1930) istorinių užtvankų nelaimių skaičiaus ir uostų, kelių bei geležinkelių transporto pavojaus kreivių palygimas (Mark Morris et al., 2001)

For example, researches and forecasts (Tammemäe, Torn, 2006) confirm that the geo-ecological and engineering-geological conditions of developed lands are often complicated. There are many questions that have not yet been solved. The main obstruction to the solution of these questions is not the lack of fiscal resources, but the lack of the general environmental geotechnical concept and model. Such concept is lacking, for example, for the planning of most of cultivated land in the world (Torn, 2003; Tammemäe, Torn, 2006).

The objectives and content of planned research are specified according to the development of the further use of the land, results of investigations of engineering-geological conditions, monitoring of processes and risk analysis of the area. The principle of research methodology shall be treatment of the territory as one geomorphological entity.

For example, analysis of geodynamic processes of the Sillamäe waste depository (WD) (Torn, 2003) showed that the stability of the waste depository in the future will depend on three main factors:

1. Erosion due to coastal processes and the resulting decrease of counterweight, causing changes in the balance condition of the soil massive.
2. Changes in bedding conditions and physical-mechanical qualities of soils due to geodynamic processes. A decrease of the strength of Cambrian clay under the dam with time facilitates development of creep processes; water infiltrating through the waste depository penetrates the micro-fractured clay massive.
3. The hydrodynamic regimen, whose change can increase or decrease the hydrodynamic force influencing the general strength situation. Due to hydrogeological constructon, groundwater moves through the pebble layer located under the WD from the clint terrace towards the sea.

At the same time, changes of water level due to storms should not be underestimated, which in the case of Western winds in the Narva Bay can raise the water level up to 150 cm over the long-term average (increasing erosion hazard for the coast) and in the case of permanent Eastern winds can in turn lower the water 110 cm below the Kronstadt zero level (decreasing the mass of the counterweight body of the WD slope, thus also the stability factor of the slope).

Taking account of the described processes, upon planning countermeasures and cleanup of the WD, the objective was to increase the counterweight of the dam of the WD, ensure the developed hydrodynamic regimen and stop coastal erosion.

Drafting the concept of the engineering-geological model at Sillamäe is especially necessary, as one of the most essential pollution sources of the Baltic Sea in the region is located on the territory and active human activities are foreseen in the future in its immediate vicinity. This requires definition of the objective, starting point and criteria.

PRINCIPLES OF THE CONCEPT OF ENVIRONMENTAL GEOTECHNICAL MODEL BASED ON MUTUAL EFFECT OF PROCESSES

The objective of the concept is first and foremost the formulation of problematic issues from the standpoint of the technical and future development of the area. It is the model through which problems and hazards are communicated from one side, while from the other side it provides solutions for control of risks and use of the area in the future in such a way that the environmental impact would be acceptable, proceeding from the established standards and standpoints of the public opinion. Furthermore, it should guide the developer of the area while finding optimal solutions (risk–price–result) and lead to long-term sustainable decisions.

In reality it means for the developer or investor a decrease of responsibility, environmental impact and pollution charges and creation of favourable conditions for bringing potential investments into the area.

If the objective is environmentally sustainable development of a whole area in a longer perspective, the starting point should be engineering-geological and environmental geotechnical conditions of the whole territory and the influencing factors.

SAMPLE TABLE OF CRITERIA AND RATES

Taking account of the specificity of the area, the concept of engineering-geological model of the Sillamäe industrial area is proceeding from the waste depository, related environmental impacts and problems. In all projects planned in the future, account shall be taken of the factors proceeding from the WD and having a negative effect on it. The concept of the engineering-geological model and mutual effects are shown in Fig. 2. Every impact is followed by a reaction or process whose final result is the effect on human beings and the environment.

In Fig. 2, the arrows show the effects that should be the basis for risk assessment:

1. Effects proceeding from the target object and accompanying risks.
2. Risks for the object, caused by interaction of the target object and the developed area.
3. Risks for the area caused by interaction of developed area and the target object.
4. Risks for the target object and change of environmental geotechnical conditions of this object in time, caused by environmental geotechnical conditions.
5. Risks for the developed area, caused by overall engineering-geological and environmental conditions.

