Chapter 5: use of theory

ct5308 Breakwaters and Closure Dams

H.J. Verhagen

March 29, 2012

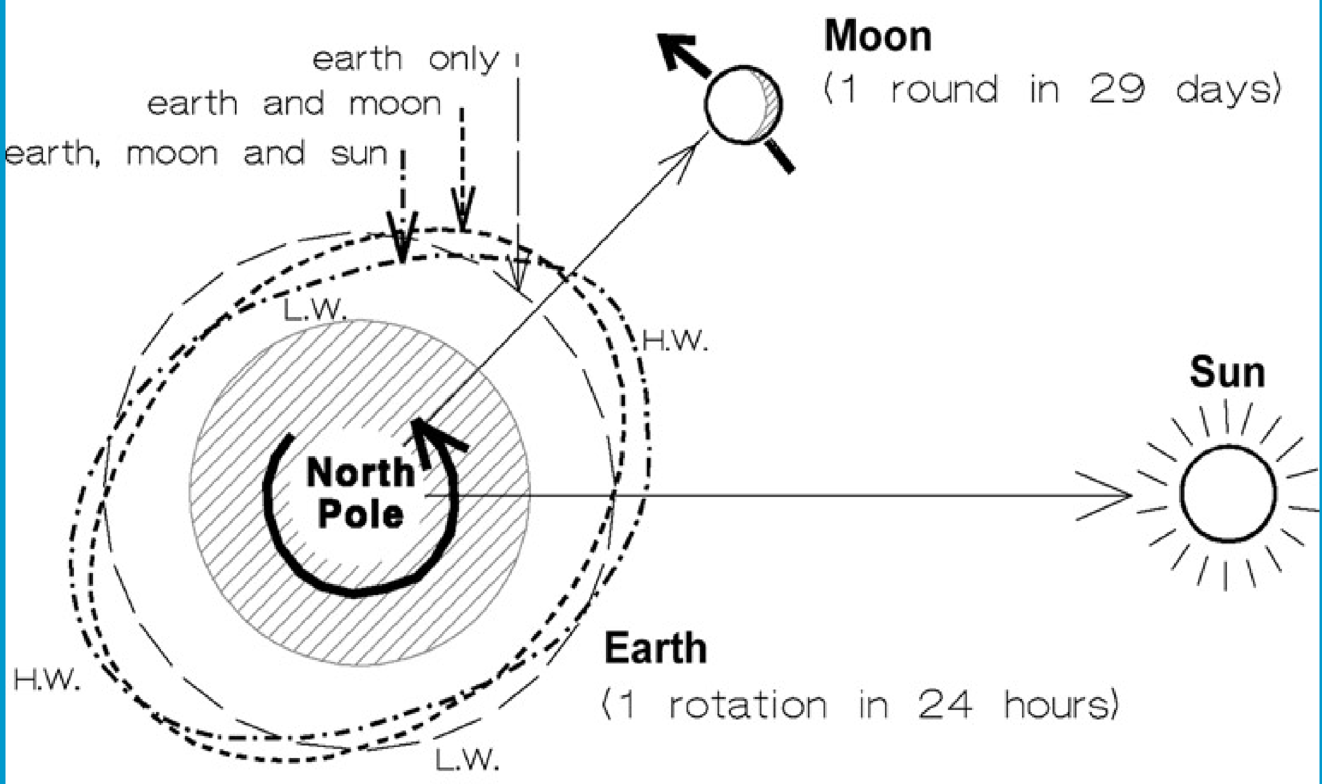
Faculty of Civil Engineering and Geosciences
Section Hydraulic Engineering

TU Delft
Delft University of Technology

Theoretical background needed

- waterlevels (tides)
- flow trough gaps
- stability of floating objects
- waves
  - basics
  - refraction, shoaling, breaking, diffraction, reflection
  - wave statistics
    - short term statistics (Rayleigh)
    - long term statistics
- Geotechnics
  - sliding
  - squeeze
  - liquefaction

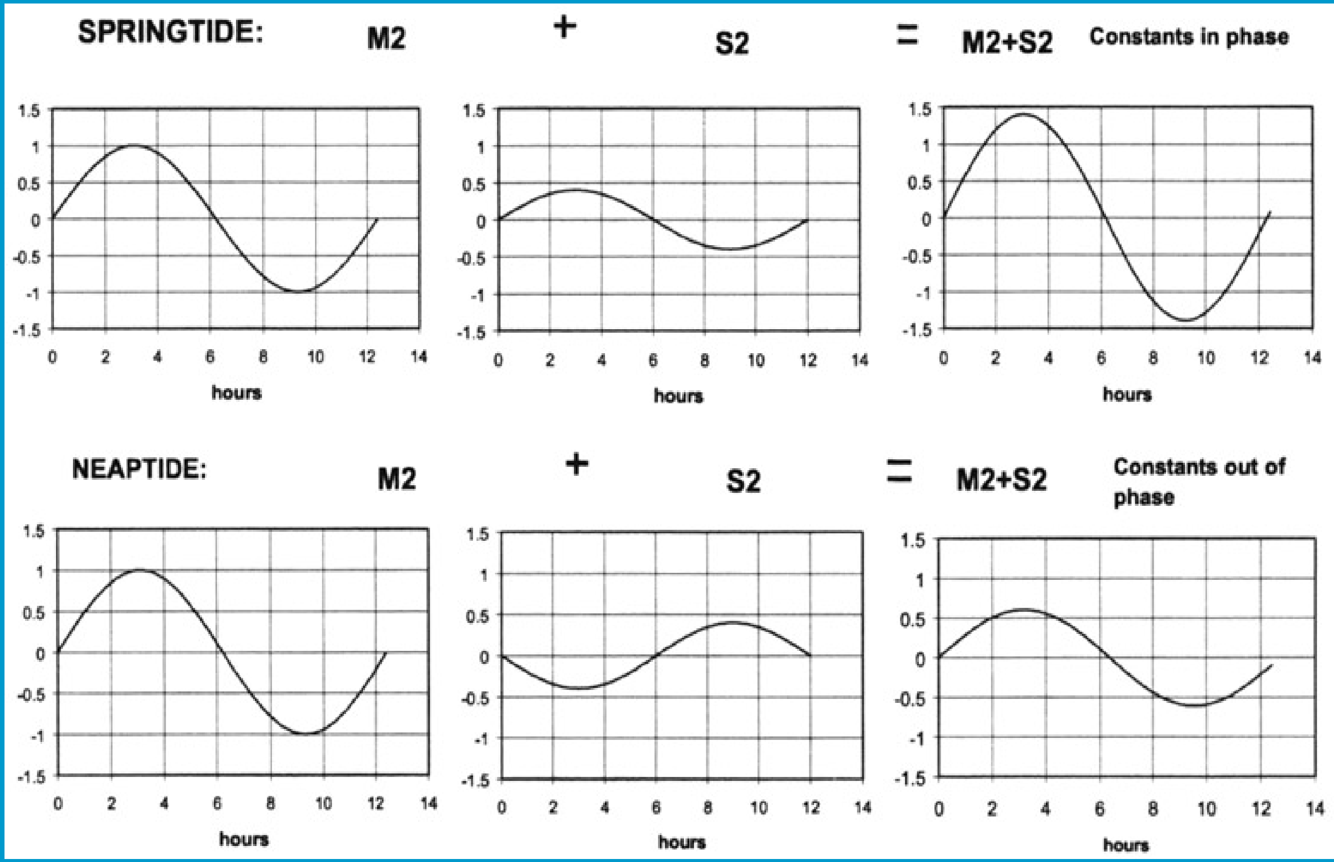
Initial tidal wave by the moon and the sun



