Flow, Erosion

Chapter 4

ct4310 Bed, Bank and Shoreline protection

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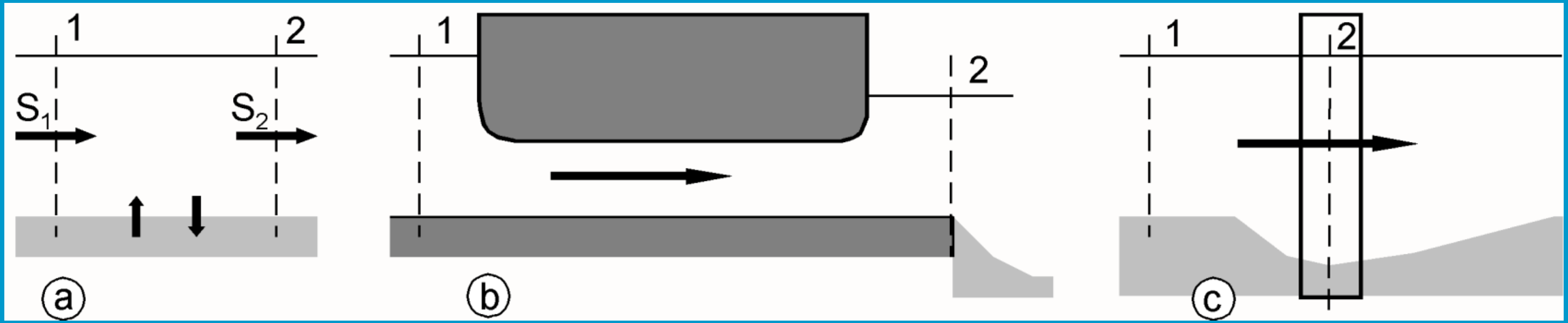
Introduction

- after the material has come into motion we have erosion
- erosion will continue until there comes a new equilibrium
- this is typically a scour problem
- scour is a gradient in sediment transport
- scour may be caused by:
  - change in hydraulic conditions (e.g. acceleration or increased turbulence)
  - availability of erodible material (difference between sediment transport capacity and sediment transport)

the scour process

$$\frac{\partial z_b}{\partial t} + \frac{\partial S}{\partial x} = 0$$

general picture local erosion



- $S_2 = S_1 > 0$ dynamic equilibrium situation
- $S_2 > S_1 = 0$ clear water scour
- $S_2 > S_1 > 0$ live-bed scour

sediment transport is not always identical to sediment transport capacity

Erosion due to turbulence

- Erosion downstream of a sill, due to turbulence
- Velocities and turbulence measured with micromill.
- Influence average velocity; v=0.2 m/s bed position and scouring hole
  - at 0 min,
  - 5 min,
  - 10 min,
  - 20 min,
  - 40 min,
  - 80 min;
- same for 0.3 m/s, 2 min, 5 min, 10 min, 20 min, 40 min,
- Influence of Turbulence, by making a rough bed on the sill, after 10, 20 and 40 min

bb: 4310-4 ErosionTurbulence1 WL-M648, 1962

sand transport formula

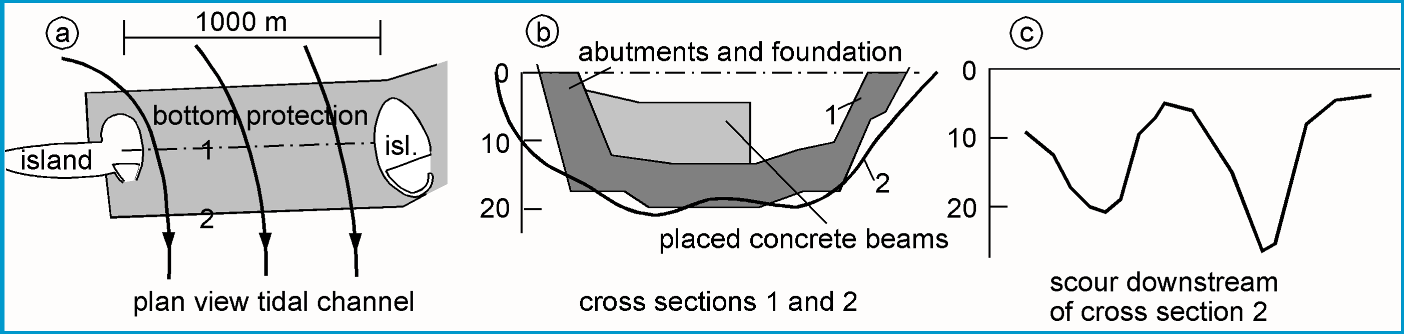
threshold value

$$S = f(\psi - \psi_c) \quad \text{or} \quad S = f(\psi)$$

dynamic equilibrium

$$w_s \, \overline{c} + \upsilon_s \frac{\partial \, \overline{c}}{\partial \, z} = 0$$

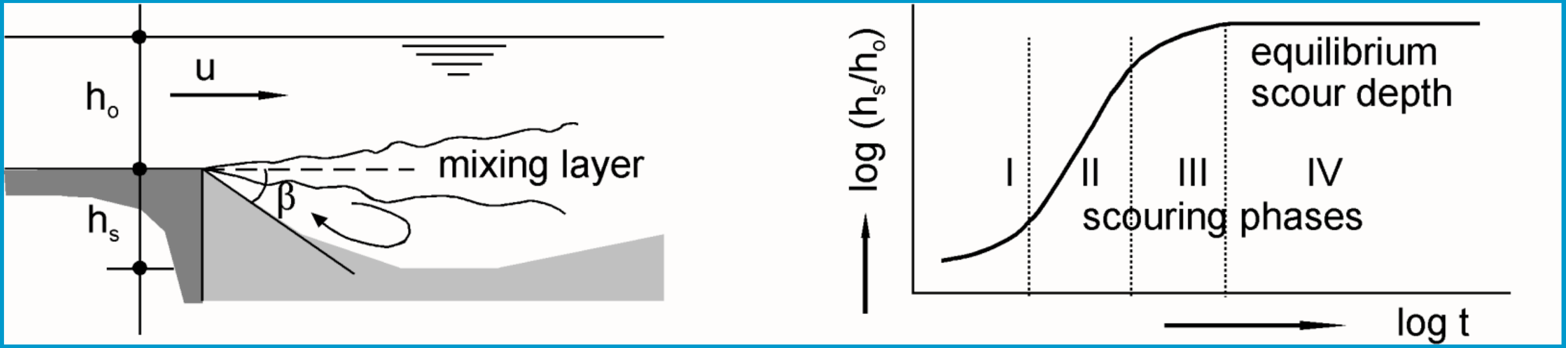
scour at the Eastern Scheldt



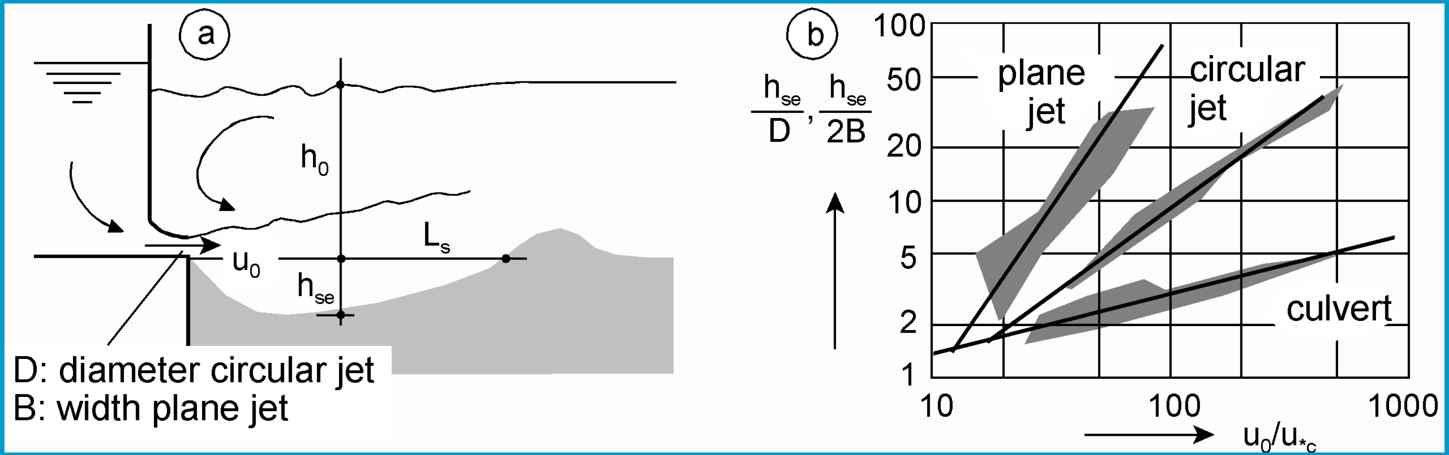
types of scour

- scour without protection
  - jets and culverts
  - detached bodies (bridge piers)
  - attached bodies and constrictions
    - abutments
    - groynes
- scour with bed protection
  - scour development in time
  - dustbin factor α
- flow slides

