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Theme C

BEHAVIOUR OF THE EMBANKMENT DAM

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The information package for the preparation of contributions to Theme C consists of:

- The formulation of the topic;
- Geometry file (1 file; .dwg format);
- Monitoring data (4 files; *.xslx formats);
- Additional time-series (1 file; *.xslx formats).

Revision history

Version (date)	Comment

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1 INTRODUCTION

Embankment dams represent in total over 80% of the dams built in the world (Wrachien, 2009). Additionally, the majority of dams were built in previous decades. Unlike concrete dams, embankment dams can accommodate a wide option of foundation conditions, construction material is usually available close to the dam location. During the construction and commissioning embankment dams are subjected to various loading conditions. Internal erosion is a common issue in embankment dams. For example, approximately 40% of all embankment dam failures have been attributed to soil instability due to uncontrolled seepage through the dam body or its sub-base (ICOLD Committee on Embankment Dams, 2017). Moreover, the dams were more or less built in the past considering different safety, design, and construction standards (United States Society on Dams, 2010). Additionally, we are often dealing with the lack of data and we need to adopt various modelling assumptions to perform numerical analysis. The main aim of this topic is to present a case from Slovenia. We prepared a case of an embankment dam with an interesting history and design. The dam is monitored, however, still there is a lack of data that demands engineering judgement that can be described using various modelling approaches.

In this document you can find information on the dam and foundation, historical data, description of the provided data in separate files, the description of the tasks and subtasks, and the expected outcomes. In the theme, the geometry, material properties, and monitoring data are provided by the Formulators. Some aspects of the numerical modelling are intentionally not defined so that the participants could make their own assumptions and choose suitable approaches to solve the problem. In particular, participants may select the analysis approach they believe to be appropriate for the case at hand. Thereby, by comparing the different solutions, it will be possible to draw conclusions regarding how different assumptions and approaches influence the results.

In case the formulator will express their interest to have a technical visit to the dam in the scope of the BW in Ljubljana, the visit can be organized (*in case the BW will be held in physical form due to the COVID-19 restrictions).

2 BASIC INFORMATION ON THE DAM

The identity of the dam in this topic will remain confidential, and may be revealed to the contributors at the conclusion of the workshop at the synthesis of the results. The downstream view of the dam is presented on Figure 1. In the following subchapters the main features of the dam are presented including its structure, material description, chronological description of the construction and operation, detailed description of leakage, and available monitoring data.

The dam was built in 1989 for agriculture purposes (irrigation) and flood protection. The reservoir provides seasonal storage of water, where the excessive rainwater is collected during the cold part of the year, when the inflow discharges are high; while in spring and summer months the reservoir water is used primarily for irrigation.

The dam site is located on impermeable Eocene flysch. At the design stage the geological conditions at the site were estimated as very good. However, this assessment was based on the execution of only basic geological and hydrological investigations. Moreover, during the construction, the excavations revealed zones with permeable limestone deposits. To ensure the lower permeability in the foundation, permeable zones were grouted with a single-row grout curtain (cement-bentonite suspension), which was used to seal the permeable zones and reduce the permeability of dam foundations. The depth of the grouting in the foundation is 68 m (the grouting reached into the ground to the elevation level 34 m asl). Grouting was done simultaneously with the dam construction, precise locations of the grouting are not known.

Figure 1: The downstream view of the dam.

The construction of the dam ended in the late 1980s and it lasted roughly one year. The reservoir was fully impounded roughly 18 months after the completion of the construction work (details of the first impoundment are presented in the chapter *Loads*). After 20 years of operation, during regular maintenance wet spot was noticed on the downstream slope of the dam (see 2.5). The basic monitoring system of the dam was established already during construction and immediately after construction of the dam was completed. Rehabilitation works are currently underway on the dam, the reservoir has been emptied and it is expected to become operational in 2023.

2.1 DESIGN OF THE DAM

The main technical data of the dam are:

- Dam height above foundation: 34.6 m;
- Elevation of the dam crest: 102.00 m asl;
- Elevation of the foundation: 67.40 m asl;
- Crest width: 5 m;
- Base width: 120 m;
- Crest length: 174 m;
- Normal Water Level: 98.8 m asl.

The dam under investigation is zoned earthfill dam with a clay core. Typical cross-section of the dam is presented on Figure 2. The main zones in the dam structure are: (A) impermeable clay zone, (B) rockfill zone, (C) mix of limestone and sandstone blocks, (D) impermeable rock foundation, and (E) filter. On the upstream side of the filter, the dam consists of rockfill material (B). The upstream slope has an inclination of 1:1.5 and has intermediate berms. The core of the dam contains clay-silty materials, obtained mostly in the area of the reservoir. The impermeable core is protected with a two-layer filter (on upstream and downstream side). Figure 2 shows the cross-section of the dam, where we can see that the impermeable clay zone (A) and zone (C) are not divided vertically. The blocks of limestone and sandstone in zone (C) are contained by the impermeable clay material, while filter is installed on the boundary. The formulators are unfamiliar with the justifications for such design. The downstream slope has an inclination of 1:2. The embankment dam is 35.40 m high and 174 m long, while the width of the dam is 5 m at the crest and 120 m at the toe. The total projected volume of the reservoir is 8.0 million m^3 of water, of which 6.8 million m^3 (84.5% of the volume) is intended for irrigation, and 1.2 million m^3 (15.5% of the volume) for flood water retention.