Exaggerated water layer on the earth globe for a given position of the moon

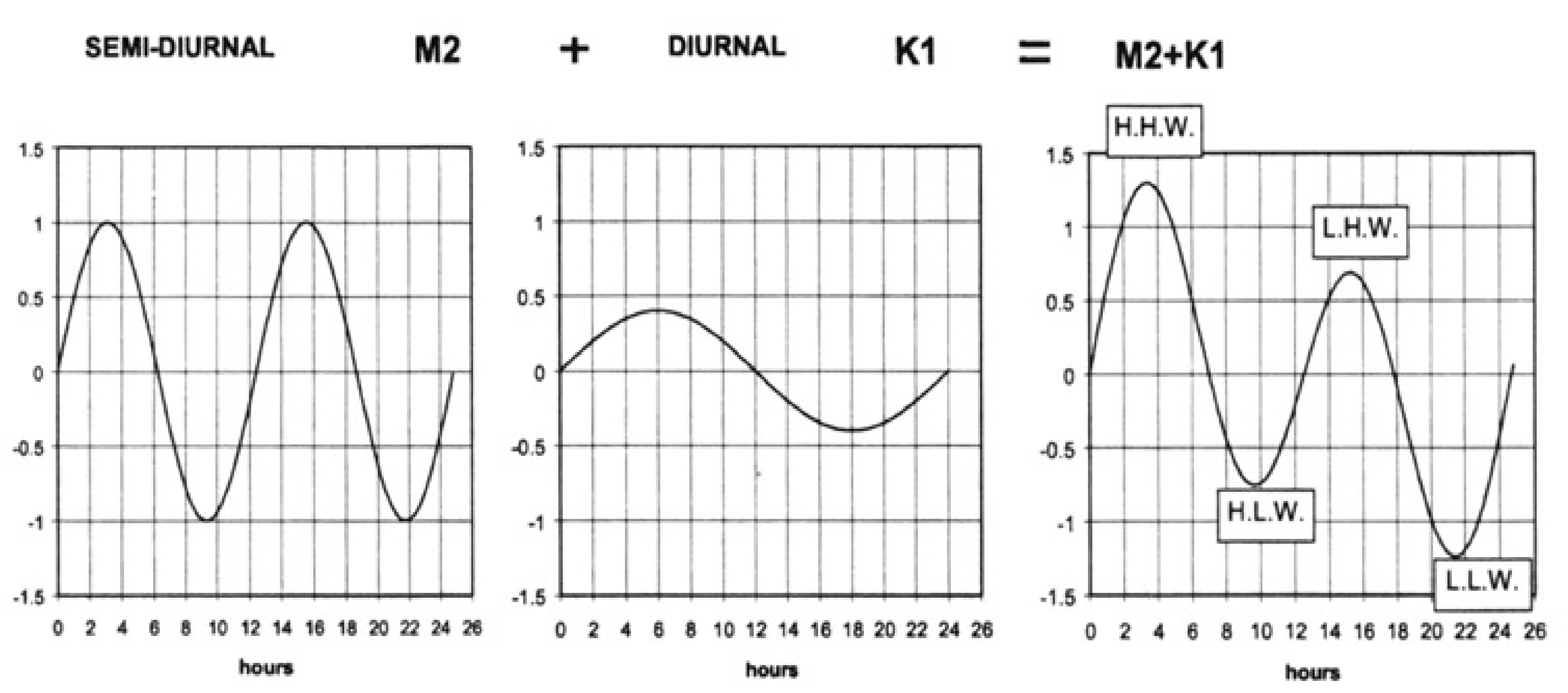
TU Delft

Adding semi-diurnal constants resulting in spring and neap tide



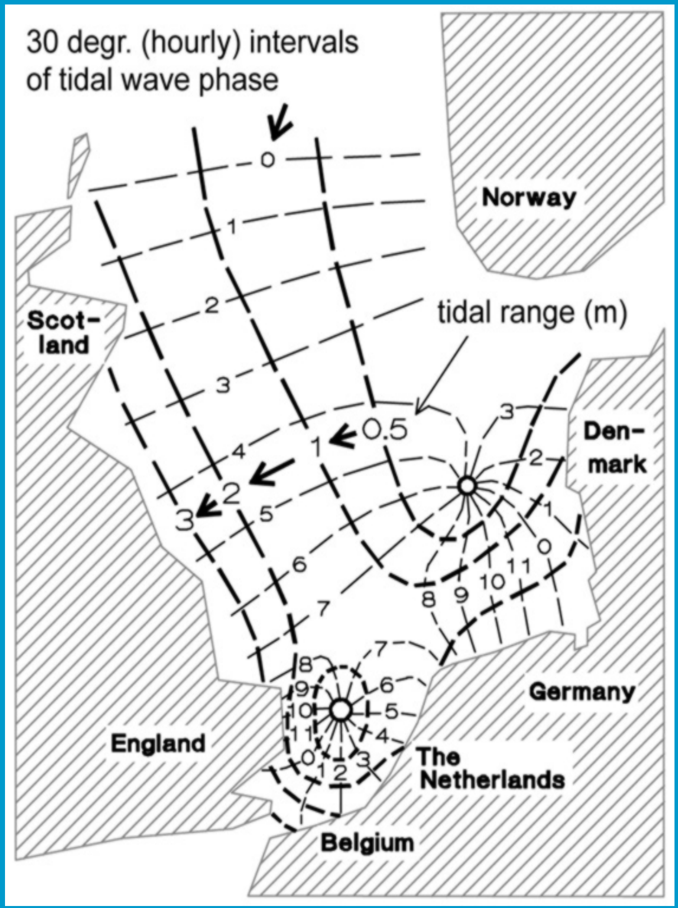
TU Delft

Adding diurnal to semi-diurnal constant



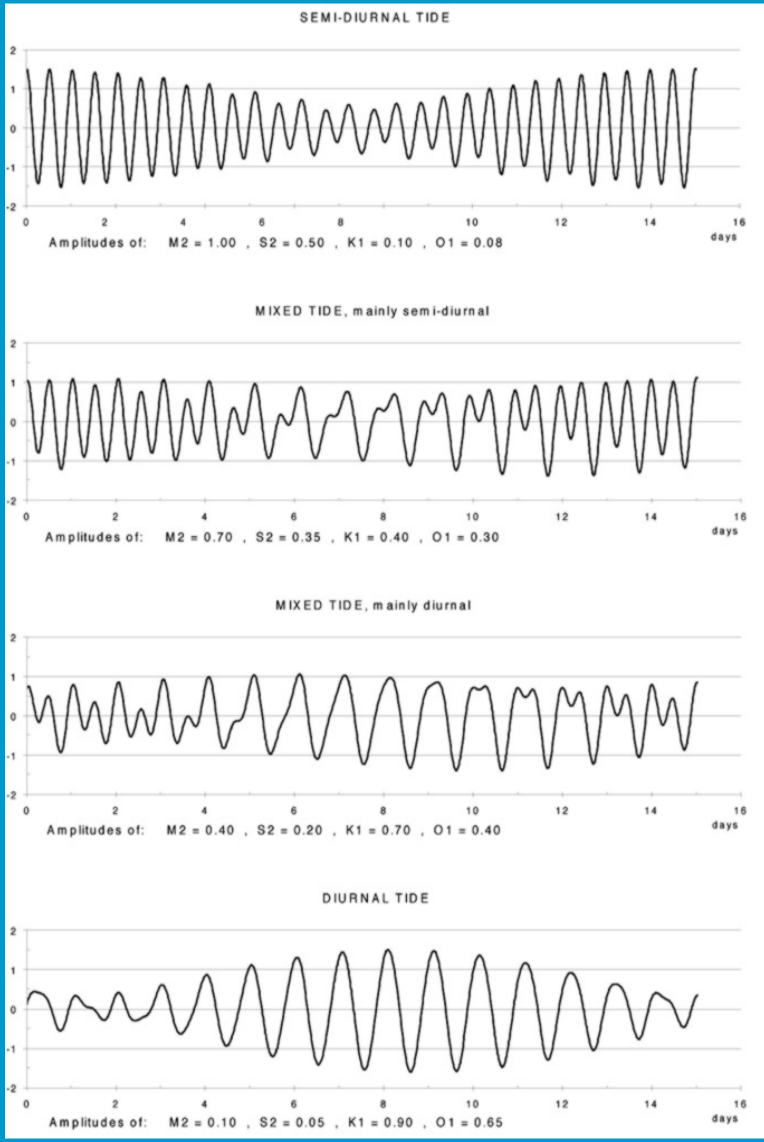
TU Delft

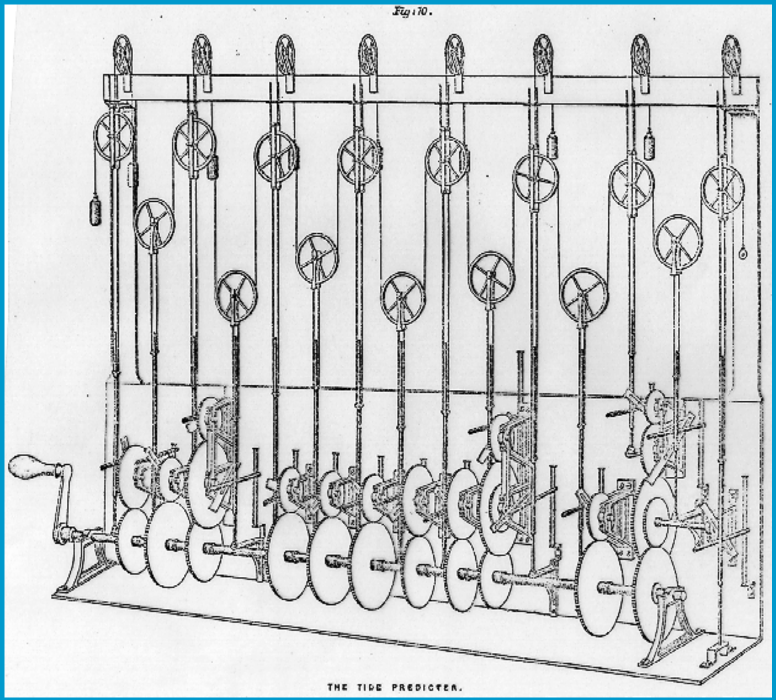
Amphidromy in the North Sea



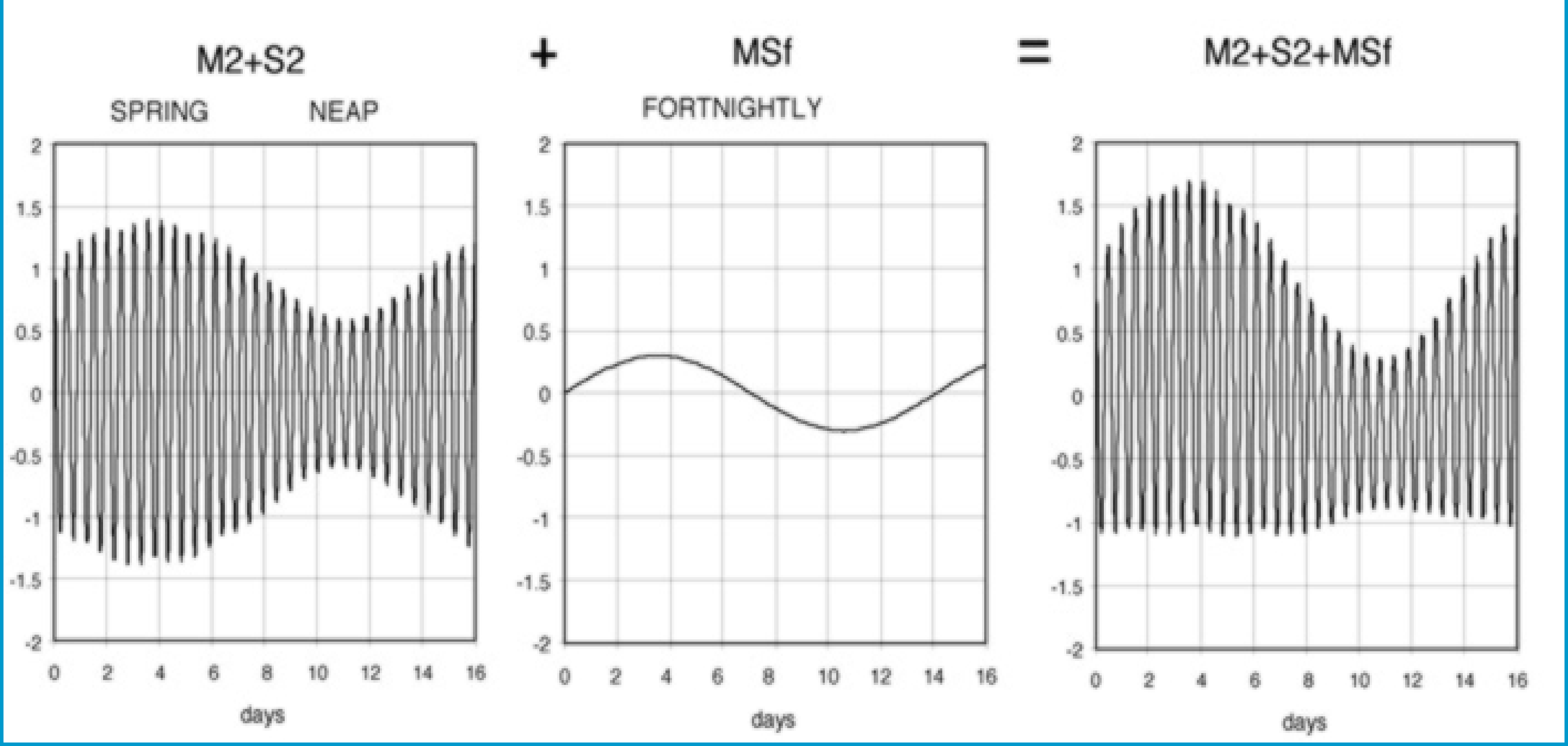
TU Delft

typical tides



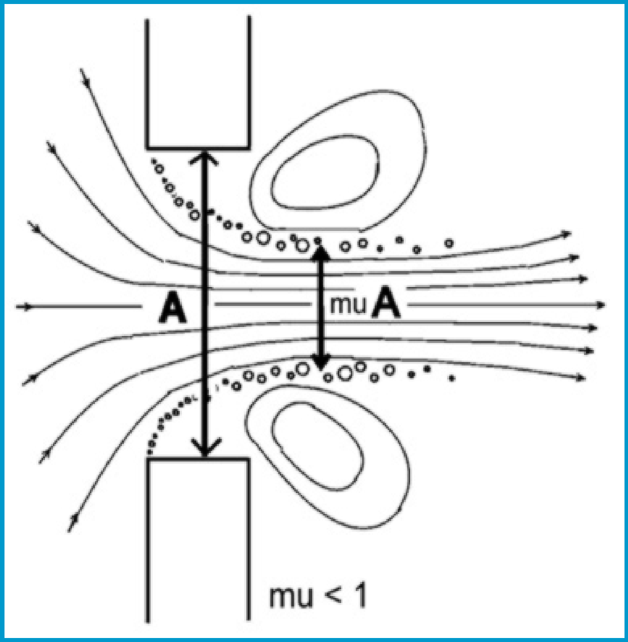


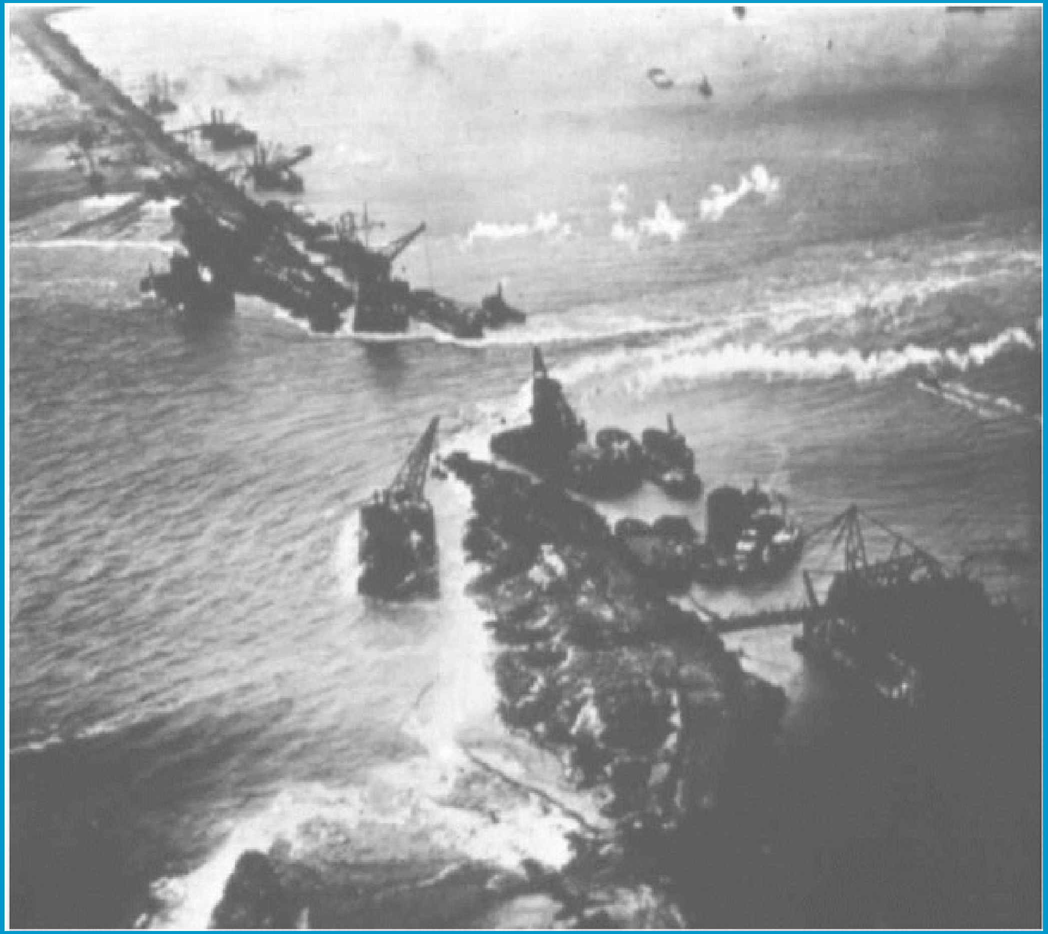
adding the fortnightly constant



TU Delft

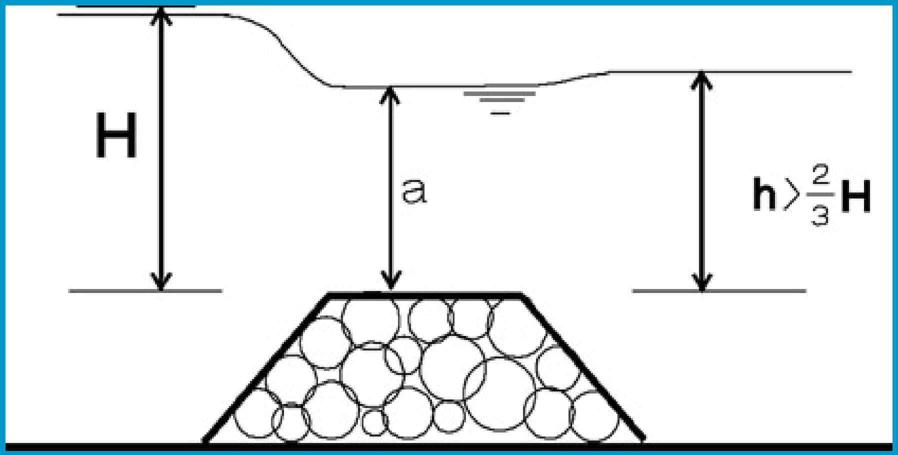
flow pattern in a gap





TU Delft

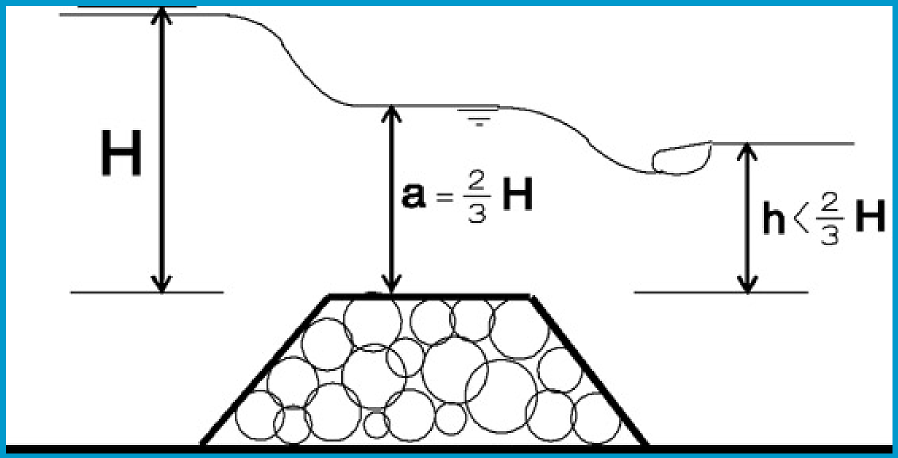
Flow over a sill



subcritical flow

$$Q = mBh\sqrt{2g\,(H-h)}$$

$$u = \frac{Q}{B\,a} = m\frac{h}{a}\sqrt{2g\,(H-h)}$$



critical flow

$$Q = m\,B\,a\sqrt{2\,g\,\frac{1}{3}\,H}$$

$$Q = m\,B(\frac{2}{3}\,H)\sqrt{2\,g(\frac{1}{3}\,H)}$$

$$u = m\sqrt{2\,g(\frac{1}{3}\,H)}$$

TU Delft

modelling

$$\frac{\delta Q}{\delta x} + B_x \frac{\delta H}{\delta t} = 0$$

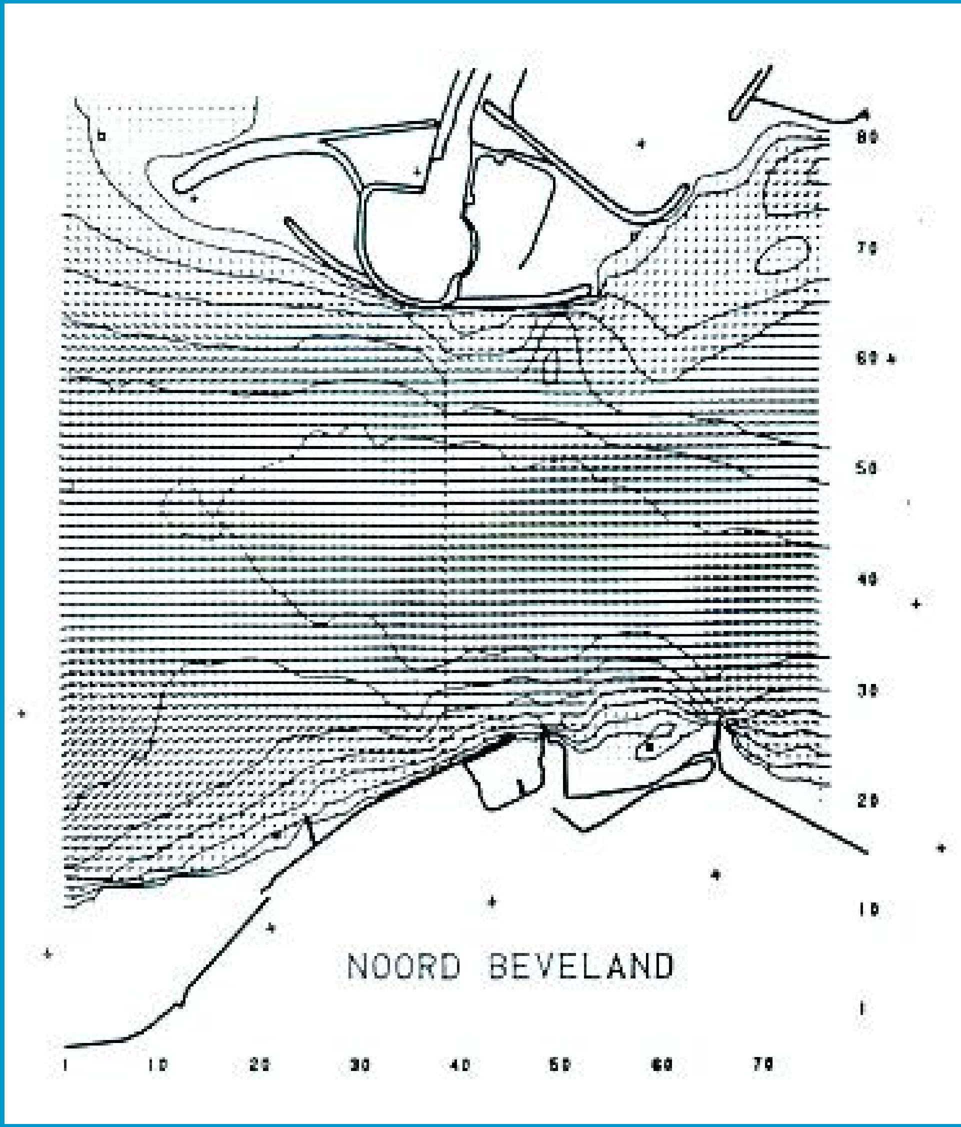
$$\frac{\delta Q}{\delta t} + \frac{\delta(\alpha Q u)}{\delta x} + g A \frac{\delta H}{\delta x} + \frac{g |Q| Q}{C^2 A R} - W_x = 0$$

Solving these equation by:

- **physical model**
- **mathematical model**
  - **2 d model**
  - **1 d model**
  - **storage area approach**