Scour hole and development in time



scour in horizontal jets and culverts



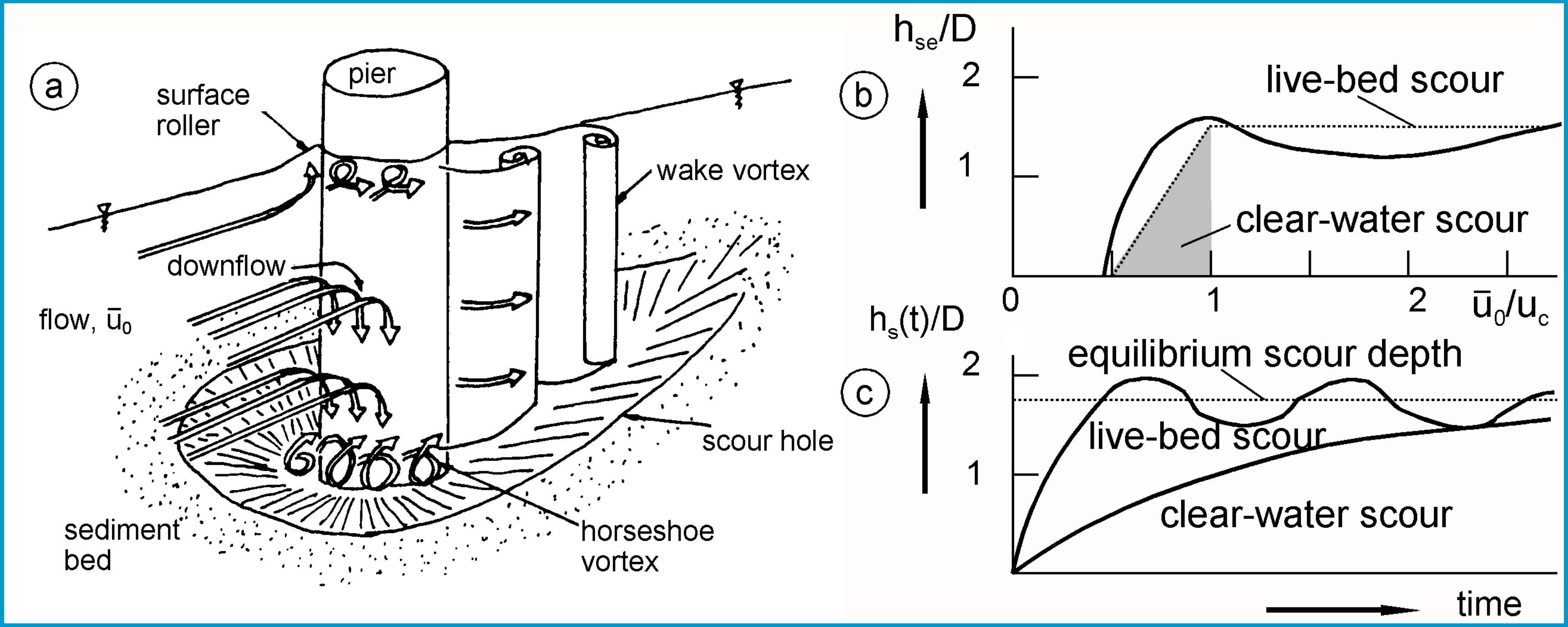
plane jet: $$\frac{h_{se}}{2B} = 0.008\left(\frac{u_0}{u_{*c}}\right)^2$$

circular jet : $$\frac{h_{se}}{D} = 0.08 \frac{u_0}{u_{*c}}$$

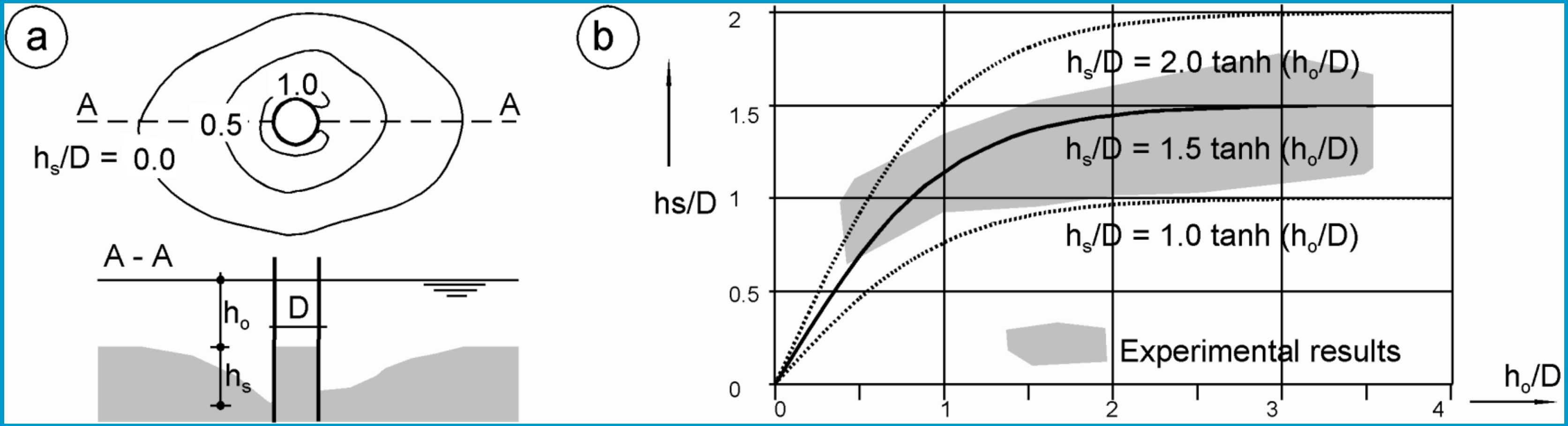
culvert

$$\frac{h_{se}}{D} = 0.65\left(\frac{u_0}{u_{*c}}\right)^{0.33}$$

scour around a cylinder



scour around a cylinder as function of waterdepth and diameter

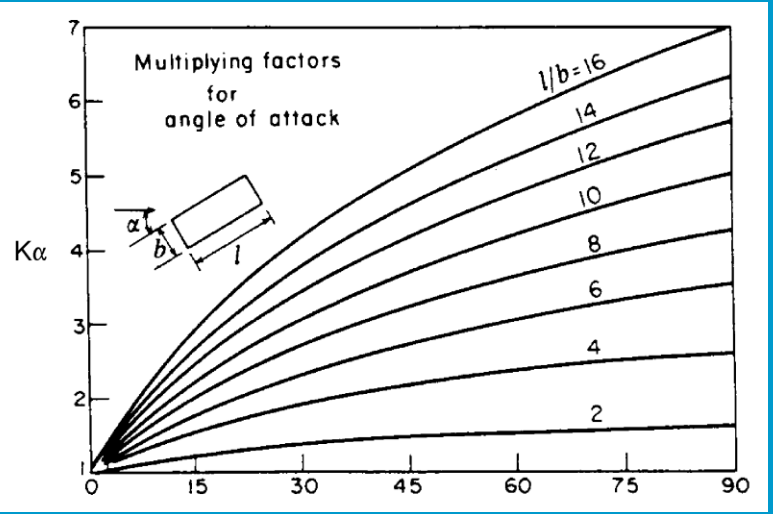


scour in case of other forms

$$\frac{h_s}{D} = 2\,K_S\;K_\alpha\;K_u\;\tanh\left(\frac{h_0}{D}\right)$$

not in example 4.1 ??

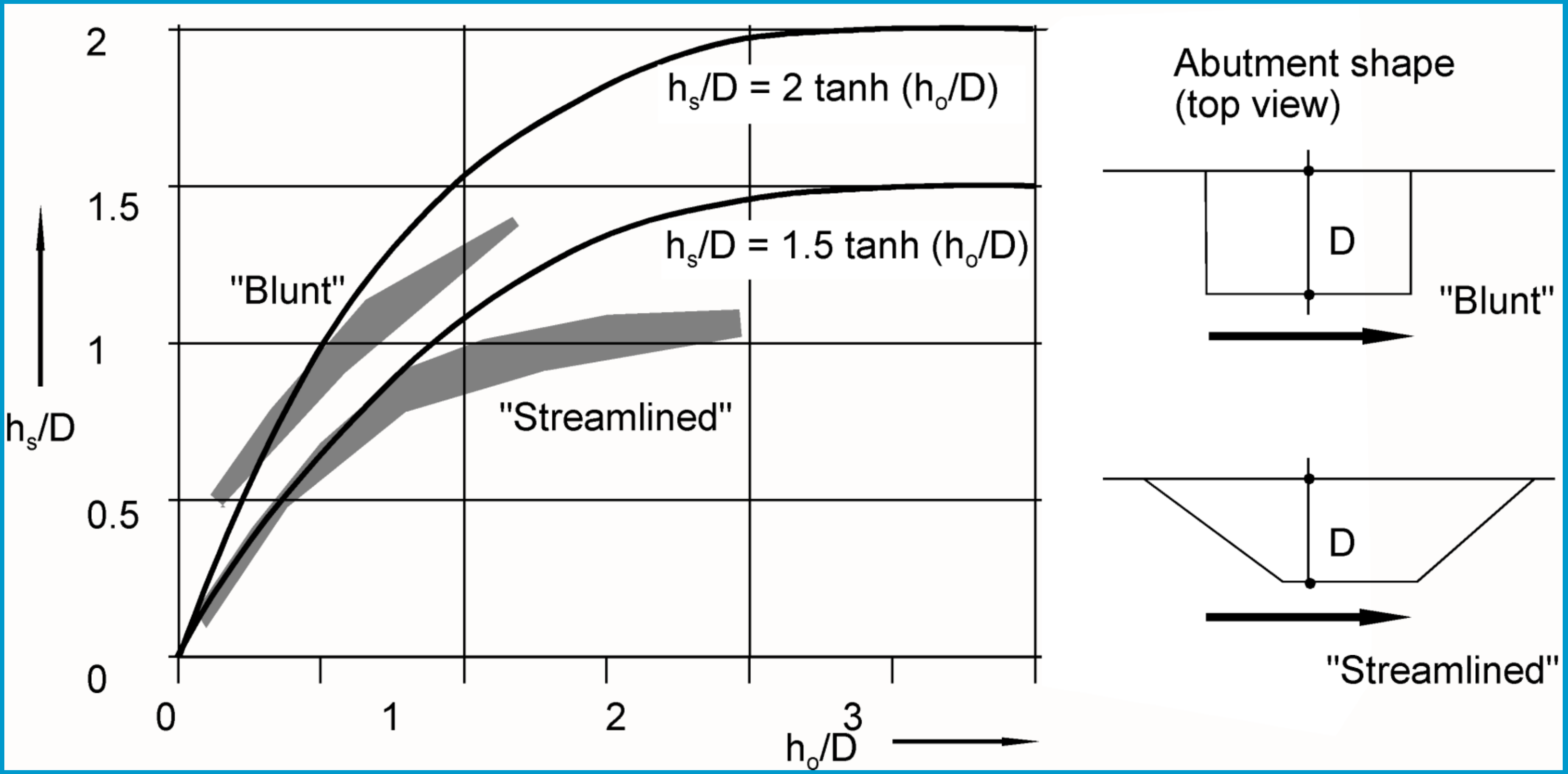
Pier shape	l/b	K_S
Cylinder	-	1.0
Rectangular	1	1.2
	3	1.1
	5	1.0
Elliptic	2	0.85
	3	0.8
	5	0.6



