

## Exam Hydraulic Engineering

Exam: Hydraulic Engineering (201800038)

Date: 13 April 2026

Time: 13:45 - 16:45 (3 hours)

Coordinator: J.J. Warmink

- This exam consists of two parts: one set of **6** multiple choice questions (total 12 points) and one set of **6** open questions about dikes and hydraulic structures (24 points).
- Do not forget to write your name and student number on all papers you hand in.
- Read the questions carefully and answer ALL required parts, otherwise you lose points, because the answer is not complete.
- Please, be concise in your answers but display as much of your knowledge as possible within the available time (so reserve some time for the questions at the end).
- Write the answers of the multiple choice questions on your answer paper and not on the exam.
- For this exam you are only allowed to use pen/pencil, calculator, liner, and the equation form handed with this exam.
- After the exam everything has to be handed in (exam, answers, equation form, questions, scrap paper).

**Good luck!**

## 1 Multiple choice questions [12pt] [time: 1 hour]

### 1.1

Given the clay dike with dimensions in Figure 2. Compute if this dike is safe for uplift. What are the values of the Load (corrected for the partial safety factor) and the Resistance? and would you expect uplift to occur?

- A) Load = 5.1 m; Resistance = 3.5 m; uplift occurs.
- B) Load = 5.1 m; Resistance = 3.5 m; uplift occurs.
- C) Load = 6.1 m; Resistance = 2.1 m; uplift occurs.
- D) Load = 6.1 m; Resistance = 4.1 m; uplift occurs.

### 1.2

Which of the following two statements is true regarding conceptual design using the sill formula for calculating the required opening size of a discharge sluice?

I: When designing your structure for bed protection, one should choose a high value for the discharge coefficient ("C").

II: The minimum size of the opening of a discharge sluice increases if the head difference between inside and outside water level increases.

- A) Both I and II are true
- B) I is true, II is false
- C) I is false, II is true
- D) Both I and II are false

### 1.3

Which of the following two statements regarding a fully probabilistic (Level III) assessment is true?

I: When dealing with exponential tailed empirical distributions, one should use linear interpolation instead of log-linear interpolation.

II: The required number of samples in a Monte Carlo analysis increases if the calculated failure probability decreases.

- A) Both I and II are true
- B) I is true, II is false
- C) I is false, II is true
- D) Both I and II are false

### 1.4

A permeable breakwater (slope 1:3) in a freshwater lake consists of loose concrete blocks (Table 7). Calculate the minimum size and mass of the concrete blocks using the Hudson equation. The design storm has a storm surge level of 2.1 m+NAP, a significant wave height of 1.4 m, wave period of 5.2 s, storm duration is 6 hours.

- A) Size = 0.44 m; Mass = 200 kg
- B) Size = 0.69 m; Mass = 800 kg
- C) Size = 0.91 m; Mass = 1.8 metric ton
- D) Size = 1.31 m; Mass = 32.8 metric ton

### 1.5

Is a discharge sluice in a dike trajectory with a safety level of 1/3000 safe for the reliability of closing criterion? Given that there are three hydraulic structures in this dike ring ( $N=3$ ), the open retaining level (OKP) is exceeded once every 1000 years, and the  $E = \min(E1, E2, E3, E4) = 2.5$  based on the score sheet. Please note that the failure probability budget factor ( $\omega$ ) needs to be considered.

- A) No this structure is not safe for reliability of closing, because  $P_{fa,req} (=1/37,500) < P_{fa,nc} (=1/400)$ .
- B) Yes, this structure is safe for reliability of closing, because  $P_{fa,nc} (=1/37,500) < P_{fa,req} (=1/400)$ .
- C) No this structure is not safe for reliability of closing, because  $P_{fa,req} (=1/316,228) < P_{req,nc} (=1/225,000)$ .
- D) Yes, this structure is safe for reliability of closing, because  $P_{fa,nc} (=1/316,228) < P_{fa,req} (=1/225,000)$ .

### 1.6

In a probabilistic safety assessment, the failure probability is determined by probabilistically evaluating  $Z = R - S$  (Figure 1, next page). What happens to the failure probability,  $P(Z < 0)$ , if the uncertainty (standard deviation) of the strength decreases, because a more accurate method for determining the soil characteristics is used in the probabilistic assessment?

