Pumped HYDROelectric Storage in post MINEd areas to support regional net-zero emission energy systems development – HYDROMINE

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D 2.2. Results of geotechnical modelling of reservoir slopes

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Partners:

TUC, WUST, VUHU

D.2.2. Results of geotechnical modelling of reservoir slopes

The geometric and geological models were created based on an initial dataset. The available data and the steps taken to model the KOSD (Poland), ČSA (Czech Republic) and Pesteana Sud (Romania) quarries are presented below.

1. KOSD

The KOSD Rutki–Ligota Basalt Quarry (Kopalnia Bazaltu Rutki–Ligota) is an active open-pit mining operation located in Ligota Tułowicka, near Tułowice, in the Opole Voivodeship of southwestern Poland. Operated by Kruszywa Opolskie Spółka Akcyjna (KOSD Niemodlin), the quarry is an important source of regional volcanic rock resources (figure 1).

Figure 1 Location of mine perimeter

The deposit forms part of the Cenozoic volcanic formations of Lower Silesia. Geologically, it comprises a basanite lava flow approximately 1 km in diameter and around 26 m thick. The quarry exposes a distinctive basalt weathering crust. Studies have identified several secondary mineral alteration processes, including

serpentinization, iddingsitization, uralitization, and carbonatization, which have modified parts of the original rock and resulted in the formation of secondary minerals, including amphiboles and iron hydroxides.

The quarry is a regional supplier of aggregates for construction and infrastructure applications. It holds Factory Production Control (FPC; Zakładowa Kontrola Produkcji, ZKP) certification and has a Type III Environmental Product Declaration (EPD). Its product range includes basalt grit, unsorted aggregates, fine aggregate mixtures, ballast, and crushed stone. The 2/8 mm and 8/16 mm aggregate fractions are intended for applications requiring compliance with relevant infrastructure specifications established by Poland's General Directorate for National Roads and Motorways (GDDKiA). These products are suitable for various road construction and concrete applications. Owing to its mineralogical and chemical characteristics, the extracted rock may also be suitable as a raw material for mineral wool production.

The 3D geological model was imported directly into PLAXIS 3D Advanced on the basis of the detailed models in the proper format sent by partners from WUST (figure 2).

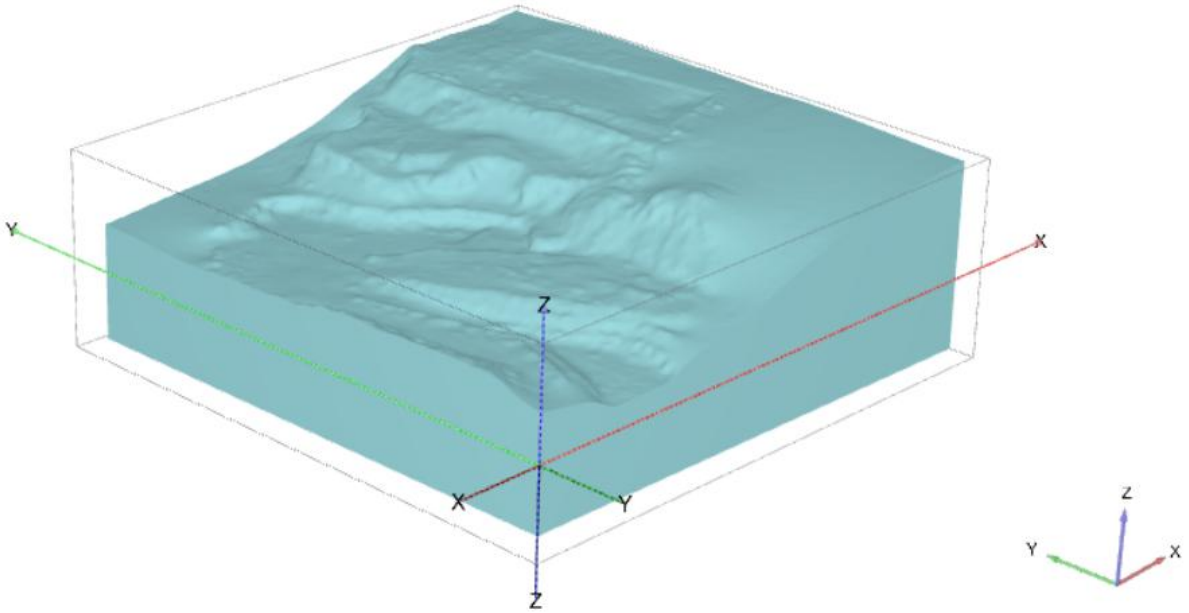

Figure 2 Three-Dimensional Geological Geometry (PLAXIS 3D Model)

2. ČSA – open pit

The ČSA Mine is located at the junction of the Most Basin and the adjacent slopes of the Ore Mountains. The regional and local geological and geographical characteristics of the area have been described in great detail in earlier reports and studies. The ČSA Mine, situated in the central part of the Most Basin (Figure 1), has been mining coal since 1901 (figure 3).