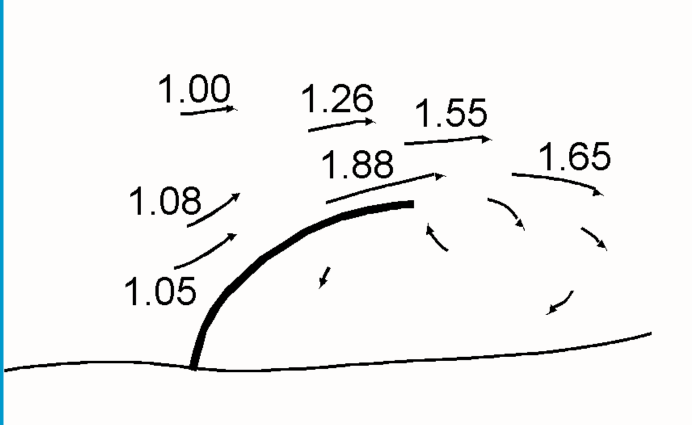
In Cress roughness is assumed to be 3 D_{90}; in book 2 D_{50} is used

K_s = shape factor
K_α = angle of attack
K_u = velocity factor

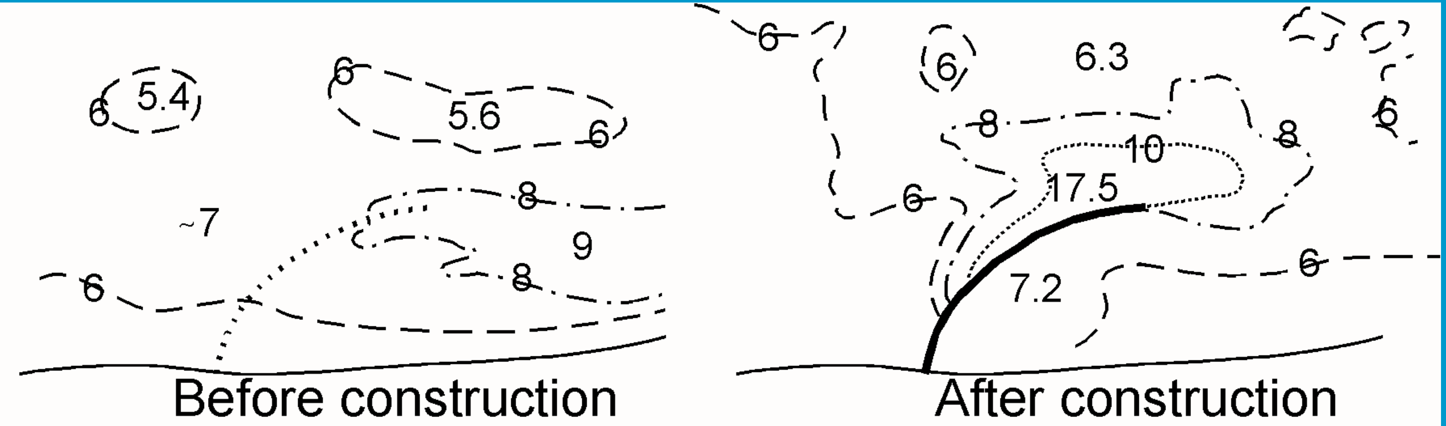
scour around abutments



Flow velocities and scour in Zeebrugge

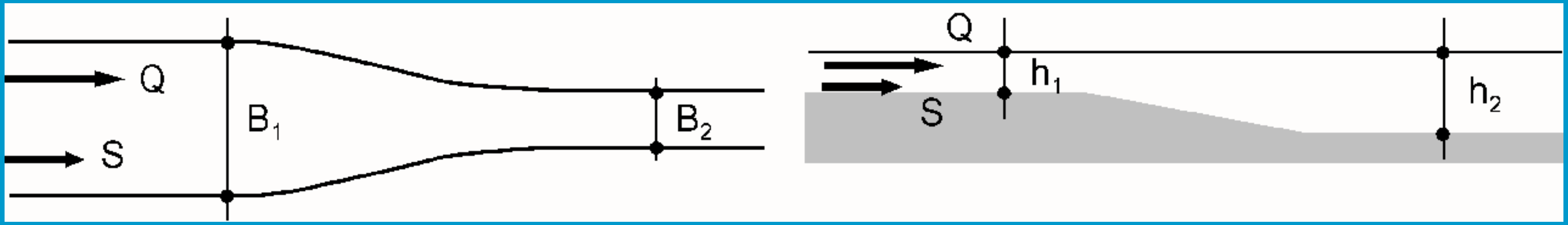


Velocities in m/s



Depth contours in MSL - m

erosion in gradual constriction

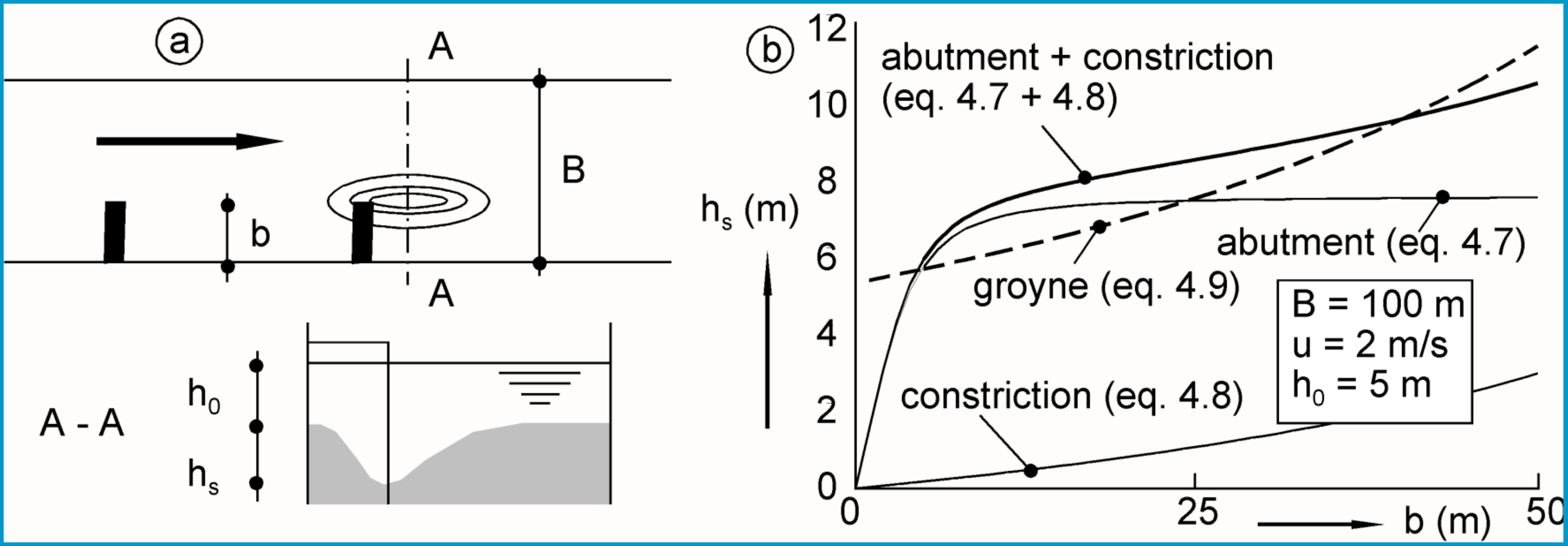


$$Q = B_1 u_1 h_1 = B_2 u_2 h_2 \rightarrow u_2 = u_1 \frac{B_1 h_1}{B_2 h_2}$$

$$S = B_1 k u_1^m = B_2 k u_2^m$$

$$\rightarrow \frac{B_1^{m-1}}{B_2^{m-1}} = \frac{h_2^m}{h_1^m} \rightarrow \frac{h_2}{h_1} = \left(\frac{B_1}{B_2}\right)^{\frac{m-1}{m}}$$