- A) The failure probability will remain the same.
- B) The failure probability will decrease.
- C) The failure probability will increase.
- D) There is not enough information to determine this.

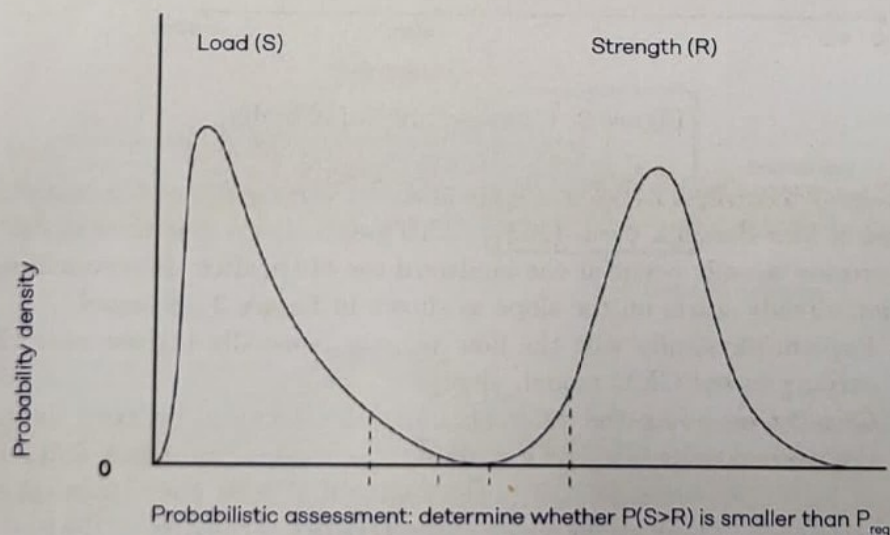


Figure 1: Probability distributions of the Load (S) and Strength (R)

## 2 Open questions

For all the following questions, in case of calculations, make clear which equations you use and which steps you take to get to the final answer.

### Dikes and Structures. [24 points; 1.5 hours]

- 2.1 (4 points) Given the clay dike with dimensions in figure 2. Calculate if this dike is safe for piping under design conditions using the Sellmeijer (2011) equation. Sea level rise, local surge, uncertainty additions and settlement can be neglected, but damping of the hydraulic head needs to be taken into account and is given as:  $r_{exit} = 0.7$  at the location of the landward toe of the dike. It is given that  $F_R = 0.37$ ,  $F_S = 0.18$  and the model uncertainty factor for Sellmeijer:  $m_p = 0.95$ , so  $F_G$  still needs to be calculated. What are the values of the critical head difference for piping ( $\Delta H_c$ ) corrected for vertical outflow and the actual hydraulic head difference for piping ( $\Delta H$ ) corrected for damping? Is piping expected to occur?

