

Exam Hydraulic Engineering

Exam: Hydraulic Engineering (195410300)

Time: 3.5 hours

Coordinator: J.J. Warmink

- This exam consists of three parts with equal points: XX multiple choice questions (total XX points) and 2 open questions (XX and XX points, respectively).
- Do not forget to write your name and student number on all papers you hand in.
- Write the answers of the multiple choice questions on your paper and not on the exam.
- For this exam you are only allowed to use pen, paper, calculator, liner, and the equation form handed with the exam.
- After the exam everything has to be handed in (answers, equation form, questions, scrap paper).

good luck!

1 Multiple choice questions [25pt]

1.1

In Figure 1 you see some failure modes, place their numbers behind the corresponding failure mode.

- A) Collision
- B) Coupures
- C) Erosion outer bank
- D) Erosion outer slope
- E) Ice
- F) Macrostability inner slope
- G) Macrostability outer slope
- H) Microstability
- I) Non water retaining elements
- J) Pipelines
- K) Piping
- L) Settlement

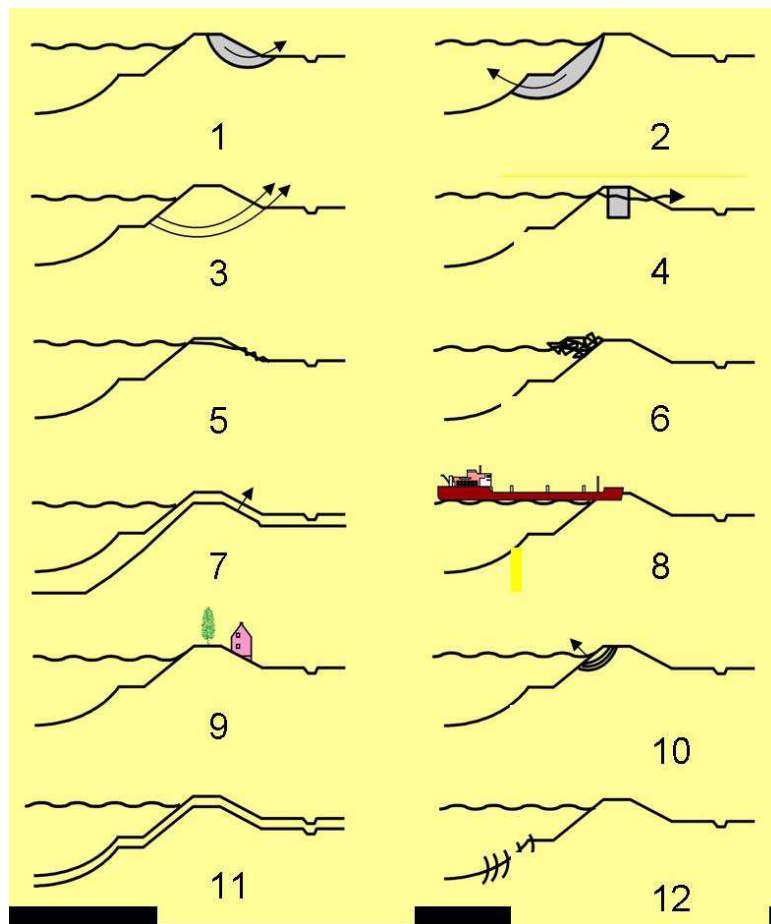


Figure 1: Failure mechanisms

1.2

A double storm barrier between a lake and the sea is closed during a storm. However, the gate closest to the sea is not closed totally but kept with 1-2m opening at the bottom. Why?

- A) To allow shelter for fish
- B) To have enough counter pressure against the water pressure under the construction
- C) To reduce the strong salt water - fresh water separation
- D) To spread the forces over both doors

1.3

There is more risk for piping under a clay dike than under a sand dike, why?

- A) Clay dikes are often narrower
- B) Under clay dikes the water flows quicker
- C) The pipes collapse under a sand dike
- D) The statement is wrong, piping occurs more often under a sand dike

1.4

Behind a dike there is often a ditch, why?