Figure 3 Location of the ČSA residual pit within the administrative boundaries of the Czech Republic

From the beginning, coal mining here has been carried out under complex engineering and geological conditions at the southeastern foot of the Ore Mountains. Overburden removal operations ended in 2016 (though rehabilitation overburden extraction in the Eliška III area continued until 2019), and complete cessation of operations at the ČSA Mine is expected in 2025. The final position and morphology of the final slopes of the ČSA Mine are fundamentally influenced by the Binding Line according to Czech Government Resolution No. 444 of October 30, 1991, which defines the territorial ecological mining limits in the Most Basin. In the assessed area and its surroundings, the upper edge of the ČSA Mine follows this line, the northern slopes of the mine thus form the SKPJ pillar (Cultural Monuments Complex of Jezeří),

which, apart from the Binding Line, is delineated by a Heritage Protection Zone established by the District Authority in Most on July 11, 1991. The crown of this zone contains remnants of the original castle arboretum. The Černice village protection pillar, defined by the decision of the District Mining Authority in Most on November 23, 1993 (referred to as the Černice Pillar), forms the northern to northeastern slopes (slopes with southern to south-southwestern exposure) of the active ČSA open-pit mine.

Towards the east, the slopes of the ČSA Mine transition into the residual pit of the former Obránci míru (Defenders of Peace) Mine, which is filled with a southwest-sloping spoil heap (with a total volume of over 600 million m³) gradually built between 1922 and 2004 (Pichler et al. 2019).

The area of the southern slopes, from the foot of the OreMountains to the Ervěnice Corridor, is made up of a large fan-shaped inner spoil heap of the ČSA Mine (figure 4).

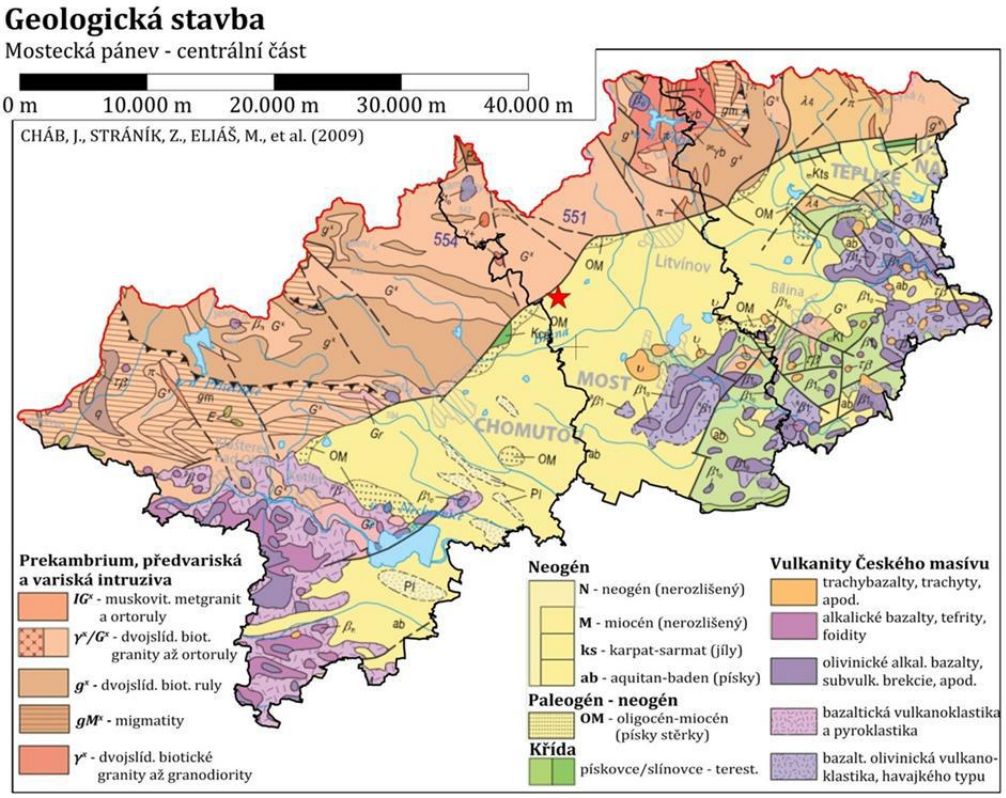

Figure 4 Basic geological structure of the central part of the Most Basin and the broader surroundings of the Chomutov, Most, and Teplice districts (the area of interest is marked with a red star)

Based on a point cloud provided by the Czech partners, the current terrain surface was modeled, and the alignments along which the profiles were generated were marked out.

The calculation profiles were defined based on the reconstructed terrain surface and the spatial configuration of the ČSA residual pit. Figure 5 presents the layout of the calculation profiles superimposed on the terrain model, illustrating their positions and orientations relative to the residual pit and the surrounding slopes. The profiles were selected to cover relevant areas of the site and to support the subsequent evaluation of slope stability under different geotechnical and hydrogeological conditions.