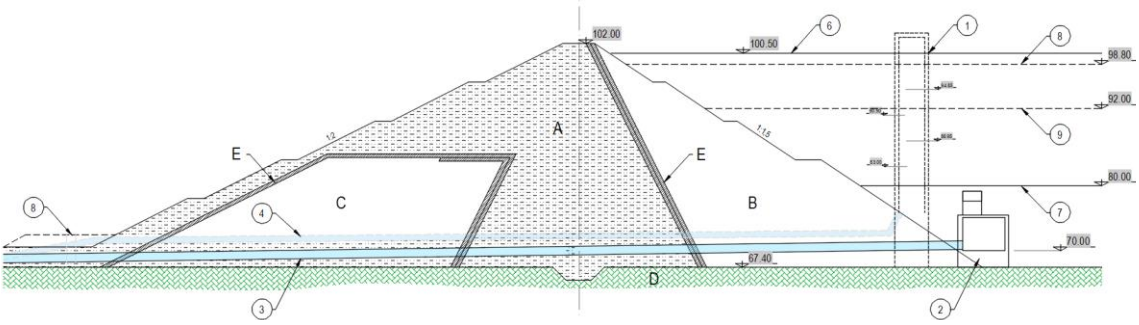

Figure 2: Typical cross-section of the dam.

Dam structure:
(A) clayey silt material
(B) rockfill material
(C) limestone and sandstone blocks
(D) impermeable rock base
(E) filter material

Hydrotechnical structures:
(1) intake tower
(2) intake structure
(3) bottom outlets
(4) irrigation pipeline

Reservoir levels:
(6) Maximal reservoir level (100.5 m a.s.l.)
(7) Minimal operating level (80.0 m a.s.l.)
(8) Normal operating level (98.8 m a.s.l.)
(9) Depleted operating level (92.0 m a.s.l)

Crest elevation 102 m a.s.l
Foundation elevation 67.40 m a.s.l.

To prevent breaching of the dam during extreme flood events an emergency spillway is situated at the right abutment of the dam. The spillway is designed to evacuate a flood with a 1000-year return period. The bottom outlet with a capacity of 14 m^3/s consists of two steel pipes, 120 cm in diameter, which are protected with a concrete cover. One of the pipes is used for abstraction of water for irrigation, while the second one is designed for emergency evacuation of water from the reservoir. Bottom outlet (number 3 on Figure 2) is regulated with Howell-Bunger valve installed on the left downstream side of the dam, meaning that the pipes are filled with water even when the valves are closed. The RC intake structure for the bottom outlet is on Figure 2 marked with a number (2).

Additionally, the intake tower (number 1 on Figure 2) is equipped with 4 hydraulic gates, that enabled abstraction of irrigation water at various elevations. The steel pipeline (number 4 on Figure 2) from the intake tower, which is protected with a concrete cover, has 100 cm in diameter, and leads toward the outtake structure downstream of the dam. Since the leakage detection this irrigation pipeline has been sealed and intake tower is no longer in operation. The disposition of the bottom outlet, the intake tower, the irrigation pipes and the bottom conduits is marked on the Figures 2 and 3.

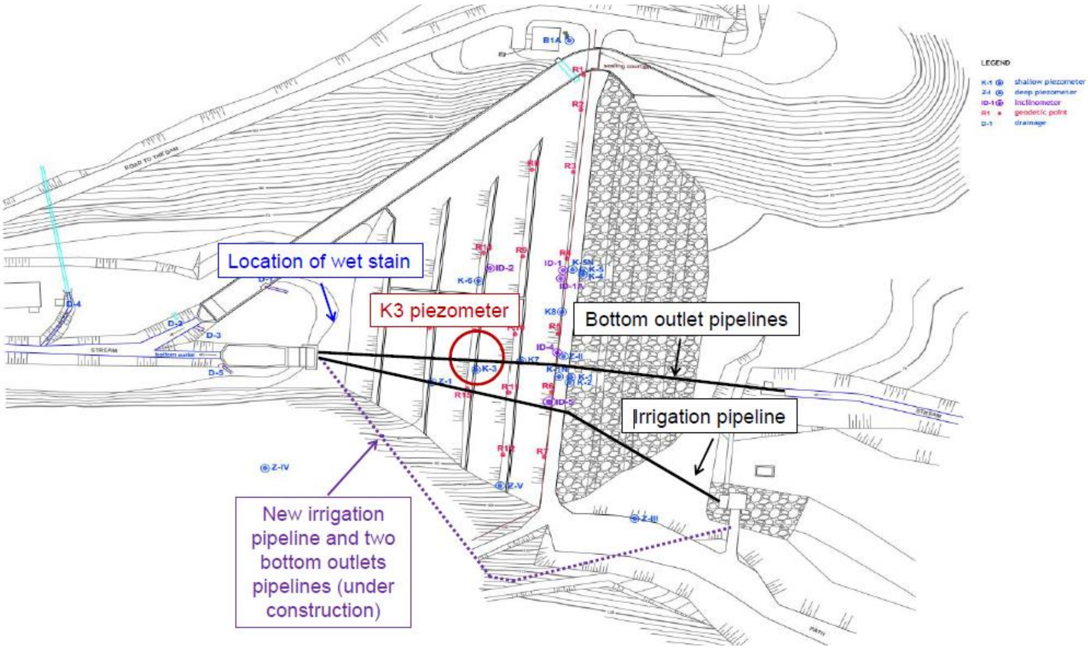

Figure 3: Plan view of the dam.

2.2 MATERIAL PROPERTIES

2.2.1 Dam

The material properties are presented in Table 1.

Table 1: Material properties.

Zone	Description	w [%]	γ [kN/m³]	c_u [kPa]	φ [°]	c [kPa]	Eoed [MPa]	E [MPa]	ν [-]	k [m/s]
A	Top layer of the dam (top 3 m from the crest) dolomite gravel mixed with silt or clay	13	21	/	36	36	15	/	0.4	10^{-6}
A	Clayey silt to silty clay	26	19.5	75	/	/	5	/	0.5	10^{-9}
B	Rockfill (limestone blocks)	/	24	/	38	/	50	/	0.3	10^{-3}
C	Blocks of limestone and sandstone	/	24	/	38	/	50	/	0.3	10^{-4}
D	Flysch	/	25	/	39	32	/	620	0.25	10^{-9}

w [%] – Soil moisture
γ [kN/m³] – Specific gravity
c_u [kPa] – Undrained shear strength
c [kPa] – Effective cohesion
Eoed [MPa] – Oedometric modulus
E [MPa] – Elastic modulus

ν [-] – Poisson coefficient
k [m/s] - Permeability

Filter characteristics are unknown.