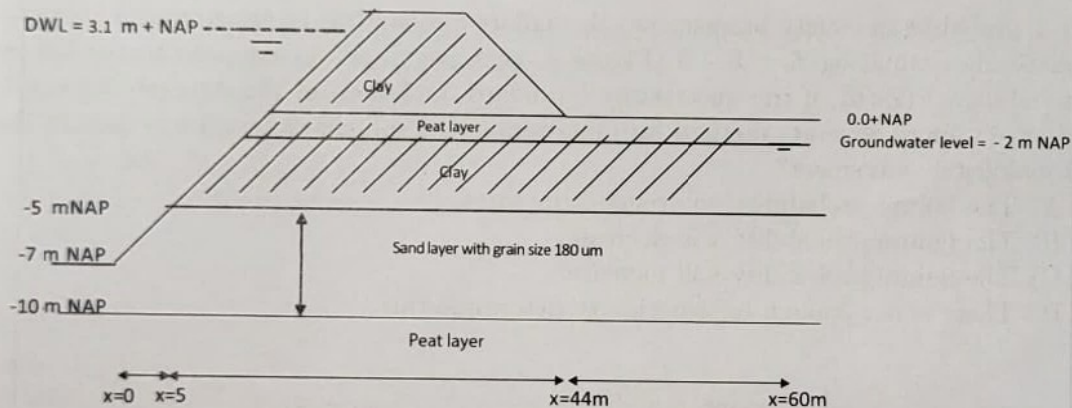


Figure 2: Cross sections of clay dike

- 2.2 (4 points) The right panel of Figure 3 shows the results of the analytical GEM model of Van Bergeijk et al. (2021). This graph shows that the highest velocities and erosion usually occur at the landward toe of the dike. However in some cases erosion already starts on the slope as shown in Figure 3 left panel.
- Explain physically why the flow velocity is usually highest near the toe according to the GEM model. [1 pt]
  - Give 2 reasons for the difference in erosion location between the model and the observations, e.g. which physical processes cause this difference. Give at least one reason related to the load and at least one reason related to the resistance. Think about which characteristics of the dike or the flow processes are thus not realistically included in the model. Briefly explain your answer. [2 pt]
  - Explain based on Figure 3 (right panel) if this dike is safe according to the GEM failure definition. [1 pt]

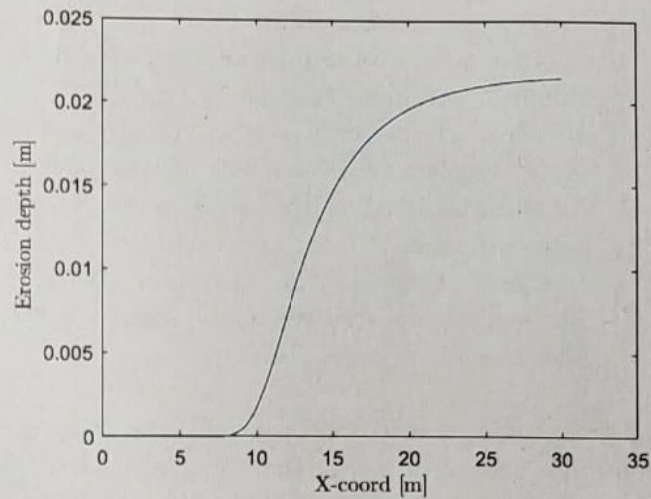


Figure 3: Left: picture of erosion after a wave overtopping test. Right: plot of erosion depth along the slope from the GEM model for the same conditions with X-coord=0 is the location of the waterside crest line.

2.3 (4 points) Figure 4 shows two screenshots from D-Stability. The top one shows the dike geometry and the bottom one the head lines and minimum slip circle.

- Which line shows the phreatic water level in the dike and which line shows the hydraulic head in the aquifer. Briefly motivate your answer. [1 pt]
- Then explain and sketch for both lines how each line affects all the driving and resisting forces for the indicated slip circle based on Bishops method. Also indicate the active and passive side in your sketch. [3 pt]

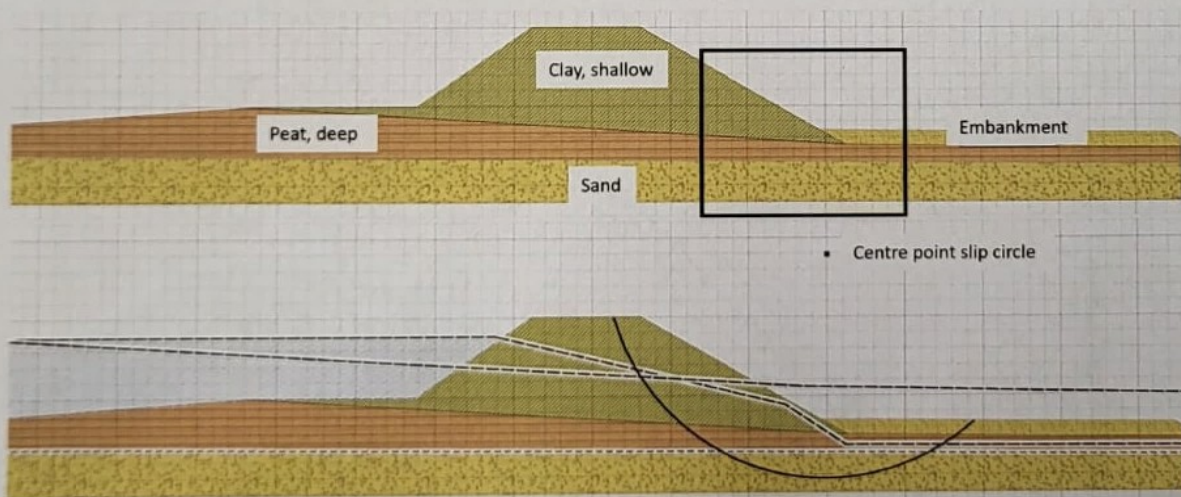


Figure 4: D-Stability screenshots. Top panel: dike geometry and materials. Bottom panel: minimum slip circle Bishop and head lines.