- A) To reduce the chance on uplift (Dutch: opdrijven)
- B) To get rid of water when overtopping occurs
- C) To reduce the chance on piping
- D) None of the statements above are true

1.5

In figure 2 you see some different gates, place the numbers of the pictures behind the correct gates.

- A) Mitering gate
- B) Radial lock gate
- C) Sliding door
- D) Tilting gate
- E) Vertical lift gate

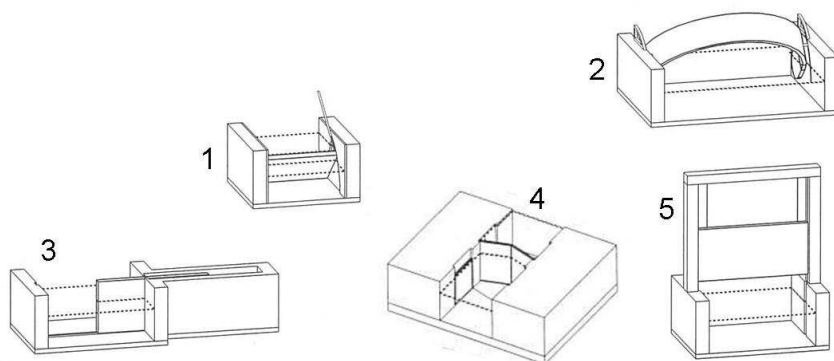


Figure 2: various gates

1.6

In figure 3 you see a side view of a hydraulic structure. Calculate the needed depth of the 2 sheet piles at both sides of the hydraulic structures to avoid piping. Additional data: Water level upstream: NAP+23.4 m, Water level downstream: NAP +21.1 m, Soil properties: fine grained sand.

- A) 1.0m
- B) 2.1m
- C) 2.7m
- D) 4.0m
- E) 5.3m
- F) 7.3m
- G) 8.1m
- H) 8.6m

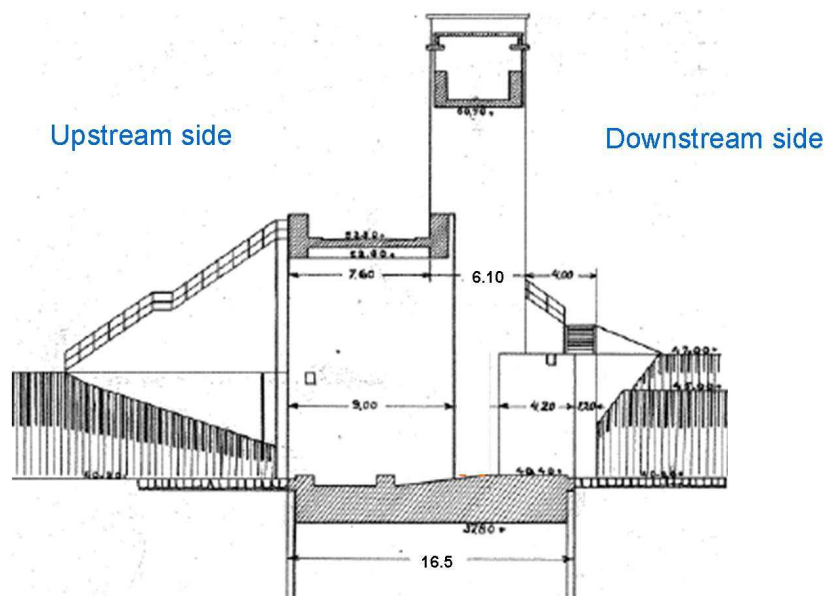


Figure 3: lockhead dimensions.

1.7

What is the relation between the accepted chances of the failure of constructions in the Dutch regulations for hydraulic works?

- A) exceedance probability open structure = exceedance probability closed structure = collapse probability
- B) exceedance probability open structure = $0.1 \times$ exceedance probability closed structure = $0.01 \times$ collapse probability
- C) exceedance probability open structure = $10 \times$ exceedance probability closed structure = $100 \times$ collapse probability
- D) exceedance probability closed structure = $0.1 \times$ exceedance probability open structure = $0.01 \times$ collapse probability
- E) exceedance probability closed structure = $10 \times$ exceedance probability open structure = $100 \times$ collapse probability

1.8

Considering the following statements about the results of a Cone Penetration Test:

- I The local skin friction (Dutch: mantelwrijving) of clay is generally larger than the skin friction of sand.
 - II A friction number (Dutch: kleeftal) larger than 10 indicates a peat layer.
- 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

1.9

Consider the following statements about resilience:

- I Resilience is the ability of the system to withstand a loading above its design standard.
 - II Resilience strategies are more important for systems with low return periods than for systems with high return periods.
- 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

1.10

In the design of an (offshore) wind turbine there is one important factor that has to be taken into account when calculating the strength and dimensions, which is not important for e.g. a lock. What is that?

