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Geotechnical site investigations used in detection of internal erosion and leakage in dam foundations – a case study

Summary:

Application of Electrical Resistivity Tomography (ERT), combined with Particle Size Distribution (PSD) curves (obtained through geotechnical drilling, sampling and laboratory testing of materials), in detection and mapping of preferred seepage paths and internally eroded soil in reservoir bottom and dam foundations.

Hydroelectric Power Plant (HPP) *Dubrava* in Croatia

- **Located on the Drava river in the North of Croatia**
- **Reservoir lake capacity:** **93 500 000 m^3**
- **Total length of reservoir embankments:** **23 km**
- **Maximum embankment height:** **15 m**
- **Geological composition of the river valley:** **alluvial plain (thick deposits of gravels and sands, sporadically overlaid with a thin layer of silt or clay on the surface)**

Issues at the reservoirs´s left embankment

- **Over time, between 2009 and 2015, around chainage km 6+500 of the reservoir lake´s left embankment, a number of issues had appeared:**
  - ***increased seepage under the embankment***
  - ***appearance of washed-out fines in the drainage canal***
  - ***appearance of sinkholes in the reservoir lake´s bottom***
- **Those issues indicated an increasing risk of hydraulic instability in the dam foundations, which could – if allowed to fully develop – lead to the failure of the dam**

Financial repercussions of reduced embankment safety

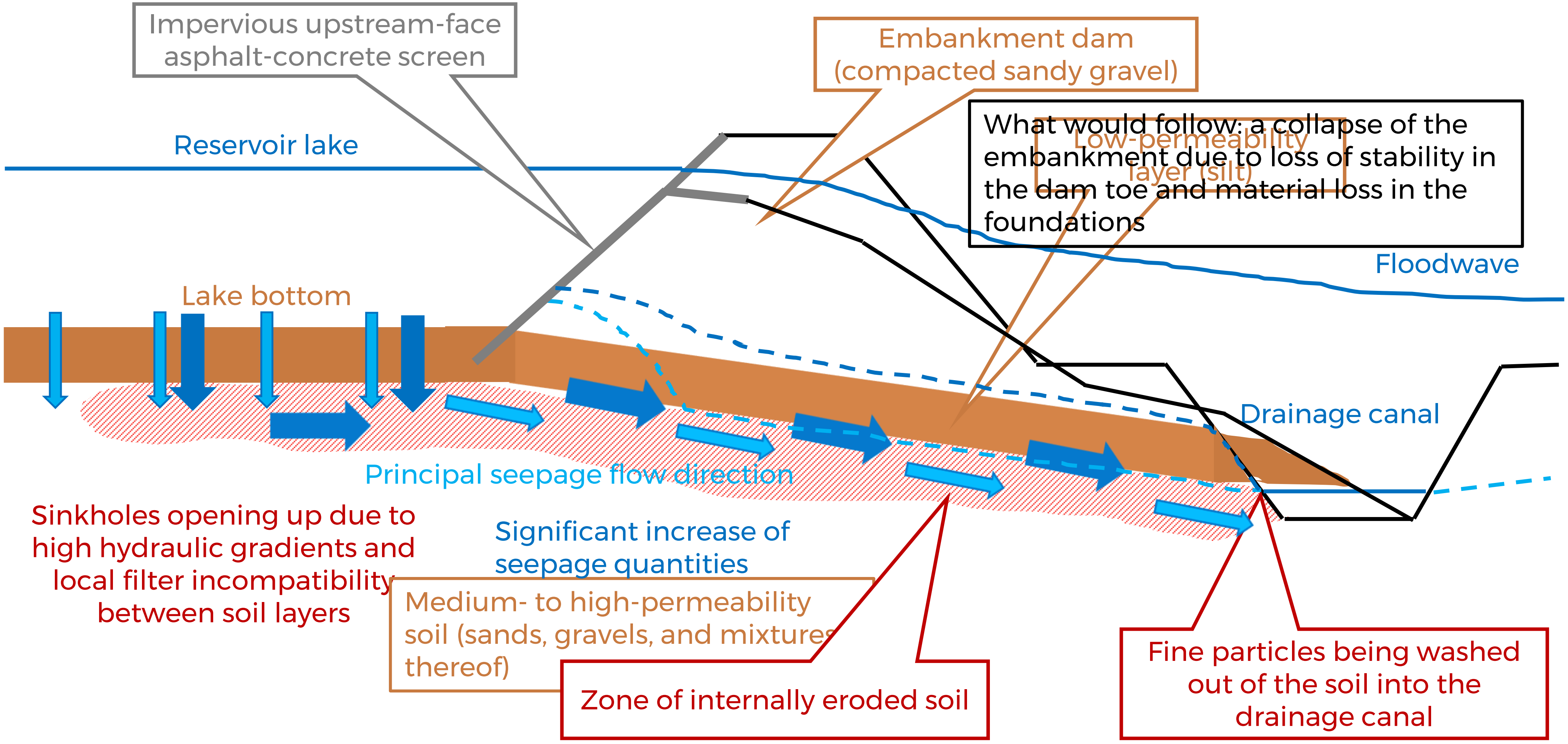
- Due to reduced safety of the reservoir embankments, the water level in the reservoir had to be kept at a level several meters below the normal operating level.
- This caused 10´s of thousands of € in financial losses per day due to decreased power production