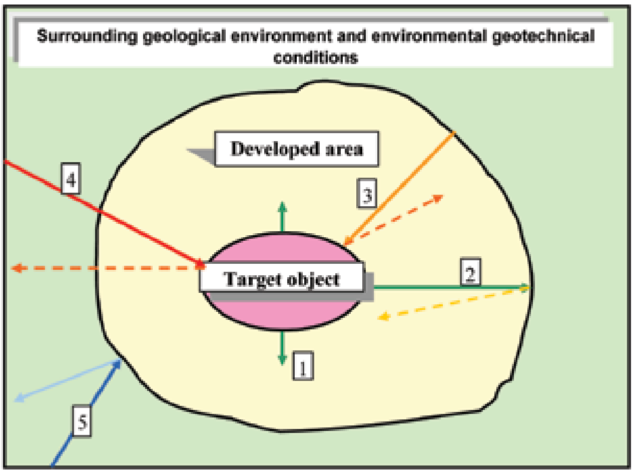

Fig. 2. Concept of the environmental geotechnical model
2 pav. Aplinkos geotechninio modelio koncepcija

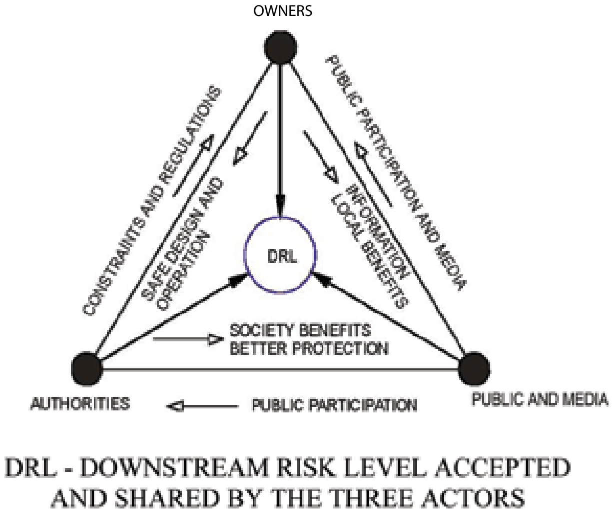

Fig. 3. Dam risk sharing among dam owners, public and authorities
3 pav. Užtvankos rizikos priklausomybė nuo jos savininko, visuomenės ir valdžios

On the example of the Sillamäe waste depository in North East Estonia, a shared risk responsibility (Fig. 3) can be developed between dam owners, safety authorities and the public due to a better consideration and as an open analysis and characterization of the dam benefits and risks as well as a mitigation or control action to protect the area according to an accepted societal risk level (e. g., the integrated and shared risk management can be a positive way to consider the problem of balancing these competing needs).

Assessment of interaction of various risks enables analysis of the so-called cumulative effect. This is the total risk formed by a simultaneous occurrence of various single effects.

CONCLUSIONS

The problem of human impacts on the surrounding environment in the context of further intensive use of areas has not been solved in the whole world. An essential part of the solution of the problem is an engineering-geological model based on risk analysis and assessment and forecast of mutual effects of the processes. The impact of developed areas on the surrounding environment always causes countereffects of the environment. If we can forecast and manage the processes, the environmental impact will remain within the limits of the criteria specified with the standards and will be acceptable for human health and environment.

Monitoring shall provide sufficient details about the existence of natural processes, the interaction of natural and man-made environments. This will enable in the future to assess the correctness of current forecasts and manage the processes towards control of risks.

The importance of communication should not be underestimated upon assessment of risks. It is a complicated theme where mutual understanding of different groups of interest – legislators, representatives of local power, the public and various specialists – is important.