2.2.2 Foundation

Assume homogenous foundation, with the following coefficient of permeability: k = 10^{-9} m/s.

2.3 LOADS

The following loads have to be considered: dead weight, hydrostatic pressure according to the reservoir level. Water is considered to have a unit weight of 1 000 kg/m^3 and compression wave velocity of 1439 m/sec. Main reservoir levels are:

- Maximum reservoir level: 100.5 m a.s.l.
- Minimal operating level: 80.0 m a.s.l.
- Operational (normal) reservoir level: 98.8 m a.s.l.
- Lowered (emergency) reservoir level: 92.0 m a.s.l.

Additionally, reservoir levels for the period from 1988–2020 are provided in an excel spreadsheet, named RL.xslx.

First filling: First filing started roughly 12 months after the completion of the construction works and lasted for 722 days, with an average increment of 2.3 cm/day. Zero level of the reservoir was at 81.84 m asl and the final level of 98.34 m asl was reached at the end of the first impoundment. Time series of the first filling of the reservoir can be found in the file: 1ST_filling.xslx.

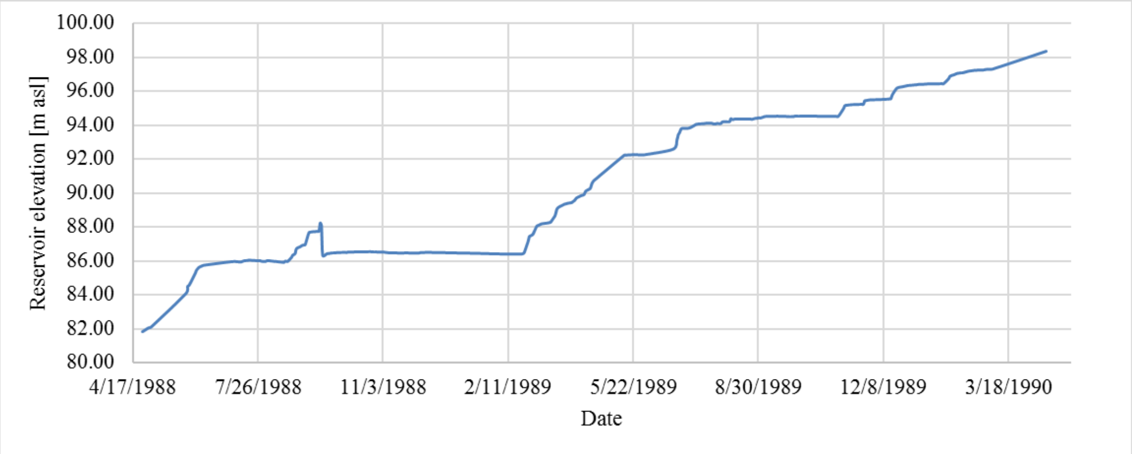

Figure 4: Time series of the first filling of the reservoir.

Filling of the reservoir after the completion of the remediation work: When the reservoir will be impounded again the following rules have to be considered: until the reservoir reaches the level of 90 m asl maximum daily rise of reservoir level may be 0.5 m/day, afterwards reservoir level can rise for only an additional 0.3 m/day until the final level of 98.8 m asl. However, based on the hydrology data, the formulators estimate that an average rise of 5 cm per day should be considered by the participants who are solving theme C. Time series of the filling of the reservoir after remediation works can be found in the file: REM_fill.xslx.

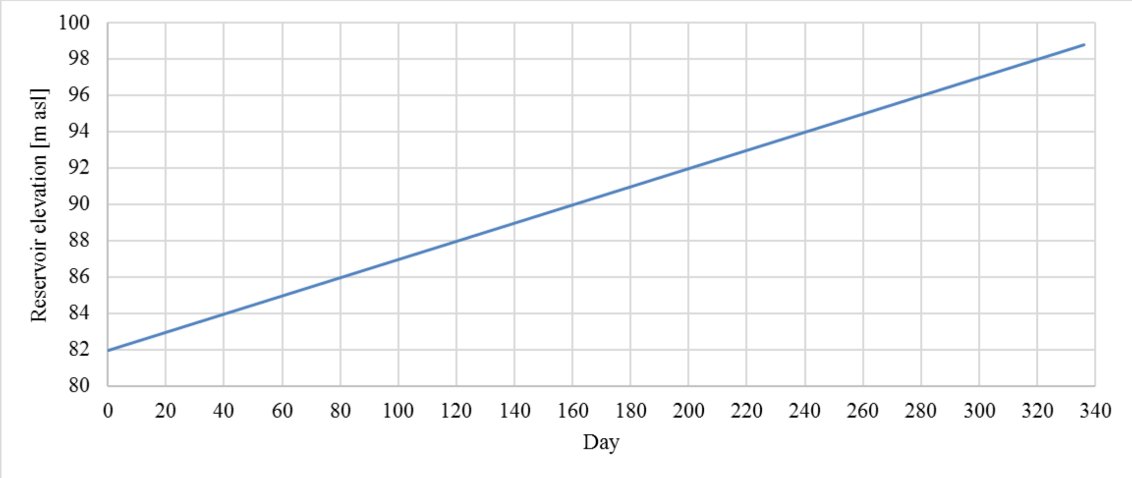

Figure 5: Filling of the reservoir after completion of the remediation works.

2.3.1 Seismic load

For the seismic analysis we ask the participants to consider horizontal peak acceleration of 0.3g and vertical accelerations to be 0.67 of the horizontal.

2.4 MONITORING

The dam is being regularly monitored, the monitoring system was designed at the design stage of the dam, and the dam is monitored since the beginning of the operation. Regular monitoring consists of the following measurements and inspections:

- Deformation measurements (vertical and horizontal displacements, inclinations);
- Visual inspections (structural, geotechnical);
- Groundwater measurements (seepage in the dam body (i.e. drainage outflow, piezometric levels), seepage in the foundation of the dam and in the abutments, pore pressure in the clay core and in the foundations).

