Chapter 12: design practice for closure dams

ct5308 Breakwaters and Closure Dams

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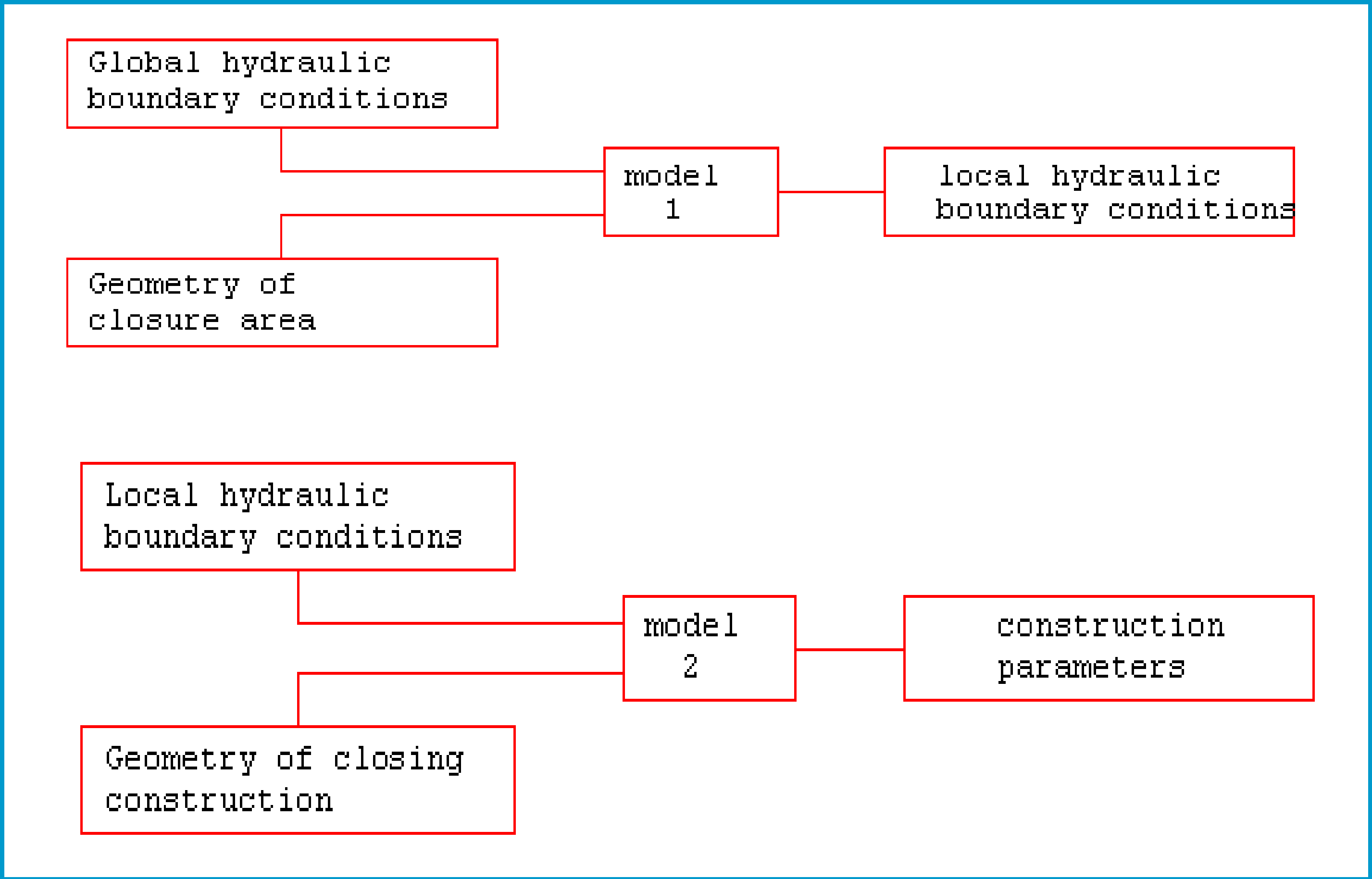
Design practice