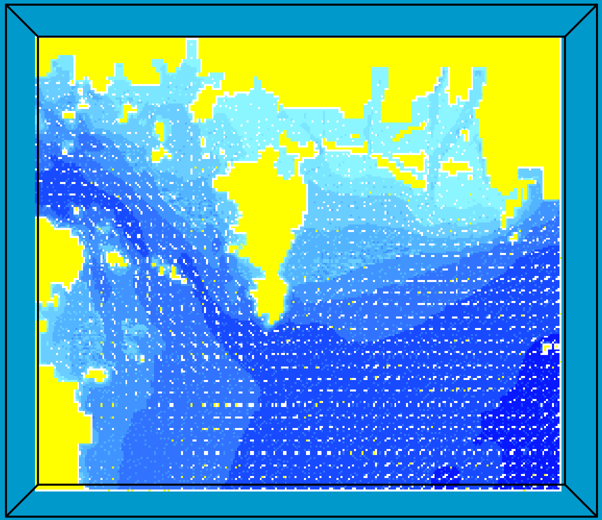
Physical model

TUDelft



Oosterscheldewerken, Waqua, Rijkswaterstaat/WL

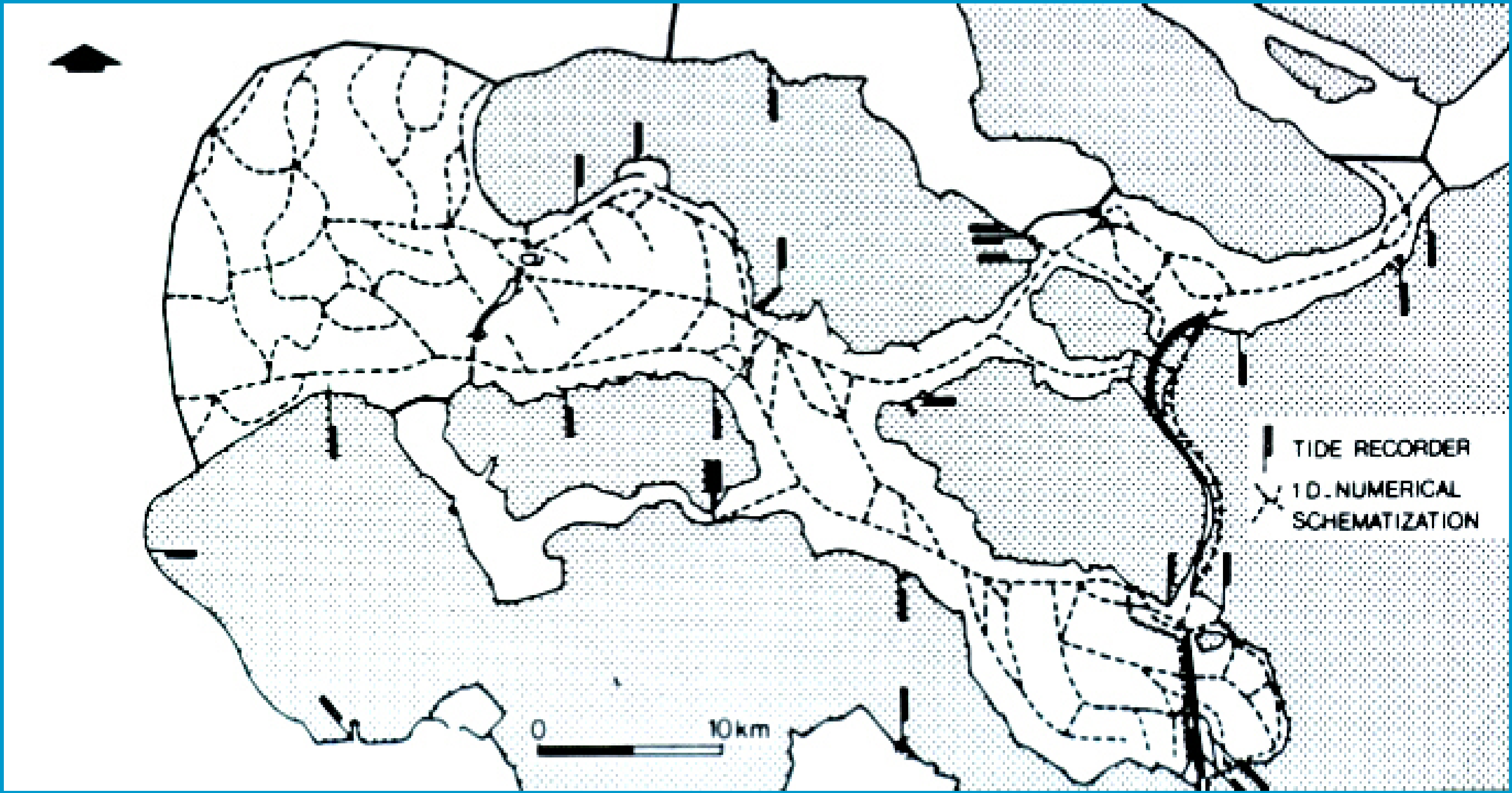
two dimensional model



Korea, Gaduk port, Mike21, DHI

TU Delft

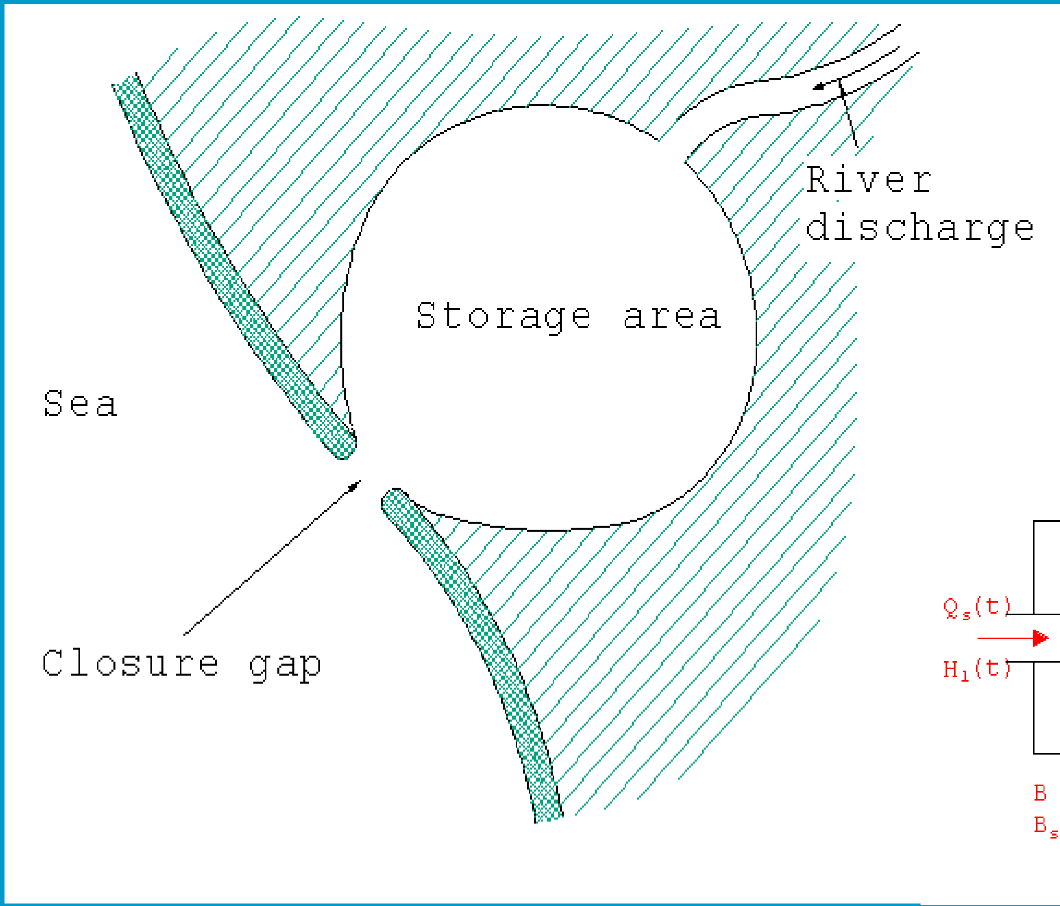
one-dimensional model

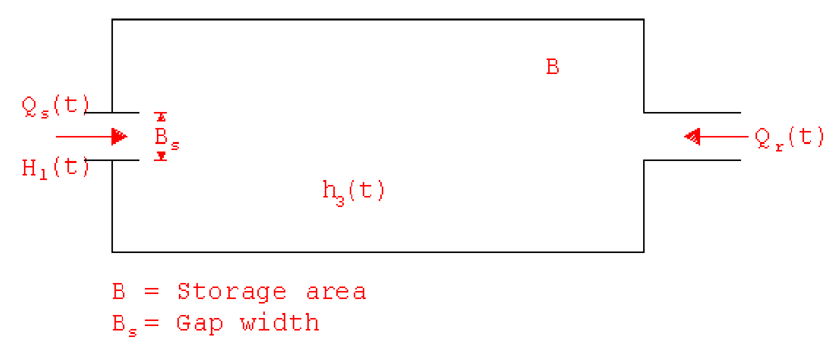


TU Delft

storage / area approach

$$\frac{\delta Q}{\delta x} + B_x \frac{\delta H}{\delta t} = 0$$





TUDelft

validity of storage/area approach

length of tidal wave: $L = c*T = \sqrt{gh} * T$
$= \sqrt{10*10} *12*3600$
$= 432$ km

basin < 0.05 L = 20 km

TU Delft

equations for storage/area approach

$$\mu A_g \sqrt{2g(H_1 - h_2)} = B\frac{dh_3}{dt} - Q_R(t)$$

$$h_2 = h_3 \quad for \quad h_3 > \frac{2}{3}H_1$$

$$h_2 = \frac{2}{3}H_1 \quad for \quad h_3 < \frac{2}{3}H_1$$

A_g and B can be combined to one input parameter

TU Delft

parameters needed

- water level in the sea
- river discharge
- ratio between storage area and width of closure gap
- sill height
- discharge coefficient of the gap

Assume for the time being that the river discharge is zero and that the tide is always semi-diurnal

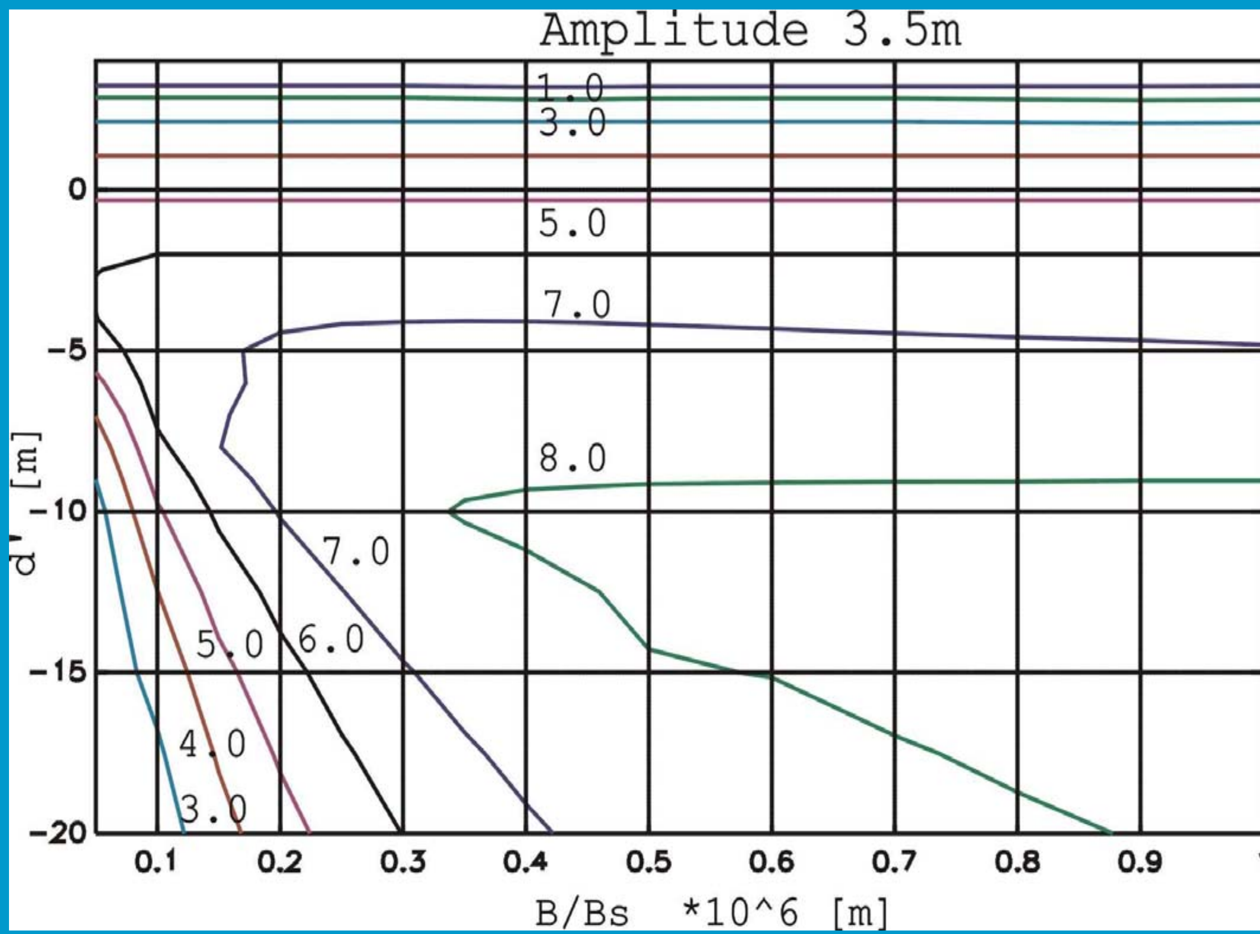
Set the discharge coefficient of the gap to 1

Remaining parameters:

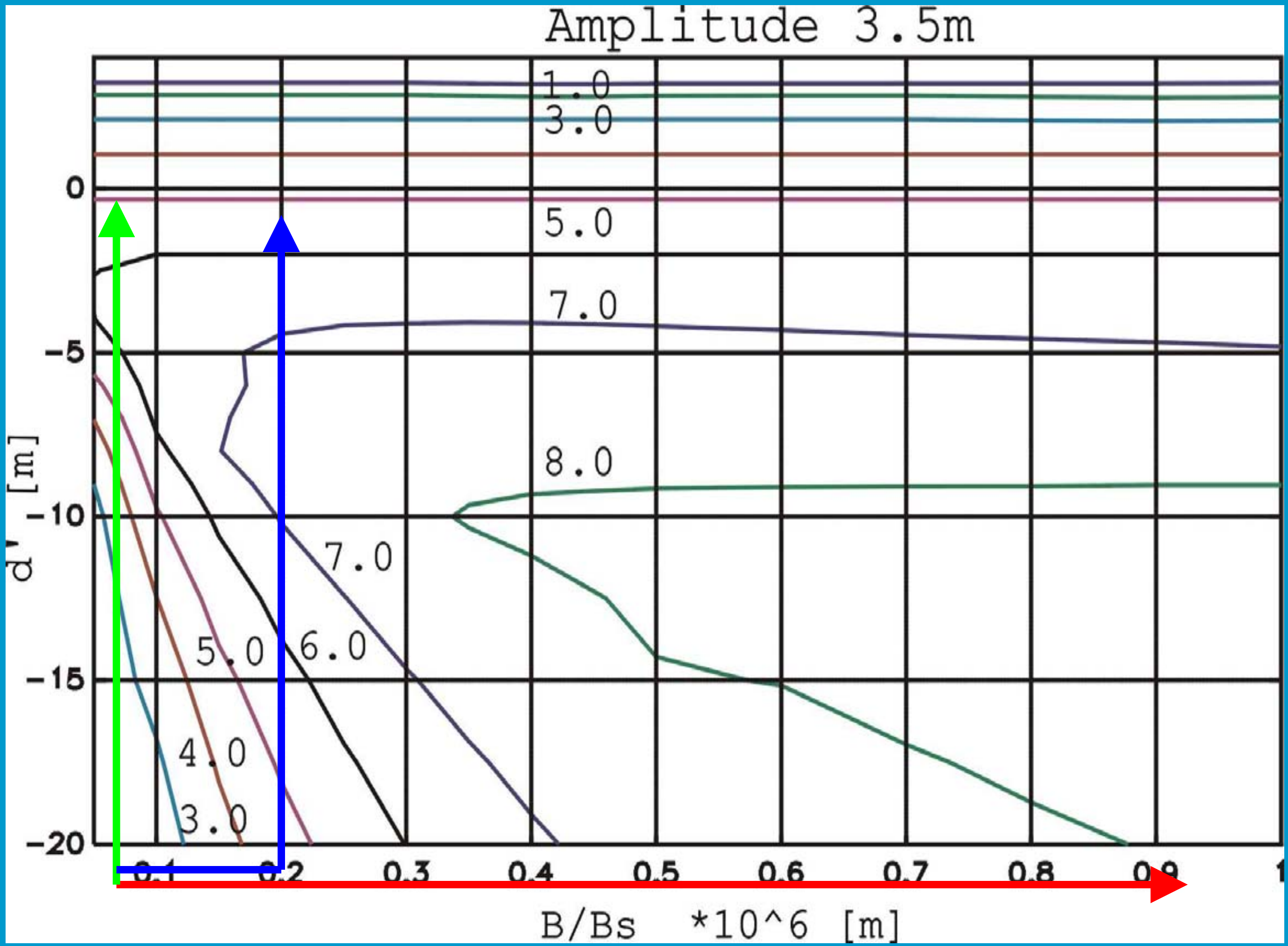
- tidal difference
- ratio storage area/gap width
- sill height