groynes

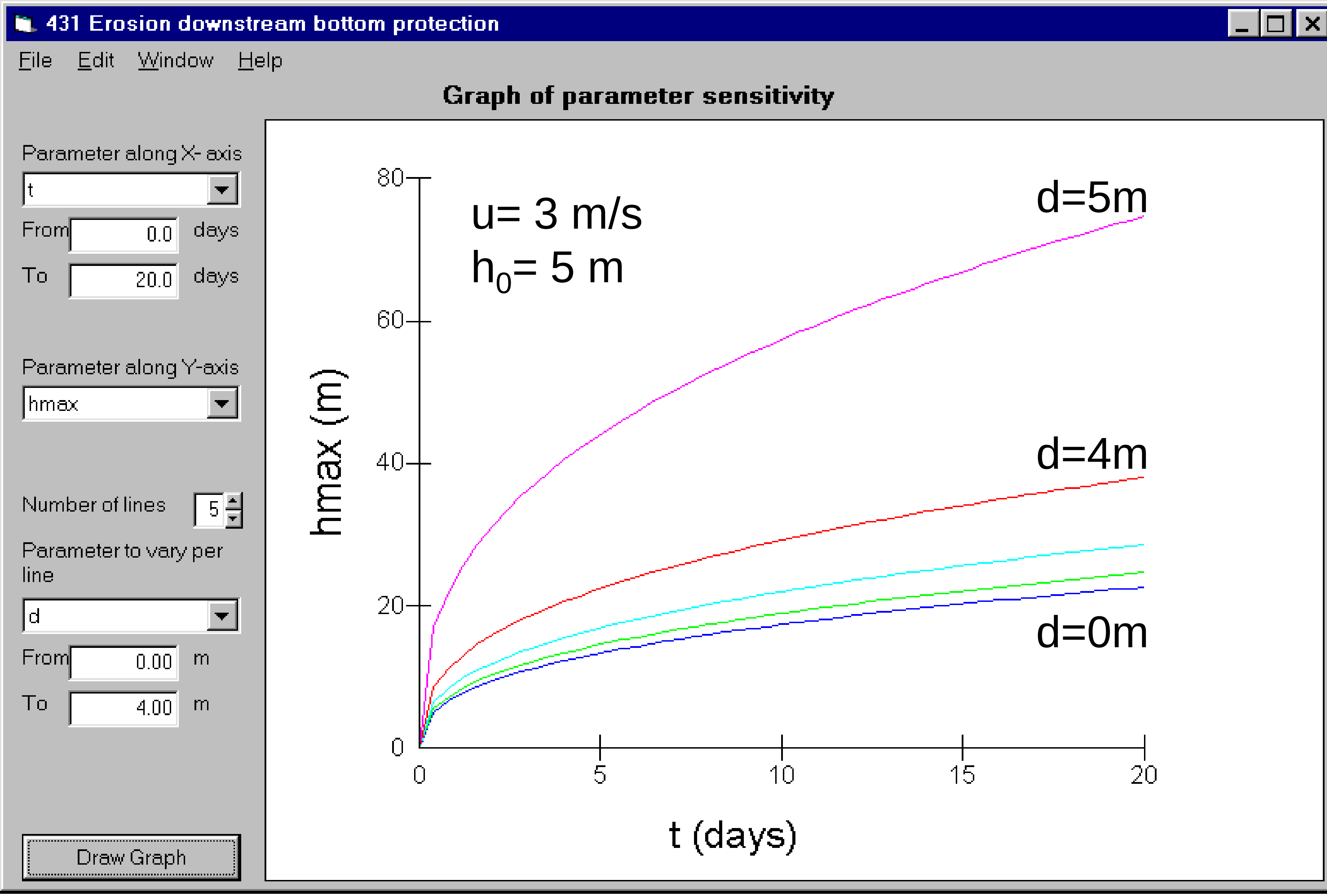


$$h_0 + h_{se} = 2.2 \left(\frac{Q}{B-b} \right)^{2/3}$$

scour behind bed protection

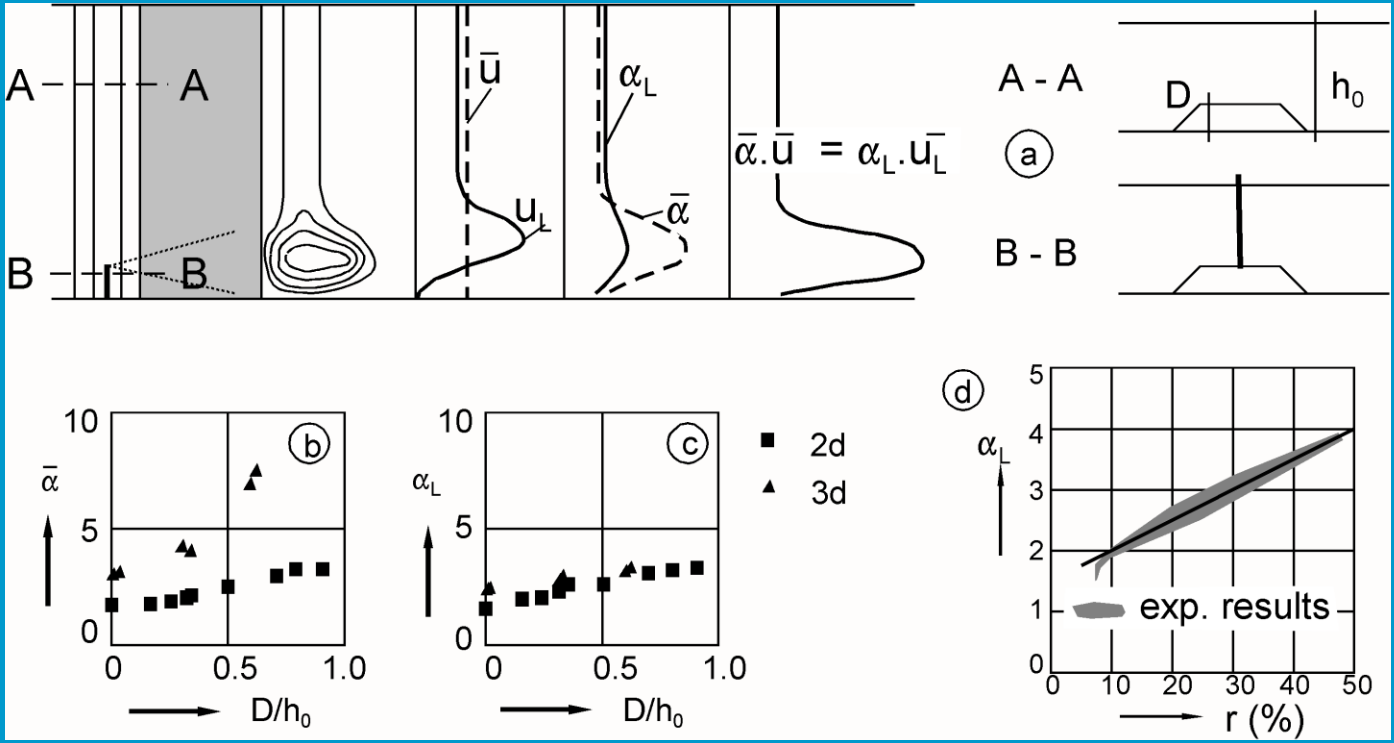
$$h_s(t) = \frac{(\alpha\,\bar{u} - \bar{u}_c)^{1.7}\, h_0^{0.2}}{10\,\Delta^{0.7}}\, t^{0.4}$$

$h_s(t)$	maximum scour depth
h_0	original water depth
u	vertically averaged velocity at end of protection
u_c	critical velocity
t	time in hours
α	dust bin parameter



431 Erosion downstream bottom protection
File Edit Window Help
Graph of parameter sensitivity
Parameter along X- axis
t
From 0.0 days
To 20.0 days
Parameter along Y-axis
hmax
Number of lines 5
Parameter to vary per line
d
From 0.00 m
To 4.00 m
Draw Graph
u= 3 m/s
h0= 5 m
d=5m
d=4m
d=0m
hmax (m)
t (days)
0
20
40
60
80
0
5
10
15
20

influence of α



use local value of α

$\alpha_L = 1.5 + 5\ r$

steps to calculate α (1)

Hinze (1975):

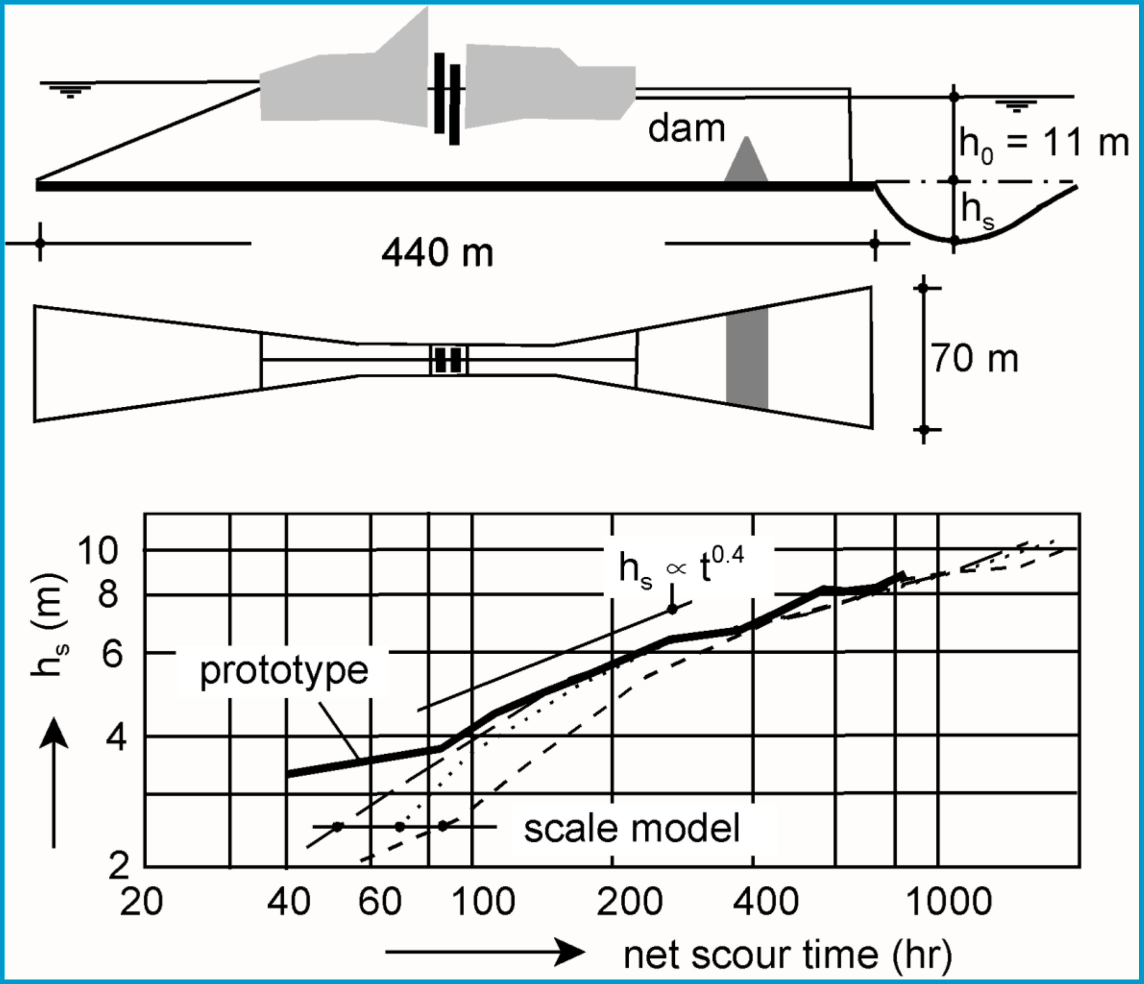
$$r_0 = \sqrt{0.0225(1-\frac{D}{h})^{-2}(\frac{L-6D}{6.67h}+1)^{-1.08} + \frac{1.45g}{C}}$$

eq. 2.13
D = step height
h = downstream waterdepth

Hoffmans (1992, 1993)