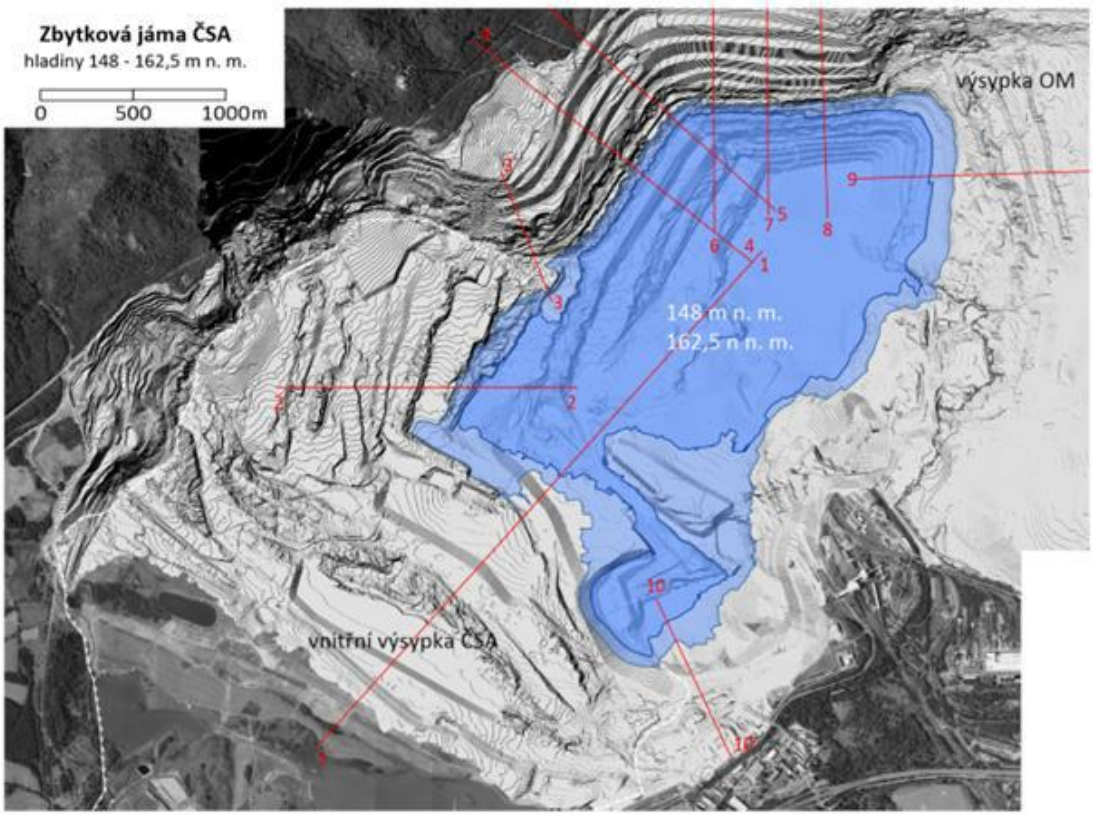

Figure 5. Layout of Calculation Profiles on the ČSA Residual Pit Terrain Model

Figure 6 shows the layout of the calculation profiles within the SURPAC model. The three-dimensional terrain representation provides additional information on the spatial distribution of the profiles in relation to the modeled topography. This model was used as a geometric reference for defining the cross-sections required for the stability calculations.

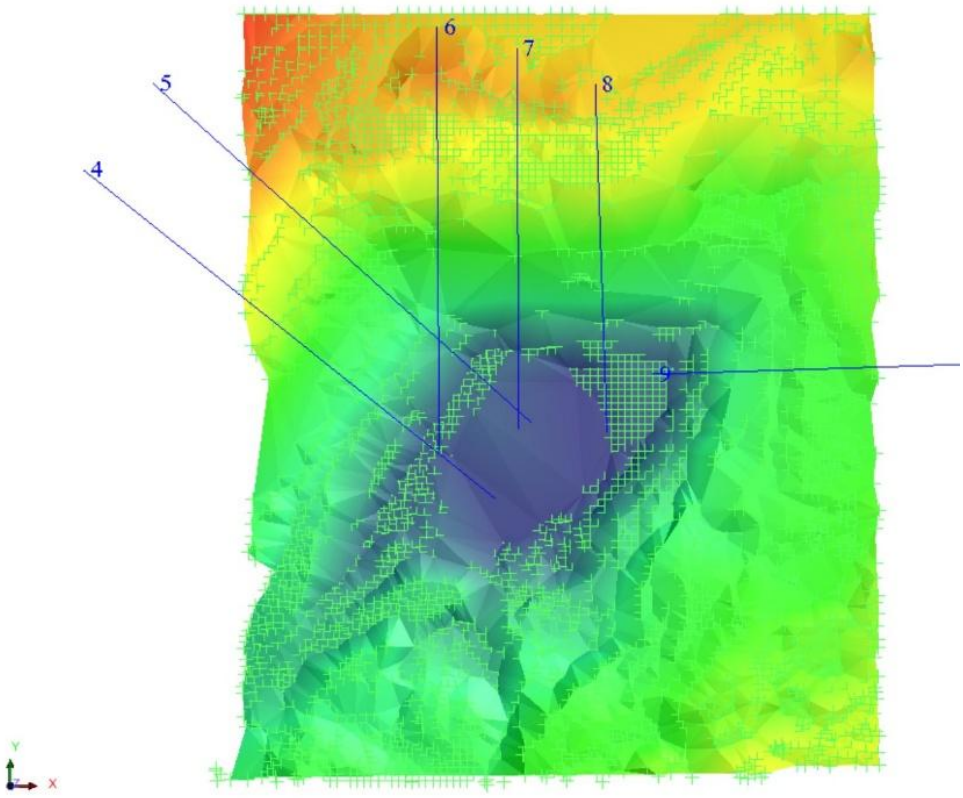

Figure 6 Layout of Calculation Profiles in the SURPAC Model

For each of the selected profiles, the stratigraphic sequence was defined, and virtual boreholes were created to represent the distribution of the geological layers along the respective cross-sections. These boreholes were subsequently positioned using real-world coordinates to ensure their correct spatial alignment with the terrain model. Based on this information, a geological model was constructed to represent the subsurface conditions along each profile. The modeling workflow is illustrated using Profile 4 as an example (figure 7).