- A) The effect of scouring
- B) The eigenfrequencies of the turbine
- C) The weight of the structure
- D) Wave effects

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.

2.1 [30 pt]

A canal is connected to a lake with a lock. The land is protected by dikes, both along the lake and the canal. Although in general the canal has a slightly higher water level, in case of a storm the water level in the lake can increase near the lock due to wind set up and waves. Figures 4(a) and 4(b) give a sketch of the lake dike and of the lock.

The dike next to the lake consists of clay covered with grass and has a crest height of $4.7\text{m}+\text{NAP}$ and a crest width of 4m . The average slope is $1:5$ on both sides. On the lake side of the dike the bed level is $-3\text{m}+\text{NAP}$ and the bottom of the lake can be assumed horizontal. The design water level for the lake is $2\text{m}+\text{NAP}$, with waves with a significant wave height of 1.6m and a wave period of 5s . You can assume that the waves are perpendicular to the dike and the lock. The water level in the canal has a constant level of $1\text{m}+\text{NAP}$.

The ground below the lake dike consists of a clay layer of 1.5m thick. Below the clay layer there is a thick sand layer with a median grain size of $180\text{ }\mu\text{m}$. The wet volumetric weight of clay is 15 kN/m^3 and of sand is 20 kN/m^3 . The land behind the dike is located at $-0.5\text{m}+\text{NAP}$ and the groundwater level is 0.5m below the land surface.

The conditions in front of the lock are equal to the conditions in front of the lake dike. The bottom of the lock is located at $-2.5\text{m}+\text{NAP}$; the space between the bottom of the lock and the lake bottom is filled up with rock armour.

- Calculate if wave overtopping occurs over the lake dike and if this is the case how much. Is this dike safe with regard to overtopping?
- Suppose that overtopping occurs and it is not feasible to heighten the dike. Give 2 possible measures that can reduce the overtopping rate.
- Calculate if there is a risk for piping for the lake dike.
- Suppose that the dike is not safe against piping. Give 2 possible measures to reduce the risk of piping.
- Describe qualitatively all the forces that work on the lock structure depicted in figure 4(b).
- Calculate the needed height of the doors. Take into account (1) an additional settlement of 10 cm in the plan period and (2) an increase in the design water level in the lake of 0.5 m in the plan period. Assume that only overtopping is allowed (max. 2 l/s/m).
- Suppose the doors have a height of 3.5m above the SWL (neglect the sea level rise and settlement in the previous question). Make a *quantitative* sketch (write the values in your sketch) of the hydrodynamic, hydrostatic and the total pressure on the lock door that connects the lock to the lake under design conditions *and* calculate the total resulting force on the door per meter width. To reduce the number of computations P_1 (GODA) is already computed and is 23 kN/m^2 and the specific weight of water is 10 kN/m^3 . (Tip: use eq. 26 and 27 to compute hyperbolic functions)
- Suppose that the bottom of the lake in front of the lock is not horizontal but sloping upward towards the lock. Describe qualitatively what would be the effect of a sloping bottom on the total pressure on the lock door.

- i) The lock will be used for transporting wind turbines from the building location to the lake. For building wind turbines and tunnels, the logistics chain is of key importance. Describe the different parts of the logistic chain and explain briefly why the logistic chain is of key importance.