TU Delft

design graph for the velocity

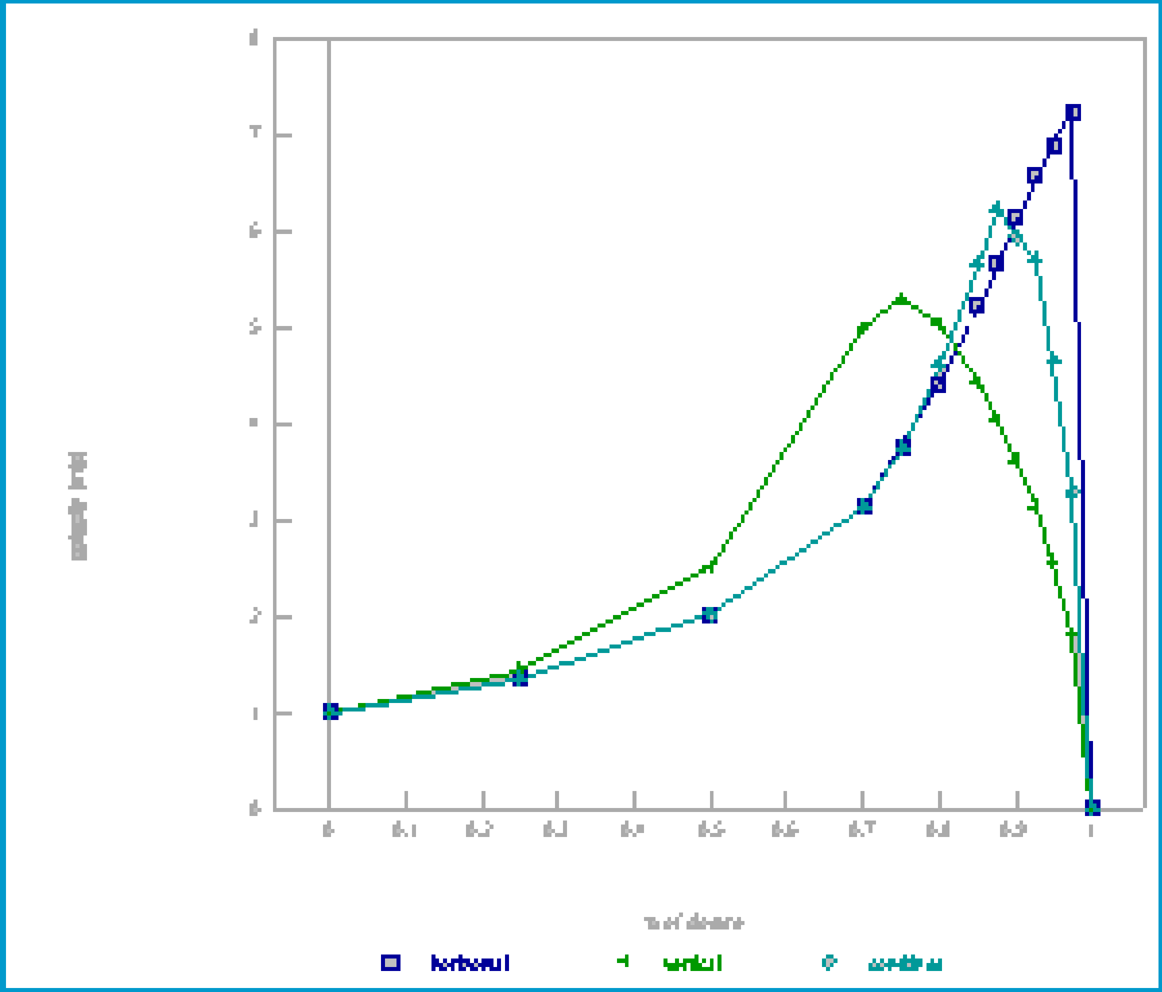


example of the use of a design graph



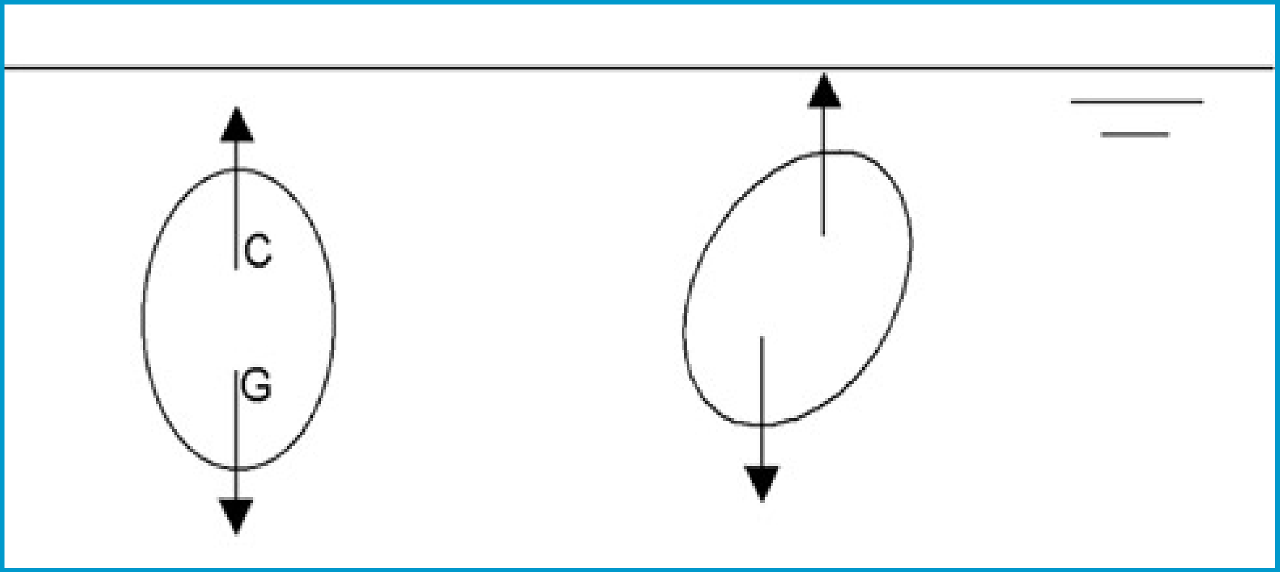
TU Delft

velocity as a function of the closure



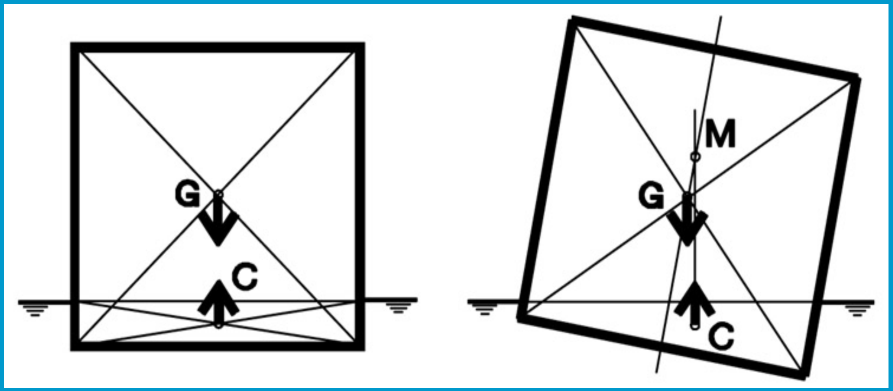
TU Delft

Stability of a submerged object



TU Delft

Stability of a floating object



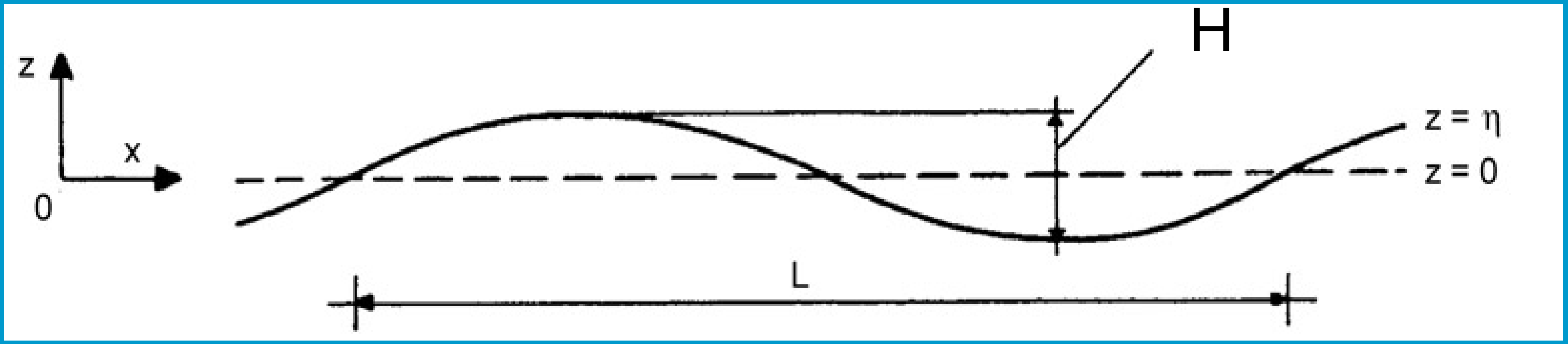
$$MC = \frac{I}{V}$$

$$I = \int_{-.5b}^{+.5b} yx^2 dx \qquad = \frac{1}{12} LB^3$$

$$V = \frac{G}{\rho g}$$

TUDelft

Definition of a regular wave



H wave height
T wave period
L wave length

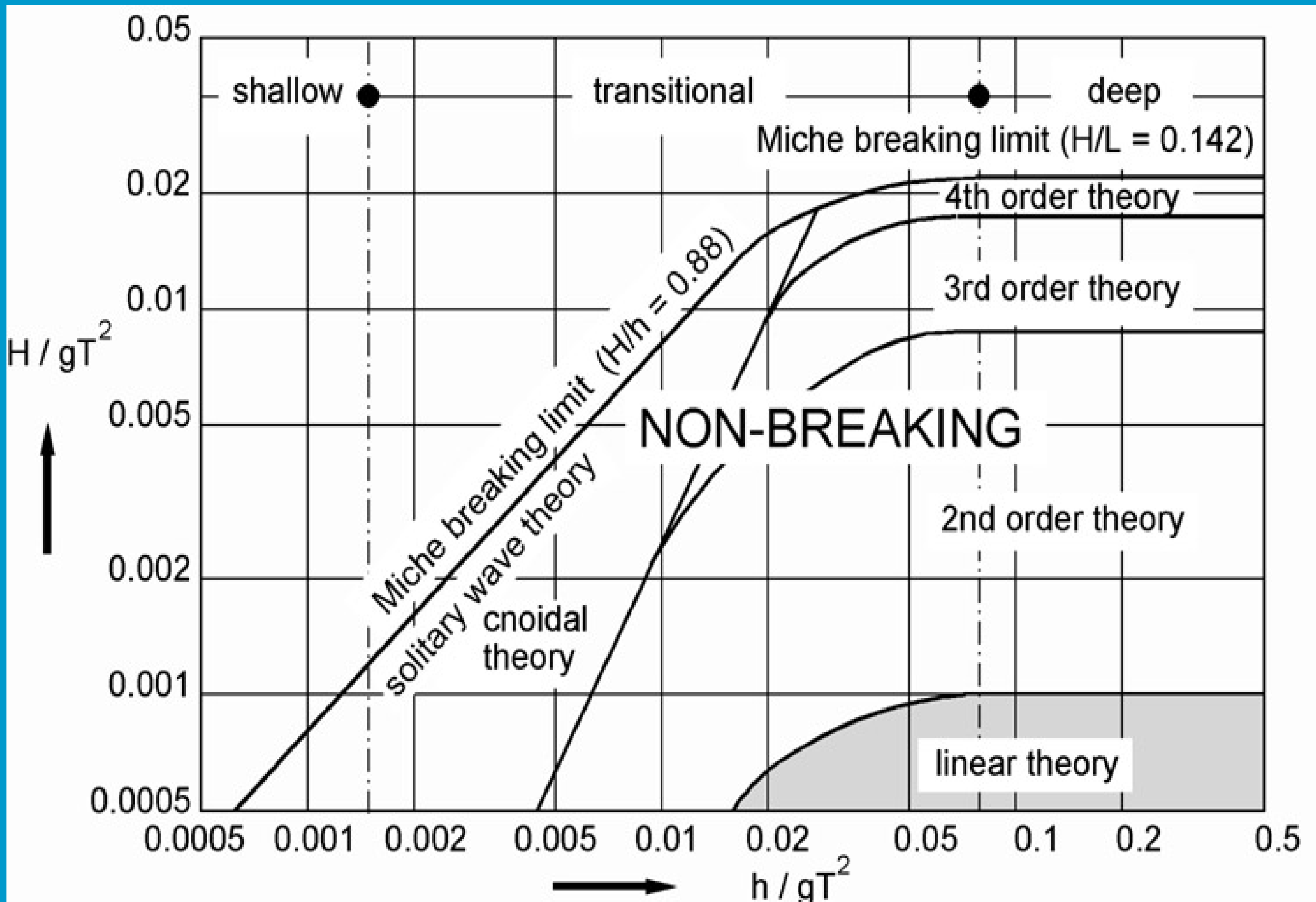
$$\eta = \frac{H}{2}\cos\left(\frac{2\pi x}{L} - \frac{2\pi t}{T}\right)$$

$$c = \sqrt{\frac{gL}{2\pi}\tanh\left(\frac{2\pi h}{L}\right)}$$

$$L_0 = \frac{gT^2}{2\pi} = 1.56T^2 \qquad c = \sqrt{gh}$$

TU Delft

validity for wave theories



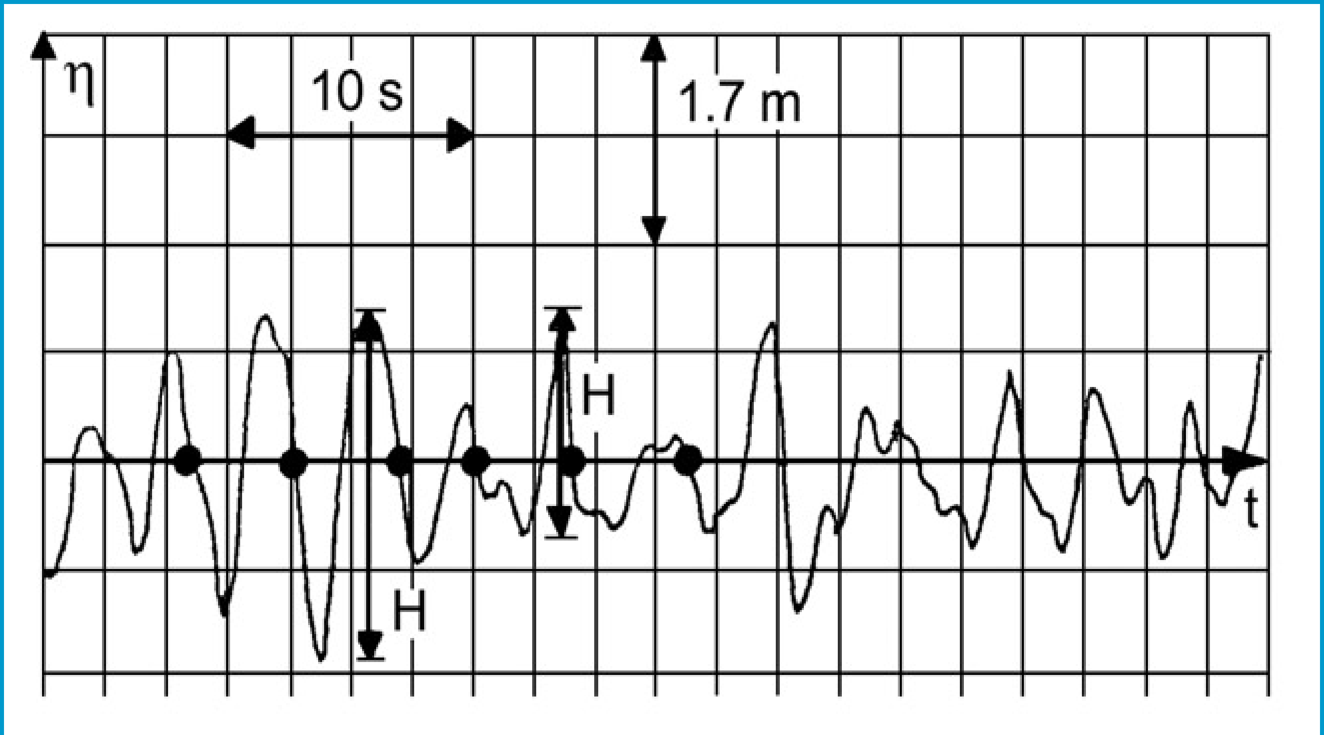
TU Delft

breaking

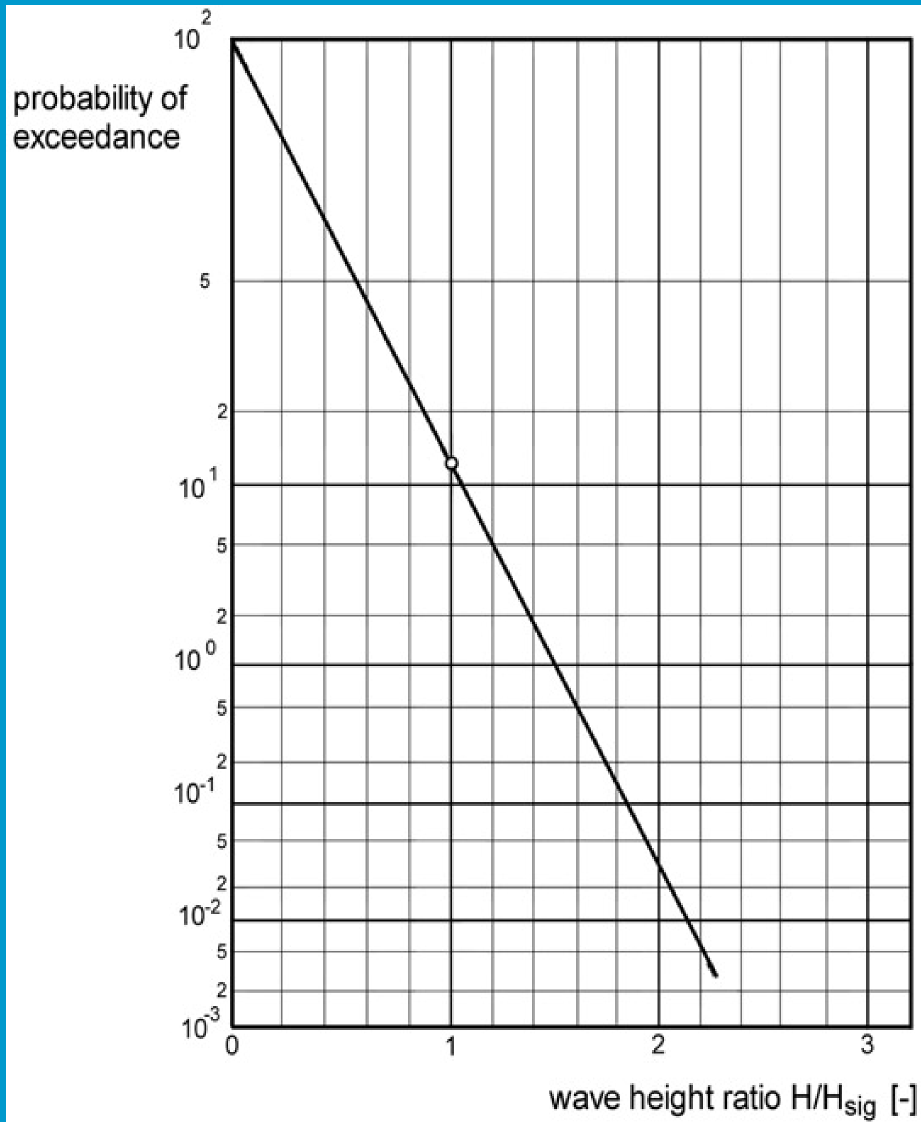
by steepness $H/L < 0.14$
by depth $H/h < 0.78$ but…………….