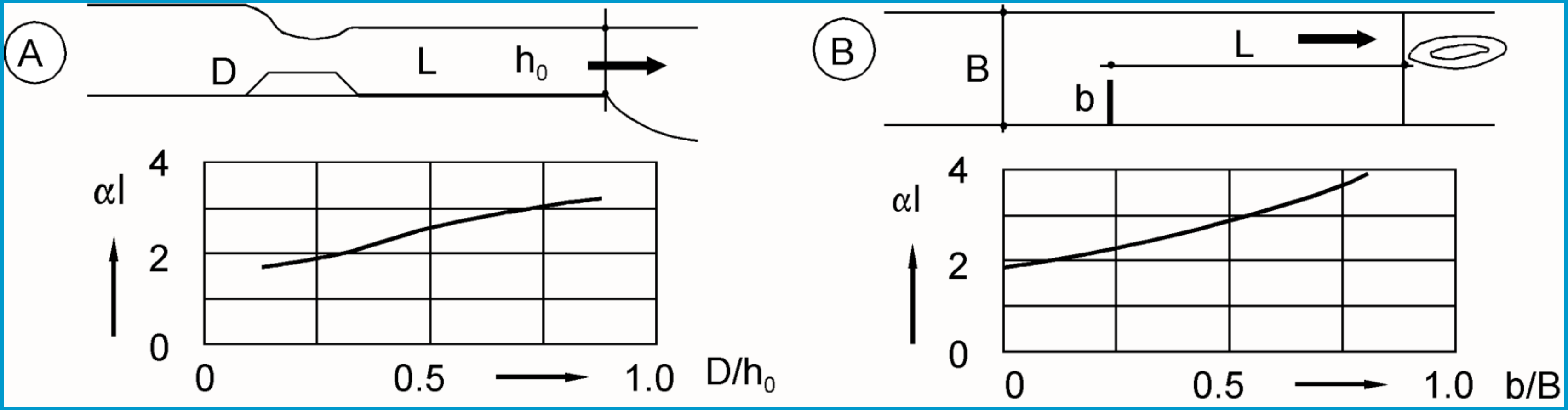
$\alpha_L = 1.5 + 5\ r$

comparison model and prototype

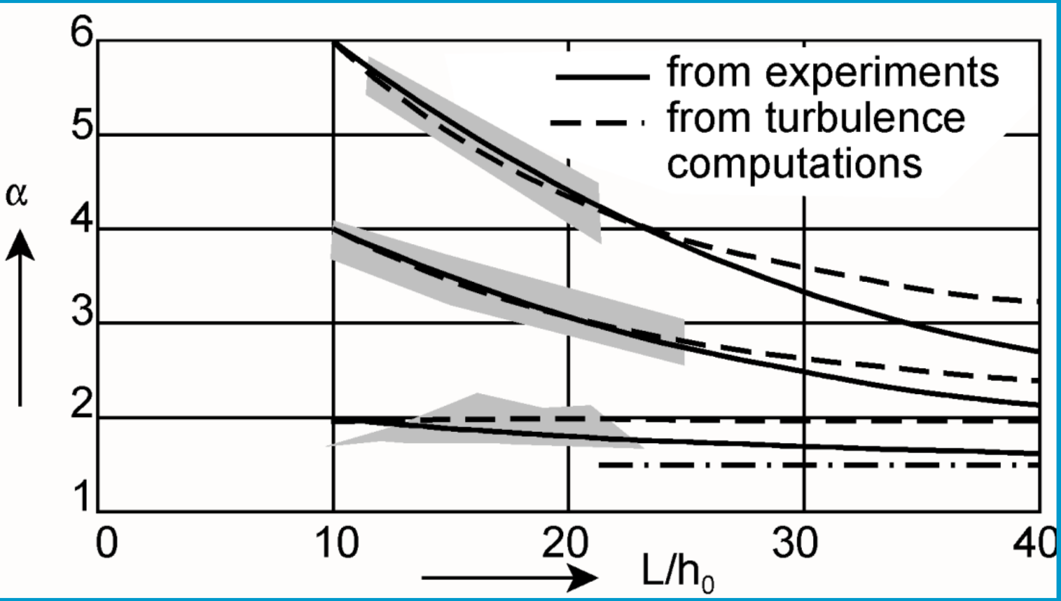


De Grauw and Pilarczyk 1981

values of α for vertical and horizontal constrictions



relation between α, turbulence and length



$$\alpha = 1.5 + 5\, r_0\; f_c \quad \text{with} \quad f_c = \frac{C}{40} \quad (f_c = 1 \text{ for } C \le 40)$$

From Hoffmans (1993)

The r_0 comes from Hoffmans and Hinze

steps to calculate α (2)

Hinze (1975):

$$r_0 = \sqrt{0.0225\left(1-\frac{D}{h}\right)^{-2}\left(\frac{L-6D}{6.67h}+1\right)^{-1.08}+\frac{1.45g}{C}}$$

eq. 2.13
D = step height
h = downstream waterdepth

Hoffmans (1992, 1993)

α_L = 1.5 + 5 r

Hoffmans and Booij (1993)

$$\alpha = 1.5 + 5\, r_0\, f_c \quad \text{with} \quad f_c = \frac{C}{40} \quad (f_c = 1 \text{ for } C \leq 40)$$

Trinh (1993)