Increased seepage (leakage) quantities, clearly visible during works to increase drainage capacity of the downstream toe of the embankment and canal slope

Fines being washed out into the drainage canal

Sinkholes in the reservoir lake bottom

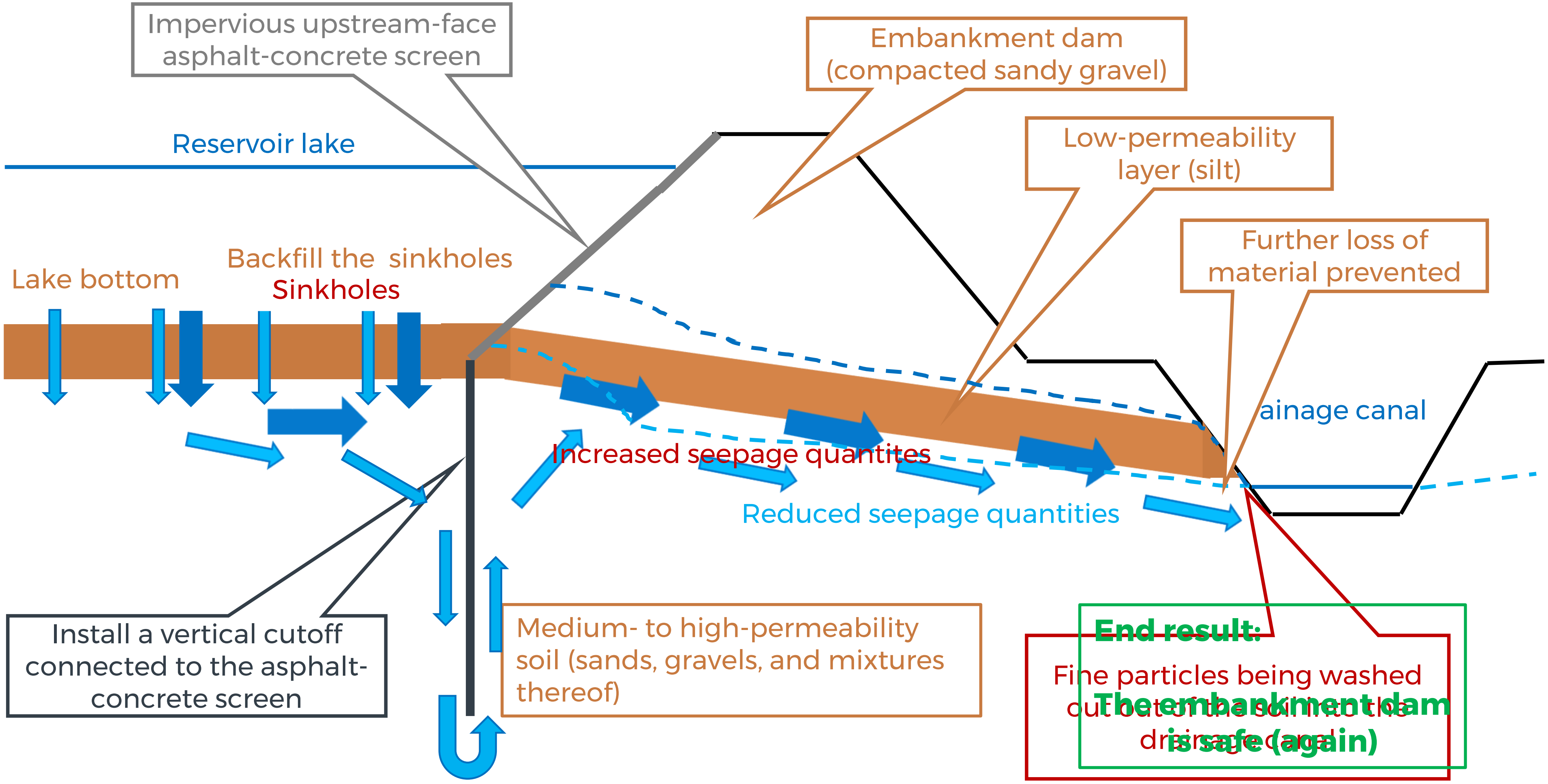
Schematic of an assumed dam failure mechanism due to hydraulic instability in the foundations (note: not to scale)