Geodetic measurements of vertical and horizontal displacements are performed once a year on 16 measuring points on the downstream slope of the dam: 7 points are located on the crest, 5 points on the fourth berm, 3 points on the third berm and one point on the second berm (see Figure 3). The inclinometer casings were installed when the dam was already in the operation, measurements are regularly performed on 4 inclinometers, 3 of them are installed on the crest of the dam and 1 is located on the upper berm.

2.5 THE APPEARANCE OF THE WET ZONE

On October 24, 2007, during a regular inspection of the dam, a wet zone was observed. The wet spot was located at the downstream toe of the dam in the central part, close to the axis of the dam (the location is shown on Figure 3). Moreover, the presence of surface water was observed at the downstream toe of the dam, between the stilling basin of the spillway channel and outlet structure of the bottom outlet. Furthermore, the extensive vegetation on the central part of the embankment dam indicated that the humid zone extends to the downstream slope of the dam above the wet spot. Emergency investigation revealed that excessive water on the downstream slope originates in the reservoir. There was a suspicion that the damaged irrigation pipeline is the cause for the seepage. After emptying the reservoir and inspection of the irrigation pipeline this hypothesis was confirmed. Under a silty layer deposited on the walls of the pipeline, air bubbles were observed in several places. The corrosion of the steel pipeline (holes were few cm to few 10 cm in diameter) enabled seepage of water into the layer between the concrete cover and the steel pipe). Even though the irrigation pipeline was emptied the wet zone still existed. Therefore, the emergency investigations were extended also to the conduits of the bottom outlet pipeline, which can be closed only on the downstream side, so in the case of the damaged pipeline the seepage into the dam body was possible. The detailed investigations revealed similar damage on the bottom outlet pipeline as in the previous case of the irrigation pipeline. Geotechnical investigations of the foundation (i.e. water permeability tests and coring) showed that there was only minimal (practically negligible) amount of seepage in the foundation layer under the dam, so piezometer levels did not show any changes in the water level. In summary, the seepage was confined to the dam body in the close proximity of both, the irrigation and the bottom outlet pipelines.

2.6 REMEDIATION WORKS

In 2008 the reservoir level was lowered to a maximum of 93.6 m asl and the irrigation pipeline was filled with the concrete. The space between the irrigation pipeline and the concrete cover was grouted with the cement grout. After this emergency remediation, the reservoir operational level was additionally lowered to a 92.0 m a.s.l. Operation with the reservoir is recorded in excel file, where you can observe the reservoir drawdown. The reservoir operated under the lowered condition for more than 10 years.

Currently the reservoir is completely emptied and remediation works are underway. During the works the bottom outlet and irrigation pipes will be sealed with concrete filling. New outlet building and outlet tunnel will be constructed in the left abutment, so all of the conduits in the dam body will be permanently sealed. It is estimated that after the completion of the works the reservoir eater level will be raised back to the initial nominal level at 98.8 m a. sl.

3 PROVIDED DATA

Participants are provided with the following data: geometry (.DWG file), reservoir levels, piezometer levels, reservoir level predictions for filling of the reservoir after the remediation works, and geodetic measurements. The description of each data set can be found below.

Data: Geometry
Data format: *.dwg
Data file: Geometry.dwg
Description: Three layers are provided: DAM GEOMETRY (cross-section), WATER LEVELS (maximal operating level: 100.5 m a.s.l., minimal operating level: 80.0 m a.s.l., normal operating level: 98.8 m a.s.l. and depleted operating level: 92.0 m a.s.l.) and BOTTOM OUTLETS. The geometry is positioned at the actual elevation.

Data: Monitoring data – geodetic measurements
Data format: *.xslx
Data file: Displacements.xslx
Description: The data is stored on the Spreadsheets in the document:

- Direction Z: settlements (settlements have a negative value)
- Direction Y: displacement in the upstream-downstream direction; positive value "+" represents displacement in the upstream direction
- Direction X: cross-valley displacement; "+" represents displacement toward the right bank side.

Units: [mm]

Positive directions are graphically presented on the figure below.

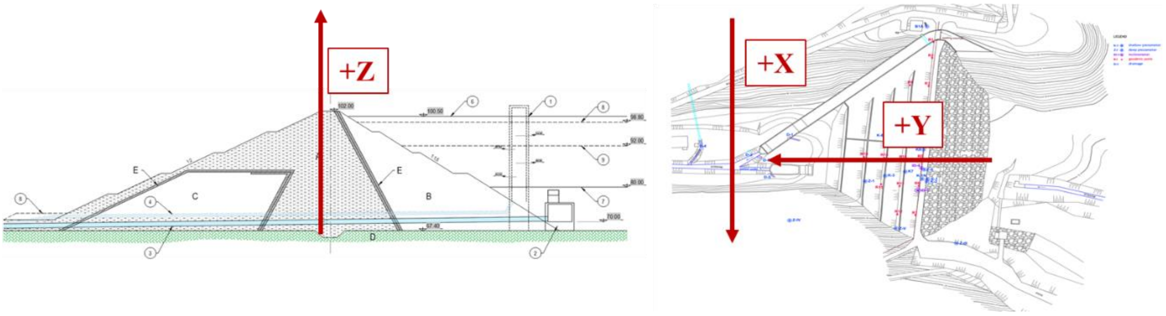

Figure 6: Positive directions for geodetic measurements.