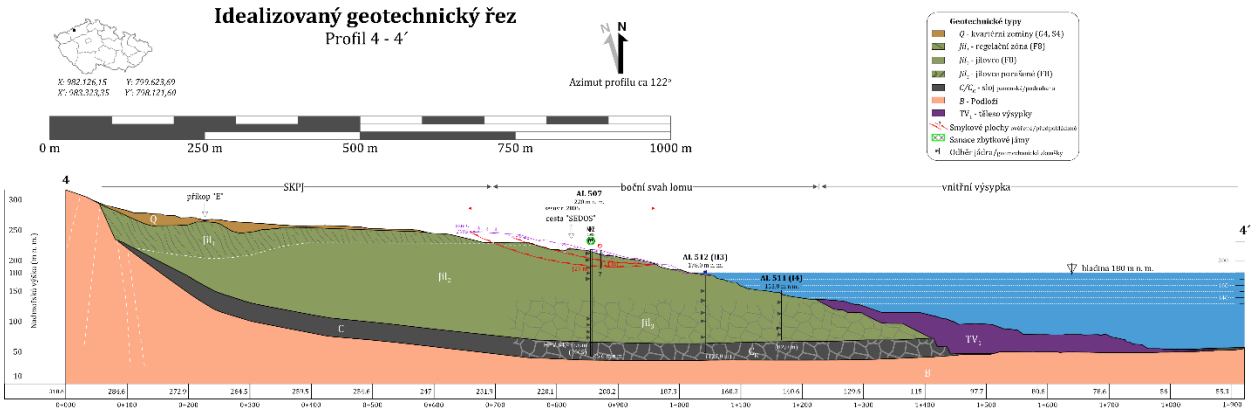

Figure 7 Geotechnical Cross-Section Profile 4

The geological cross-section illustrates the interpreted stratigraphic structure along profile 4, including the distribution and geometry of the main geological units. The section incorporates the existing terrain surface, the underlying geological formations, and the materials associated with the ČSA residual pit and the surrounding waste dumps. This interpretation provides the geological basis for defining the material boundaries and geotechnical units required for the subsequent numerical modeling (figure 8).

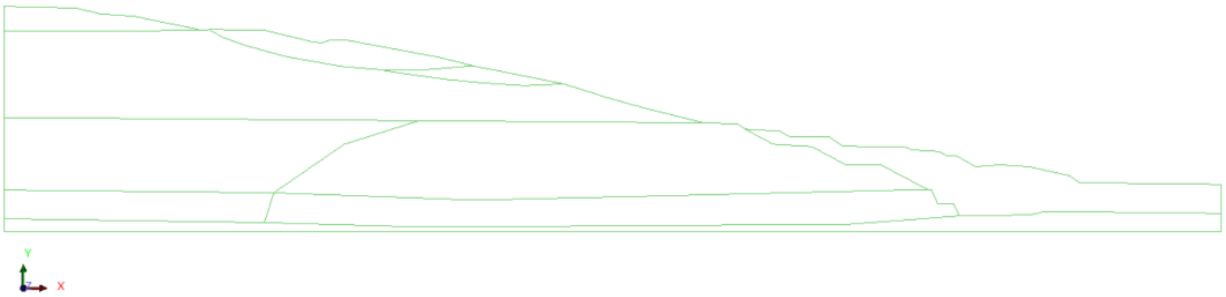

Figure 8. Simplified Geological Cross-Section of Profile 4

The geological interpretation was subsequently converted into a simplified geometric representation suitable for numerical analysis. The terrain surface and internal boundaries between the geological units were delineated to reproduce the cross-sectional geometry of the study area (figure 9_. This representation was used to establish the model geometry and distinguish the individual material zones. Particular attention was paid to maintaining consistency between the interpreted geological structure and the geometry used in the stability calculations.

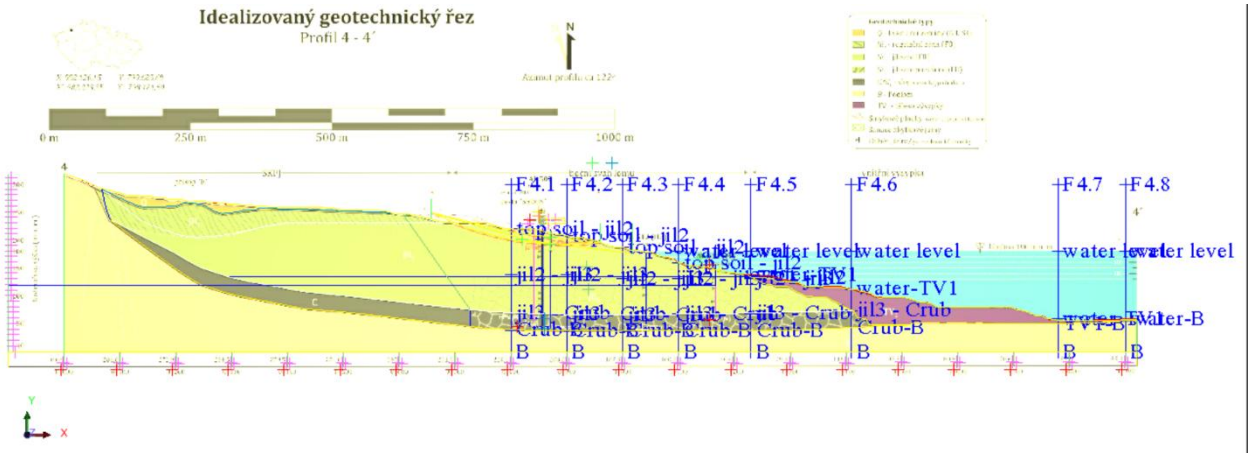

Figure 9 Geological Cross-Section of Profile 4, with Virtual Boreholes and Groundwater Levels

