

Exam Hydraulic Engineering

Exam: Hydraulic Engineering (201800038)

Date: 18 April 2023

Time: 8:45 - 11:45 (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 **7** open questions about dikes and hydraulic structures (26 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 answer all parts of the question. 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: 0.5 hours]

1.1

A fitted Gumbel distribution on historical peak water levels is characterized by $\mu = 1.05$ and $\sigma = 0.75$. What is the water level that corresponds to a 3000 years return period?

- A) WL=2.61 m+MSL
- B) WL=6.23 m+MSL
- C) **WL=7.05 m+MSL**
- D) WL=9.16 m+MSL

1.2

Which of the following two statements is/are true for improving an unsafe dike?

I: A berm on the waterside slope of the dike may decrease the required crest level.

II: An increase of the groundwater level on the landward side of the dike may decrease the risk of failure due to piping.

- 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

Your colleague has used the D-stability software and computed a safety factor FS of 1.31. Given the following values of the partial safety factors: $\gamma_{norm} = 1.05$, $\gamma_{mod} = 1.1$ and $\gamma_{dam} = 1.2$. What is the final safety factor (γ_{Bishop}) for this dike and is it safe for macrostability?

- A) $\gamma_{Bishop} = 0.86$, the dike is not Safe
- B) $\gamma_{Bishop} = \mathbf{0.95}$, the dike is not Safe
- C) $\gamma_{Bishop} = 1.20$, the dike is Safe
- D) $\gamma_{Bishop} = 1.58$, the dike is Safe

1.4

Given the fixed failure budget, depicted in the equation form (table ??). What is the maximum allowed probability of failure for piping below a single structure, given that the dike trajectory has a maximum allowed probability of flooding of 1/30,000 and there are three independent hydraulic structures in the dike trajectory.

- A) $P_{req,sect} = 1/1,800 \text{ year}^{-1}$
- B) $P_{req,sect} = 1/30,000 \text{ year}^{-1}$
- C) $P_{req,sect} = 1/375,000 \text{ year}^{-1}$
- D) $P_{req,sect} = 1/1,500,000 \text{ year}^{-1}$
- E) $P_{req,sect} = \mathbf{1/4,500,000 \text{ year}^{-1}}$

1.5

Figure ?? shows the cross sections of a shipping lock. Place the 10 letters on your answer sheet. Place the 8 numbers in the figure behind the corresponding terms of the lock components below. Note that there are 10 letters: give both components that are *not* depicted in figure ?? the number 0.

- | | |
|--------------------------------|--------------------------|
| A) Lock heads | F) Bottom protection |
| B) Lock gates | G) Screens (sheet piles) |
| C) Stop logs | H) Guard wall (jetty) |
| D) Lock chamber | I) Waiting berth |
| E) Filling and emptying system | J) Sill |

- correct A2, B1, C0, D3, E4, F7, G8, H6, I5, J0;
- or 1B, 2A, 3D, 4E, 5I, 6H, 7F, 8G, 0C, 0J
- pts: -0.25 pt each wrong; so 2 correct = 0 pts. 6 correct = 1 pt; 10 correct = 2 pts.

1.6

Consider the lock system with a pile foundation drawn in figure ?? and the sand layer below the lock floor consists of average course sand. Which would be the optimal design of the sheet piles?

- A) Use 1 sheet pile of 24 m below the lock door at the low water level side.
- B) Use 1 sheet pile of 9.7 m below the centre of the lock.
- C) **Use 2 sheet piles of 6 m each below the doors at both sides of the lock.**
- D) Use 1 sheet piles of 4.8 m below the lock door at the low water level side.
- E) No sheet piles are required in this case, because the lock has a pile foundation.