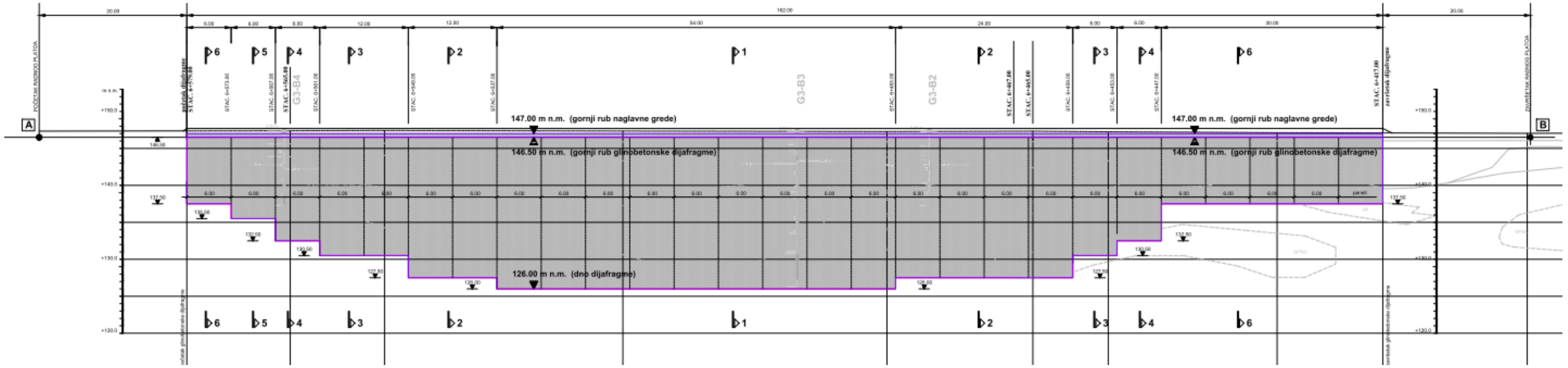

… what would follow …

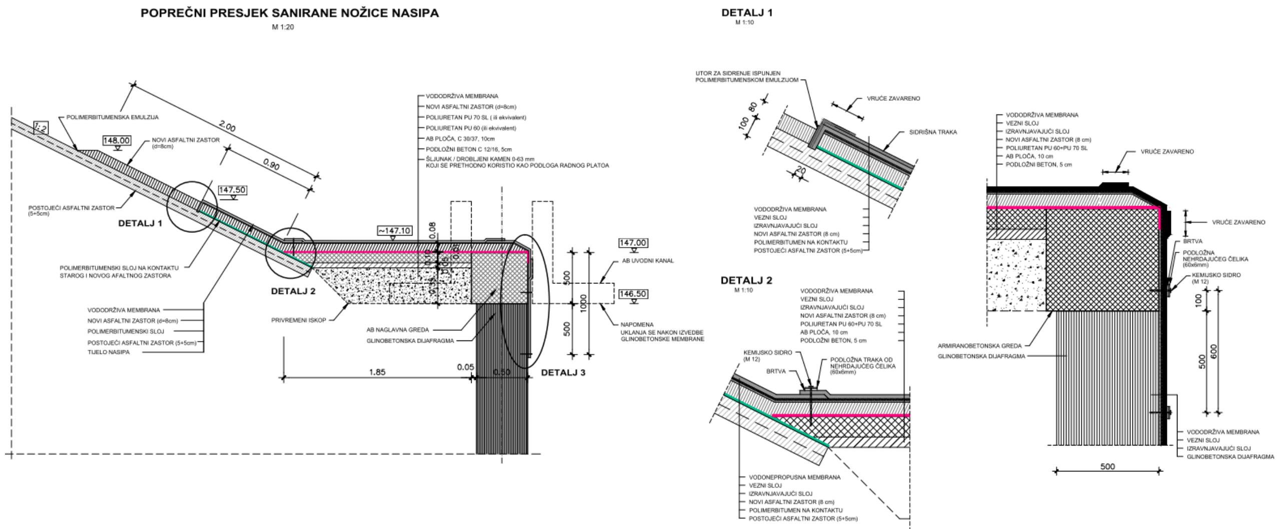

... what would follow ...

Solution design from the present state of the embankment (not to scale)



Design solution: vertical cutoff (slurry wall) 190 m long and up to 20 m deep, connected to the upstream asphalt-concrete screen to form one single impervious barrier





However, to be able to design a vertical cutoff which would prevent further hydraulic instability of the embankment, one must have the following input about the vertical cutoff:

1. How **long** should it be?