The final cross-section integrates the interpreted geological structure with the virtual boreholes positioned along profile 4 using real-world coordinates. The boreholes were used to support the spatial interpretation of the geological units and to define their distribution along the selected profile. In addition, the groundwater levels considered in the analysis were incorporated into the model to account for the influence of hydrogeological conditions on slope stability. The resulting cross-section provided the basis for assigning geotechnical parameters to the modeled materials and defining the conditions for the subsequent stability calculations.

Under these conditions, the landslide susceptibility map projected onto the final Digital Terrain Model (DTM) of the ČSA residual pit was analyzed to identify areas potentially prone to slope instability. The spatial distribution of susceptibility classes, together with the geometry of the residual pit and the surrounding terrain, was considered when selecting the geotechnical profiles for further investigation. Based on this assessment, profile 4 was selected for the slope stability analysis due to its location within the area of interest identified on the susceptibility map (figure 10). The selected profile provides a basis for evaluating slope stability under the considered geotechnical and hydrogeological conditions.

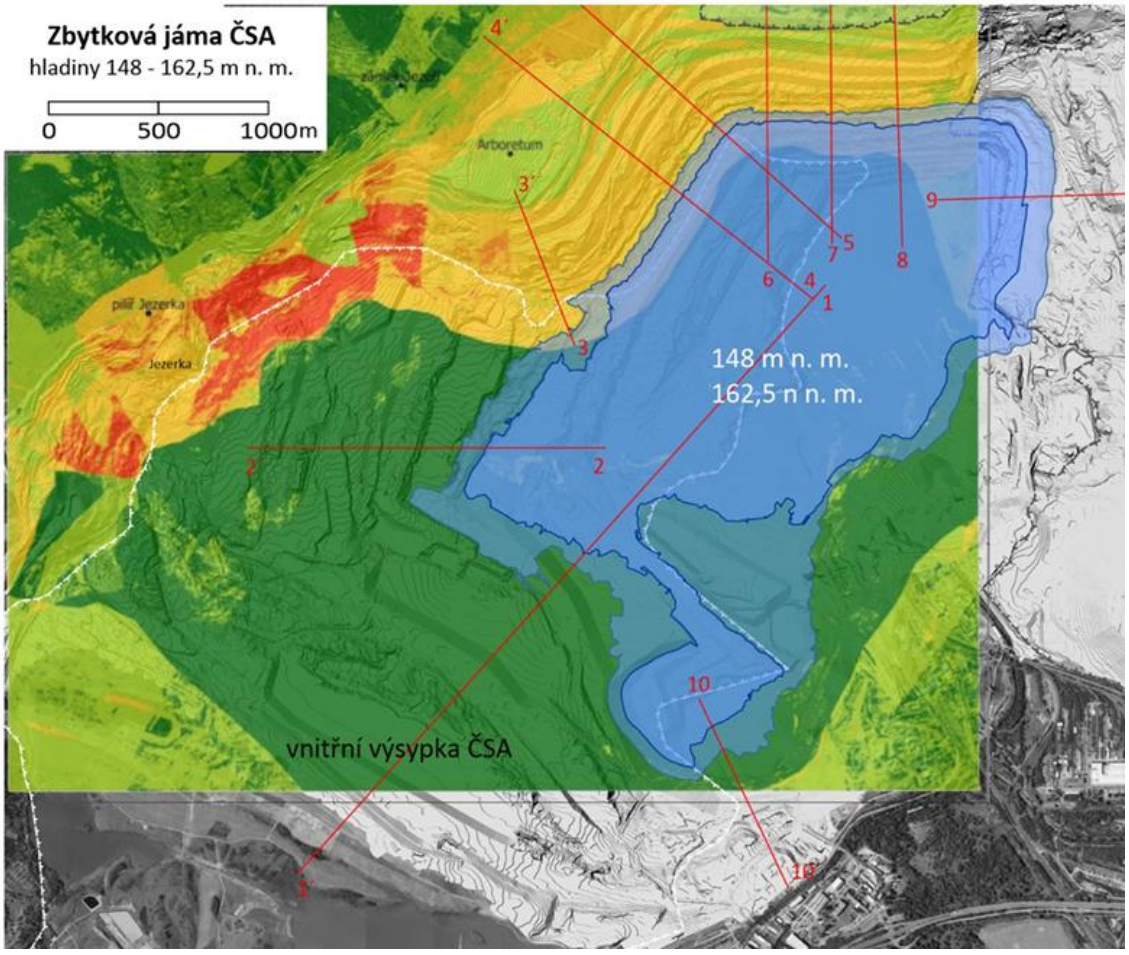

Figure 10 Landslide Susceptibility Map Projected onto the Final Digital Terrain Model (DTM) of the ČSA Residual Pit with Geotechnical Profile Lines.