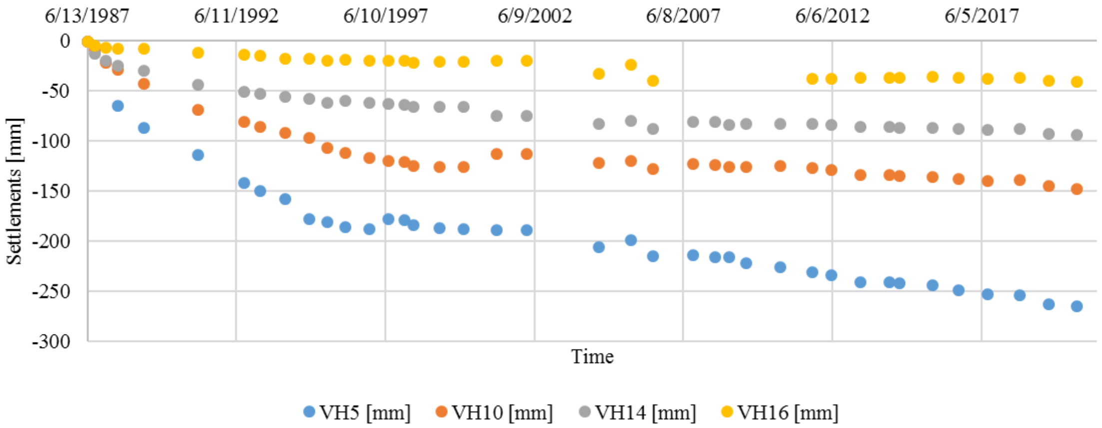

Figure 7: Settlements.

Locations of the geodetic points (VH5, VH10, VH14, and VH16) are marked on the figure below.

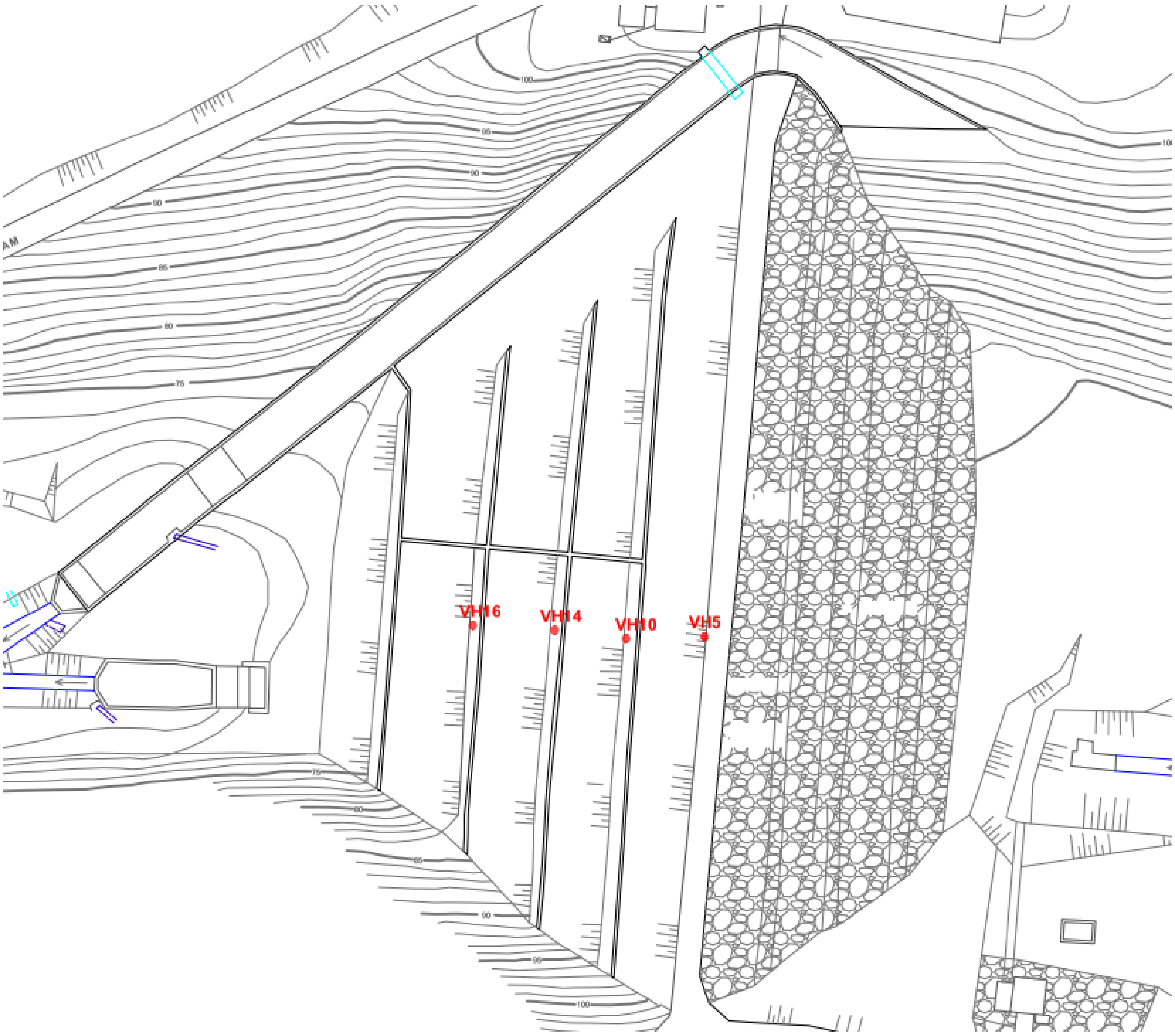

Figure 8: Locations of the geodetic points (VH5, VH10, VH14, and VH16).

Data: Piezometers
Data format: *.xslx
Data file: PiezometersTS
Description: Raw data of the seepage level measured in piezometers. The data are piezometric water level in m a.s.l. The date format is mm/dd/yyyy. There are no empty cells in the data set. Data are for each piezometer is in a separate column. Measurements are taken manually, and have an uneven frequency. Recorded data has been under some basic pre-processing but there may still be some faulty data in the data set.

Piezometer	K2	K3
Length of the piezometer [m]	30.5	20.7
Elevation of the top [m asl]	102.3	91.5

Location of the piezometer in presented on figures 10 and 11.