2. How **deep** should it be?

Since the main purpose of the vertical cutoff was to increase the hydraulic stability and reduce the seepage by blocking the dominant seepage paths , it is critical to accurately determine where these dominant seepage paths lie (first indication being the data from dam monitoring and safety inspections).

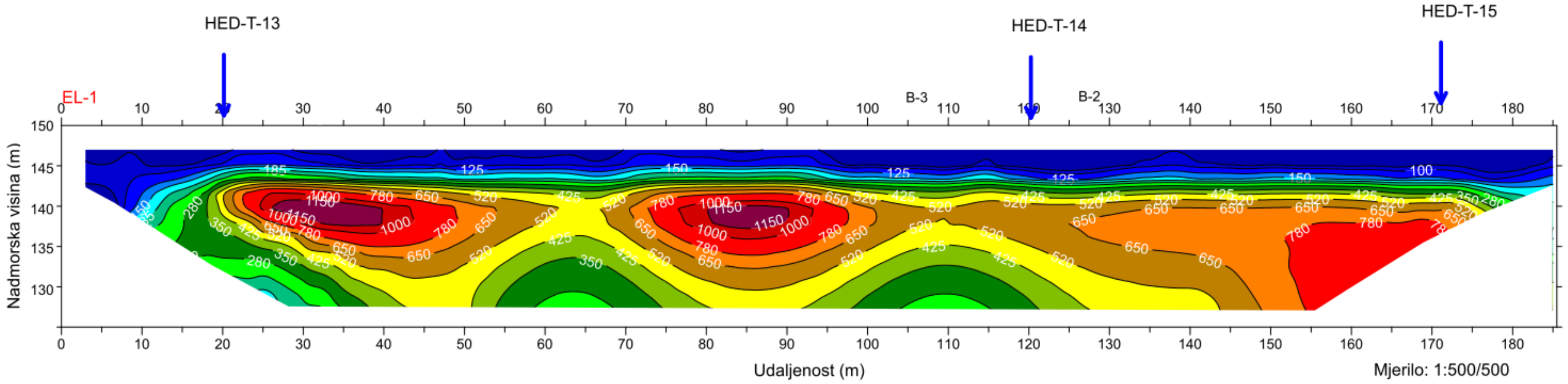
A combination of the following site investigation methods was used:

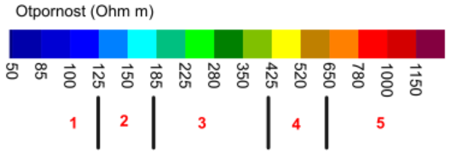
1. Electrical Resistivity Tomography (ERT)
2. Geotechnical drilling and sampling (incl. laboratory testing)