The geological model was constructed based on the assumption that the stratigraphic conditions remain consistent within a distance of 100 m on either side of the selected profile alignment. The modeling process initially involved reconstructing the geological volumes using virtual boreholes. However, extending this approach to the entire ČSA residual pit resulted in computational difficulties, as the mesh generation process could not be completed successfully for the full model. Consequently, the modeling domain was restricted to the area surrounding Profile 4, allowing a more manageable three-dimensional geometry to be developed for the subsequent stability analysis in PLAXIS 3D.

The selection of Profile 4 was guided by the landslide susceptibility map (Figure 11), which was used to identify areas potentially prone to instability. This approach enabled a focused investigation of the slope geometry and the associated geological

and hydrogeological conditions, while avoiding the meshing limitations encountered when attempting to model the entire residual pit.

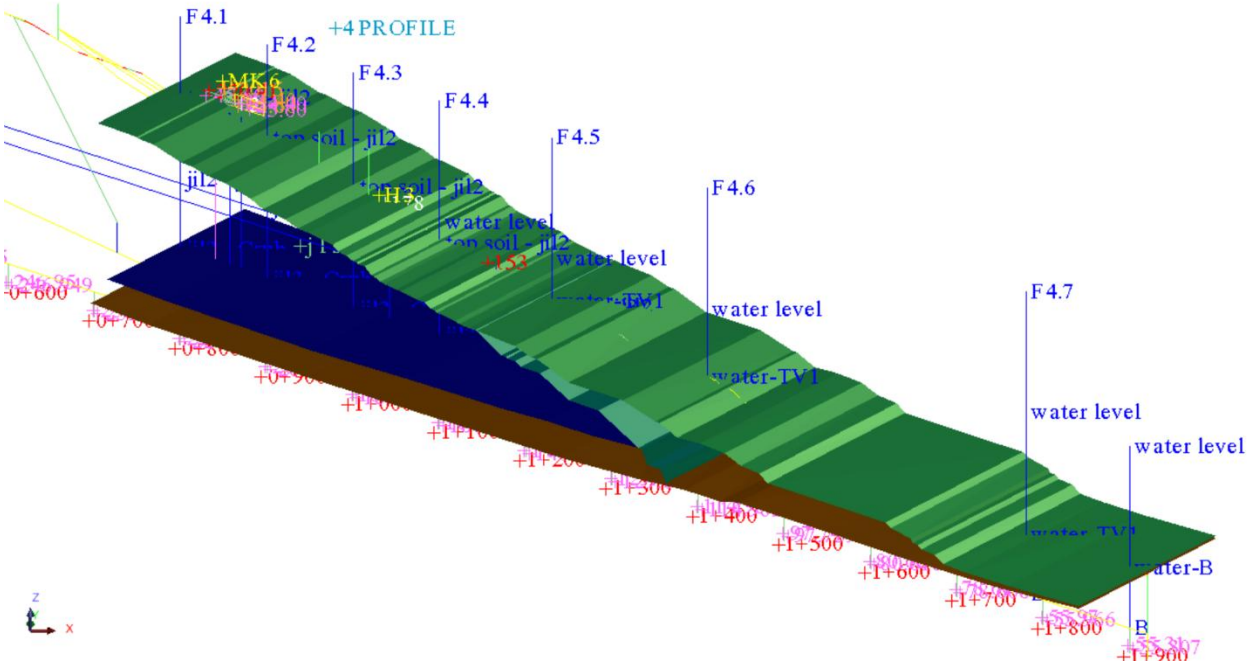

Figure 11 Geological Model of Profile 4 with Virtual Boreholes and Groundwater Levels (SURPAC Model)

The figure presents the geological model developed for Profile 4, including the interpreted geological units, the positions of the virtual boreholes (F4.1–F4.7), and the groundwater levels considered in the analysis. The boreholes provide spatial reference points for interpreting the stratigraphic sequence, while the groundwater levels indicate the hydrogeological conditions incorporated into the model. This representation was used to verify the spatial arrangement of the geological units and prepare the geometry for subsequent slope stability calculations.

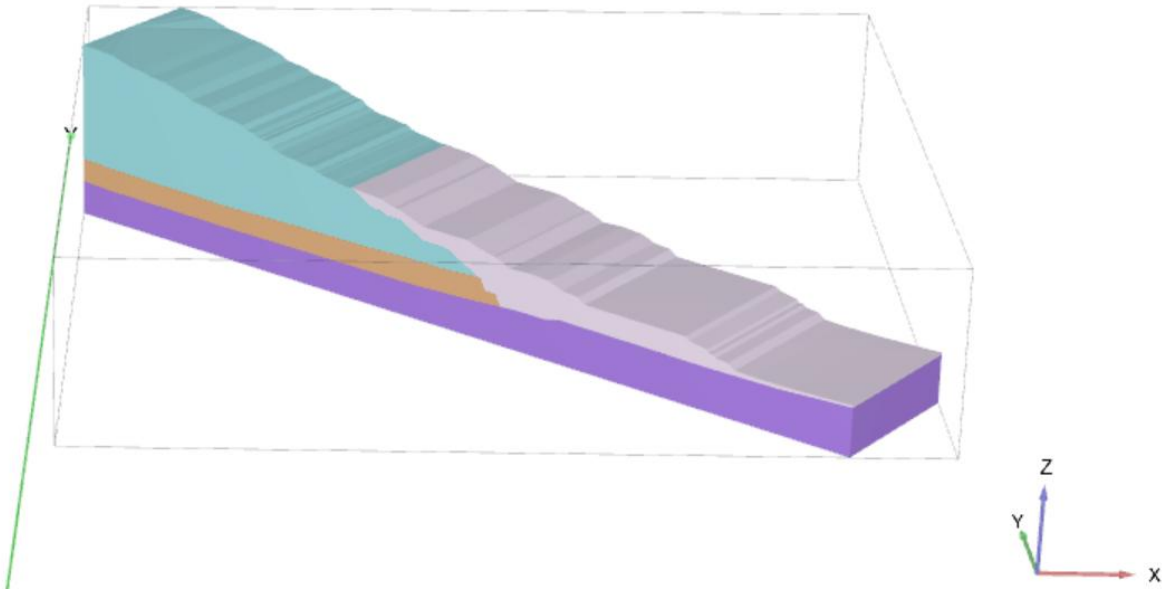

Figure 12 Three-Dimensional Geological Geometry (PLAXIS 3D Model)