- 2.4 (4 points) Physical model testing is used to test hydraulic structures in a laboratory under design storm and wave conditions to verify the design of specific structures or to acquire knowledge and data for the development of design guidelines.
- Explain why it is important to have active reflection compensation in wave flumes to simulate realistic waves? [1pt]
  - Physical model facilities are typically classified as either small scale or large scale. Explain why for some situations you would need a small flume, while for other situations you would need a large flume. Give at least two reasons/situations. [1.5pt]
  - In a near-shore situation, a general rule of thumb is that 1 m of sea level rise will lead to an increase in the required crest level of dikes of 2.5 m. Explain why this is the case. [1.5pt]
- 2.5 (4 points) Given a vertical seawall protecting a harbour, calculate the minimum required crest level given that 50 l/s/m overtopping discharge is allowed. The design storm has a storm surge level of 2 m+NAP, a significant wave height of 2.7 m, wave period of 7.1 s, storm duration is 6 hours, waves approach the structure perpendicularly and no nose is present. You need to account for SLR (0.6 m) and include water level uncertainty (0.4 m).
- 2.6 (4 points) See figure 5 below.
- Give two reasons that may explain where the scatter in the data points comes from. [2pt]
  - Explain physically why there is an inflection point around  $\xi_{m-1,0} \approx 1.7$  in the fitted trend line. [1pt]
  - Which fitted line (solid line, upper dotted line, lower dotted line) you would use in a design situation. Briefly motivate your answer. [1pt]

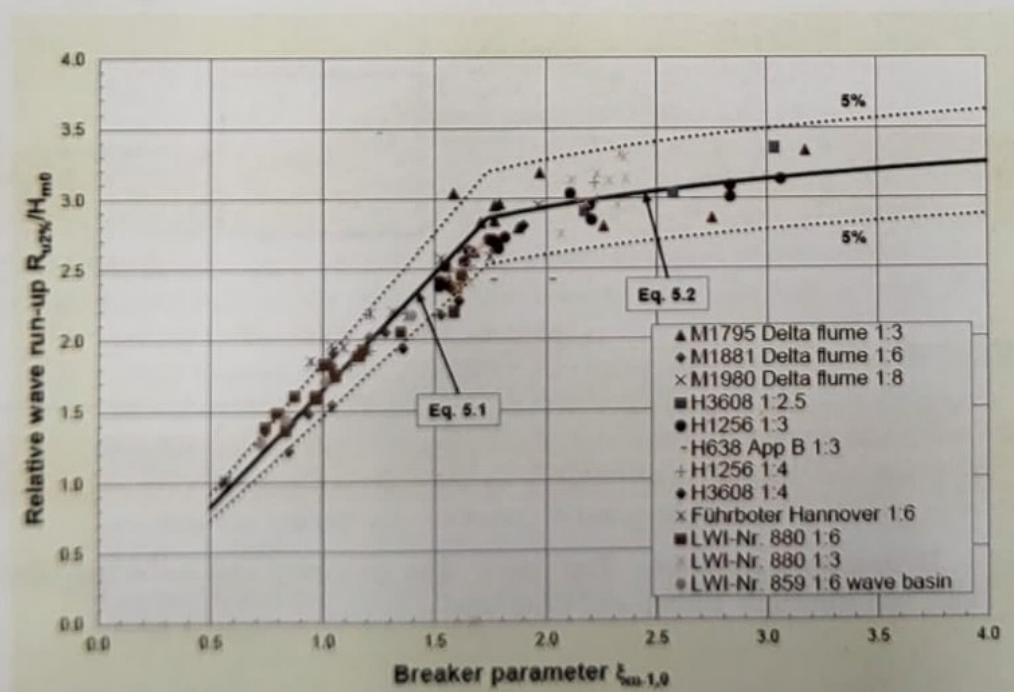


Figure 5: source EurOtop II (2018)