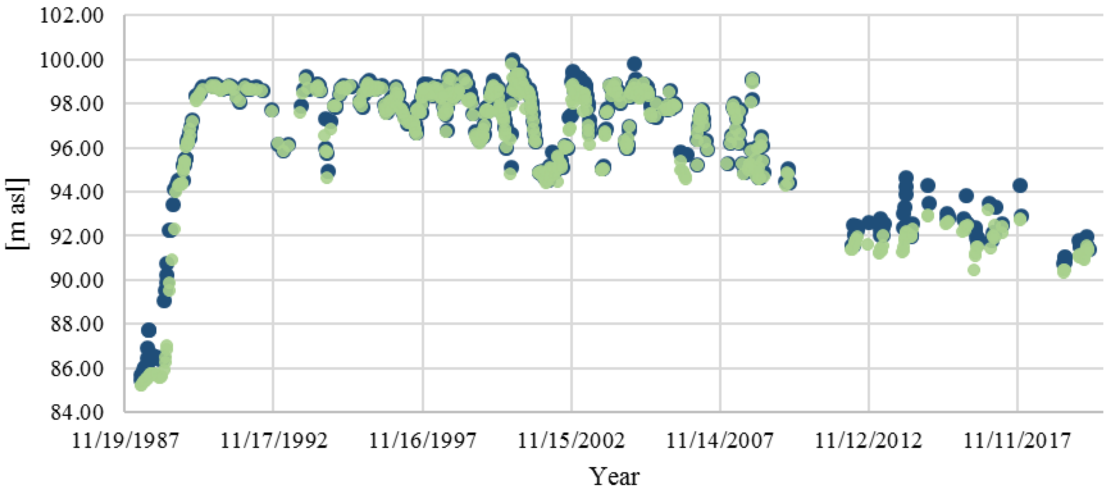

Figure 9: Piezometer levels.

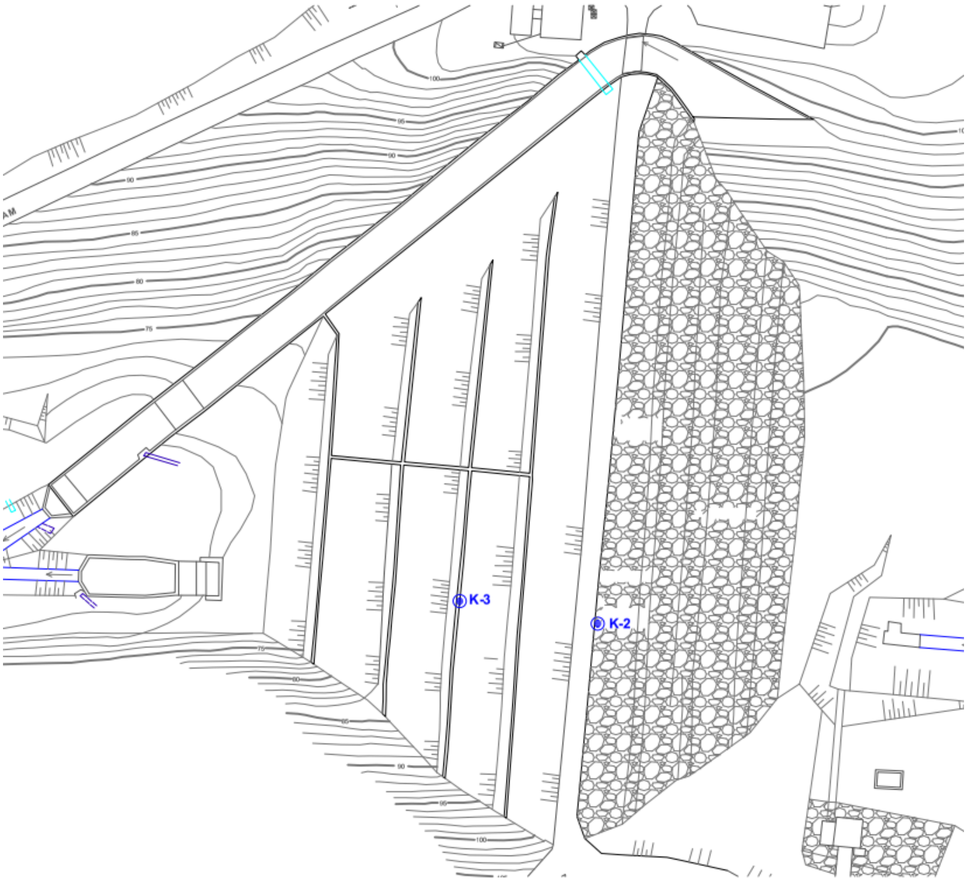

Figure 10: Location of piezometers.

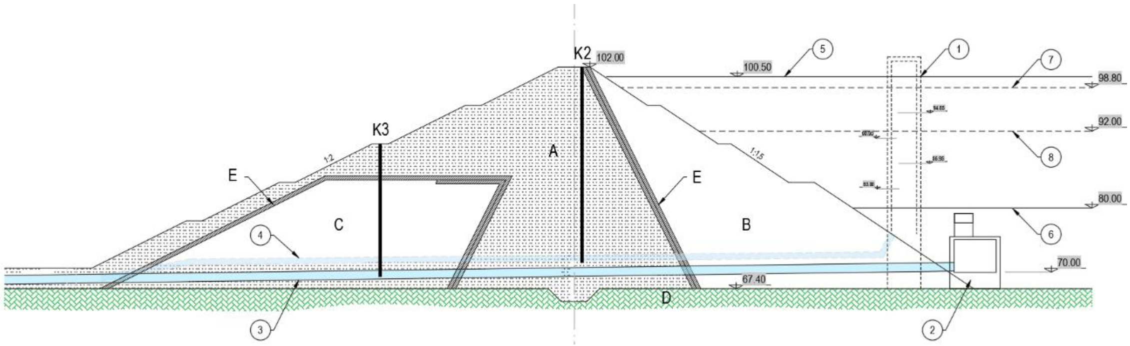

Figure 11: Location of the piezometers K3 and K2 in the cross-section.

Data: Reservoir levels from 1988–2020
Data file: RL.xslx
Description: The data of the reservoir levels are presented in the column and are presented as m above sea level. The date format is mm/dd/yyyy.