Electrical Resistivity Tomography (ERT) method

- Geophysical site investigation method
- Very fast
- Non-destructive and virtually non-invasive
- Based on measuring the voltage on the surface and calculating the electrical resistivity of the material (soil) below
- Electrical resistivity of soil depends on:
  - *Type of soil*
  - *Compaction degree*
  - *Saturation degree*
  - *Mineral content*
  - *other factors*

Interpreted ERT sections (parallel to the embankment axis)





HED-T-

Pozicija kolca na terenu

1 Prah, prah pjeskovit, pijesak prahovit

2 Pijesak, pijesak prahovit

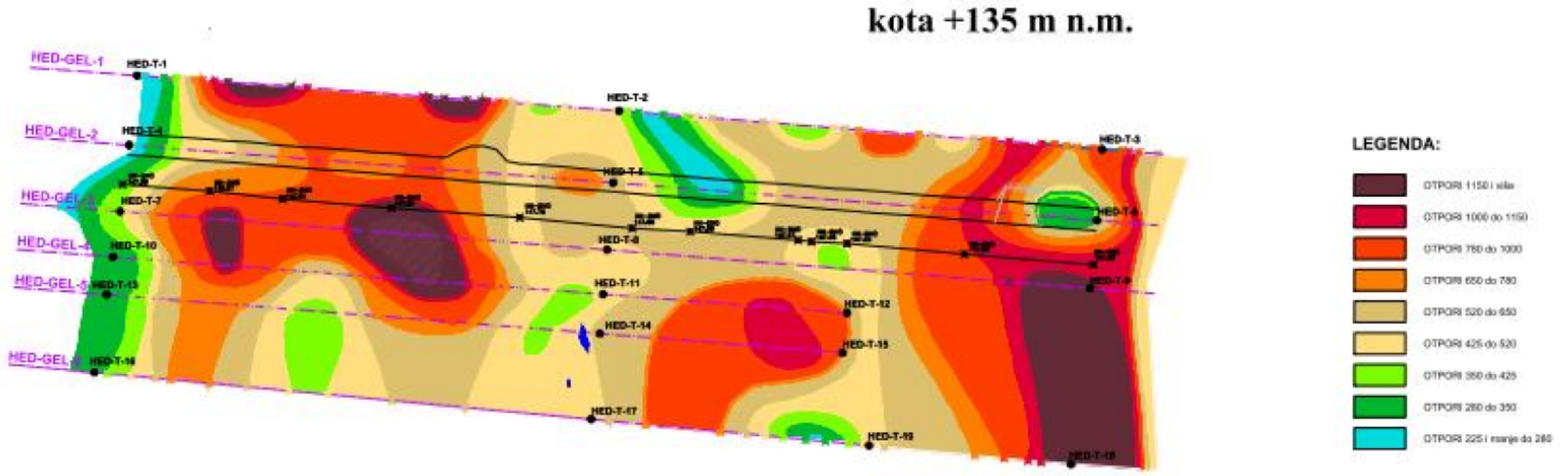
3 Šljunak pjeskovit

4 Šljunak srednje do krupnozrnati

5 Šljunak krupnozrnati