TU Delft

Irregular wave



TU Delft



Rayleigh graph paper

$$P(\underline{H} > H) = e^{\left[-2\left(\frac{H}{H_s}\right)^2\right]}$$

TU Delft

characteristic wave heights

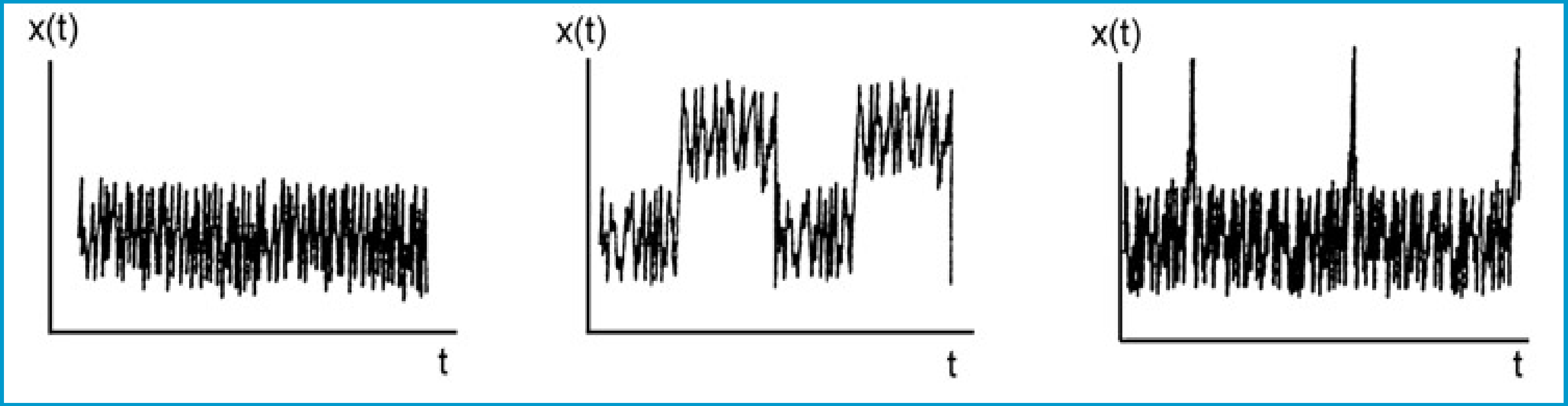
Name	Notation	$H/\sqrt{m_0}$	H/H_s
Standard deviation free surface	$\sigma_\eta = \sqrt{m_0}$	1	0.250
RMS height	H_{rms}	$2\sqrt{2}$	0.706
Mean Height	$\bar{H} = H_1$	$2\sqrt{\ln 2}$	0.588
Significant Height	$H_s = H_{1/3}$	4.005	1
Average of 1/10 highest waves	$H_{1/10}$	5.091	1.271
Average of 1/100 highest waves	$H_{1/100}$	6.672	1.666
Wave height exceeded by 2%	$H_{2\%}$		1.4

TU Delft

characteristic wave periods

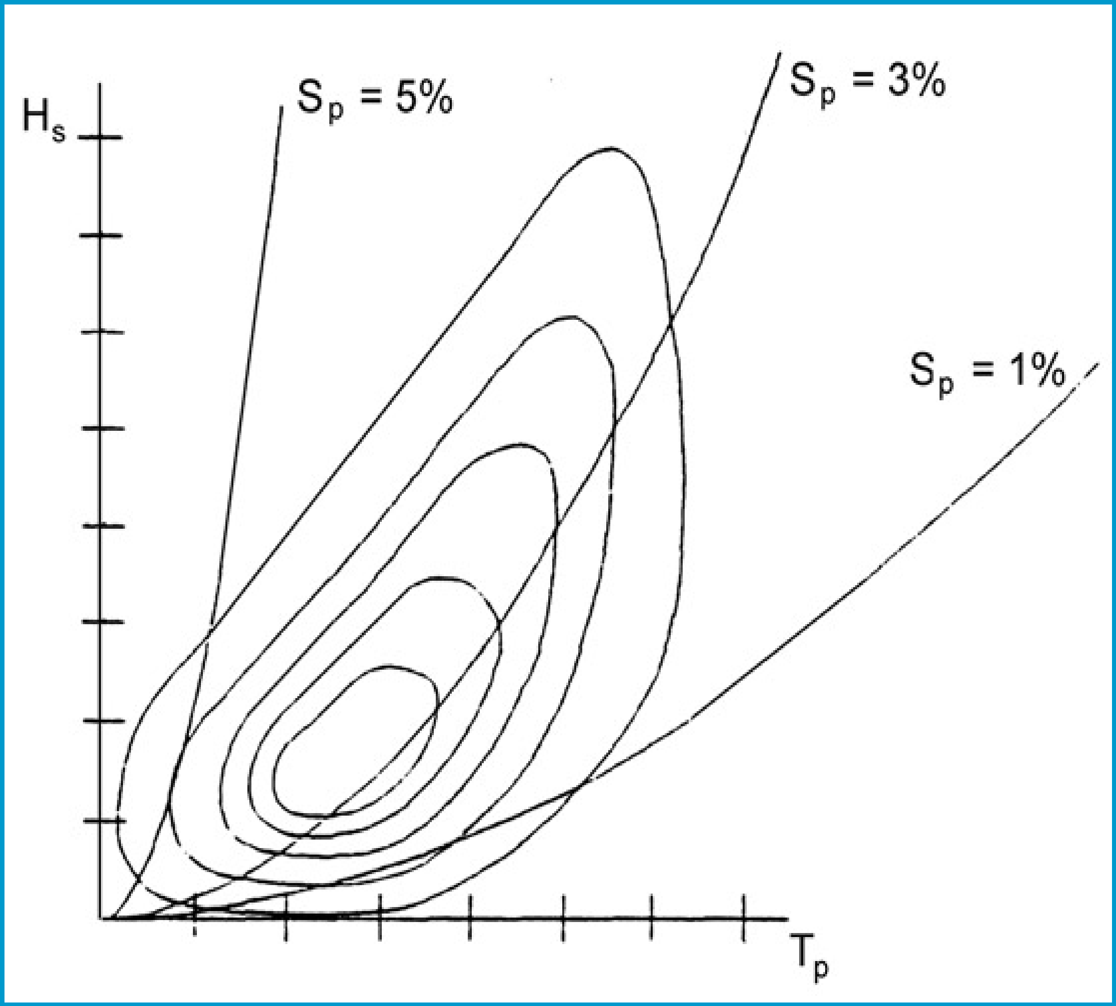
Name	Notation	Relation to spectral moment	T/T_p
Peak period	T_p	$1/f_p$	1
Mean period	T_m	$\sqrt{(m_0/m_2)}$	0.75 to 0.85
Significant period	T_s		0.9 to 0.95

typical types of wave statistics patterns



TU Delft

H/T-diagram



TUDelft

waves in shallow water

shoaling
refraction
breaking
diffraction
reflection

$$\frac{H}{H_0} = \sqrt{\frac{1}{\tanh(2\pi h / L)} + \frac{1}{1 + \frac{(4\pi h / L)}{\sinh(4\pi h / L)}}} = k_{sh}$$

TU Delft

the iribarren number (surf similarity parameter)

$$\xi = \frac{\tan \alpha}{\sqrt{H / L_0}}$$

tan α	**slope of the shoreline/structure**
H	**wave height**
L_0	**wave length at deep water**

TU Delft

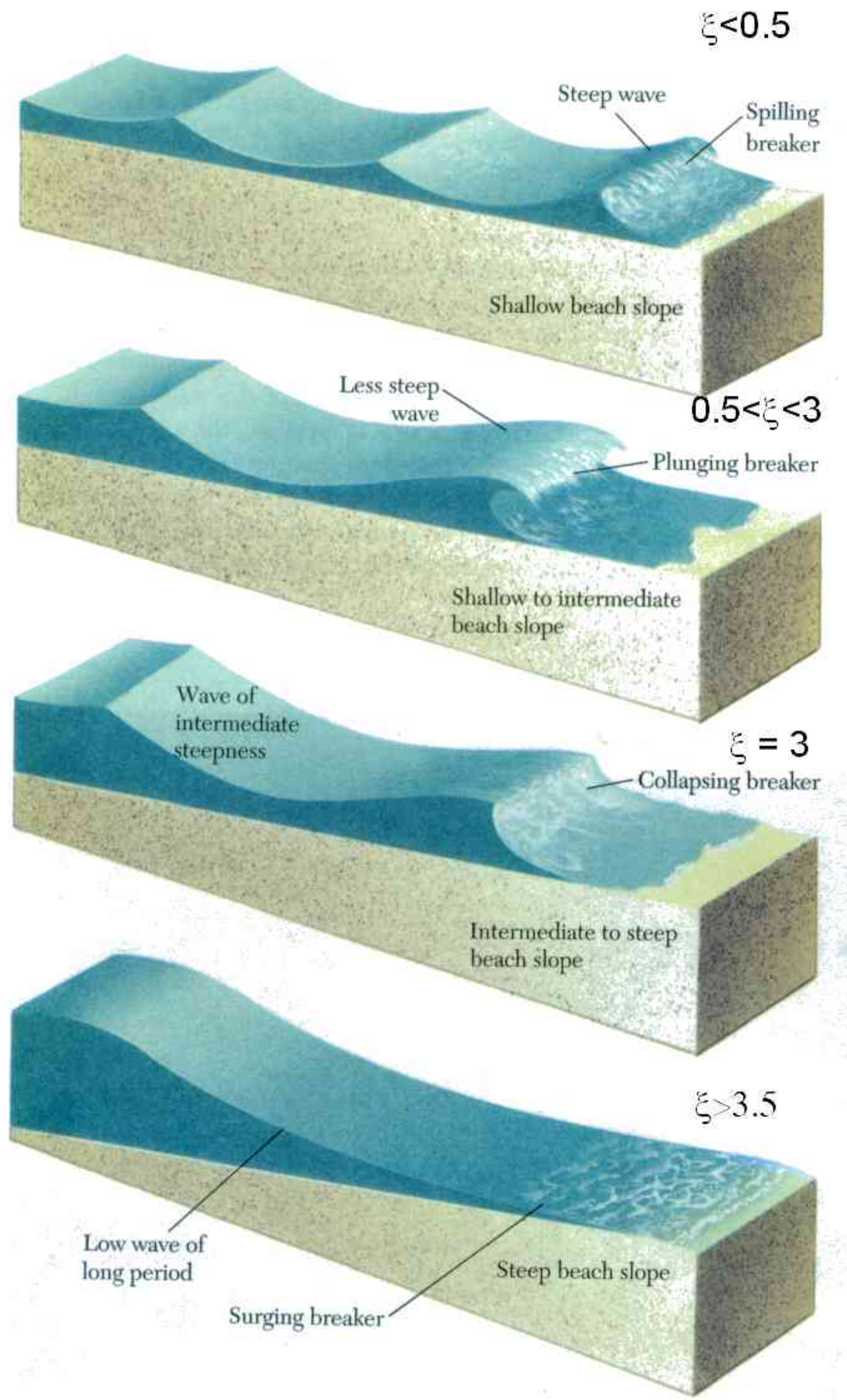
breaker types (2)

spilling $\xi < 0.5$

plunging $0.5 < \xi < 3$

collapsing $\xi = 3$

surging $\xi > 3$



breaking waves

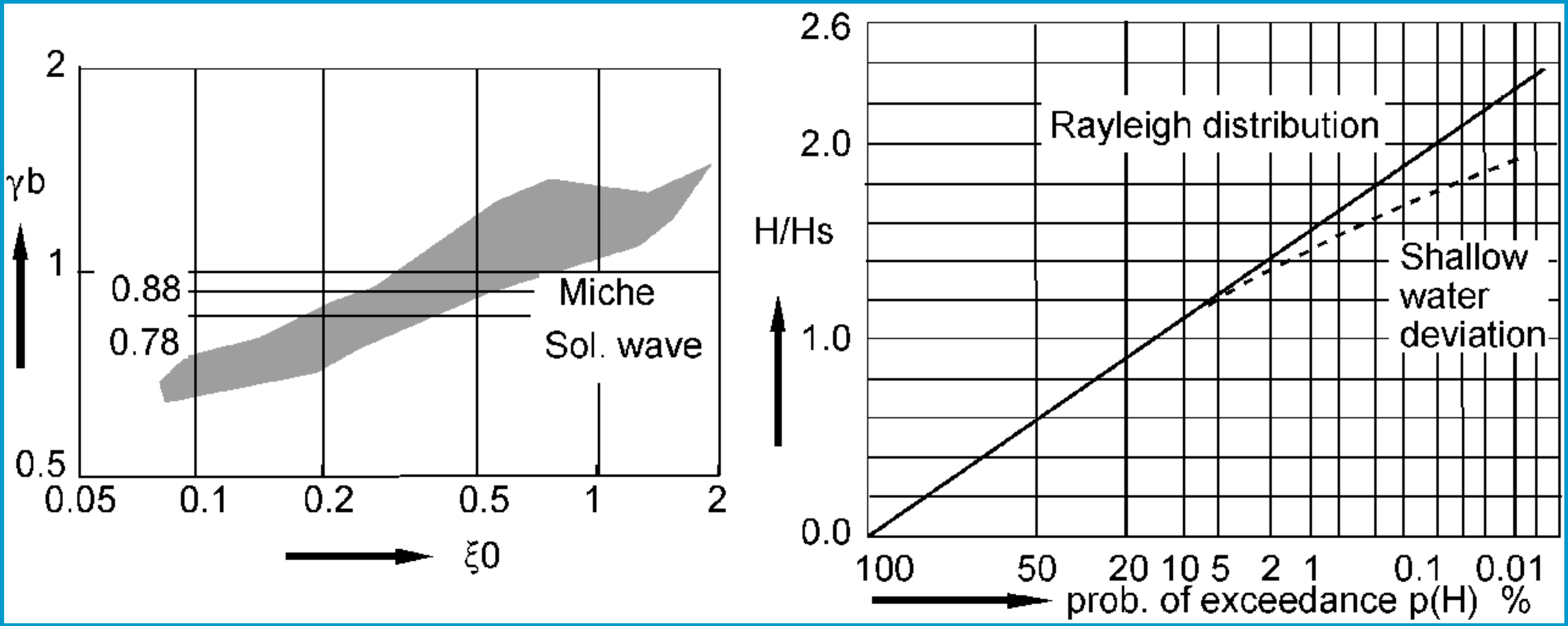
$$H_b = 0.142\, L \tanh\left(\frac{2\pi}{L} h\right)$$