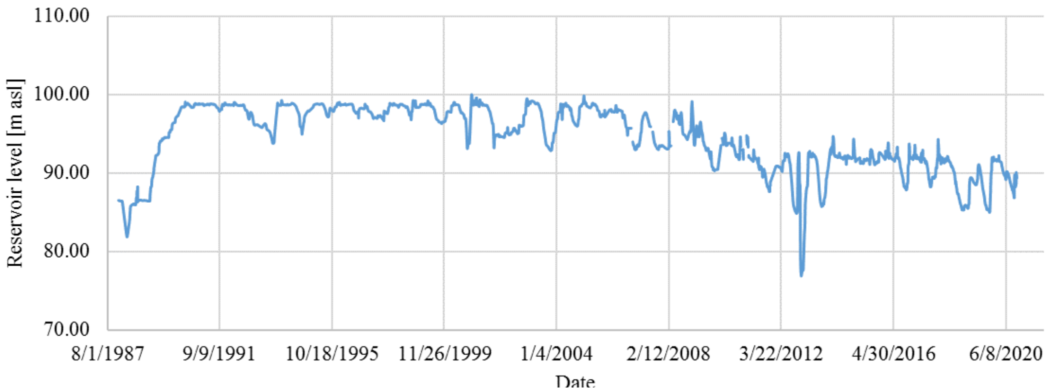

Figure 12: Reservoir levels.

Data: Rising of the reservoir level
Data file: REM_fill.xslx
Description: The data of the reservoir levels are presented in the column and are presented as m above sea level. The date format is mm/dd/yyyy.

4 SIGN CONVETION

To provide consistency among the results, the sign convention of the tension shall be POSITIVE « + » and for compression NEGATIVE « - ». The displacement in the downstream direction shall be POSITIVE « + » and in the upstream direction shall be NEGATIVE « - ».

5 TASKS TO BE PERFORMED

The embankment shape and geometry is very complex. We will ask the contributors to consider 2-D analyses as obligatory and 3-D analysis as optional. In the analysis, the consideration of the foundation layer is obligatory, material properties of the foundation layer are provided. During the geotechnical investigations it was estimated that the foundation is almost impermeable, some permeable zones were grouted and are now considered almost impermeable. The contributors may decide of which constitutive laws and material models for the foundation rock will be used. For the ground we ask the participants to assume ground as homogenous. We ask the participants to describe their modelling assumptions in details. The theme is divided in 4 cases which are presented in Table 2 and detail described in the chapters below. In the analysis we anticipate that all contributors will use the same geometry, material properties, and basic loads, in case when the participants decide to use different parameters, we ask them to explain their decision. The majority of the cases are obligatory, with some optional cases.

Table 2: Division of the tasks.

Case	Tasks
Case 1 (Mandatory, Optional)	**Task 1:** Construction of a 2D model. Calibrate the model using dam surveillance. Estimate the as-built characteristics of the dam. **Task 2:** Evaluate the initial state after the reservoir is filled to the nominal level. Estimate the dam condition before the detection of leakage. **Task 3 (Optional):** Using calibrated data of 2D model, build a quasi 3D FE model (20 m wide section of the dam).
Case 2 (Mandatory, Optional)	**Task 1:** Consider the wet stain using 2D or quasi 3D model. **Task 2:** No action after the appearance of the wet stain.
Case 3 (Mandatory)	**Task 1:** Consider remedial works of the dam, consider long period of reservoir draw-down and its effect of the clay core. **Task 2:** Consider elevation of the reservoir back to nominal level according to the assumed filling times. Evaluate the safety of the dam under the final water level condition of the reservoir.
Case 4 (Optional)	**Task 1:** Seismic analysis.
Finalisation (Mandatory)	**Task 1:** Preparation of the technical paper. **Task 2:** Preparation of the presentation and presentation at the workshop.

* as an optional case the participants can build a full 3D model and perform the required analysis

5.1 DETAILED DESCRIPTIONS OF THE TASKS AND CASES

5.1.1 Case 1: Creation of a 2D model.

In Case 1 a preparation of a 2D numerical model is considered (consider geometry in .dwg file). Prepare the model that captures and represents initial operation conditions in the dam and foundation as realistic as possible. Soil characteristic data from the design phase and also monitoring data of the operation of the dam before the leakage are provided in the data. Boundary conditions are to be defined and justified by the participant.

(a) Task 1 (Mandatory)

While creating 2D model, you should use geometry from the references and soil data from design phase. Consider suitable material properties for the dam and foundation.

The participants are provided with: reservoir levels from 1988–2020, piezometer data, geometry (.DWG file), and geodetic measurements. Provided data should be used for creation and calibration of the numerical model. During the calibration process, any of the soil properties and constitutive laws can be modified, e.g. Mohr-Coulomb, Hardening Soil (i.e. back-analyses should be performed).

For the initial state analysis consider a fully constructed dam and empty reservoir, groundwater level is at the surface elevation.

Perform stability analysis of the dam. Estimate the as-built characteristics of the dam. Estimate settlements at the end of construction and before the first filling of the reservoir. Provide for the critical sliding plane, deformation and stress state of the dam.

(b) Task 2 (Mandatory)

In this task first filling of the reservoir should be considered. The schedule of the filling of the reservoir is provided in excel file and describe in previous chapters. Please evaluate the data and include the process of the reservoir filling in the FE model. Describe the assumption on the inclusion of the reservoir in the FE model. In this scope of this task evaluate the consolidation process over the years. The participants are provided with the data on reservoir and piezometer fluctuations. Perform numerical analysis of the dam, and evaluate stress and steady seepage state for representative situation until the year 2006. Elaborate on any additional changes in the numerical model of the dam. Perform stability and seepage analysis of the dam.

(c) Task 3 (Optional)

In this task we would like the participants to build a quasi 3D model using calibrated data form 2D model of the dam. Add thickness to the 2D dam section, assume plane strain boundary condition on the lateral boundaries of the model. The thickness of the model is 20 m.