Obrada: mr.sc. Božo Padovan, dipl. inž. fizike

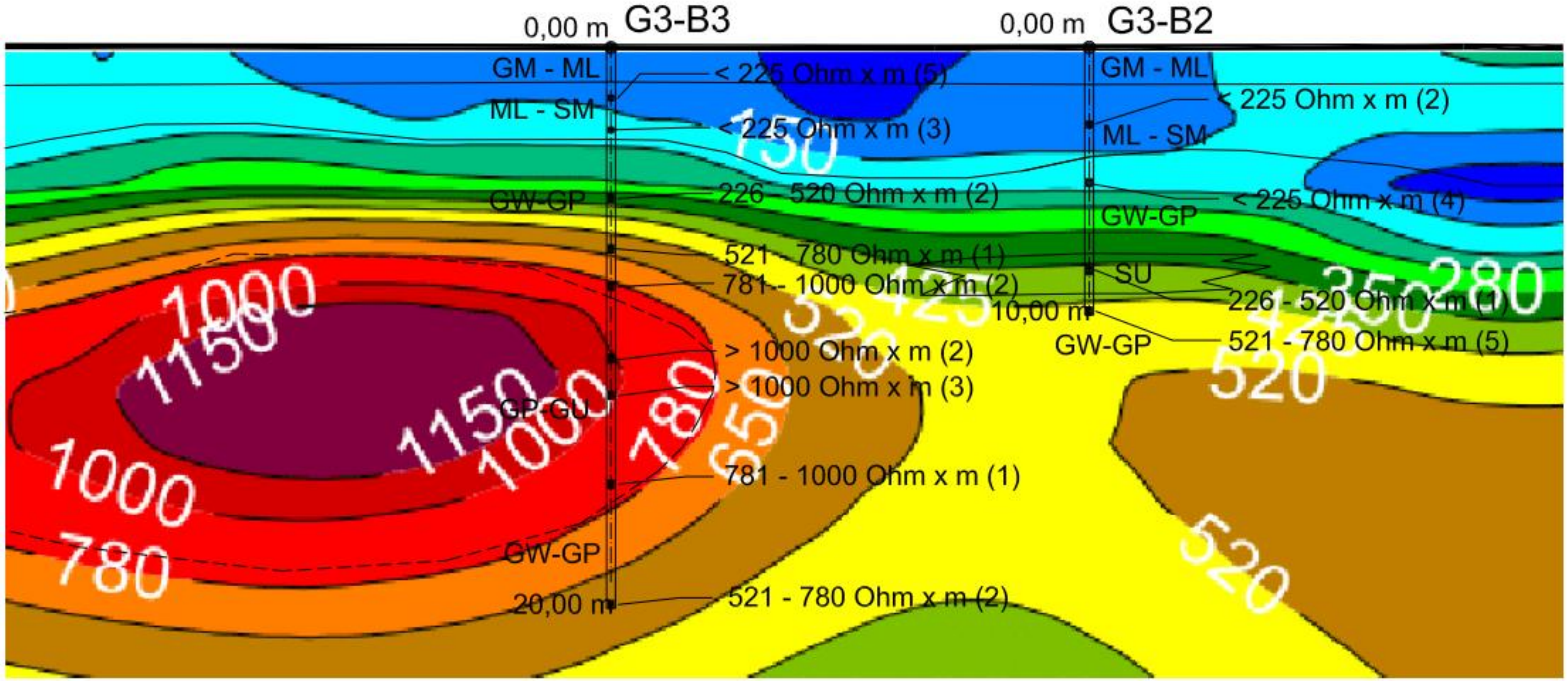
ERT ”plan views” (one for each specific depth) created from interpreted parallel ERT sections



Combining ERT with geotechnical drilling, sampling and laboratory testing

- Well-recorded and well-interpreted geoelectrical profiles allowed for quite accurate borehole placement
- Samples were taken at specific depths and taken into laboratory for PSD testing
- Borehole logs were superimposed over interpreted ERT sections to scale, with depths at which samples were taken clearly marked
- This allowed for clear linking of electrical resistivity value fo the soil to its composition in terms of grain size

