EXERCISE 3

Verification of an embankment dam

a) Introduction

The dam XYZ has a concrete and an embankment section. The safety assessment of the concrete structures has already identified some shortcomings, so special attention should be paid to the embankment part.

It is requested to carry out the static and seismic safety verifications of the earth-fill embankment parts of the structure according to international practices. The specifications are detailed at the end of this document.

b) Data

<u>Dam type and geometry</u>

The earth-fill embankment on both banks has a clay core, and gradually turns into a rockfill embankment when approaching the concrete structures located on the thalweg of the river. Two embankment cross-sections are available in Figures 1 and 2 (earth- and rockfill embankment). The two sections feature significantly different geometries and materials. The characteristics of the dam are as follows:

Crest:	577.5 MSL
Full supply level:	572 MSL
Maximum water level:	576 MSL
Total reservoir volume:	250'000'000 m^3
Crest length:	780 m

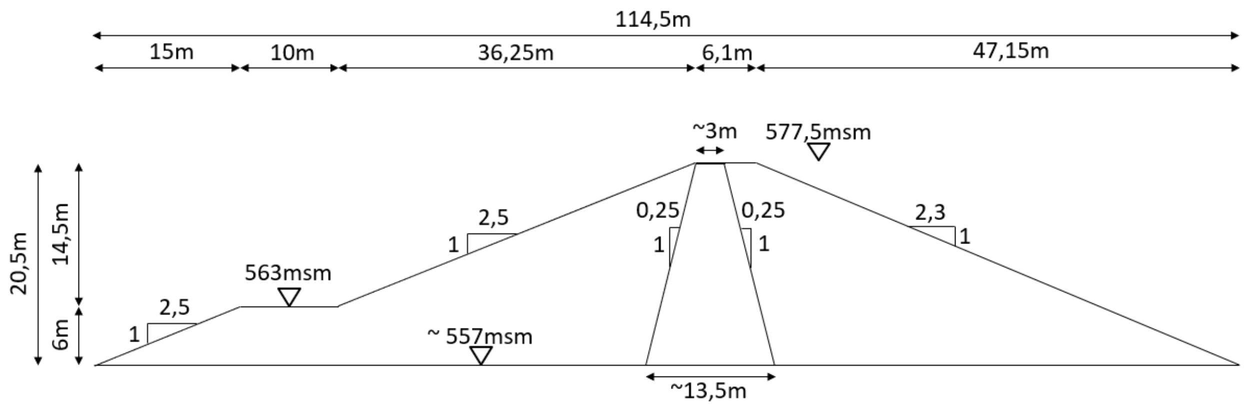

Figure 1 : Earthfill dam with clay core

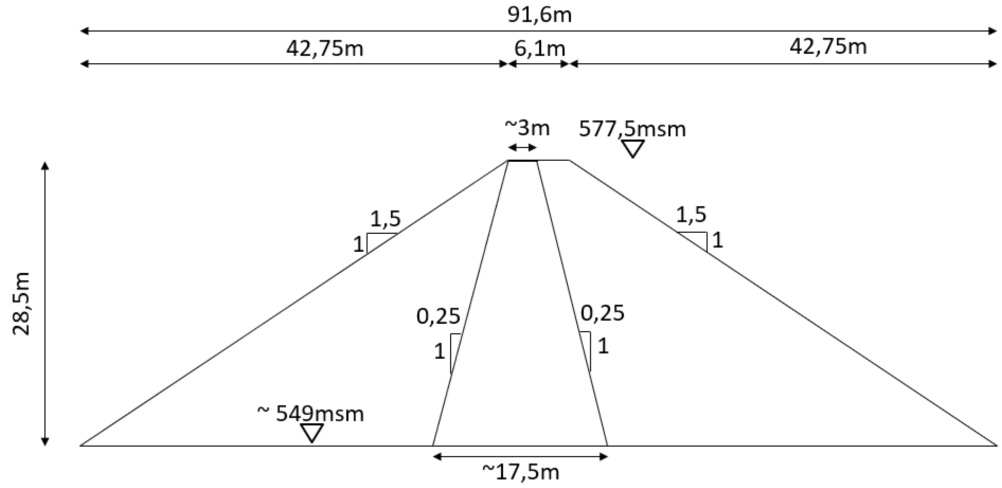

Figure 2 : Rockfill dam with clay core

Earthquake

The horizontal soil acceleration in the region is estimated at 0.15g.

Modeling requirements

In the absence of directives specific to the jurisdiction of the country in question, the application of the Swiss directives is proposed. The modeling requirements of the Swiss C1 directive are presented in Figure 3. The load cases to be considered according to this same directive are presented in Figure 4.

	Water retaining facility category		
Topic	**I**	**II**	**III**
Determination of pore water pressures (em-bankment dams)	2D finite elements or finite differences model	2D finite elements or finite differences model	2D model (empirical)
Determination of interior temperature (arch dams)	2D finite elements or finite differences model	2D finite elements or finite differences model	2D model (empirical)
Verification of overall stability, dams with es-sentially two-dimensional behaviour	2D Model	2D Model	2D Model
Verification of overall stability of other dams	3D finite elements model	3D finite elements model	2D model for each block
Verification of internal resistance, dams with essentially two-dimensional behaviour	2D finite elements model of dam and foundations	2D finite elements model of dam, coarse modelling of foundations	Modelling as simple beam (gravity dams) or analysis of sliding stability (embank-ments); coarse modelling of foundations
Verification of internal resistance of other dams	3D finite elements model of dam and foundations	3D finite elements model of dam, coarse modelling of foundations	Arch-cantilever modelling without torsion (arch dams) or analysis of sliding stability (embankments); coarse mod-elling of foundations

