The influence of engineering-geological conditions on construction of the radioactive waste dump

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ABSTRACT: Secure stability and reliable serviceability of radioactive dump is a difficult engineering problem. Due to difficult geological formations determined mainly by great compressibility, low shear strength of soils, and high groundwater level, or great upward hydrostatic pressure will these demands increase. Influence of required reliability and lifespan on the structure of these specific objects is considerable. We are trying to contribute to a problem solving of these difficult and complicated problems in submitted contribution.

1 INSTRUCTION

The Republic Radioactive Waste Dump (RRWD) located about 2 km from the area of the Mochovce Nuclear Plant in south-western Slovakia, Central Europe, was built to store waste with low and medium activity arising from operation and disposal of nuclear power facilities as well as from research institutes, laboratories, hospitals and other institutions engaged in activities generating nuclear waste. Ensuring stability and reliable operation of RRWD in Mochovce is a challenging engineering task. The dump is built in demanding engineering-geological conditions determined in particular by high compressibility, low shearing strength of soil and high underground water level and/or high lifting forces exerted in the basement. Also required reliability and lifetime have a significant influence on layout of these specific structures. This paper discusses a solution for this complex engineering task.

The topic of how to secure a reliable storage of final processed low and medium radioactive waste in the long term is a complex interdisciplinary issue. The time aspect is a significant factor affecting a complex approach to this problem and specific periods of active operation and planned lifetime of the repository must be taken into account. The repository is built in fairly difficult geological and hydro-geological conditions. It consists of a complex of buildings and technological facilities. In the first construction stage, two double lines of storage boxes with the total surface area of approx. 112,000 m² were built. The general situation around the dump and its adjacent territory is shown on Figure 1. Section of the RRWD is shown on Figure 2.

Such large structural work challenging in terms of operational safety will have a significant impact on the surrounding natural environment during its lifetime. Extensive construction activities, active operation of the repository and the final coverage will have a significant influence on a change in the balanced state.
of the rock environment. This change in the balanced state will cause deformation symptoms at the affected territory with a number of structural buildings and functional (technological) units. Knowing the extent of the modified basement and construction at the territory concerned will be decisive to determine stability of the territory and functionality of the already built or planned drainage systems, engineering and technological distribution lines. This paper will discuss in detail the issue of repository reliability in terms of assessing the basement according to requirements of group I and II limit states, i.e. according to safety and usability of the structural work. A set of geotechnical issues is related to the draft construction project of the final repository coverage with its primary function to prevent water infiltration to premises housing the storage boxes after the active operation of the structural work until its lifetime.

2 MORPHOLOGICAL, GEOLOGICAL AND HYDROGEOLOGICAL CONDITIONS AT THE REPUBLIC DUMP

Republic Radioactive Waste Dump is located in southwestern Slovakia, Central Europe. The terrain is slightly folded with an unstable superficial water river. The basement is made of sandy limestone clay with spots of dusty fine-grain sand and clay silt. These spots form lenses separated from each other. Sediments of Ivanian strata (lower Panonium) with thickness of 11.5–23.0 m were identified at the northern part of the repository. They are represented by sandy clay with thin spots of dusty sands and isolated lenses of gravel sands. Quaternary deposits are represented primarily by deluvial rain-wash sand clay with thickness up to 3.0 to 4.0 m. The basement directly under the first double-line of boxes is made of residual quaternary deposits (clays), especially in the middle of the box structure and under the bottom doubleline. Panonian deposits (clays, sands) are found underneath.

Hydrogeological conditions in the RRWD basement and in its direct vicinity are one of the crucial factors with regard to operational safety of the dump. It can be said that the hydrogeological conditions at the site are fairly complicated due to the complex nature of the geological environment with flows of underground water. Surveys had done show existence of several continuous water-saturated aquifers of underground water. The highest main aquifer (H) is an aquifer with a free water level, fairly sensitive to precipitation. Other two aquifers are more permeable, hydraulically fairly isolated sandy spots in deeper zones of the Sarmatian basement. The underground water has lifting characteristics and its piezometric level reaches 1.0 to 2.0 m above the free level of the H aquifer. The original hydrogeological conditions were significantly modified by constructional activities. In terms of assessing the foundation conditions, the engineering-geological and hydrogeological conditions at the area of interest can be assessed as difficult.