$$\alpha = (1.5 + 5 r_0\, f_c)\, f_u$$

$$f_u = 1 + 3.6\left(1-\frac{b}{B_s}\right)^{2.2}$$

B_s is original gap width
b is reduced gap width

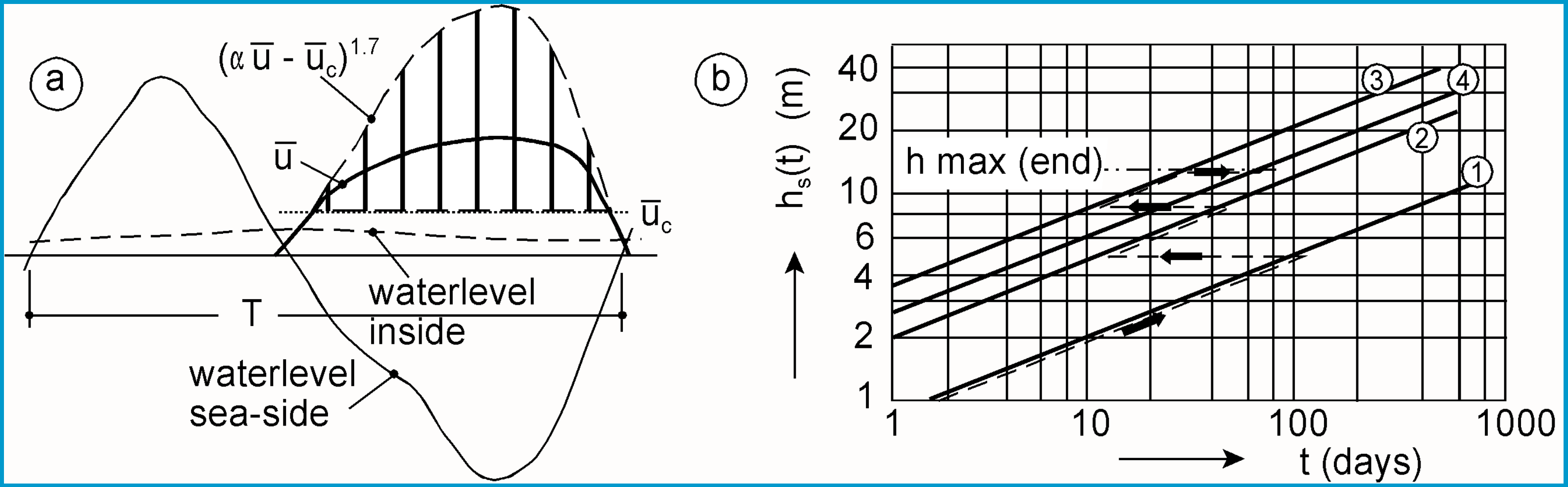
Scouring tests in the lab

- No obstacle, 10 cm/sec
- No obstacle, 20 cm/sec
- No obstacle, 30 cm/sec

- With obstacle, 10 cm/sec

bb: 4310-04: ErosionTurbulence 2 - 5

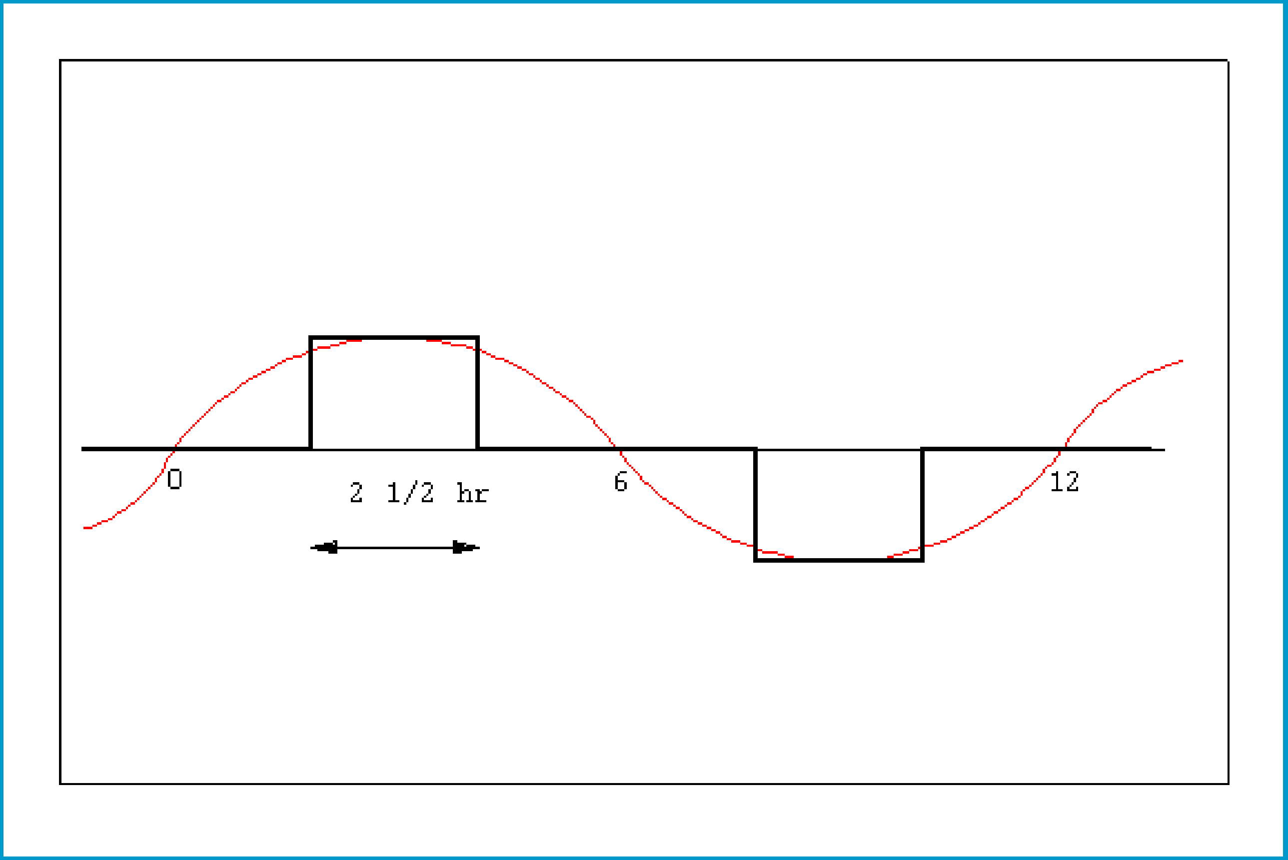
varying conditions



$$\left(\alpha\bar{u} - \bar{u}_c\right)^{1.7} \longrightarrow \frac{1}{T}\int_0^T \left(\alpha\,\bar{u} - \bar{u}_c\right)^{1.7} dt$$

How to do this in practice ??

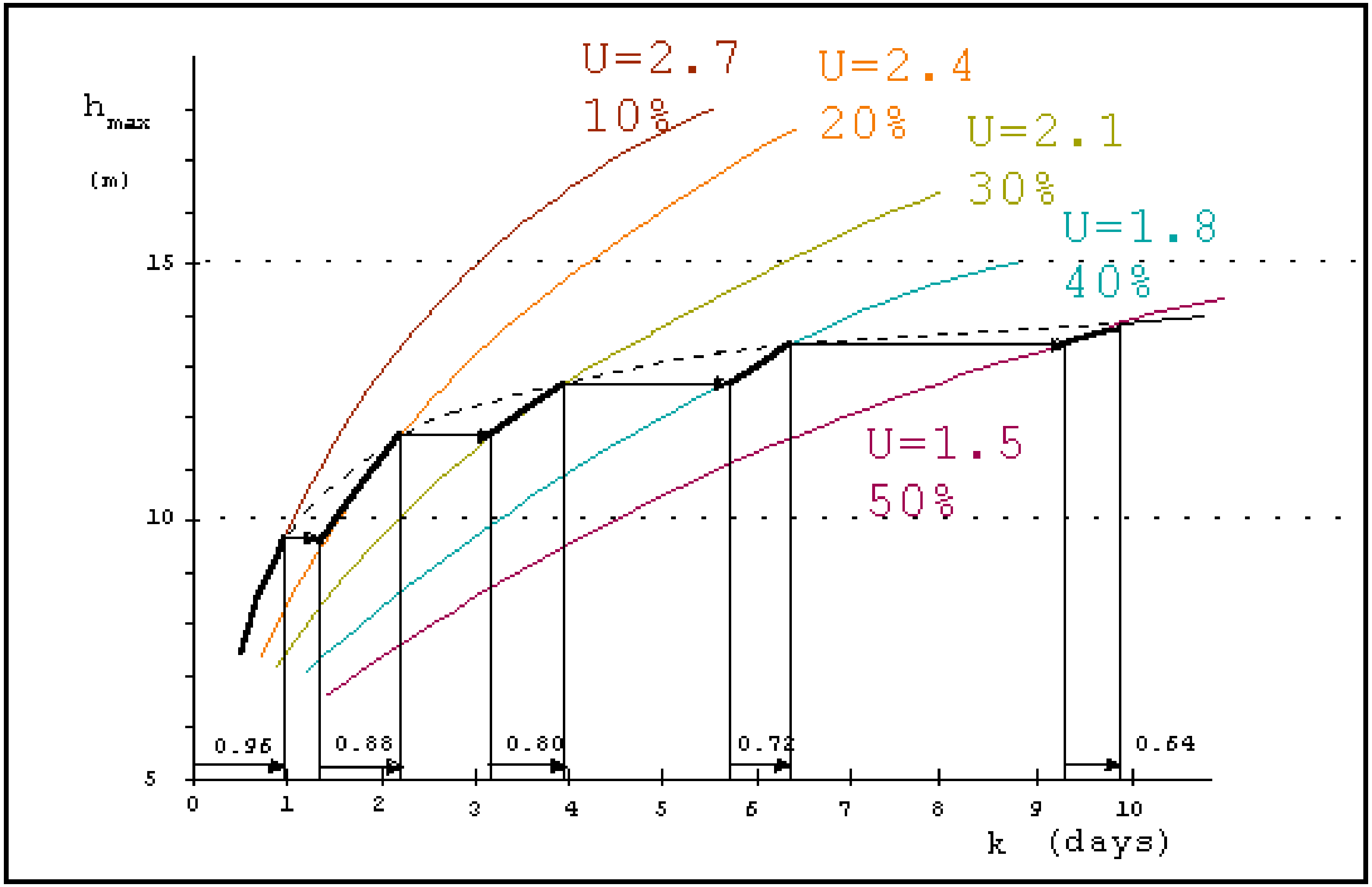
rough approximation of the tide



in case of closing works..

- tide varies
- gap becomes smaller
- sill becomes higher

stepwise calculation



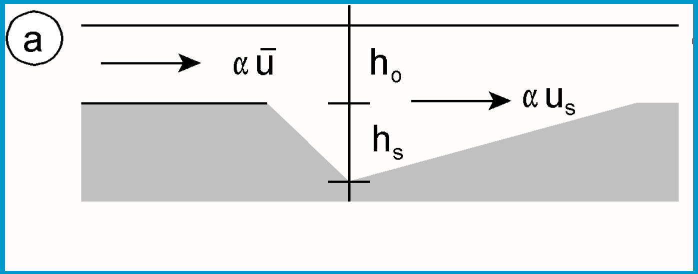
example scouring during closing

Vertical closure, 20 m deep, 200 m long, tidal amplitude 3.5 m
Maximum stone supply 4000 m^3/day, so 4000/200 = 20 m^2/day.

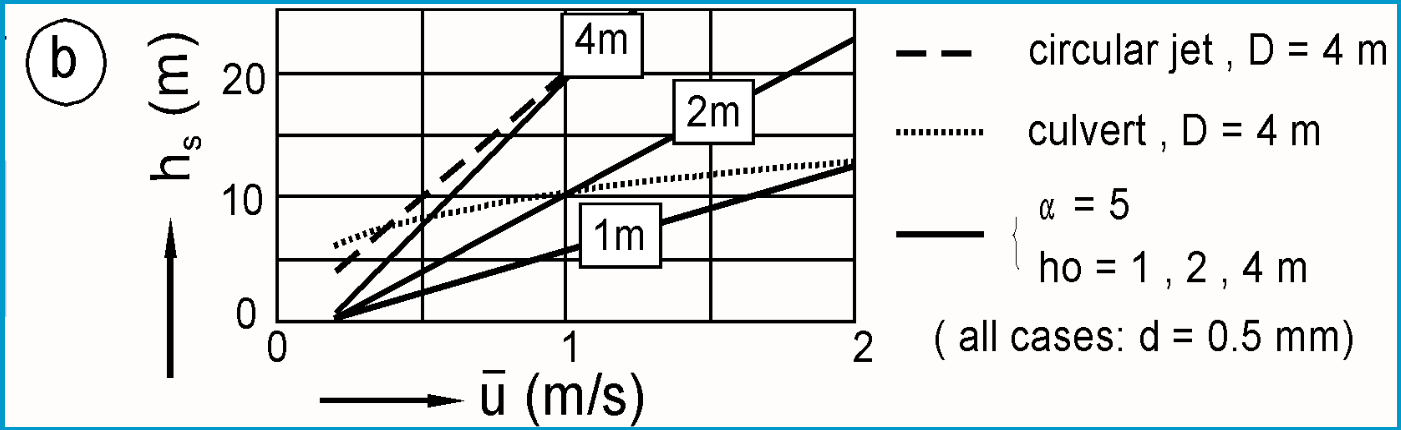
Calculation in 10 slices of 2 m thickness; crest with is 10 m, slope 1:2.
Volume deepest slice (2*19+10)*2 = 96 m^3/m, this takes 4.8 days.
Divide by 5 for tidal conditions.