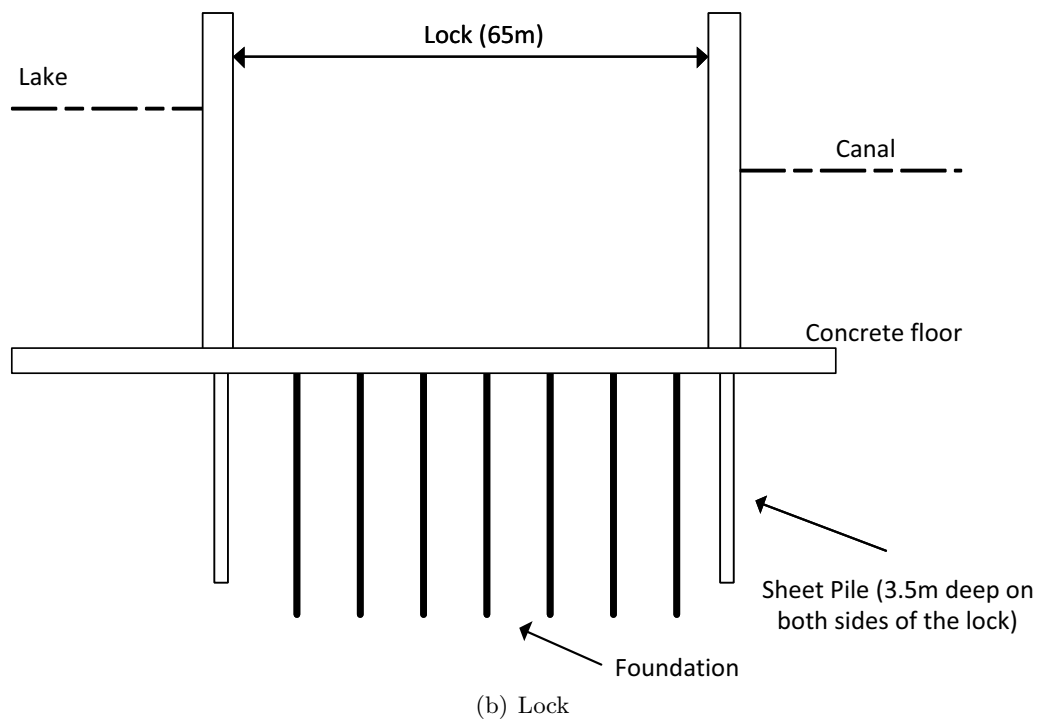
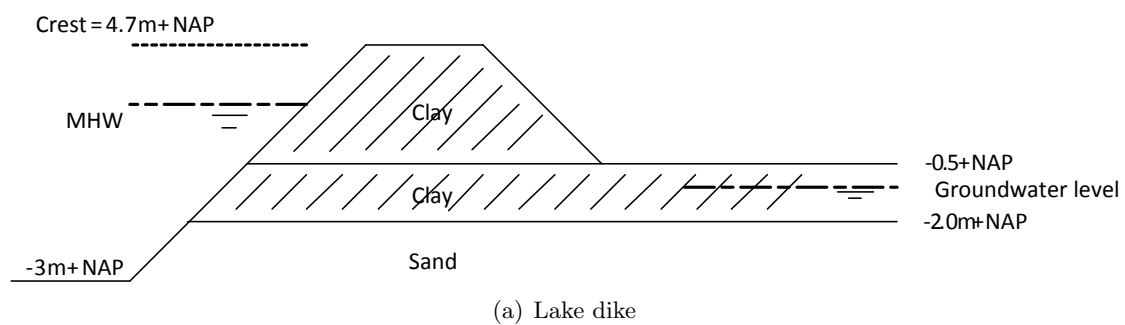
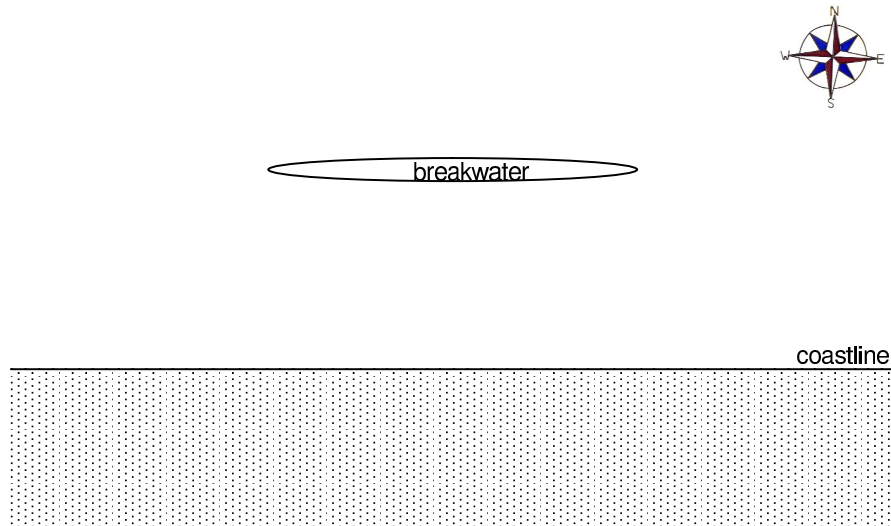