3 CONSTRUCTIONAL AND TECHNICAL CHARACTERISTICS OF THE REPOSITORY

At present, the Republic Radioactive Waste Dump consists of two double-lines of storage boxes made from reinforced concrete. Four boxes are grouped into one dilatation block with layout dimensions of 18.6 × 6.0 m and height of 5.5 m, placed on a common foundation slab 0.6 m thick. There are five dilatation blocks in one line. An expansion gap between the blocks is planned to be 50.0 mm thick. The storage boxes are covered by 0.5 m thick panels from reinforced concrete. A system of two drainages (control drainage and monitored drainage) is built at the bottom of the storage boxes and under the foundation. The main goal of the dump drainage system is to ensure inspection and safe removal of potential leaks of underground and surface water contaminated by radioactive substances from the inner space of the storage boxes into the basement and/or from the basement into the storage boxes. Side walls and the bottom of the monolithic storage boxes from reinforced concrete are protected by a layer of clayish soil. A 1.0 m thick layer of compacted clayish soil is located under the tanks to ensure waterproof basement for the storage boxes. Placed on this layer is a 0.6 m thick layer of sandy gravel. Side walls are protected by a 3.5 m thick vertical clay sealing linked with a horizontal sealing soil layer, forming a compact unit – the so-called clay sealing tub. The double-lines are protected against climatic effects by a mobile steel hall when the storage boxes are filled with waste. Considering the general reliability of RRWD, the structures of the storage boxes are the most important and decisive building structures. At the same time, these structures will face the highest demands due to effects of forces, deformation and radiation. A typical cross and longitudinal section of the 1st and 2nd double-line is shown on Figure 3 and Figure 4.
4 ASSESSING STABILITY IN RRWD
ACCORDING TO LIMIT STATES

In order to make a general assessment of RRWD safety and usability, it is necessary to examine a set of geotechnical issues predetermined by the challenging nature of building structures at the dump and by complex engineering-geological conditions. In terms of compliance with requirements according to group I and II of limit states, solutions for the problems can be divided into two main sets as follows:

- Stability calculations to assess overall stability of RRWD and the adjacent rock environment affected by the construction in specific stages of construction, operation and expected lifetime of the repository, including basement for the storage boxes.
- Deformation calculations to assess final and uneven settlement of decisive building structures of the dump, taking into account specific stages of construction, operation and expected lifetime of the dump.

To solve the first set of problems related to security and operative capacity of RRWD in Mochovce in every construction stage and after the construction, it was necessary to make a series of stability calculations to determine:

- Stability of the 1st and 2nd double-line,
- Stability of adjacent slopes,
- Bearing capacity of reinforced concrete boxes.

The second set of problems deals with how to ensure usability and smooth operation of the building structures and technological units at the dump in terms of size of the final and uneven settlement of the storage boxes. A requirement to assess horizontal shifts of storage box walls at places of expansion gaps, planned to be 50.0 mm wide, stems out from the structural-technical solution of decisive bearing structures, including bearing walls of the storage boxes. Considering the height of storage box walls, even a small uneven settlement or inclination of tough reinforced concrete structures of the storage boxes can cause their damage, resulting in a loss of their planned function. The extent of settlement and uneven settlement of the repository basement must be known to assess also function of the drainage and sealing systems located in revision and inspection shafts. In case of drainage systems, this involves especially the required gradient needed for a gravitational drainage of leaked water. The structural design of the dump shows a concentrated intensity of load in the geometric centre of the double-lines with storage boxes, so the method and system of placing fiber-concrete containers into the storage boxes of the dump is very important.

The effects of uneven settlement of the basement result in formation of local depressions in the drainage system, so their thickness must follow the extent of the uneven settlement of the basement to ensure the required gradient for gravitational water drainage in the long term. Occurrence of local depressions would result in higher and permanent hydraulic load of specific sealing layers in the dump, affecting physical properties of the soil in the sealing layer, in particular the state of consistency and then strength and deformation properties. Such changes would result in higher permeability of the sealing tub, higher compressibility and lower bearing capacity of the RRWD subsoil. Localization of maximum tensions and deformations given by effects of external and deforming load can indicate potential defect areas that must be taken into account in the design of structures of specific layers for the final coverage.