5.1.2 Case 2: Appearance of the wet zone (2D and/or quasi 3D)

This case is devoted to the analysis of the wet zone. First of all, we would like for the participants to elaborate on the reasons for the appearance of the wet stain, explain modelling assumptions to consider this extraordinary event. Mandatory part of this task is to analyse the effect of the lowering of the reservoir.

(a) Task 1 (Mandatory)

In your model try to consider a wet stain and different possibilities of occurrence. The results of the emergency investigation on the dam are explained in section 2.5. Moreover, evaluate monitoring data and use the data in the model based on your engineering judgement.

For the quasi 3D model, consider the location of the wet zone to be in the centre of the segment.

Perform stability and stage seepage analysis of the dam.

(b) Task 2 (Optional)

Analyse the scenario that after the appearance the wet stain, the water level would remain at the operational level of 98.8 m asl for 20 years. Perform stability and seepage analysis; and estimate the safety of the dam, provide yearly safety assessment for 20 consecutive years.

5.1.3 Case 3: Remedial works (2D and/or quasi 3D)

This case is devoted to the analysis of the long-term drawdown of the reservoir and its effect on the dam body (i.e. clay core). As can be observed from the monitoring documentation the reservoir is operating at the lowered elevation for over 10 years. Currently the reservoir is emptied and it is estimated that after the completion of the remedial works the maximum reservoir level will be restored. Consider the effect of long-term drawdown of the reservoir on the clay core and modify the FE model. In this task consider that bottom outlet and irrigation pipelines have been permanently sealed.

(a) Task 1 (Mandatory)

In this task analyse the long-term drawdown of the reservoir. Modify the material properties if you assume material changes, for example changes in core permeability. In the paper explain modelling assumptions.

Perform steady seepage and stability analysis of the dam after a yearlong drawdown period (until the last record of the reservoir levels in 2020).

(b) Task 2 (Mandatory)

Task 2 is devoted to the analysis of future state of the dam, after the reservoir is again filled to the maximum level. Gradually rise the level in the reservoir, follow the filling timetable presented in file REM_fill.xslx. Perform seepage and stability analysis of the dam

5.1.4 Case 4: Seismic analysis (Optional)

This case is devoted to perform basic seismic analysis of the dam, after the remediation works.

We ask the participants to decide on whether they will consider the mass of the foundation for the dynamic analysis or not. Moreover, explain on how do you consider damping. Water in the reservoir should be considered to have a unit weight of 1000 kg/m^3 and compression wave velocity of 1439 m/sec.

Estimate natural frequencies for dam-foundation-reservoir system, at the following elevation of the reservoir: empty, operational low, normal operational, maximum. Present the first 6 first natural frequencies of the model and mode shapes.

Perform liner on non-linear dynamic analysis for various reservoir levels at the following elevation of the reservoir: empty, operational low, normal operational, maximum. Consider horizontal peak acceleration of 0.3g and vertical accelerations to be 0.67 of the horizontal. Explain the consideration of the hydrodynamic effect in the reservoir, the reservoir length is 500 m.

6 SCHEDULE AND TIME ESTIMATION

6.1 SCHEDULE

- Announcement of the theme: beginning May 2021
- Model information and input data available for all contributors: September 2021
- Deadline for results and paper submission by the contributors: February 15, 2022
- Instructions from formulators on the BW presentation: February 2022
- BW presentation submitted by the contributors: March 20, 2022
- Draft summary of the results provided to the contributors: March 25, 2022
- Workshop presentations: April 5 or 6, 2022

6.2 TIME ESTIMATION

- Data preparation: 1 week.

- Numerical model and the results: 3 weeks.

- Finalisation:
  - Preparation of the paper: 2 weeks
  - Preparation of the presentation: 1 week. Instructions on the preparation of the presentation will be provided 1 month prior the workshop.

7 SUBMISSION

7.1 GENERAL

The formulators will provide excel spreadsheet for the submission of the results.

The contributors will also be asked to provide basic information, which will help with the synthesis of the results:

- Participants (the team);
- Country;
- Affiliation;
- Numerical code.

The participants are asked to indicate whether their name and affiliations may be revealed during the BW and in the publications.

Before the submission of the. xslx file, please name the file: **Surname*- Theme-C-Data.xslx**

7.2 ANALYSIS RESULTS

The following results should be presented and delivered to the formulators of the theme via the excel template file (will be provided later):

- Properties of the model after the calibration;
- Estimation of the as-built characteristics of the dam;
- Deformation of the dam along the dam centre line in the cross-section (vertical and horizontal displacements);
- Safety factors for the upstream and downstream slope;
- Prediction of the settlements;
- Phreatic line;
- Estimation of the time used to solve the tasks.

7.3 PAPER

Every team is also asked to prepare a summary paper to be included in the Workshop proceedings. Template will be available on the events webpage. In the paper include summary of the results, discussion on the lessons learned, general observations on the parameters that influence the analysis results, modelling assumptions, recommendations for further studies and analysis. The paper should not exceed the length of 12 pages, and should be summited using the file format: **Surname*- Theme-C-Paper.docx**
*surname of the first author

7.4 WORKSHOP PRESENTATION

At the Workshop the formulators will provide a general presentation describing case studies, geometry of the dam, and general information. The formulators will ask the contributors to present their general findings, interesting aspects of their analysis and results, and highlights. The contributors should not include the general presentation of the case study in their presentation, only the information specific to their work and results. The formulators will also prepare summary of all the results and present them at the BW. All the presentations will be followed by the discussion of all workshop participants.

8 REFERENCES

ICOLD Committee on Embankment Dams. (2017). *ICOLD Bulletin 164 INTERNAL EROSION OF EXISTING DAMS , Levees and Dikes , and their Foundations*. Paris: ICOLD - CIGB.

United States Society on Dams. (2010). The aging of embankment dams, (May), 11 p.

Wrachien, D. De. (2009). Dam-break Problems, Solutions and Case Studies, (September), 334. https://doi.org/10.2495/978-1-84564-142-9/04