1.7 Summary

1:C; 2:A; 3:B; 4:E; 5:list; 6:C

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 For each of the *three* main failure mechanisms for dikes, describe two realistic measures during design of a dike reinforcement to increase the safety of the dike *and* describe which of the two solutions you would recommend. So in total $3 \times 2 = 6$ different design solutions need to be described. (3 points)

Answer [3 pt]

Overflow/topping: increase height [0.5 pt] decrease slope/increase roughness [0.5 pt], recommended measure depends on reasoning [-0.5 pt if unrealistic]

Macrostab: add landward berm [0.5 pt] or decrease landward slope [0.5 pt] or drain dike or add sheet pile (expensive). recommended measure depends on reasoning [-0.5 pt if unrealistic]

Piping: add berm [0.5 pt], decrease landward slope [0.5 pt] or increase water level or add sheet pile (expensive) recommended measure depends on reasoning [-0.5 pt if unrealistic]

Not indicating the preferred solution [-0.5pt]

- 2.2 Describe for each of the *three* main failure mechanisms for hydraulic structures, how a decrease of the maximum allowed failure probability of the dike trajectory in which the structure is located (e.g. from 1/4000 to 1/10,000) will affect the detailed safety assessment *and* the final safety judgement of a shipping lock in that trajectory. The lock itself does not change. In other words, explain which values or parameters in the detailed safety assessment will change for the three main failure mechanisms for the lock due to the more strict safety level. Do not compute. (3 points)

Answer : [3pt]

Failure due to overflow/overtop (HTKW): increase of design water level and/or design wave height/period [0.5pt], lock becomes less safe due to more overtopping due to change in design conditions [0.5pt]

Failure due to not-closing BSKW: n_f remains the same, but higher required prob,nc [1pt], more strict norm, same situation less safe w.r.t. norm.

Failure due to collapse: higher loads [0.5pt], so stronger construction required [0.5pt]

- 2.3 Describe the different stages in the dike cover erosion process during wave overtopping for a dike. In your explanation follow the steps of the analytical grass erosion model (GEM) of Van Bergeijk et al. and explain how overtopping may lead to dike breach (i.e. how does overtopping start and lead to dike breach). Use at least the terms storm duration, significant wave height, wave runup, wave volume, critical flow velocity and headcut erosion in your answer and sketch the consecutive steps. (4 points)

answer : [4 pt]

Sketch with wave volumes on dike crest flowing over dike, causing erosion hole [1 pt];

waves in front of dike are characterized by certain **significant wave height**, but individual different heights. waves **runup dike** during **storm** [0.5pt]

some waves reach crest and overtop, with **different volumes** [0.5 pt]

water flows over crest and slope with certain (front) velocity [0.5 pt]
 where flow has higher velocity than **critical velocity** erosion starts [0.5 pt]
 after **cumulative erosion** causing a cliff,
 retreating by **head-cut** causing dike breach [0.5 pt]
 NO individual wave volumes [-1 pt], NO cumulative erosion [-1 pt]

- 2.4 Given the clay dike in figure 1. Compute if there is a danger for uplift under design conditions. Sea level rise, local surge, uncertainty additions and settlement can be neglected. Give the value of the critical water pressure difference for uplift (dH_{crit} in [m]) and the actual hydraulic head difference for uplift corrected for the partial safety factor (see equation form) ? Explain your calculation and state if uplift is expected to occur or not. (3 points)

Answer: [3 pt]

2 layers, $\gamma_{sat, clay} = 17$; $\gamma_{sat, peat} = 10$; $dH_{crit} = 17 - 10/10 \cdot 1.5 + 10 - 10/10 \cdot 0.5 = 1.05 + 0 \text{ m}$ [1pt], only 1 layer [-0.5]
 $dH = 1.2 \cdot (2.5 - 0.5) = 3.6 \text{ m}$ [1pt], no correction [-0.5 pt], no groundwater [-0.5 pt]
 conclusion $dH > dH_{crit}$, so uplift is expected to occur [1pt]