The figure illustrates the three-dimensional geological geometry imported into PLAXIS 3D for numerical analysis. The model represents the main geological units and their spatial distribution within the selected computational domain. Its geometry was adapted to facilitate mesh generation and address the computational limitations encountered when attempting to model the entire ČSA residual pit. The resulting model provided the basis for assigning material properties, defining boundary conditions, and establishing the parameters required for slope stability analysis.

Stability analysis was subsequently performed using the developed geological model to evaluate slope behaviour under the defined calculation scenarios. The results enabled the assessment of the mechanical response of the modeled area and the determination of the corresponding factor of safety. Furthermore, the analysis provided a basis for examining slope stability under different hydrogeological conditions and identifying potential variations in the stability of the modeled domain.

3. Pesteana South – open pit

The mining activity is currently carried out in 12 perimeters (9 of them in Jilt, Motru an Rovinari sub-basin), and there are also mining perimeters with ceased activity. In the southern part of the Rovinari basin, there are two former open pits, Urdari and Pesteana Sud, located a short distance from each other, which ceased

operations in 2003 and 2015, respectively. In the remanent voids of the open pits, two lakes were naturally formed (figure 13).

Figure 13 Rovinari, Motru and Jilț mining basins

South Pesteana open pit is located in the southeastern extremity of Rovinari coal basin, in the Jiu River meadow. The investigated site represents a typical abandoned mining area characterized by steep excavated slopes, heterogeneous geological formations, and varying degrees of rock mass degradation. From the morphological point of view, the perimeter of the South Pesteana open pit is part of the Getic Plateau. Situated at the junction between Jiu and Jilţ rivers, the perimeter comprises the Jiu Plain (meadow) about 2.5 km wide, with elevations ranging from +153 m to +130 m, with inclinations from west to east (to the Jiu riverbed) and from north to south. In the South Pesteana perimeter, there are more aquifer horizons, respectively free-level aquifers and under-pressure aquifers with ascending or artesian levels. The remaining gap resulting from the cessation of exploitation activity is located in the southern part of the perimeter, and the decision regarding its rehabilitation and reuse took into account the flooding and the formation of a lake that may take on different functions in the future.

The dimensions of the remaining gap of the Pesteana Sud open pit are +150 m at the top of the waste dump, +131 m at the top of the final slope, and +83 m at the level of the open pit sole. The lake formed has the water level at an altitude of +118

m, with an area of 97.5 ha, a depth of 35 m and a water volume of 36 million m^3. The perimeter of the lake at the top is 4435 m, represented by dump slopes on a distance of 1365 m and excavation slopes on a distance of 3070 m (figure 14).

Figure 14 Location of the South Pesteana perimeter

Based on the available topographic measurements, the residual void at Pește ana Sud was modeled in SURPAC, the slopes on the southern, eastern, and western sides are excavated, while the northern slope is formed by material deposition in the internal dump (figure 15).