$$\frac{H_b}{h} \approx 0.78\ (solitary wave)$$

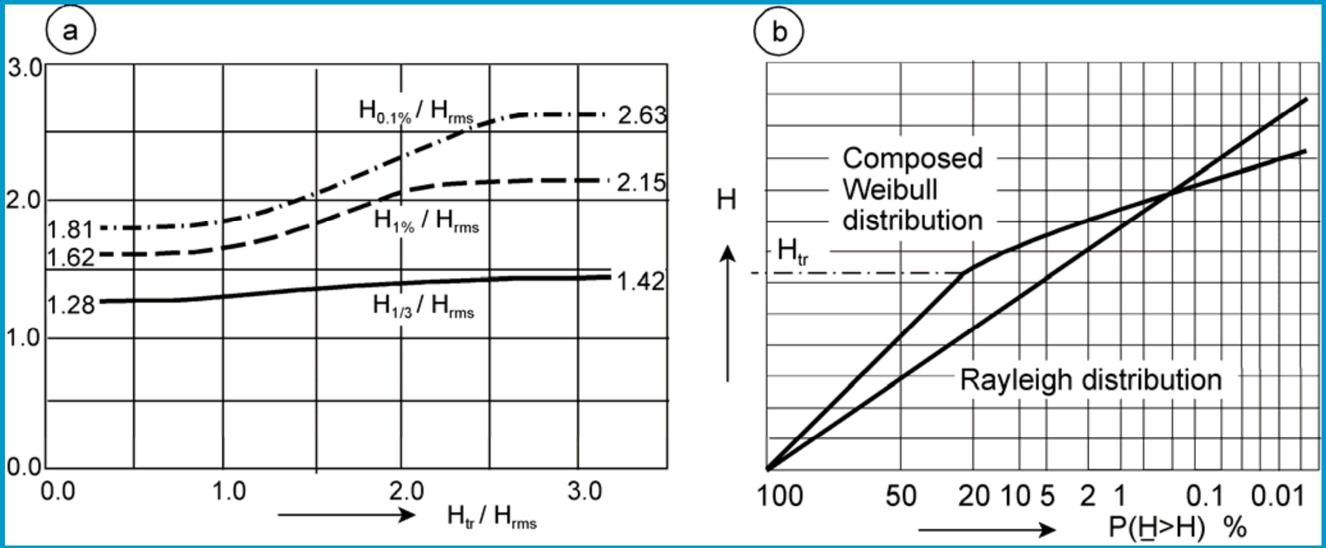
$$\frac{H_s}{h} \approx 0.4 - 0.5$$

TU Delft

change of distribution in shallow water



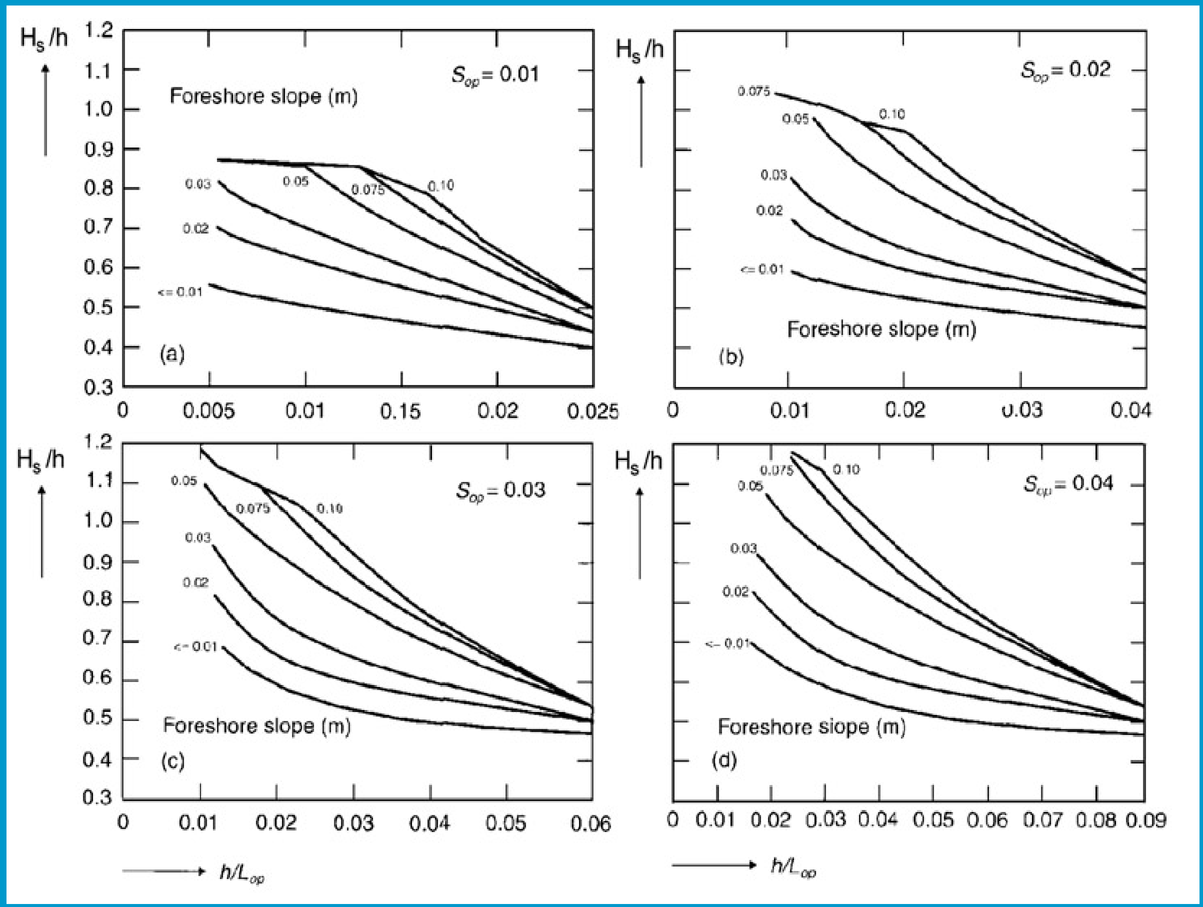
Battjes Jansen method



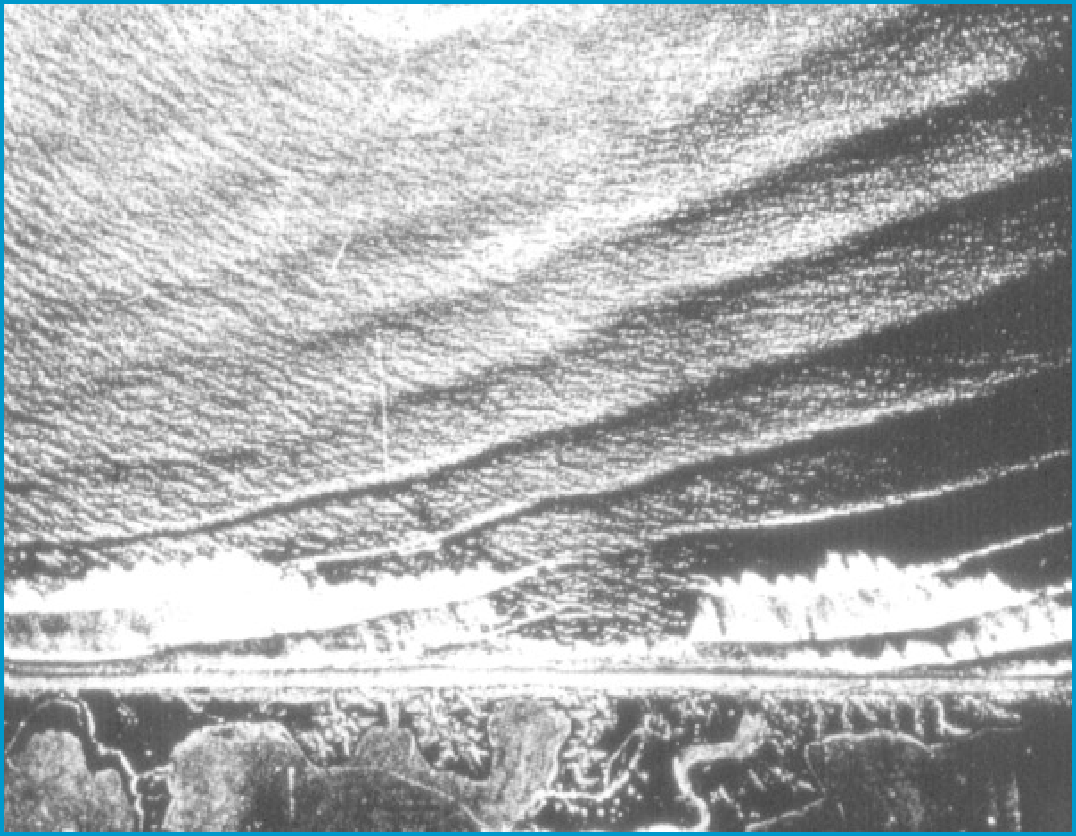
$$\Pr\{\underline{H} \le H\} = \begin{cases} F_1(H) = 1 - \exp\left[-\left(\dfrac{H}{H_1}\right)^2\right] & H \le H_{tr} \\ F_2(H) = 1 - \exp\left[-\left(\dfrac{H}{H_2}\right)^{3.6}\right] & H > H_{tr} \end{cases}$$

TU Delft

Influence of shallow water on the wave height



Wave refraction



$$\sin\alpha_2 = \left(\frac{c_2}{c_1}\right)\sin\alpha_1$$

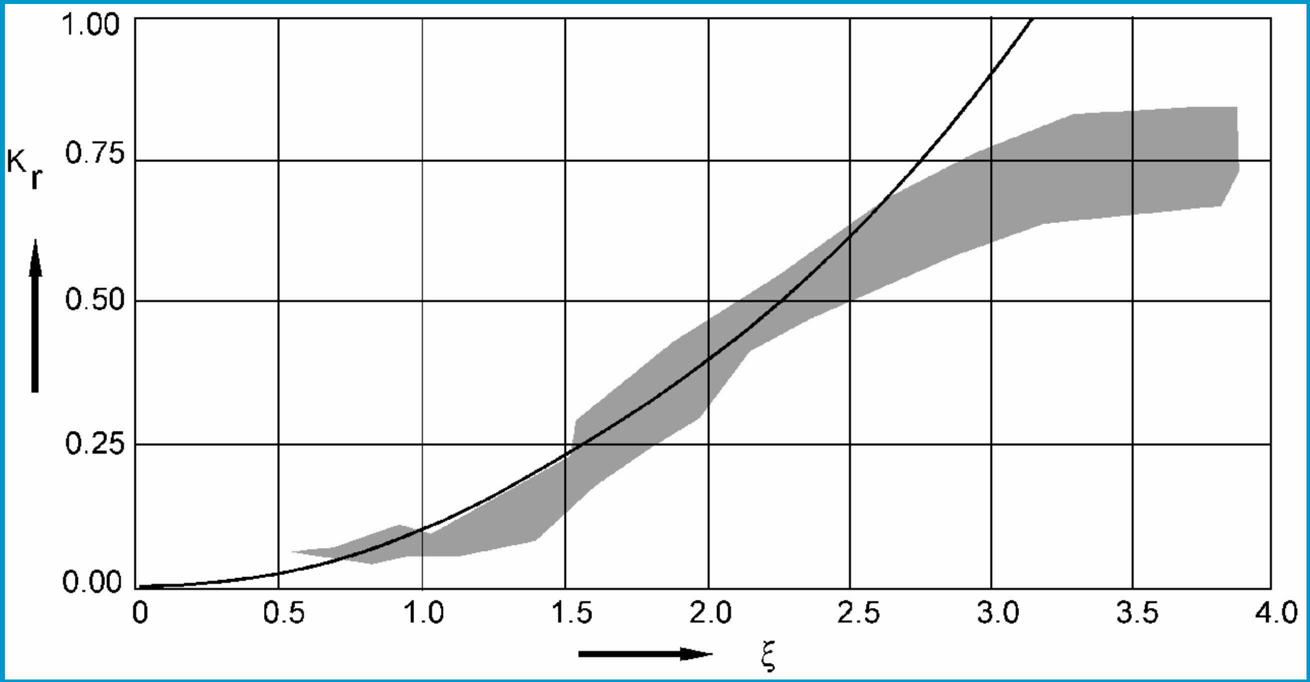
$$\frac{H_2}{H_1} = \sqrt{\frac{b_1}{b_2}}$$

TU Delft

Diffraction behind a detached breakwater

reflection

$$K_r = \frac{H_R}{H_I} \approx 0.1\xi^2$$

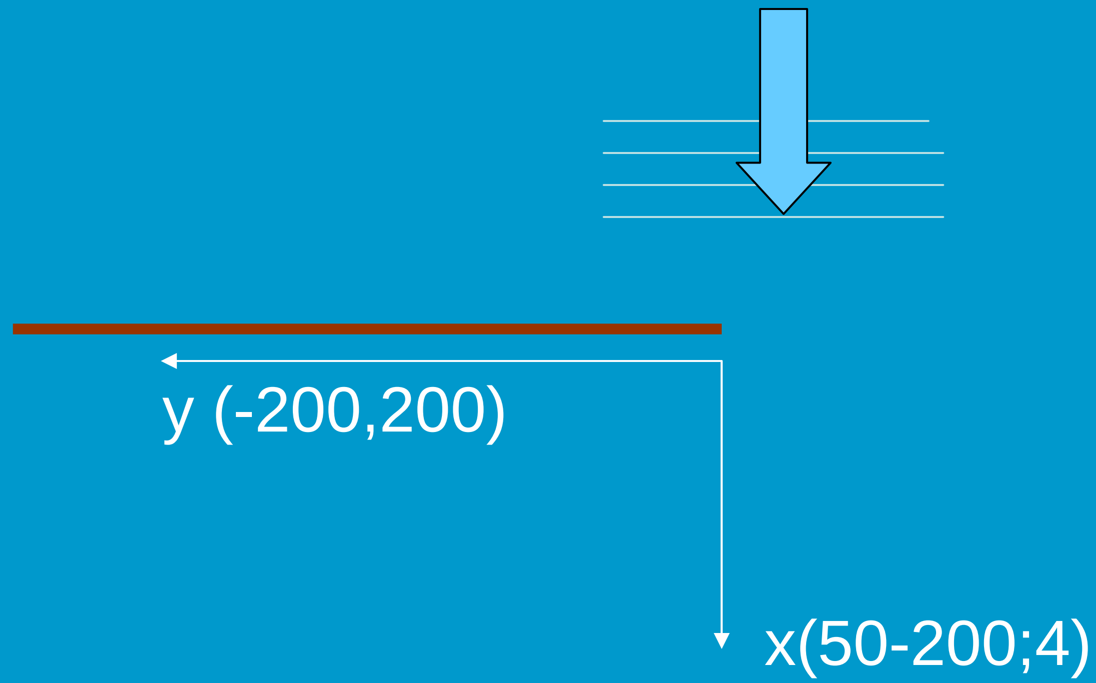


$$\eta_{tot} = \eta_i + \eta_r = (1+r)\frac{H_i}{2}\cos\left(2\pi x/L\right)*\cos\left(2\pi t/T\right) + (1-r)\frac{H_i}{2}\sin\left(2\pi x/L\right)*\sin\left(2\pi t/T\right)$$