very basic equations (the "model") for the Stone Closure

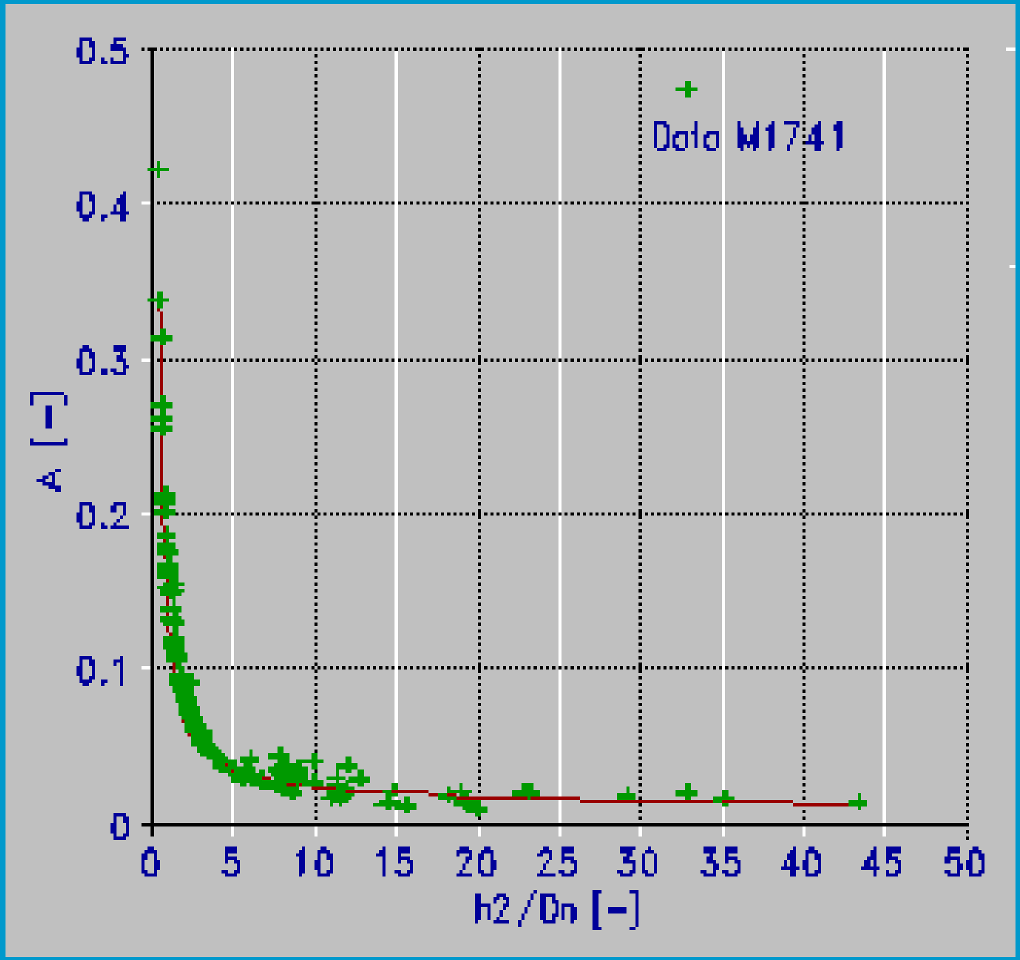
$$\frac{u^2}{\Delta d_n} = C^2 \Psi$$

$$A = \frac{K^2}{\Psi C^2}$$

$$C = 18 \log\left(\frac{6h}{d_n}\right)$$

$$\Delta d_n = A u^2$$

results of the re-analysis



$$\Delta d_n = A u^2$$

$$A = \frac{K^2}{\Psi C^2}$$

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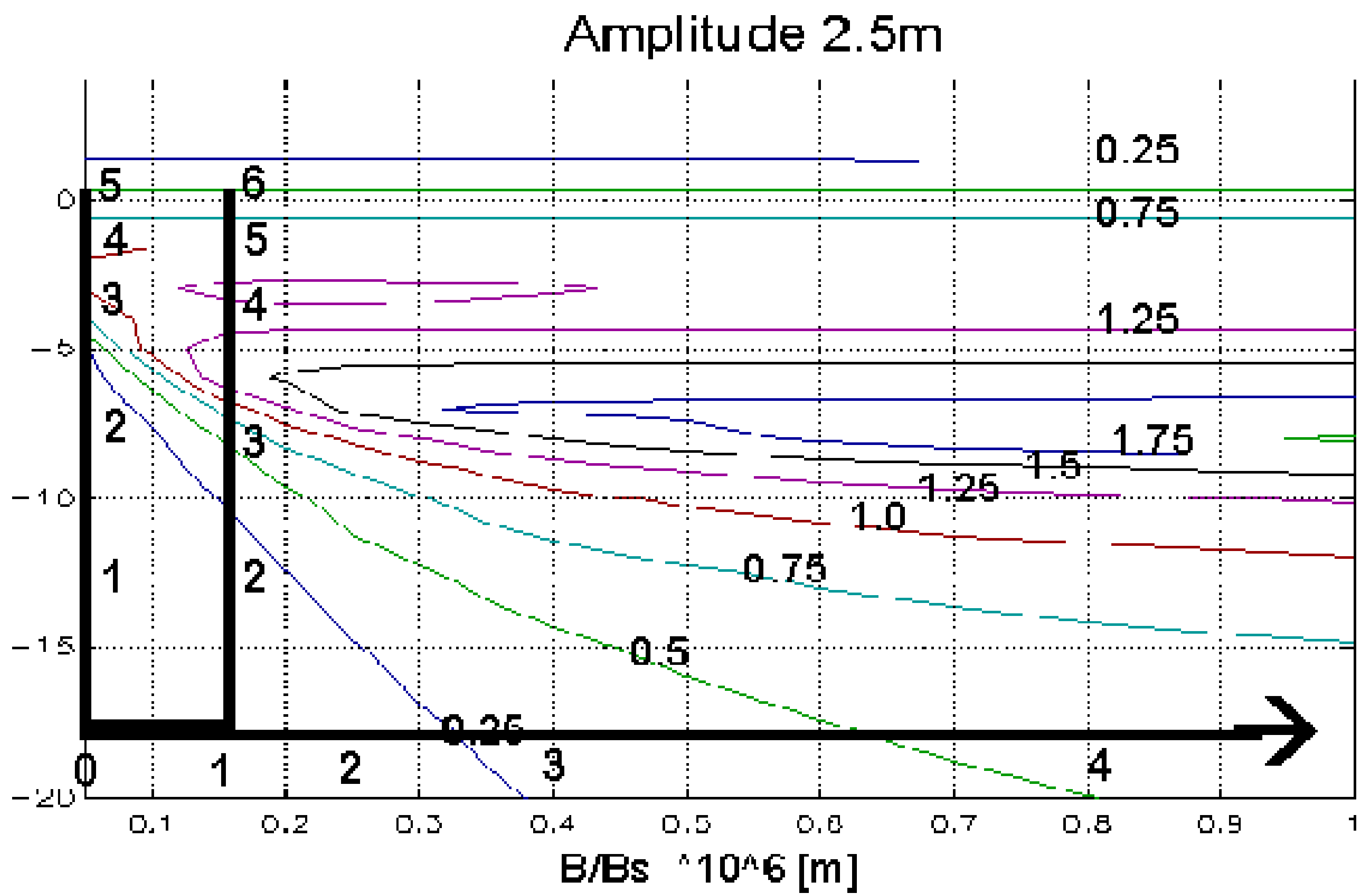
Example: channel, 4000 m wide, storage area 200 km^2, channel depth 17.5 m, tidal amplitude 2.5 m

Determine velocities and stone sizes, using simple equation

Point	Horizontal (d'=17.5)			Vertical				Combined			
	%close	u_0	d_{n50} cm	%close	d' m	u_0 m/s	d_{n50} cm	%close	d m	u_0 m/s	d_{n50} cm
0	0 %	1.0	<1	0 %	17.5	1.0	<1	0 %	17.5	1.0	<1
1	70 %	3.1	5	25 %	12.5	1.4	1	70 %	17.5	3.1	5
2	80 %	4.4	13	50 %	7.5	2.5	3	77 %	12.5	3.8	13
3	87 %	5.7	27	75 %	2.5	5.3	73	85 %	7.5	5.7	50
4	93 %	6.8	44	80 %	1.5	5.0	53	92 %	2.5	5.7	80
5				90 %	-0.5	3.6	20	94 %	1.5	4.7	53
6								97 %	-0.5	3.3	20



Values of ΔD_N as a function of B/B_s and d' (on vertical axis)