Figure 4: Schematized cross sections of the lake dike and the lock

2.2 [30 pt]

In order to protect an eroding coast, the plan is launched to build an offshore breakwaters, parallel to the coast, as shown in the figure below. Waves approach the coast predominantly from the North-North-East.



- a) (15 points) This question deals with the expected changes in the coastline in the initial period after the construction of the breakwater.

Explain in detail:

- how the coastline will respond to the presence of this breakwater and
- where the changes in the coastline will occur

In your answer to these questions describe:

- which hydrodynamic and sediment transport processes are affected by the breakwater
- how and why these processes change as a result of the breakwater and
- how this leads to the changes in the coastline that you expect

Illustrate your answer with a sketch of the expected coastline in which you specify as accurate as possible where the coastline will change.

The design conditions for this breakwater are as follows:

- water depth: 7.8 m
- wave height: 3.2 m
- wave period: 6.8 s
- wave direction: North-East

The breakwater is constructed at the shoreface, which has a slope of 1:50. The core of the breakwater consists of fine sand with a median grain diameter of $180\ \mu\text{m}$. The top layer of the breakwater consists of concrete blocks and has a slope of 1:3. Several filter layers will be applied between the core and the top layer of the breakwater.

- b) (7 points) Determine the required dimensions of the concrete blocks, such that the top layer of the breakwater remains stable under the design conditions.
- c) (8 points) Give four reasons why filter layers should be applied and explain these reasons briefly

3 Equation Form

Bligh and Lane:

$$\Delta H_L < L/C_{creep} \quad \text{for Bligh} \quad (1)$$

$$\Delta H_L \cdot c_l < L_v + L_h/3 \quad \text{for Lane} \quad (2)$$

where:

$$\Delta H_L = \Delta H - 0.3d \quad (3)$$

Uplift:

$$\frac{\gamma_s - \gamma_w}{\gamma_w} d < \gamma(\psi_z - h_p) \quad (4)$$

where:

ψ_z = hydraulic head directly under covering layer [m]

h_p = groundwater level or surface water level [m]

d = thickness of the impermeable layer [m]

Retaining height:

$$h_{kr} = -\frac{1}{3}\gamma_\beta\gamma_n H_s \ln \left[\frac{q}{0.13\sqrt{gH_s^3}} \right] \quad \text{for } h_{kr} > 0 \quad (5)$$

$$h_{kr} = -\left[\frac{q - 0.13\sqrt{gH_s^3}}{0.6\sqrt{g}} \right]^{2/3} \quad \text{for } h_{kr} < 0 \quad (6)$$

Waves:

Wave propagation velocity: $c = \sqrt{gh}$

Wave length $L = T\sqrt{gh}$ (Shallow water)

Wave length $L = \frac{gT^2}{2\pi}$ (Deep water)

Bretschneider:

$$\frac{gH_s}{u^2} = 0.283 \tanh \left(0.530 \left(\frac{gd}{u^2} \right)^{0.75} \right) \tanh \left[\frac{0.0125 \left(\frac{gF}{u^2} \right)^{0.42}}{\tanh \left(0.530 \left(\frac{gd}{u^2} \right)^{0.75} \right)} \right] \quad (7)$$

$$\frac{gT_s}{u} = 2.4\pi \tanh \left(0.833 \left(\frac{gd}{u^2} \right)^{0.375} \right) \tanh \left[\frac{0.077 \left(\frac{gF}{u^2} \right)^{0.25}}{\tanh \left(0.833 \left(\frac{gd}{u^2} \right)^{0.375} \right)} \right] \quad (8)$$

u = Wind speed on a height of 10 meters [m/s]

d = Water depth [m]