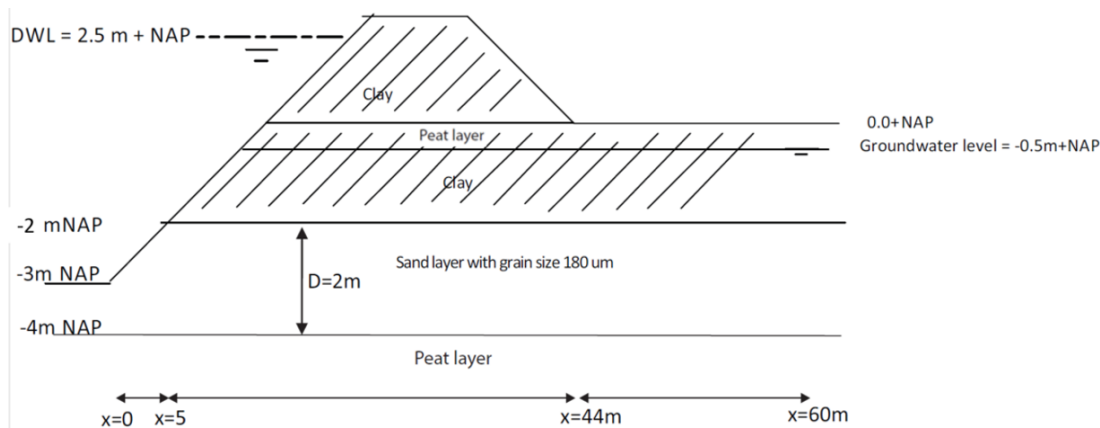


Figure 1: Cross-section of a dike and subsoil.

- 2.5 Copy figure 1 on your answer sheet and sketch the minimum normative slip circle (approximately). Assume that uplift occurs and explain how uplift affects macrostability. Indicate in the sketch and explain where all the driving and resisting forces for macrostability are located and how they might lead to failure of the dike. You can assume a saturated situation. (4 points)

answer: [4 pt]

Sketch, minimum through crest [1/2] and bottom through peat [1/2] and sketch uplift horizontal plane [0.5 pt]; [sketch total max 1 point]
 Driving forces are weight of soil in active side [1/2 point].
 Resisting is shear along plane [1/2] and weight in passive side [1/2].
 If driving $>$ resisting, plane slips and dike fails. [Description total 1 1/2 pt]
 Explain uplift reduces grain friction along uplift plane (and slip plane) to zero [1 pt]

- 2.6 The crest level of a dike is 4.21 m + NAP, the design water level is 1.98 m + NAP, sea level rise, local surge and settlement can be neglected. The significant wave height in front of the dike is 1.25 m with a wave length (in deep water) of 34 m. The landside and waterside slopes of the dike are 1:4 and the dike cover consists of an open sod on good clay (see table ?? in equation form). There are no berms and

no walls on the slope and the waves approach the dike perpendicularly. Calculate if the freeboard between the dike crest and the still water level is sufficient to comply with the safety standards for overtopping (design conditions). Explain your calculation and state if the dike is safe or not. (4 points)

Answer: [4 pt]

$q_{\max} = 5 \text{ l/s/m}$ (open sod, good clay) [0.5 pt] $R_c = 4.21 - 1.98 = 2.23 \text{ m}$ [0.5 pt]

$s_0 = 0.0368$; slope = 1/4; calculate $\xi = 1.3048$ (so breaking waves) [1pt]

use correct equation [0.5 pt]

fill in $q=5$ to calculate $R_c = 1.91 \text{ m}$ (minimum needed) [1 pt]

OR: fill in $R_c = 2.23$; $q = 2.14 \text{ l/s/m}$ (expected overtopping [alt 1 pt]

Conclude: $R_{c_{\min}} < R_c$, so safe; OR: $q > q_{\text{allowed}}$, so safe [0.5 pt]

2.7 Figure 2 shows experimental data from very shallow foreshores (Van Gent; squared data points) and experimental data from deep water conditions (Van der Meer; circle data points), both for plunging waves. Both the best fit line (solid) and 5% exceedance line are shown.

a Which condition (shallow foreshore or deep water in front of the structure) requires larger rocks for the same damage level and storm conditions. Explain your answer based on the information in the figure. (2 points)

Answer: [2pt]

Circles (deep water) are generally located below the squares [1pt]