The most demanding and the most important task in the process of addressing these problems is to transform actual material properties of the natural rock to an idealized calculation model that must realistically depict the actual behavior of the assessed structures. It is therefore necessary to pay proper attention to this task. This issue is complicated even more by significant non-homogeneity of the natural rock environment, but primarily by the fact that material properties of fine-grain soil in the subsoil are very variable in time and tension. It is very difficult to define complex constitutional relationships in calculation models that would truly describe the actual processes in the soil massif resulting from effects of the load. This task can be simplified to a certain degree by a reasonable idealization (simplification) of actual soil properties, respecting the inevitable requirement to preserve the physical essence. It is therefore necessary to determine physical, strength and deforming properties of the basement soil and of the soil incorporated in the sealing tub based on standard laboratory test on integral and undamaged samples in accordance with applicable standards.

To define calculation models and limit conditions of specific tasks, it is necessary to define the following input data:

- Spatial arrangement and geometrical shape of building structures and construction at the area concerned;
- Extent and distribution of permanent, incidental, extraordinary loads and their combinations;
– Physical, strength and deforming properties of artificial building materials (concrete and reinforced-concrete structures);
– Physical, strength and deforming properties of the natural rock environment at the area of concern and of the soil incorporated in RRWD.

In order to assess general reliability of the dump, it is not permissible to exceed any limit state and to allow deformation of any structural unit during the whole period of active operation of the repository (organization of filling the storage boxes by fiber-concrete containers) and during the period of the planned and/or actual lifetime of the dump once it is finally covered. Specific calculations must therefore depict all the crucial load states that occur or might occur in the future. The extent of load on specific building structures and subsoil in RRWD and effects of the load on the environment is a very variable quantity in terms of time. It will depend mostly on the construction process applied for the main dump building structures, schedule of organized filling of the storage boxes by fiber-concrete containers during active operation of the dump and constructional stage of the final dump coverage. The intensiveness of load will therefore depend on a progressive increase in permanent, long-term and short-term, incidental and extraordinary load and their combinations.

Mathematical modeling using the method of finite elements was used to calculate tensions and deformations in the RRWD subsoil. The spatial model for the model calculations was developed according to assumptions of the linearly elastic half-space theory (Figure 5).

Basic parameters of the geotechnical model arise from an engineering-geological survey and structural design of the dump. Geotechnical calculations define four load states (LS) describing the following crucial stages of dump construction and operation:

– LS 1 – Load on the subsoil due to own weight of the reinforced-concrete storage boxes,
– LS 2 – Load after filling the 1st double line with waste containers,
– LS 3 – Load after filling the 2nd double line with waste containers,
– LS 4 – Load after closing the 1st and 2nd double lines and the final coverage of the dump.

Resultant settlement (vertical displacement) of the subsoil under the storage boxes calculated for the Load State 2 is shown on Figure 6.

The factor of time is very important to address these problems, because the expected lifetime for RRWD was determined by the Slovak Nuclear Supervision Office to be 300 years based on the period of the institutional inspection of the dump. Consolidation processes in the dump basement and progressive redistribution of forces occurring in dependence on the rate of loading the foundation gap (filling the storage boxes by containers) are closely related to the time factor. Calculations on forecasts make it possible to design a suitable method of container placement, with favorable effects on the overall average settlement and uneven deformations that will have been developed depending on time in couples of decades. Stability of the Republic Radioactive Waste dump must be ensured with required reliability during the whole term of its lifetime.

5 CONCLUSION

Construction of specific buildings intended to store low and medium radioactive waste is an extremely
challenging task for engineers. Given the demands and required reliability of storing radioactive waste in RRWD Mochovce, the issue must be discussed in its complexity. The time aspect is a significant factor affecting a complex approach to this problem and specific periods of active operation and planned lifetime of the dump must be taken into account. To formulate specific geotechnical problems, it is necessary to focus primarily on assessment of structural works in terms of safety and usability of building structures and technological units. Much emphasis should be given on definitions of limit conditions for specific tasks with focus on their variability in time. A correct definition of interactions between the subsoil and the building structure to ensure the required level of environmental protection is an essential requirement to address such a complex interdisciplinary issue.

ACKNOWLEDGEMENT

This paper was developed in terms of a grant task of the Slovak Republic Ministry of Education No 1/2135/05.

REFERENCES