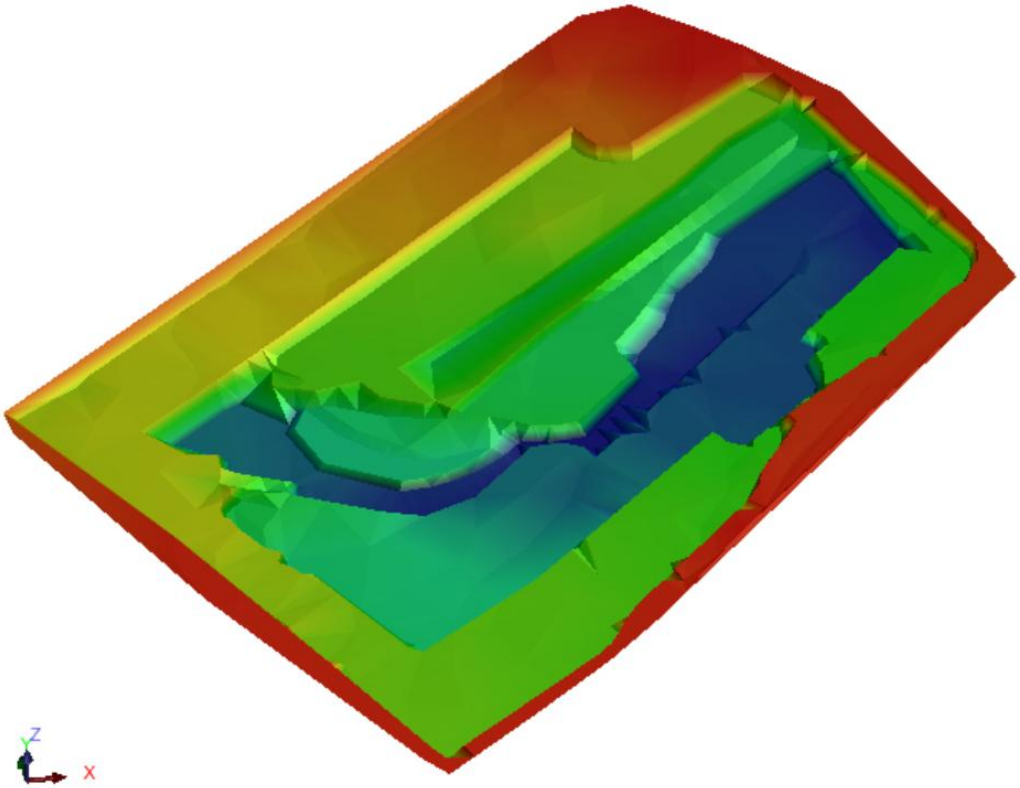

Figure 15 Three-dimensional SURPAC model of the Pesteana Sud residual void

The relatively simple geological structure, characterized by nearly horizontal coal seams interbedded with barren rock, facilitated the development of the geological model used as the basis for the stability analyses. Based on geological data describing the position and thickness of the individual strata, a geological model was constructed for the excavated quarry slopes. In contrast, the geological model for the northern dump slope was developed using available information on the composition and distribution of the deposited material, reflecting the different geological and geotechnical characteristics of the two slope types.

The resulting three-dimensional geological model illustrates the distribution of the main stratigraphic units within the quarry slope, as shown in Figure 16.

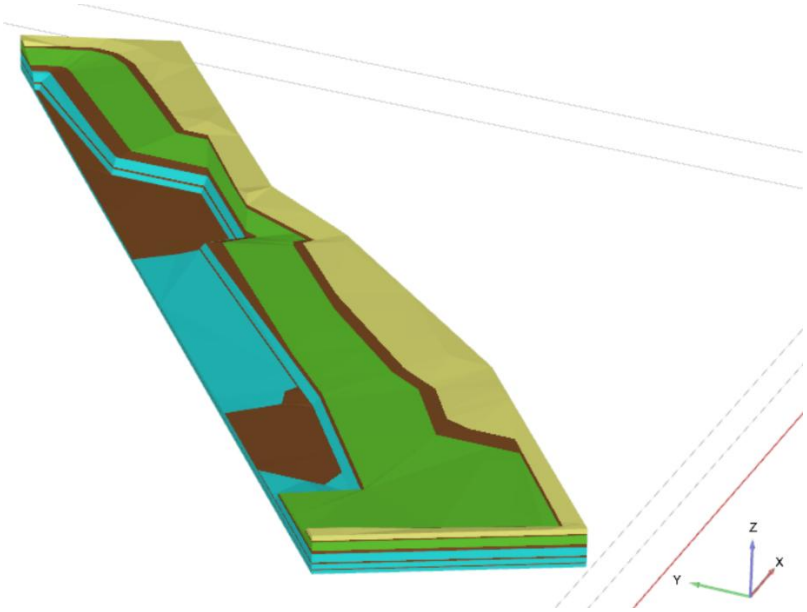

Figure 16 Three-dimensional geological model of the quarry slope

The figure illustrates the three-dimensional geological model developed from available geological data, highlighting the spatial distribution and thickness of the main stratigraphic units. The model provides the geological framework for the subsequent numerical slope stability analyses in PLAXIS 3D. The three-dimensional geological model of the waste dump illustrates its overall geometry and the configuration of the deposited material, as shown in Figure 17.

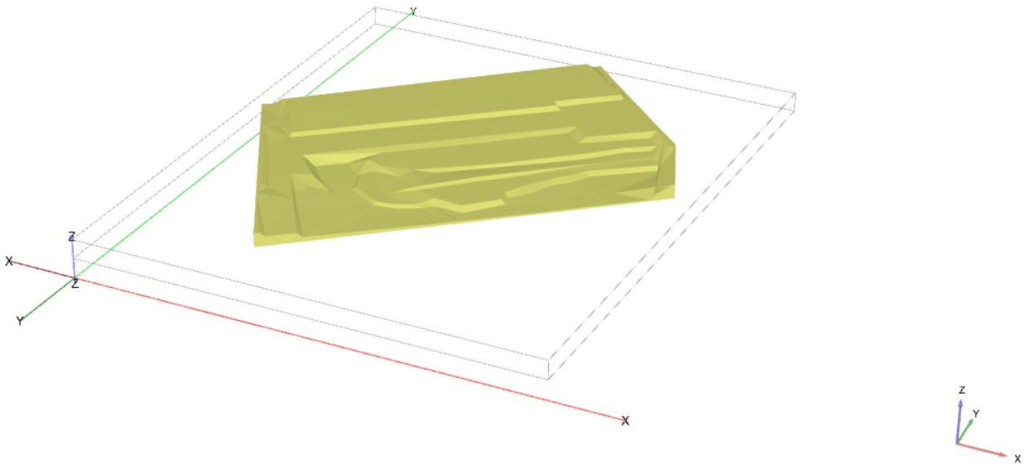

Figure 17 Three-dimensional geological model of the Pesteana Sud internal waste dump

The model represents the geometry of the internal waste dump and the spatial configuration of the deposited material. It provides the basis for defining the dump slope geometry and developing the numerical model for subsequent slope stability analyses.

Note:

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