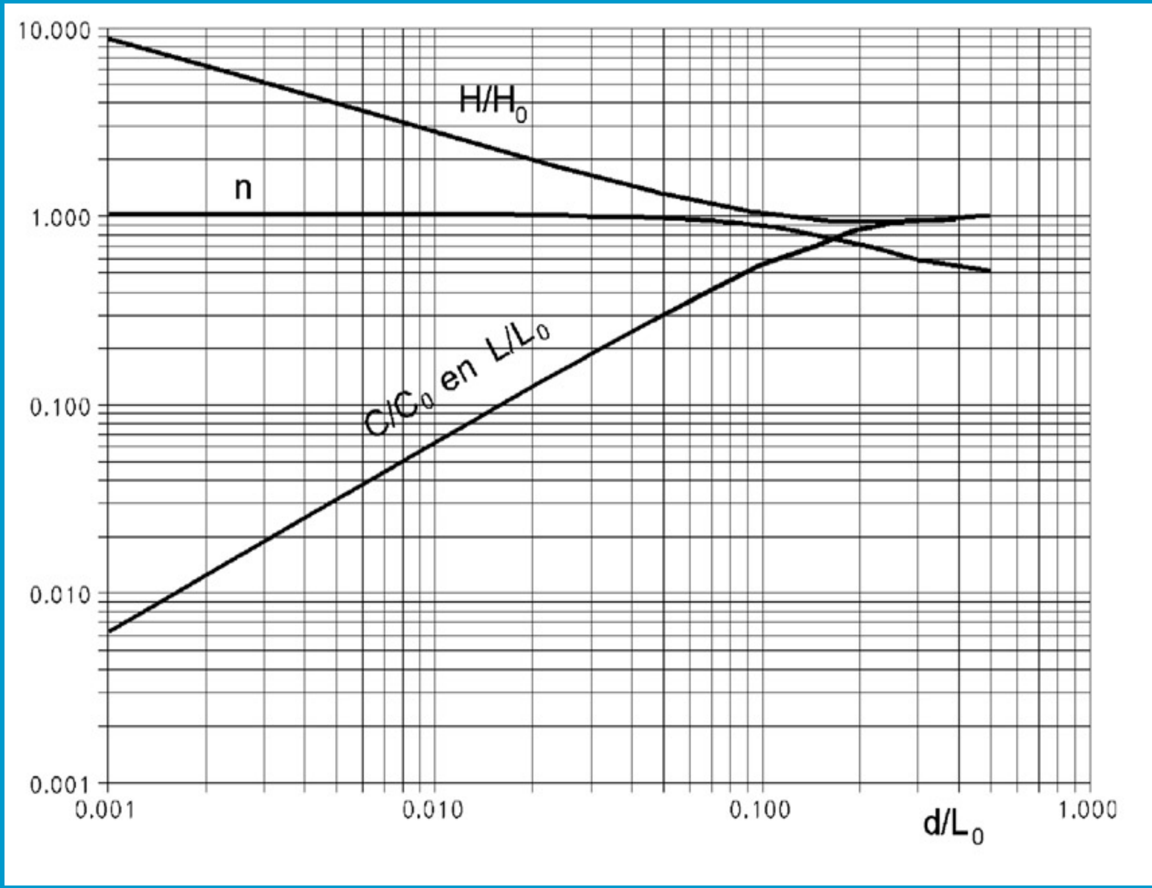
Example with Cress

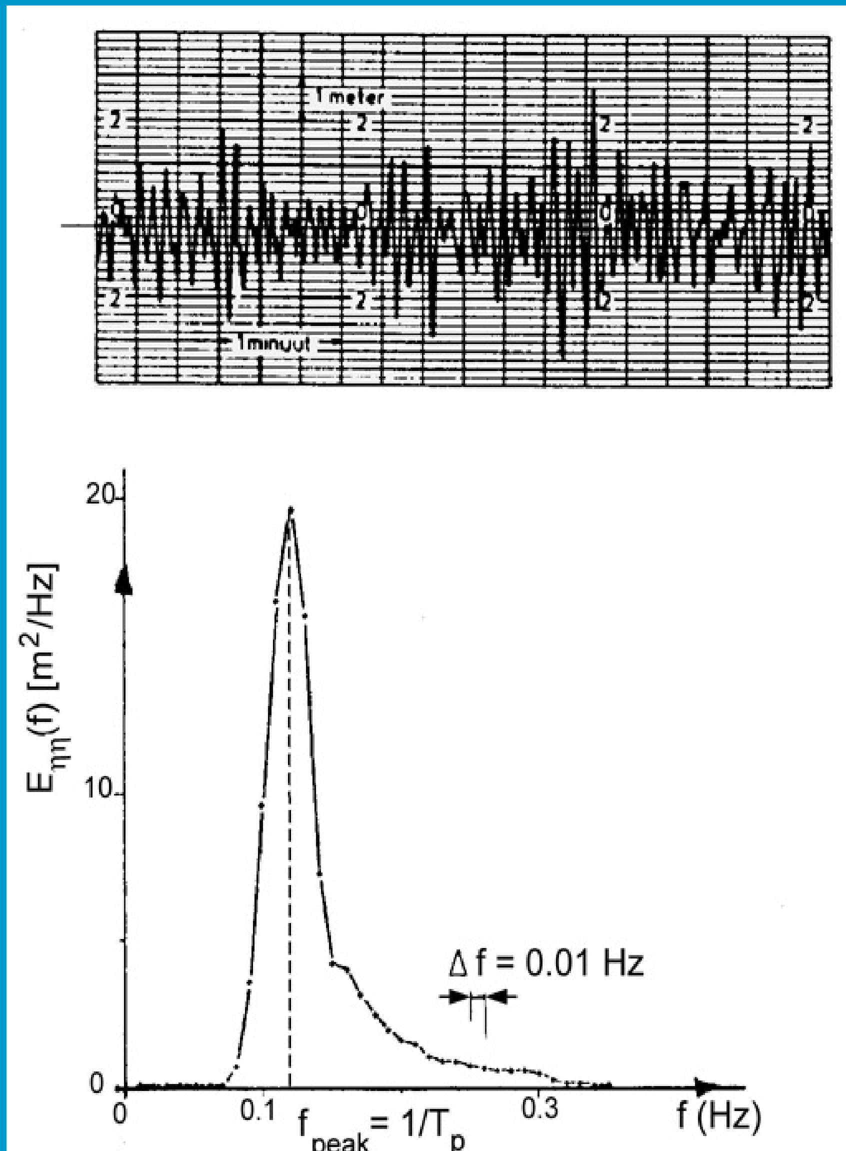
run demo Cress

refraction
shoaling, etc
diffraction



The effect of shoaling on wave parameters





Typical wave record of the North Sea

$$\eta(t) = \sum a_i \cos(2\pi f_i t + \varphi_i)$$

$$S(\omega) = \tfrac{1}{2} \sum^{\Delta\omega} a_i^2 / \Delta\omega$$

$$H_s = 4\sqrt{m_0} = H_{13.5\%}$$

Spectral wave periods

The use of different wave parameters to obtain better results for wave structure interaction

$$m_n = \int_0^\infty f^n S(f)\,df$$

ct5308 Breakwaters and closure dams

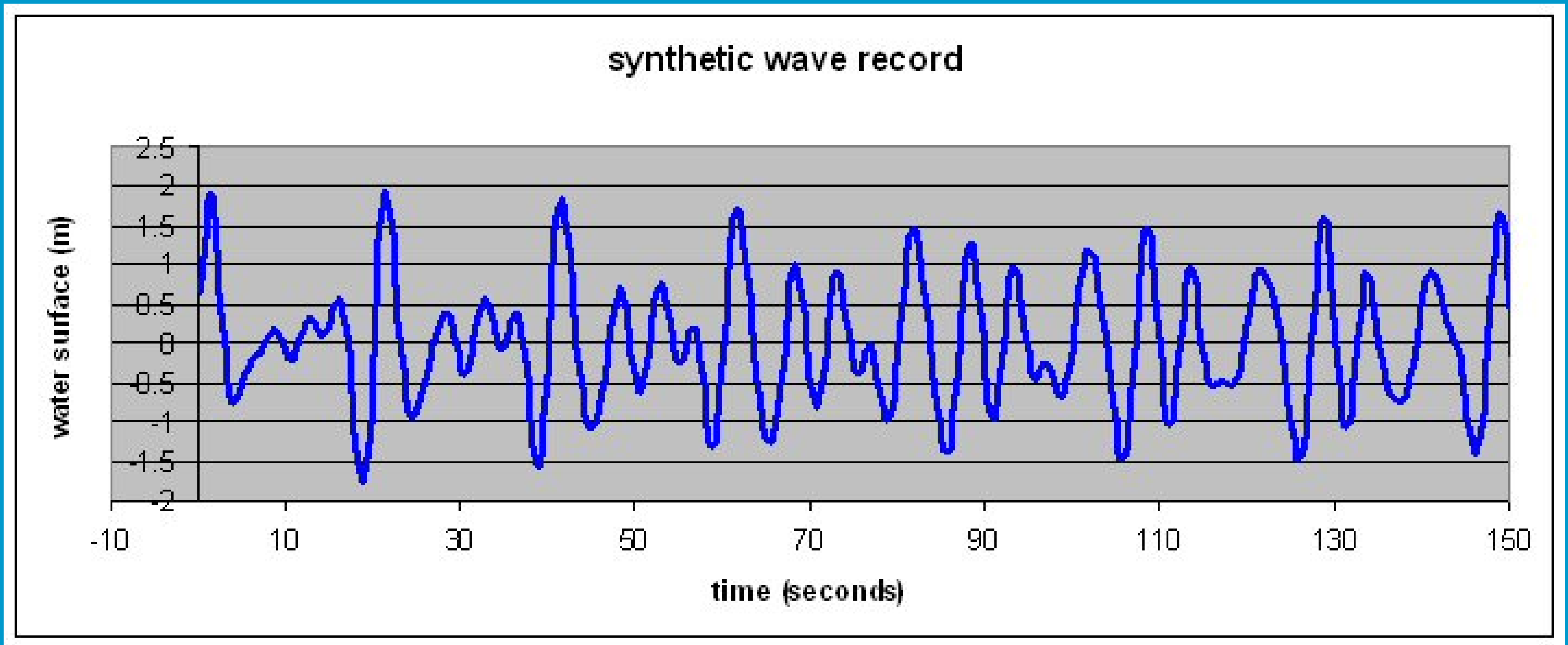
H.J. Verhagen

March 29, 2012

Faculty of Civil Engineering and Geosciences
Section Hydraulic Engineering

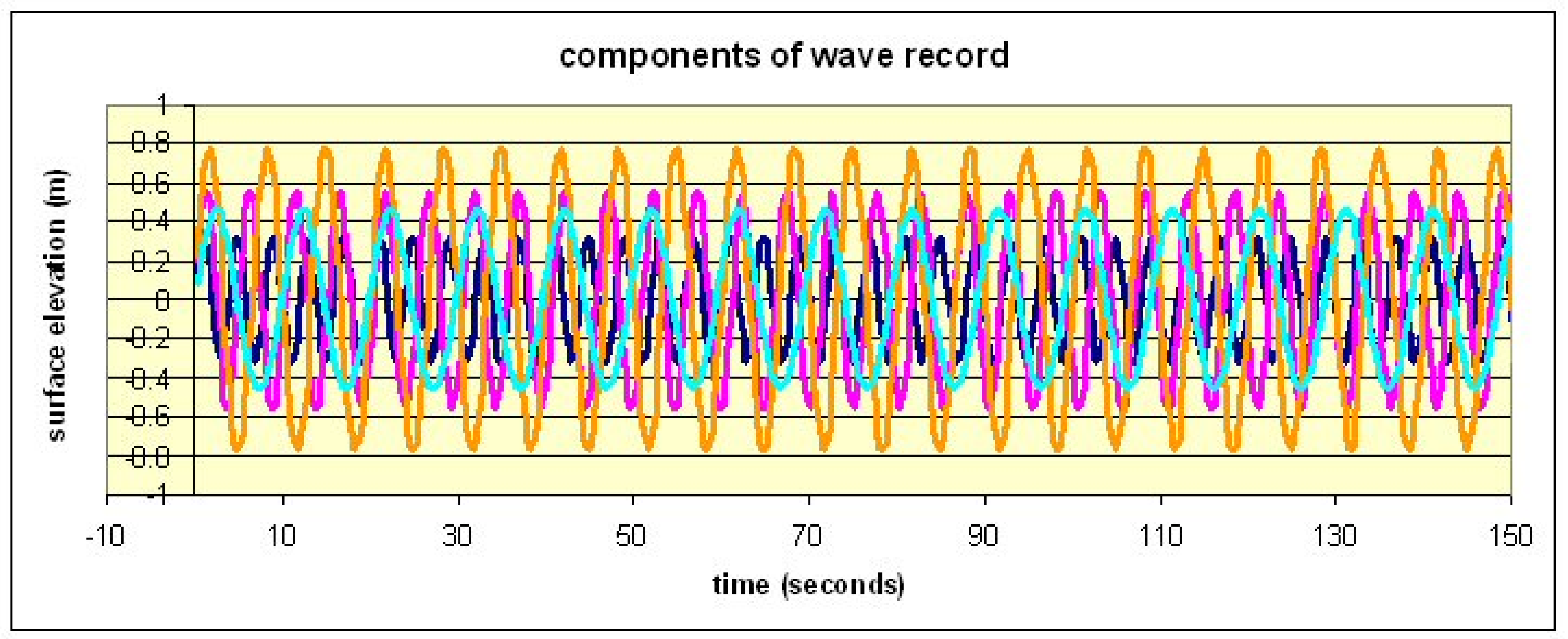
TU Delft
Delft University of Technology

Example wave record



28 waves, H_s = "13% wave", H_s= wave nr 4, $H_s \approx 3.8$
28 waves in 150 seconds, so $T_m = 5.3$ s

composition of the record



H_1 = 0.63 m T_1= 4 sec

H_2 = 1.80 m T_2 = 5 sec

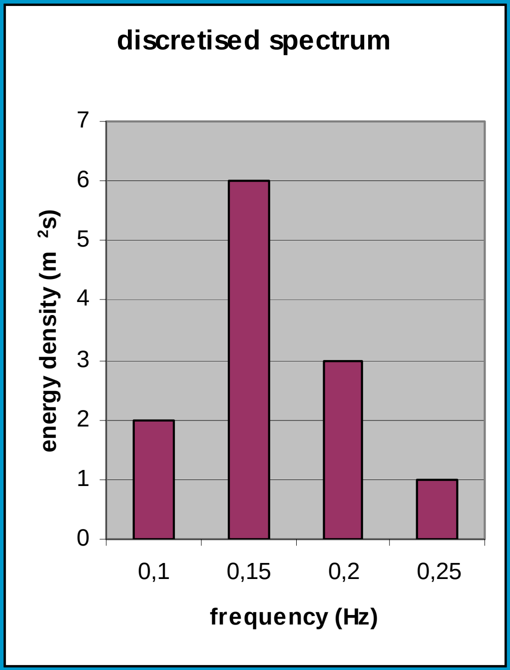
H_3 = 1.55 m T_3 = 6.67 sec

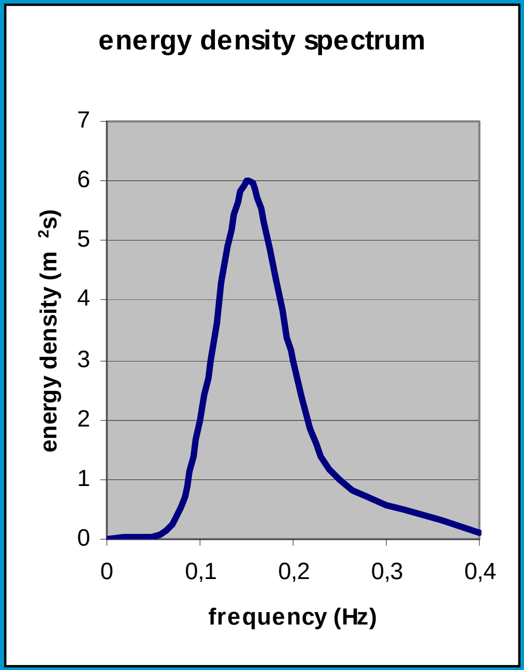
H_4 = 0.90 m T_4 = 10 sec T_m = 5.3 sec

TUDelft

Spectrum

$$\frac{1}{2}a^2 = S \cdot \Delta f$$

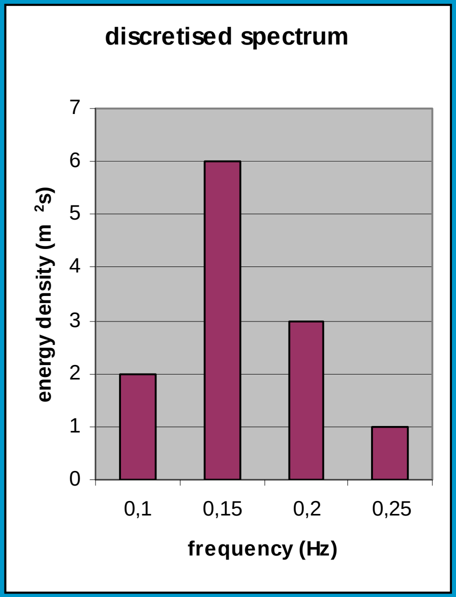




$$H = \sqrt{8S \cdot \Delta f} \qquad S = \frac{H^2}{8\Delta f} = \frac{1.55^2}{8 \cdot 0.05} = 6\ [m^2 s]$$