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PAVOJAUS ĮVERTINIMAS IR GEOTECHNINIS APLINKOS MODELIAVIMAS

Santrauka

Remiantis aplinkos sąlygų geotechniniu modeliavimu ir nagrinėjant tiriamas teritorijas ir besivystančius regionus kaip vientisą sistemą, straipsnyje pateikiami pavojaus analizės pagrindai ir numatomos prevencinės priemonės jam išvengti. Pavojus lydi visą žmonių veiklą, tačiau finansiniu požiūriu ypač svarbu išvengti rizikos žemės ūkyje, transporte ir kitose ekonomikos srityse. Neatsižvelgus į galimą pavojų didėja už juos atsakingų asmenų atsakomybė, išauga draudimo išlaidos, kyla užterštumo ir katastrofinių pasekmių grėsmė.

Atliekant aplinkos geotechninį modeliavimą, minėti principai padeda įvertinti įvairių gamtinių ir technogeninių veiksnių sąveikos rezultatus, numatyti pagrindinius tikslus ir pasirinkti tinkamus svarbiausių problemų sprendimus. Dažnai nagrinėjamuose plotuose geoekologinės ir inžinerinės geologinės sąlygos yra sudėtingos, todėl lieka daug neišspręstų klausimų. Pagrindinė priežastis yra ne finansinių resursų trūkumas, bet geotechninių koncepcijų ir modelių, kurie įvertintų tiriamąjį rajoną kaip geomorfologinį vientisą objektą, nebuvimas. Kelių negatyvių veiksnių sąveikos įvertinimas leidžia prognozuoti bendrą kylantį pavojų.

Inžineriniai geologiniai stebėjimai ir priežiūra sukaupia būtiną informaciją apie esamus gamtinius procesus ir gamtinės bei technogeninės aplinkos sąveiką. Gauti rezultatai padeda įvertinti priimtų sprendimų efektyvumą ir esant būtinybei pakoreguoti mūsų veiksmus mažinant pavojaus galimybę.

Олави Таммемяэ, Харди Торн

УПРАВЛЕНИЕ РИСКАМИ ПРИ ГЕОТЕХНИЧЕСКОМ МОДЕЛИРОВАНИИ ОКРУЖАЮЩЕЙ СРЕДЫ

Резюме

Рассматриваются основы анализа, оценки и управления рисками при создании геотехнических моделей окружающей среды, которые позволяют исследовать территории или развивающиеся регионы как одну целостную систему. Риски сопровождают деятельность человека во всех отраслях, и управление рисками в настоящее время широко используется в финансовых, сельскохозяйственных, транспортных и других отраслях экономики.

Пренебрежение рисками сопровождается повышением ответственности управляющего территориями, повышенными страховыми взносами, непредвиденной нагрузкой загрязнения и, часто, разрушениями в результате непредсказуемых чрезвычайных происшествий. Чтобы управлять рисками, их, как и любые другие процессы, в первую очередь следует идентифицировать, сформулировать, оценить, затем – разработать меры решения, направленные на понижение опасности. Целью управления рисками является их контроль. Процесс управления рисками в целом включает в себя анализ риска, его оценку и непосредственно управление:

1. Анализ риска покажет, в чем состоит риск;

2. Оценка риска должна показать, является ли данный риск акцептируемым;

3. В ходе управления риском разрабатываются действия и мероприятия по его понижению до акцептируемого уровня.

Принципами управления риском можно пользоваться при геотехническом моделировании окружающей среды, поскольку методика позволяет оценить результаты взаимодействия различных природных и техногенных процессов, определить приоритетные цели и в первую очередь начинать разработку решений для самых важных проблем. Часто геоэкологические и инженерно-геологические условия в пределах разрабатываемых территорий сложны и многие вопросы не решены. Главной причиной при этом является не отсутствие финансовых ресурсов, а отсутствие геотехнической концепции и модели, которая позволила бы рассматривать исследуемый район как единое геоморфологическое целое. Оценка взаимодействия рисков позволяет анализировать кумулятивный риск, т. е. риск происшествия, которое может произойти при совпадении нескольких негативных факторов.

Инженерно-геологические наблюдения и мониторинг дают необходимую информацию о существующих природных процессах, о взаимодействии природной и техногенной среды. Результаты мониторинга позволяют оценить эффективность принятых решений, при необходимости корректировать действия и контролировать риски.