This means that for same wave conditions less damage is observed for deep water conditions compared to shallow conditions. [1pt]

b Given a significant wave height and period of 1.8 m and 6.4 s (wave steepness = 0.023) in deep water conditions, a structure with an impermeable core (Figure ??) and a waterside slope of 1:4. Calculate the minimum *Mass and Diameter* of concrete blocks in a rock revetment to prevent initial damage of the rock revetment. For simplicity you can assume plunging waves if $\xi \leq 2$. (3 points)

Answer: [3 pt]

Calculate rock stability (vd Meer), if Hudson used also ok (see below)

Storm duration assumption (6 hours) $N = 3375$; 5 hours $N = 2250$; 1 hour $N = 562$; 8 hours $N = 4500$ [0.5pt]

$\rho_{\text{rock}} = 2400$; $P = 0.1$; $S_d = 3$ (slope =4) [0.5 pt]

$\xi = 1.65$ [0.5 pt]

Gives $D_{50} = 0.69 \text{ m}$ [0.5 pt] (so 2 points total for correct calculation).

Convert diameter to mass = 799 kg [1pt]

Alternative HUDSON (because not given that vdMeer should be used)

$K_D = 1$ (reason impermeable and initial damage) [1 pt]

Filling in Hudson gives $W_{50} = 12.5 \text{ kN}$ [1pt]

Converting to diameter and mass gives 1275 kg and diameter = 0.81 m

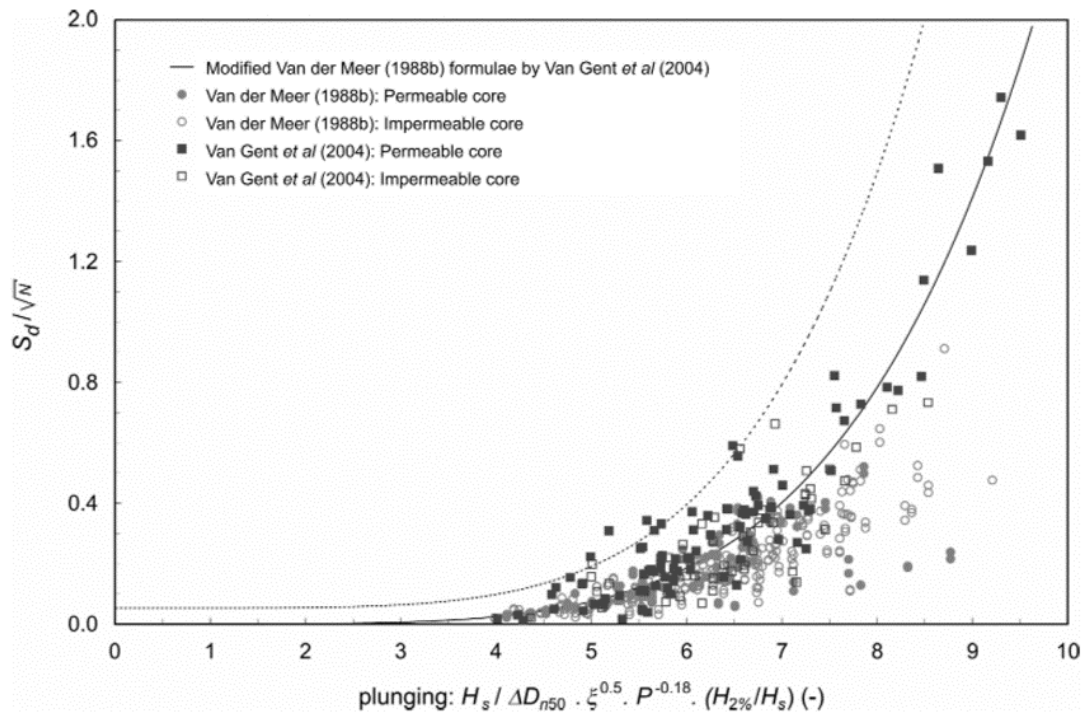


Figure 2: Data from Van der Meer (1998) in deep water and Van Gent *et al.* (2004) in shallow foreshores, both for plunging waves.