Figure 3 : Modeling requirements according to Swiss directive C1

Individual loads	Load combinations for embankment dams, including abutments and foundations							
	Normal load combinations (Type 1)		Extraordinary load combinations (Type 2)				Extreme load combinations (Type 3)	
							Static	Dynamic
	Empty reservoir (drained embankment)	Full reservoir	Empty reservoir (upon completion of construction)	Design flood	Rapid discharge	Avalanche or mudslide	Flood safety level	Earthquake
Own weight	X	X	X	X	X	X	X	X
Hydrostatic pressure at normal operating level[i)]		X				(X)		X
Pore water pressure at normal operating level[i)]		X			X[iv)]	(X)		X[iii)]
Hydrostatic pressure corresponding to flood level				X			X	
Pore water pressure corresponding to flood level[ii)]				X[ii)]			X[ii)]	
Pore water pressures before consolidation		(X)	X					
Earthquake								X
Pressure due to avalanche or mudslide						X		

Comments

- i) **Normal operating level**: maximum operating level at reservoir with active operation; other facilities, relevant threshold for calculating the storage height in accordance with Part A of the Directive. An **intermediate level** also has to be taken into account if this leads to higher loads.
- i) **Pore water pressures in the event of flood:** adaptation is possible according to duration of flood and effectiveness of drainage system
- iii) **Pore water pressures in the event of earthquake**: or in accordance with the details in Part C3 of the Directive.
- iv) **Pore water pressures in the event of rapid discharge**: a reduction of pore water pressures is permissible for fills comprising well-drained material.
- X Individual influence that has to be taken into account in the load case.
- (X) To be taken into account according to the case.

Please note

- a) Load cases also depend on the type of embankment.
- b) Generally speaking, **ice pressure** does not play a role in the verification of stability of embankment dams.
- c) The other individual loads (cf. section 4.5) have to be taken into account as necessary, in the most detrimental way.

Figure 4 : Combination of forces for load cases, Swiss directive C1.

c) Hypotheses and characteristic material values

The following hypotheses have been accepted on the basis of the project documents as well as the literature for embankment dams.

- The materials constituting the dam are isotropic.
- The material parameters were taken from the detailed preliminary design of the structure and are presented in Table 1. Few geological and geotechnical data are available. The permeability of the materials was estimated using several years old pore pressures measurements, the measuring instruments being non-functional today.
- The absence of as-built drawings or drawings representing the current geometry means that you will use the standard sections dimensioned at the preliminary design stage.
- It is assumed that the clay core is functioning and that the water flows downstream correctly through external drains. **The pore water pressure downstream of the core at the base of the dam must therefore be zero.**
- Type 1 load cases must respect a safety factor of 1.5
- Type 2 load cases must respect a safety factor of 1.2
- Type 3 load cases must respect a safety factor of 1.0 for static cases or have a freeboard of at least 1 m after settlements for dynamic cases
- Parameter values can be used as is in calculations.

Table 1: Material parameters of the embankment

Material	Humid density $[kN/m^3]$	Saturated density $[kN/m^3]$	Friction angle [°]	Cohesion kPa	Permeability $\left[\frac{m}{s}\right]$
Embankment – Shoulder laterites	19,9	20,9	30	10	$1 \cdot 10^{-8}$
Embankment – Core laterites	19.0	19.9	30	10	$1 \cdot 10^{-10}$
Embankment – Rockfill	20.0	22.0	40	0	1
Foundation – Weathered schist	15.7	17.7	26	0	$1 \cdot 10^{-5}$

d) Questions (i.e., particular demands of the client in the contractual Terms of Reference)

It is requested to carry out the verification of static and seismic safety of the earth-fill section of the embankment according to international practices.

Among the load cases proposed by the C1 directive, the customer is interested in the following load cases. For these load cases, it is necessary to respect the modeling requirements for the water flow line inside the dam. Present the seepage line for each case. Also, use the Simplified Bishop and Simplified Jambu methods for each case.

a. Reservoir at full supply level
b. Rapid draw-down
c. Seismic loading

1. Start with the first two load cases.

   Help: for the rapid draw-down load case, you can make the conservative assumption that the water did not have time to escape from the dam body. The flow line will follow the geometry of the dam on the upstream part. You can use the "water table" function to define the level of the water table. To plot the flow line on the entire model, import the profile obtained by the underground flow calculations that you did to obtain the water line inside the dike, then complete the profile manually.

2. As the uncertainty for the permeability values is large, especially for the fill zones, study the impact of this parameter by implementing the first load case with a completely permeable earth-fill embankment. **Comment on the previous results, then use the most unfavorable permeability for the seismic calculations.**

3. Perform the following dynamic load case analyses:

   a. Apply the seismic analysis necessary for a structure of this class according to the C3 directive without taking into account the vertical stress. An accelerogram is available in txt format to import into the Slide 2D software. The freeboard after permanent settlements must be greater than 1 m.

   b. However, as the accelerogram provided was recorded very far from the position of the dam, the client would like to confirm the results with the seismic analysis expected for class II dams. An Excel file and an explanatory note of the Makdisi & Seed calculation method are available for help. **The critical acceleration can be calculated with the simplified Bishop method only.**

   c. In addition, assess the critical multiplication factor that can be applied to the given accelerogram to not exceed a (horizontal) displacement of more than 50 cm, as such a displacement is estimated to compromise the structural functioning of the core.