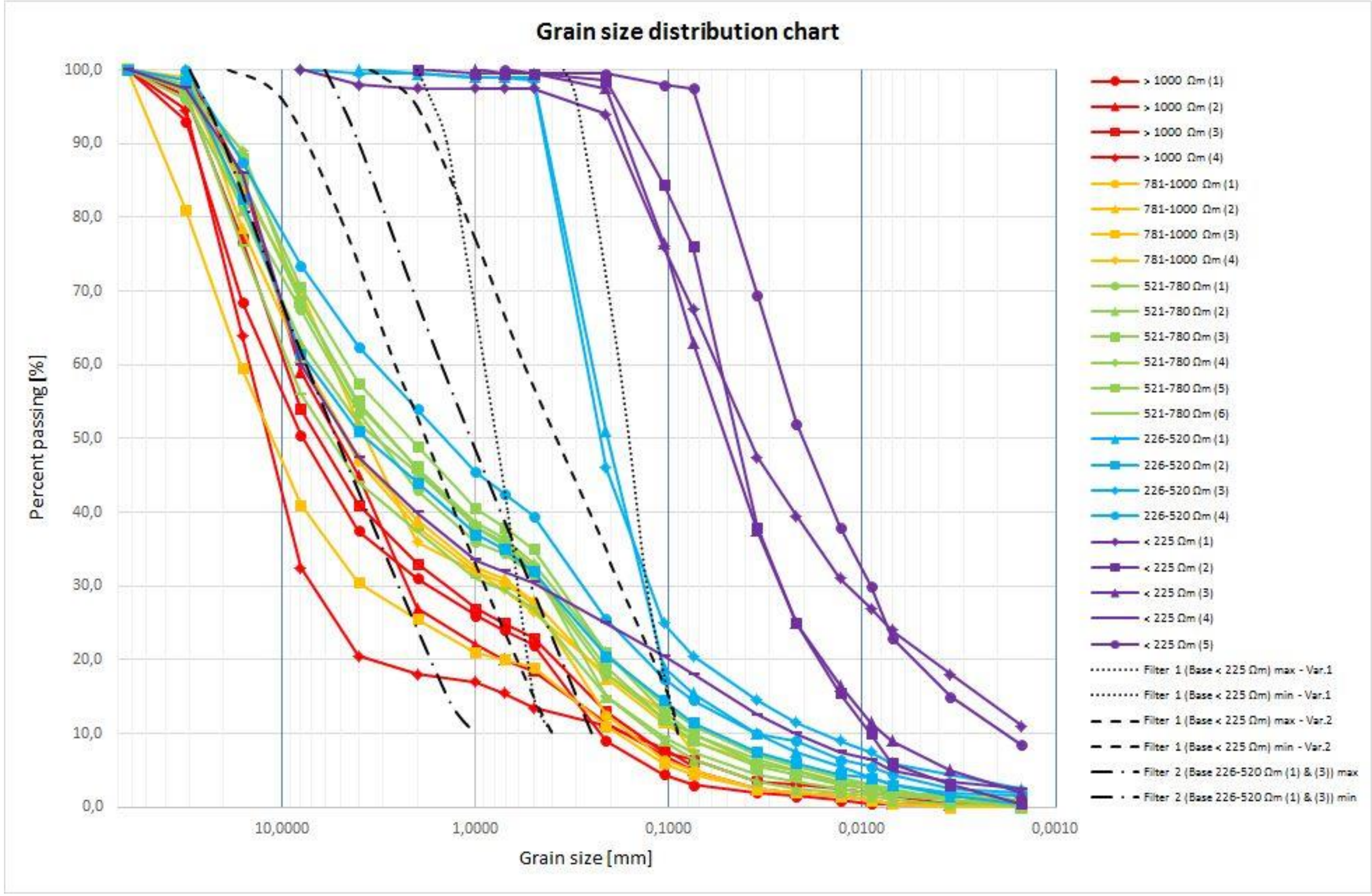
Part of an interpreted ERT section with superimposed borehole logs and soil sample markings



- This allowed for plotting of PSD curves on a joint graph, with the color of the curve depending on the resistivity of the surrounding soil from which a sample was taken
- Above-stated procedure showed the following:

1. *Coarser materials, have higher resistivity than finer materials*
2. *Well-executed and interpreted ERT method can distinguish between very small differences in material composition*
3. *ERT results still need verification via drilling and sampling*
4. *Dense spacing between contour lines in interpreted ERT sections (profiles) denotes a sudden change in material layers in terms of particle size*

Chart with PSD curves linked to electrical resistivity values



Outputs

Combination of site investigation methods (ERT, drilling and sampling) and interpretation of their results allowed for the following to be done:

1. *Determine the potential for internal erosion (procedure proposed by Kenney and Lau, 1985) in underlying gravelly and sandy material*

2. *Map the areas where internal erosion was likely*

3. *Produce a credible and accurate model for geotechnical seepage analyses (via FEM) in order to optimize the depth of the vertical cutoff along its length*

Conclusions

1. Early detection of unfavourable processes in the dam foundation is critical. It is usually achieved by efficient safety monitoring of the dam

2. Selection of appropriate site investigation methods is essential to the process of finding a quality solution. It should be combined with data from dam monitoring.

3. Costs of appropriate site investigations is negligible compared to the costs which could be incurred by faulty solutions based on wrong assumptions

Thank you!

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