TU Delft

Calculation of m_0



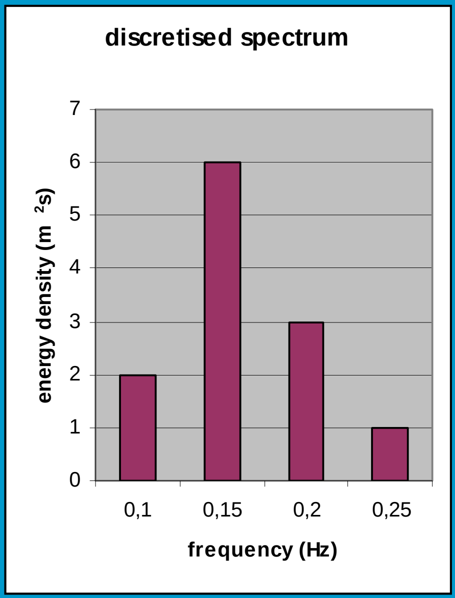
0.05*2	0.10
0.05*6	0.30
0.05*3	0.15
0.05*1	0.05
	0.60

$$4\sqrt{m_0} = 3.1\ m$$

$$m_n = \int_0^\infty f^n S(f)\,df$$

TU Delft

Calculation of m_1

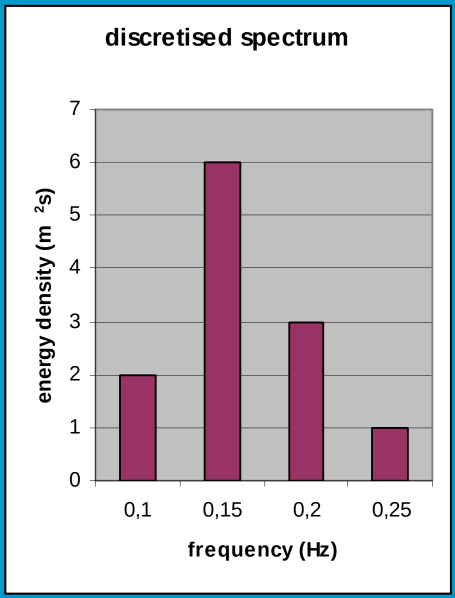


dist * SΔf	
0.10*0.10	0.010
0.15*0.30	0.045
0.20*0.15	0.030
0.25*0.05	0.013
	0.098

$$m_n = \int_0^\infty f^n S(f)\, df$$

TU Delft

Calculation of m_2



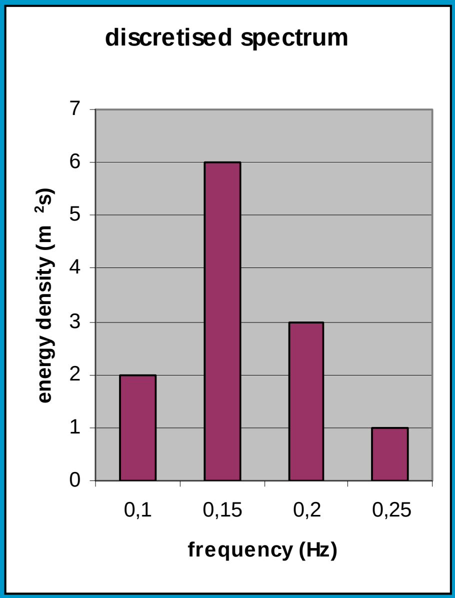
dist² * SΔf	
$0.10^2 * 0.10$	$1.00\ 10^{-3}$
$0.15^2 * 0.30$	$6.75\ 10^{-3}$
$0.20^2 * 0.15$	$6.00\ 10^{-3}$
$0.25^2 * 0.05$	$3.12\ 10^{-3}$
	$1.69\ 10^{-3}$

$$T = \sqrt{\frac{m_0}{m_2}} = 10\sqrt{\frac{0.60}{1.69}} = 5.69\,\text{sec}$$

$$m_n = \int_0^\infty f^n S(f)\,df$$

TU Delft

Calculation of m_{-1}



1/dist * SΔf	
1/0.10*0.10	1.0
1/0.15*0.30	2.0
1/0.20*0.15	0.75
1/0.25*0.05	0.20
	3.95

$$T_{m-1,0} = \frac{m_{-1}}{m_0} = \frac{3.95}{0.60} = 6.58 \text{ sec}$$

$$m_n = \int_0^\infty f^n S(f)\, df$$

TU Delft

Overview

- H_{m0} = 3.1 m
(1.55+1.10+0.90+0.63=4.18)
- T_{m0} = 5.69 sec
- $T_{m-1,0}$ = 6.58 sec
- T_{peak} = 6.67 sec
- $\frac{T_{m-1,0}}{T_{m0}} = \frac{6.58}{5.69} = 1.16$
- T_m = 5.35 sec
- $\frac{T_{m0}}{T_m} = \frac{5.69}{5.35} = 1.06$

Usual assumptions:
$T_{m0} = T_p$
$T_{1/3} = T_m$

For standard spectra:

Goda:	$T_p=1.1\ T_{1/3}$
PM:	$T_p=1.15\ T_{1/3}$
Jonswap:	$T_p=1.07\ T_{1/3}$
TAW (vdMeer):	$T_p=1.1T_{m-1,0}$
Old Test (vdMeer):	$T_p=1.04\ T_{m-1,0}$
Also:	$T_{m-1,0}=1.064T_{1/3}$

TU Delft

Overview to determine shallow water wave condition

- Determine deep water wave condition, this gives wave height, peak period and spectrum shape type (e.g. Jonswap)
- Calculate shallow water condition using spectral model (e.g. with SWAN), this gives H_{m0}, T_{m0} and $T_{m-1,0}$
- Use Battjes-Jansen method to determine $H_{2\%}$

TU Delft

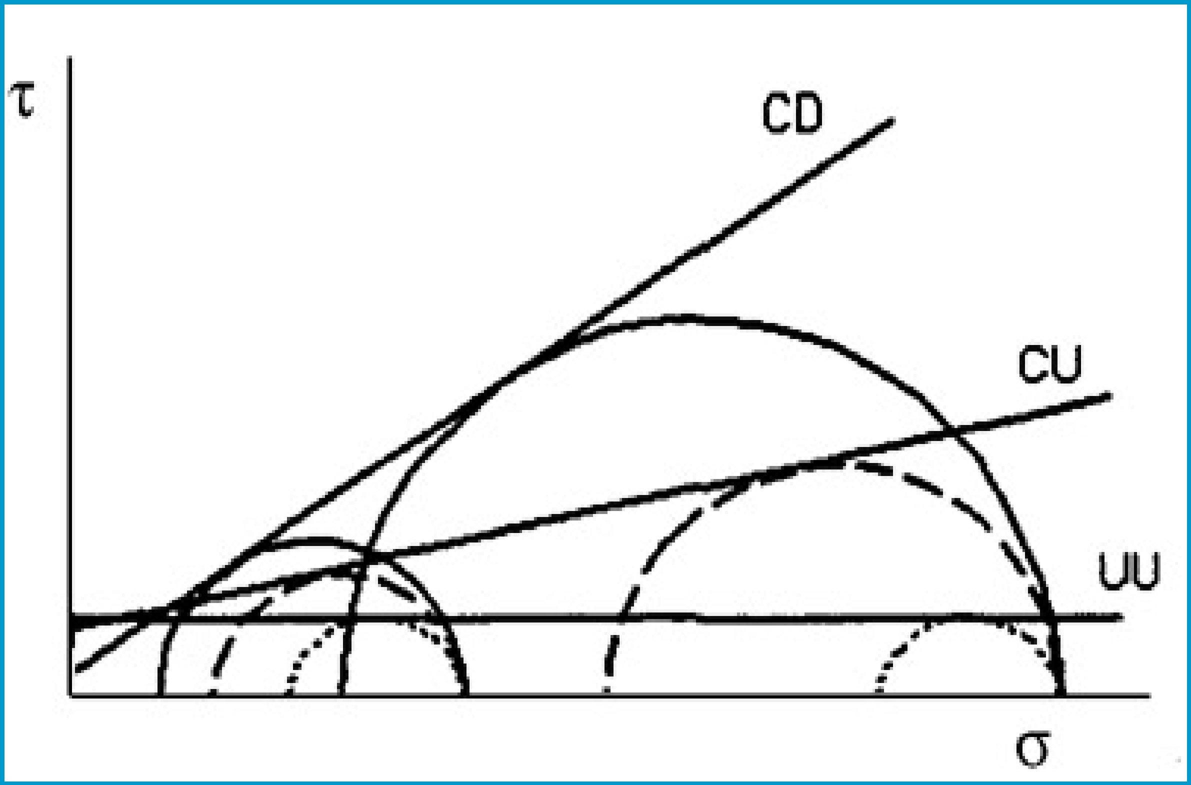
Why these parameters ?

$$\frac{H_{2\%}}{\Delta d_{n50}} = c_{pl} P^{0.18} \left(\frac{S}{\sqrt{N}} \right)^{0.2} \left(s_{m-1,0} \right)^{0.25} \sqrt{\cot \alpha} \qquad \textit{for plunging waves}$$

$$\frac{H_{2\%}}{\Delta d_{n50}} = c_{s} P^{-0.13} \left(\frac{S}{\sqrt{N}} \right)^{0.2} \left(s_{m-1,0} \right)^{-0.25} \left(\xi_{s-1,0} \right)^{P-0.5} \qquad \textit{for surging waves}$$

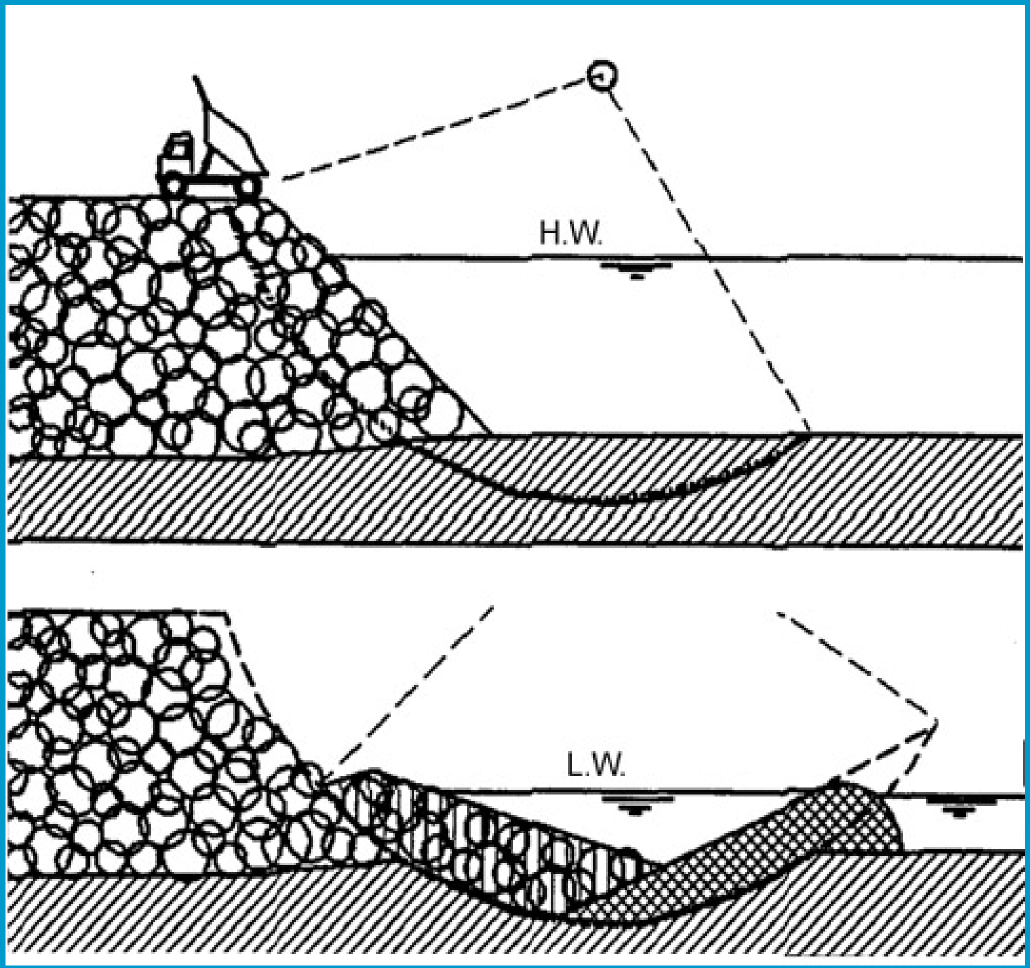
TU Delft

stress relations determined by soil testing



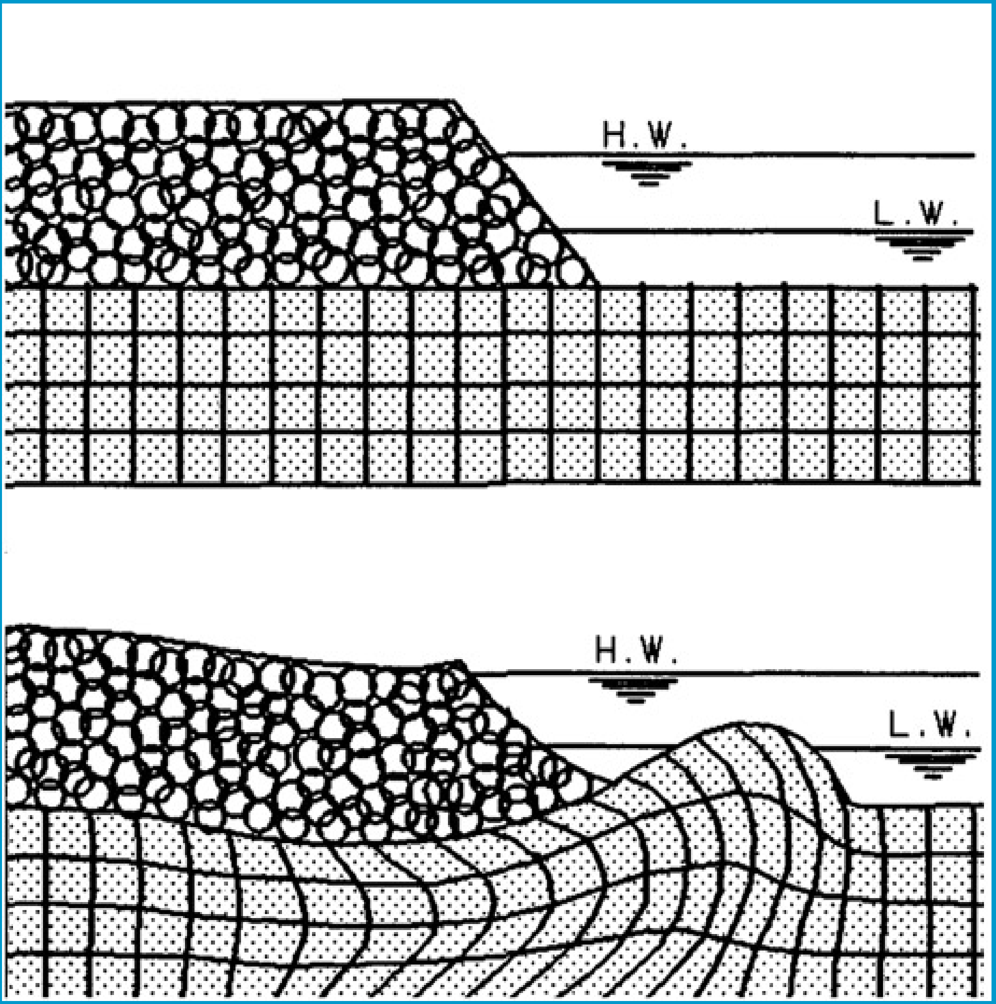
TU Delft

Dam profile after the slide

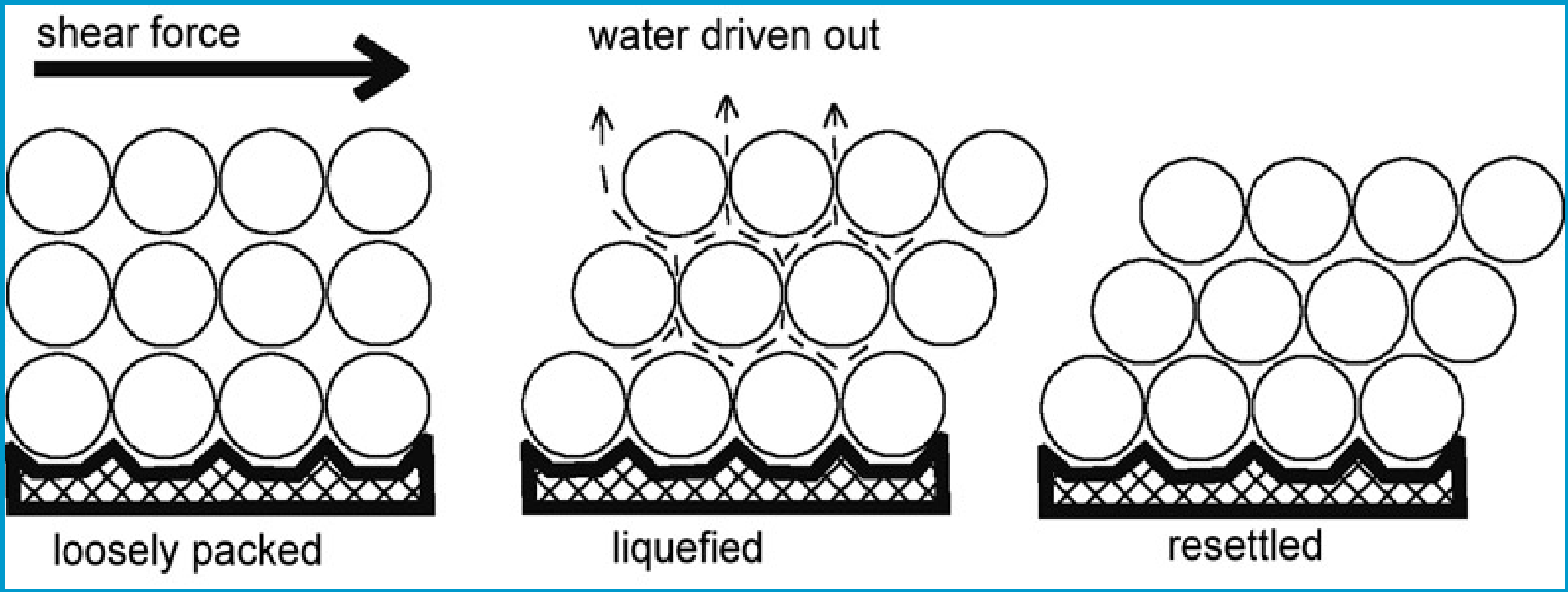


TU Delft

Squeeze



Liquefied sand



TU Delft