%	Depth (m)	U_0 (m/s)	d (m)	Vol (m^3/m)	Time/5 (days)	U_{eb} (m/s)	t* (days)	t (days)	h_{max} (m)
10	19	2.8	2	96	.96	2.7	0.00	0.96	9.54
20	17	3.2	4	88	.88	2.4	1.35	2.23	11.56
30	15	3.8	6	80	.80	2.1	3.15	3.95	12.56
40	13	4.7	8	72	.72	1.8	5.70	6.42	13.16
50	11	5.7	10	64	.64	1.5	9.30	9.94	13.48
60	9	6.5	12	56	.56	1.2	14.50	15.06	13.67
70	7	6.7	14	48	.48	0.9	21.90	22.38	13.79
80	5	5.5	16	40	.40	0.6	32.00	32.40	13.86
90	3	4.0	18	32	.32	0.3	44.40	44.72	13.90
total			567	5.76					

equilibrium clear water scour



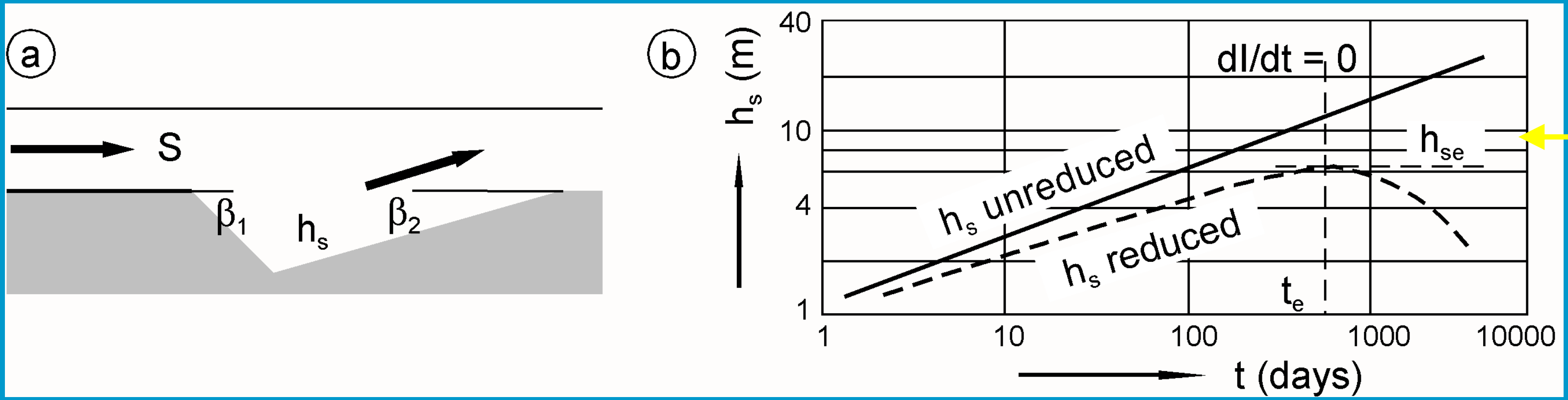
$$\left.\begin{aligned} u_c &= 0.5\,\alpha\,\bar{u}_s \\ \bar{u}_s\left(h_0 + h_{se}\right) &= \bar{u}\;h_0 \end{aligned}\right\} \rightarrow \frac{h_{se}}{h_0} = \frac{0.5\,\alpha\,\bar{u} - \bar{u}_c}{\bar{u}_c}$$



live bed scour

$$I = \frac{1}{2}\left(\cot\beta_1 + \cot\beta_2\right) h_s^2$$

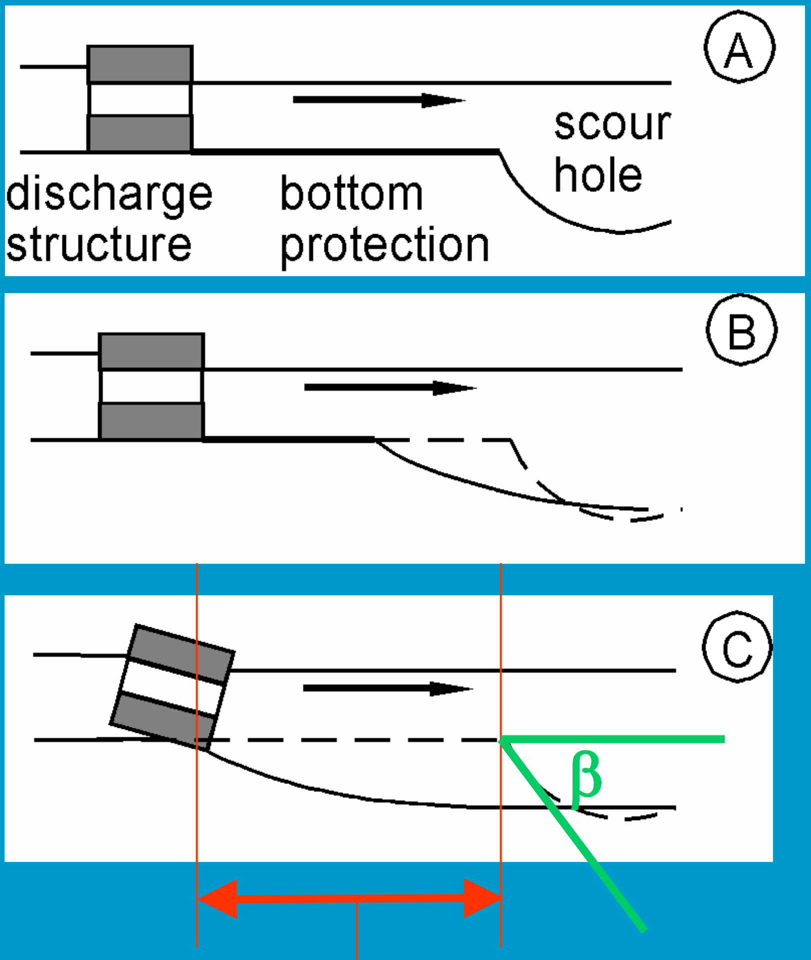
$$= \left[\ .005\left(\cot\beta_1 + \cot\beta_2\right)\Delta^{-1.4}\ h_0^{0.4}\ \left(\alpha\,\bar{u} - \bar{u}_c\right)^{3.4}\right] t^{0.8} = K\ t^{0.8}$$



$$I_{\text{red}} = K\ t^{0.8} - S\cdot t \quad\rightarrow\quad h_{s\ \text{red}} = \sqrt{\frac{I_{\text{red}}}{0.5\cdot\left(\cot\beta_1 + \cot\beta_2\right)}}$$

$$\frac{dI}{dt} = 0 \rightarrow 0.8\,K\,t^{-0.2} = S \rightarrow t_e = \left(\frac{0.8\,K}{S}\right)^5 \rightarrow h_{se} = \sqrt{\frac{K\,t_e^{0.8} - S\cdot t_e}{\frac{1}{2}\left(\cot\beta_1 + \cot\beta_2\right)}}$$

stability of protection



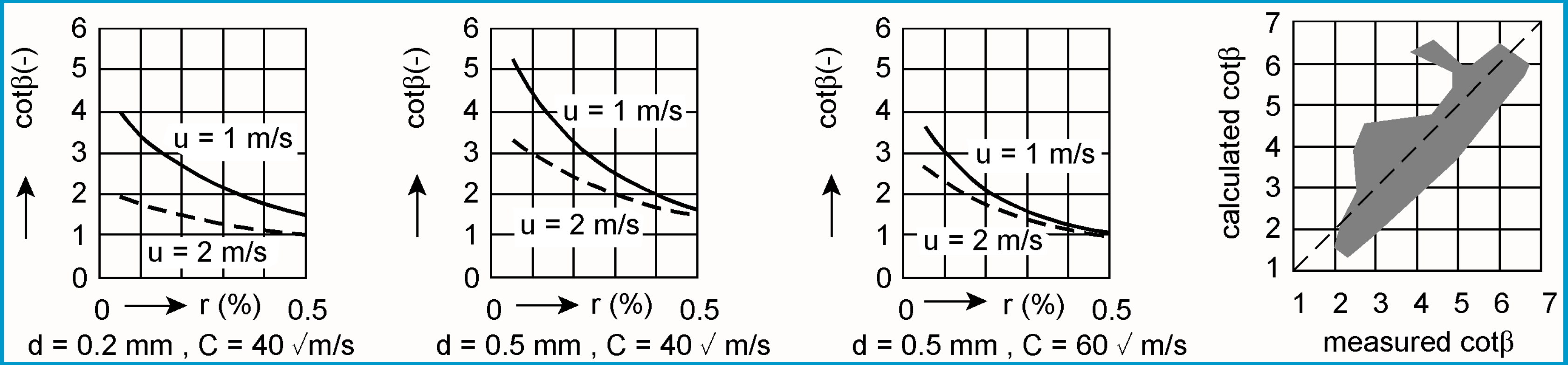
This distance has to be large enough

$L = f(\beta)$

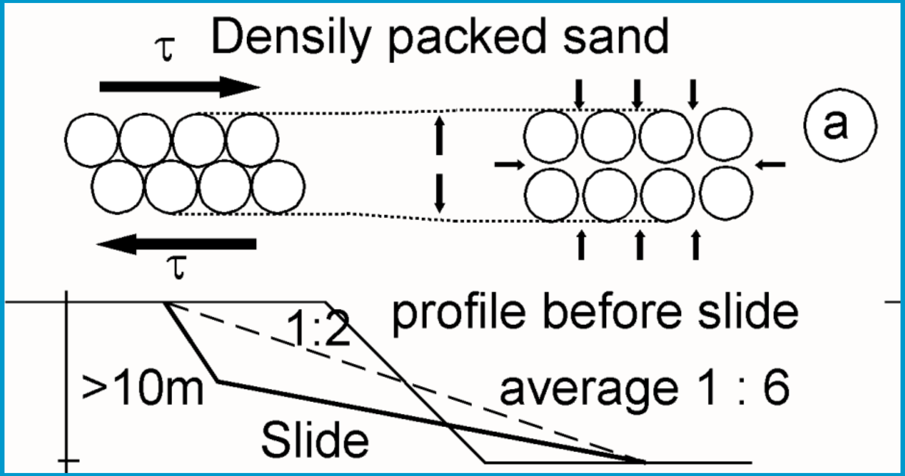
the slope angle β

$$\beta = \arcsin\left[3\cdot10^{-4}\frac{u_0^2}{\Delta g d_{50}} + \left(0.11+0.75\,r_0\right) f_c\right]$$