F = Fetch [m]

H_s = Significant wave height [m]

T_s = Significant wave period [s]

Fetch:

$$F_e = \frac{\int_{+\alpha_m}^{-\alpha_m} w(\alpha) l(\alpha) d\alpha}{\int_{+\alpha_m}^{-\alpha_m} w(\alpha) d\alpha} \quad (9)$$

with $w(\alpha) = \cos(\alpha)$

Wave run-up:

valid in the area $0.5 < \gamma_b \xi_0 < 8$ to 10.

$$\frac{z_{2\%}}{H_{m0}} = 1.75 \gamma_b \gamma_f \gamma_\beta \xi_0 \quad (10)$$

with a maximum for larger ξ_0 of:

$$\frac{z_{2\%}}{H_{m0}} = \gamma_f \gamma_\beta \left(4.3 - \frac{1.6}{\sqrt{\xi_0}} \right) \quad (11)$$

with $\xi_0 = \frac{\tan \alpha}{\sqrt{s_0}}$

$z_{2\%} = 2\%$ wave run-up (m)

$\xi_0 =$ breaker parameter (-)

$\alpha =$ angle of slope ($^\circ$)

$s_0 =$ wave steepness $= \frac{2\pi H_{m0}}{g T^2}$ (-)

$H_{m0} =$ significant wave height at toe of dike (m)

$\gamma_b =$ influence factor for a berm (-)

$\gamma_f =$ influence factor for roughness elements on slope (-)

$\gamma_\beta =$ influence factor for angled wave attack (-)

Table 1: Influence factor for roughness of slope

Reference type	γ_f
Concrete	1.0
Asphalt	1.0
Closed concrete block	1.0
Grass	1.0
Vilvoorden stone	0.85
Basalt	0.90

Influence factor for angled wave attack:

The maximum influence is limited to 0.6.

$$\gamma_\beta = 1 - 0.0022 \cdot |\beta| \quad \text{for } (0^\circ \leq |\beta| \leq 80^\circ) \quad (12)$$

$$\gamma_\beta = 1 - 0.0022 \cdot 80 \quad \text{for } (|\beta| > 80^\circ) \quad (13)$$

Influence factor for berm:

$$\gamma_b = 1 - r_B(1 - r_{dh}) \text{ with } 0.6 \leq \gamma_b \leq 1.0 \quad (14)$$

$$r_B = 1 - \frac{2 \frac{h_{m0}}{L_{berm}}}{2 \frac{H_{m0}}{L_{berm} - B}} = \frac{B}{L_{berm}} \quad (15)$$

$$r_{dh} = 0.5 - 0.5 \cos \left(\pi \frac{d_h}{x} \right) \quad (16)$$

where:

r_B is the influence of the berm width

r_{dh} is the position of the berm with respect to the SWL

$x = z_{2\%}$ if $z_{2\%} > -d_h > 0$ (berm above still water line)
 $x = 2H_{m0}$ if $2H_{m0} > d_h \geq 0$ (berm below still water line)
 $r_{dh} = 1$ if $-d_h \geq z_{2\%}$ or $d_h \geq 2H_{m0}$ (outside influence area)

Wave overtopping:

for breaking waves ($\gamma_b \xi_0 < \approx 2$)

$$\frac{q}{\sqrt{g} H_{m0}^3} = \frac{0.067}{\sqrt{\tan \alpha}} \gamma_b \xi_0 \exp \left(-4.3 \frac{h_k}{H_{m0}} \frac{1}{\gamma_b \gamma_f \gamma_\beta \gamma_v \xi_0} \right) \quad (17)$$

with a maximum for non-breaking waves ($\gamma_b \xi_0 > \approx 2$) of:

$$\frac{q}{\sqrt{g} H_{m0}^3} = 0.2 \exp \left(-2.3 \frac{h_k}{H_{m0}} \frac{1}{\gamma_f \gamma_\beta} \right) \quad (18)$$

with

q = average wave overtopping discharge (m^3/s per m)

h_k = free crest height above still water line (m)

γ_v = influence factors for vertical wall on slope (-)

Table 2: Design overtopping rates	
q	armour
0.1 l/m/s	sandy soil with poor grass cover
1 l/m/s	clayey soil with reasonably good grass cover
10 l/m/s	clay soil covering and good grass cover

Goda (see Figure 5 for symbols):

$$P_1 = (a_1 + a_2) \gamma_w H_b \quad (19)$$

$$P_3 = a_3 P_1 \quad (20)$$

$$P_4 = \left(1 - \frac{r}{R} \right) P_1 \quad \text{for } R \geq r \quad (21)$$

$$= 0 \quad \text{for } R < r$$

where

$$R = 1.5 H_b \quad (22)$$

$$a_1 = 0.6 + 0.5 \left(\frac{4\pi D}{L \sinh \left[\frac{4\pi D}{L} \right]} \right)^2 \quad (23)$$

$$a_2 = \min \left(\left(\frac{h - d_s}{3h} \right) \left(\frac{H_b}{d_s} \right)^2, \frac{2d_s}{H_b} \right) \quad (24)$$

$$a_3 = 1 - \frac{d_s}{D} \left(1 - \frac{1}{\cosh \left(\frac{2\pi D}{L} \right)} \right) \quad (25)$$

γ_w = specific weight of water

H_b = highest of the random waves breaking at a distance of $5H_s$ seaward of the wall
 $= 1.8H_s$

h = water depth at where H_b is determined

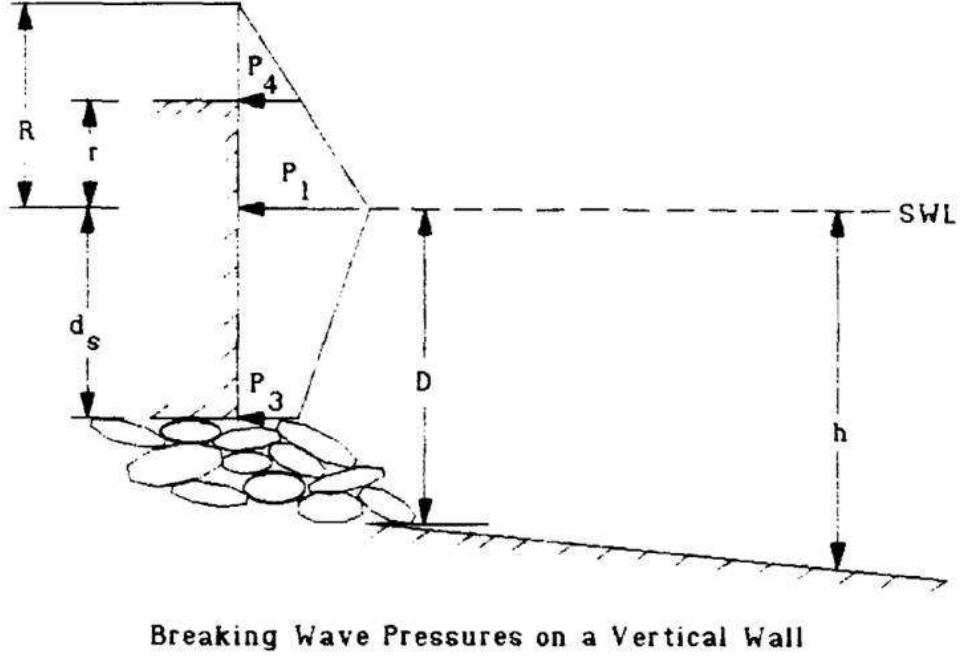


Figure 5:

L = wave length calculated by linear wave theory at the wall

Hyperbolic functions:

$$\cosh(x) = \frac{1}{2} (e^x + e^{-x}) \quad (26)$$

$$\sinh(x) = \frac{1}{2} (e^x - e^{-x}) \quad (27)$$

$$\tanh(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} \quad (28)$$

Gumbel equation:

$$F(x; \mu, \sigma) = e^{-e^{-(x-\mu)/\sigma}} \quad \text{for } x \in \mathbb{R} \quad (29)$$

$$\text{Weibull} : P(x \geq X) = \frac{r}{N+1} \quad (30)$$

$$\text{Gringorten} : P(x \geq X) = \frac{r - 0.44}{N + 0.12} \quad (31)$$

Macrostability:

$$FS = \frac{\tau_f}{\tau_m} = \frac{(T_f)_j}{T_j} \quad (32)$$

$$N'_j = \frac{W_j(1 - r_u) - c' \sin \theta_j / FS + X_j - X_{j+1}}{\cos \theta_j + \tan \varphi' \sin \theta_j / FS} \quad (33)$$

$$\sum T_j = \sum W_j \sin \theta_j \quad (34)$$

$$T_f = \sum N' \tan \varphi' + c'_j \quad (35)$$

N' = normal force on slice

W = weight of slice

r_u = force due to pore water pressure = $\frac{u_j b_j}{W_j}$

b = width of the slice

θ = angle of base of slice with the flat bed

φ = friction angle

c' = cohesion

Table 3: Soil characteristics

soil	median grain size μ m	C_{creep} (Bligh)	c_l (Lane)
silty sand	<105		8.5
very fine sand	105-150	18	
fine sand	150-210	15	7
average coarse sand	210-300		6
very coarse sand	300-2000	12	5
find gravel	2000-5600	9	4
average coarse gravel	5600-16000		3.5

Table 4: When a nose is present the following values should be taken for γ_n

$\frac{h_{kr}}{H_s}$	γ_n
<0.04	1
0.06	0.9
0.08	0.8
0.1	0.7

Coastal protection:

$$\left(\frac{7.6}{H_s}\right) y = 0.4714 \left[\left(\frac{7.6}{H_s}\right)^{1.28} \left(\frac{12}{T_p}\right)^{0.45} \left(\frac{w_s}{0.0268}\right)^{0.56} x + 18 \right]^{0.5} - 2.0 \quad (36)$$

$$x_{max} = 250 \left(\frac{H_s}{7.6}\right)^{1.28} \left(\frac{0.0268}{w_s}\right)^{0.56} \quad (37)$$

$$y_{max} = \left[0.4714 \left\{ 250 \left(\frac{12}{T_p}\right)^{0.45} + 18 \right\}^{0.5} - 2.0 \right] \frac{H_s}{7.6} \quad (38)$$

Sediment transport:

$$Q_0 = \alpha \sin(2\alpha_0) \quad (39)$$

$$Q_g = \alpha \sin(2\alpha_g) \quad (40)$$

Sea walls

$$\left(\frac{R}{H_i}\right) = \frac{1}{8}KT \tan \alpha \left(\frac{2g}{H_i}\right)^{0.5} \quad (41)$$

$$R = \frac{1}{8}KT \tan \alpha \sqrt{2gH_i} \quad (42)$$

$$Q_m = Q_* T_m g H_s \quad (43)$$

$$Q_* = A \exp\left(-\frac{BR_*}{r}\right) \quad (44)$$

$$R_* = \frac{R_c}{R} \quad (45)$$

$$r = \frac{K_{actual}}{K_{smooth} = 2.3} \quad (46)$$

Hudson, Van der Meer

$$W_{50} = \frac{\rho_r g H^3}{5\Delta^3 \cot \alpha} \quad (47)$$

$$D_{n50} = \left(\frac{W_{50}}{\rho_r g}\right)^{1/3} \quad (48)$$

$$\Delta = \frac{\rho_r}{\rho} - 1 \quad (49)$$

$$\frac{H_s}{\Delta D_{n50}} = 6.2P^{0.18} \left(S_d \sqrt{N}\right)^{0.2} \varepsilon_m^{-0.5} \quad (50)$$

$$\frac{H_s}{\Delta D_{n50}} = 1.0P^{-0.13} \left(S_d \sqrt{N}\right)^{0.2} \sqrt{\cot \alpha} \varepsilon_m^P \quad (51)$$

$$= 1.0P^{-0.13} \left(S_d \sqrt{N}\right)^{0.2} \sqrt{\frac{1}{\tan \alpha}} \varepsilon_m^P \quad (52)$$