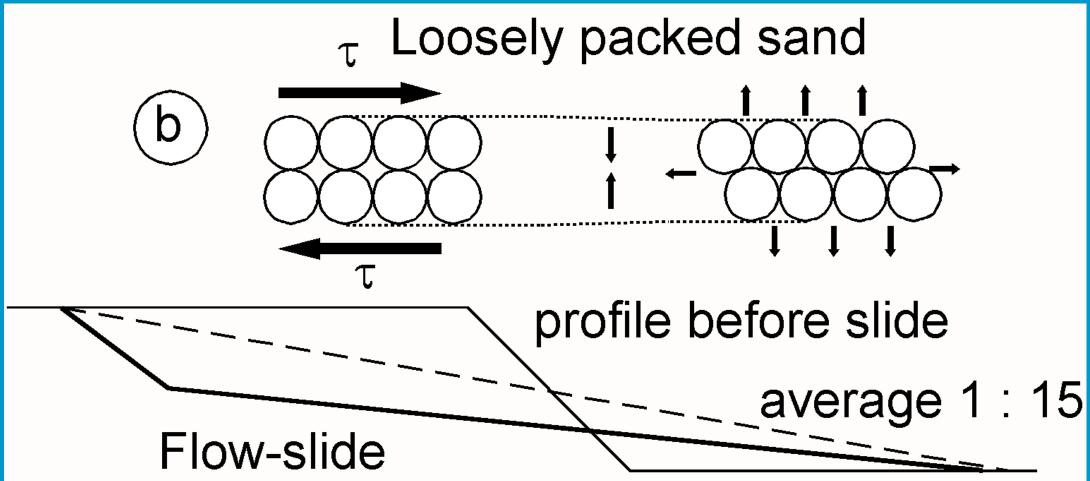
$$\left(f_c = \frac{C}{40},\ f_c = 1 \text{ for } C \leq 40\right)$$



stability and slides



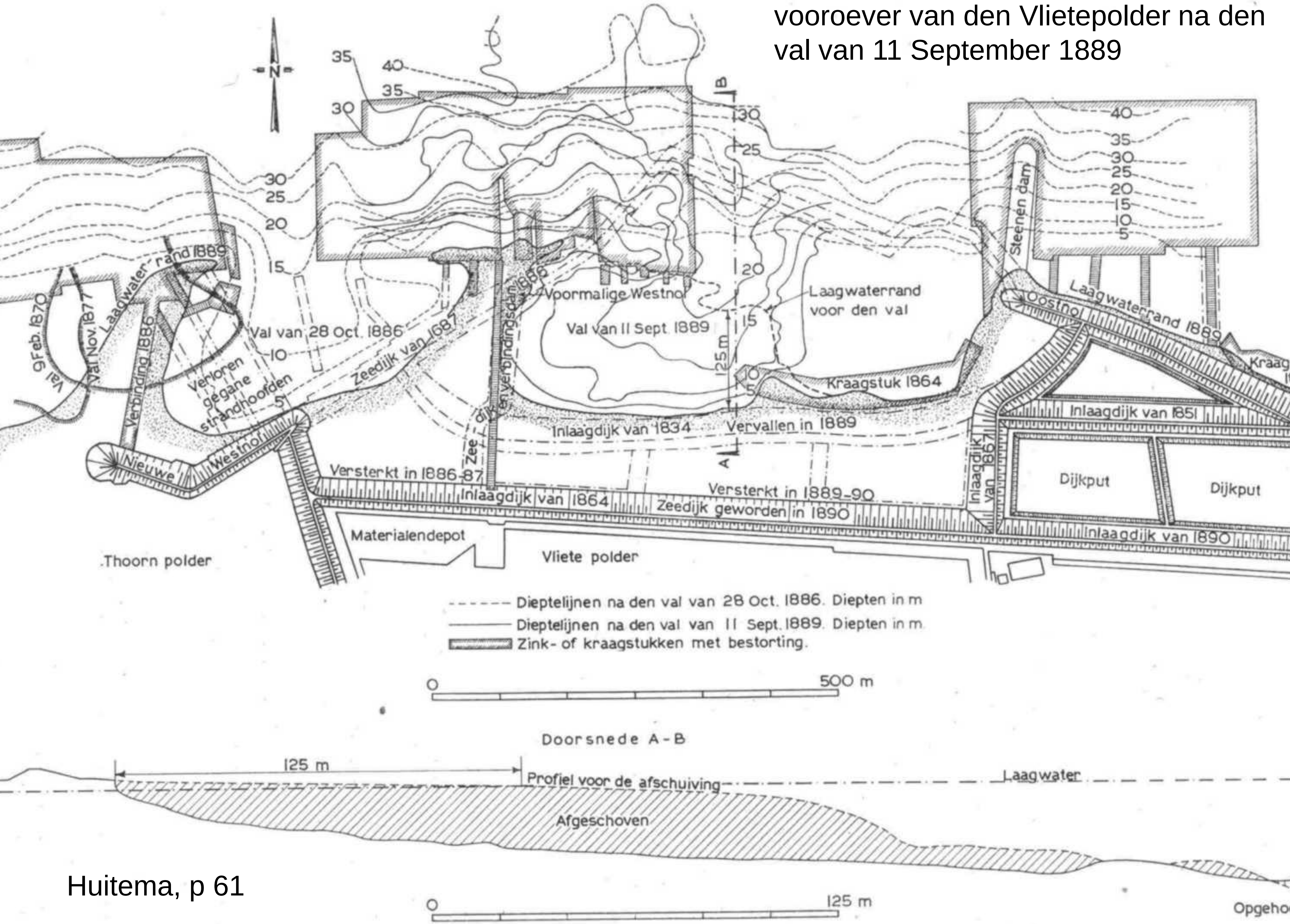
values for the two slopes follow from an analysis of various flowslides



flow-slide - zettingvloeiing
liquefaction

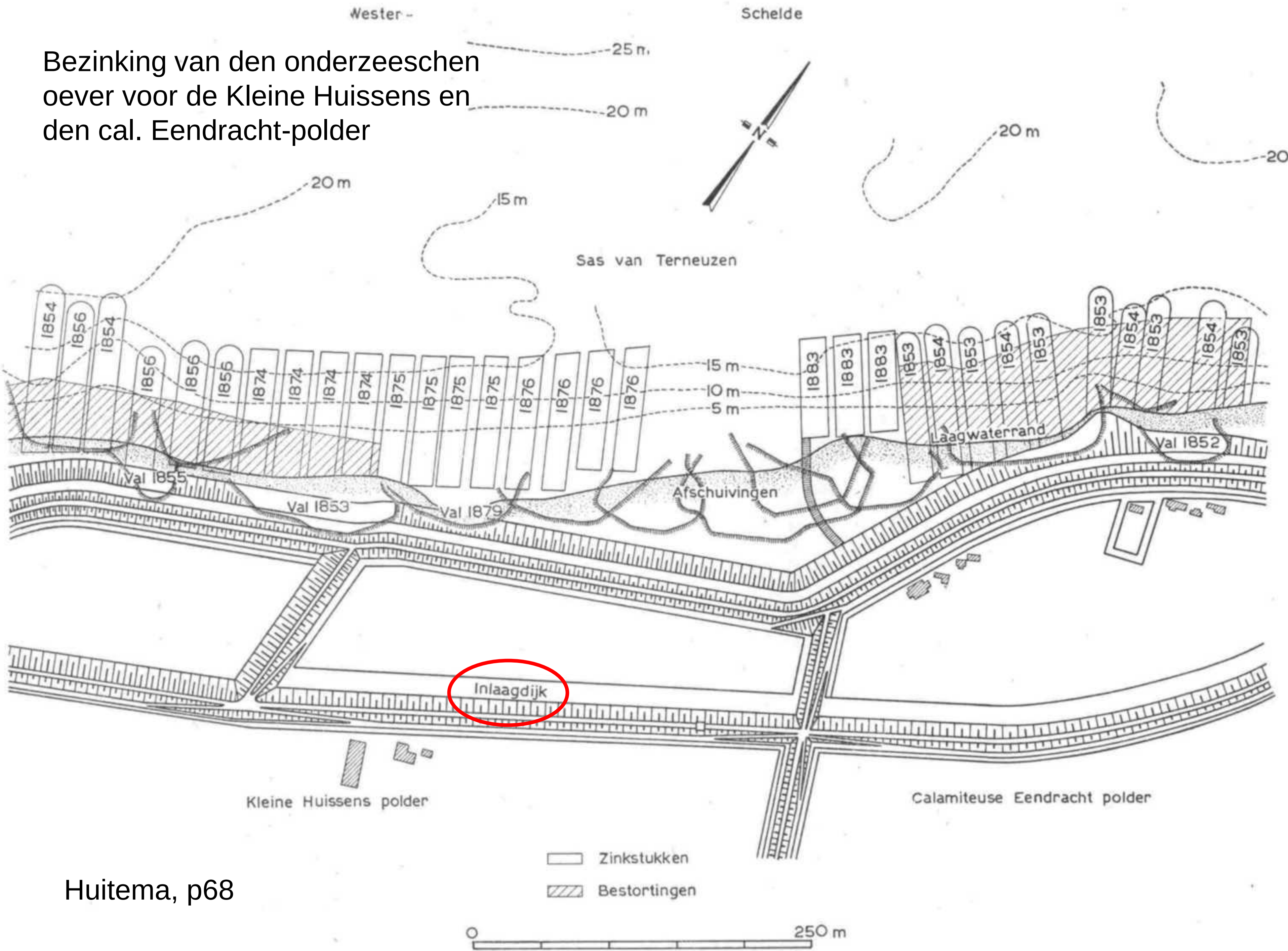
oeverval/dijkval

vooroever van den Vlietepolder na den val van 11 September 1889



Huitema, p 61

Bezinking van den onderzeeschen oever voor de Kleine Huissens en den cal. Eendracht-polder



Huitema, p68