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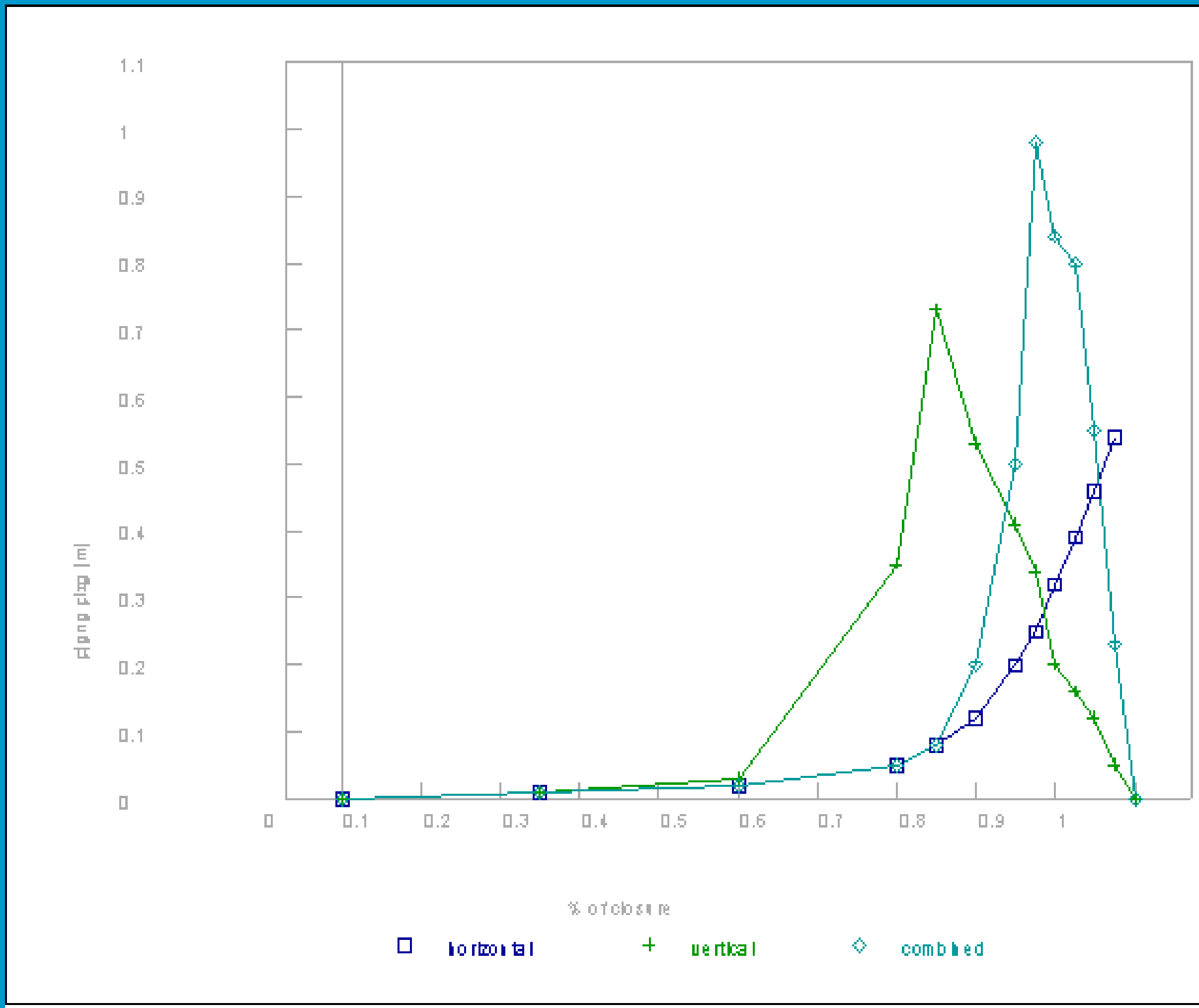
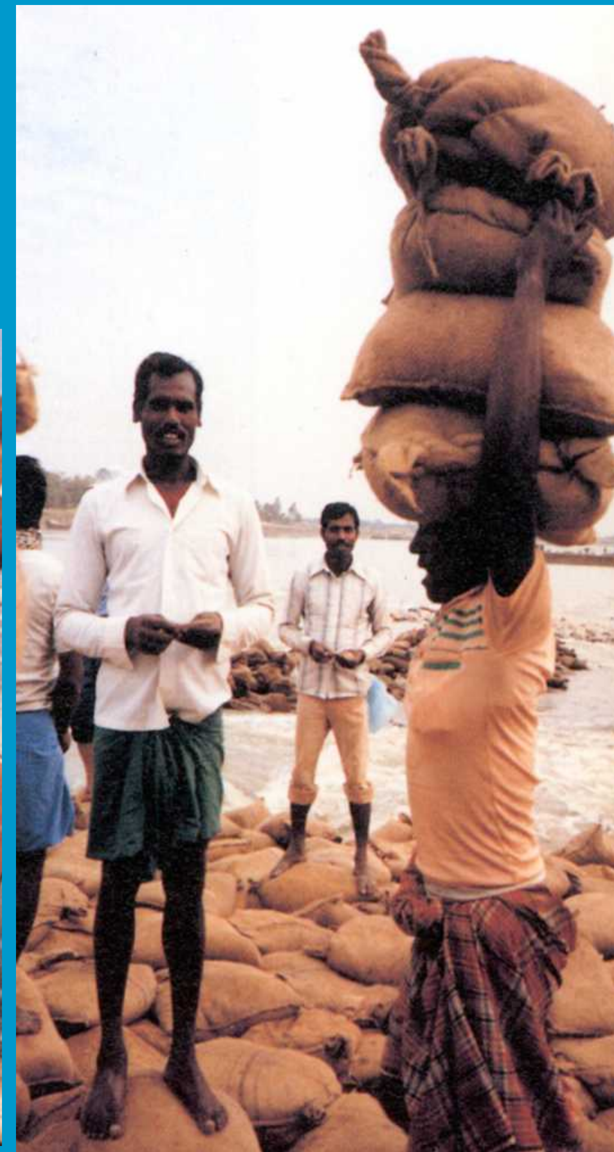


strategy	requir
vertical	0.7
combined	0.98
horizontal	0.5

Jamuna



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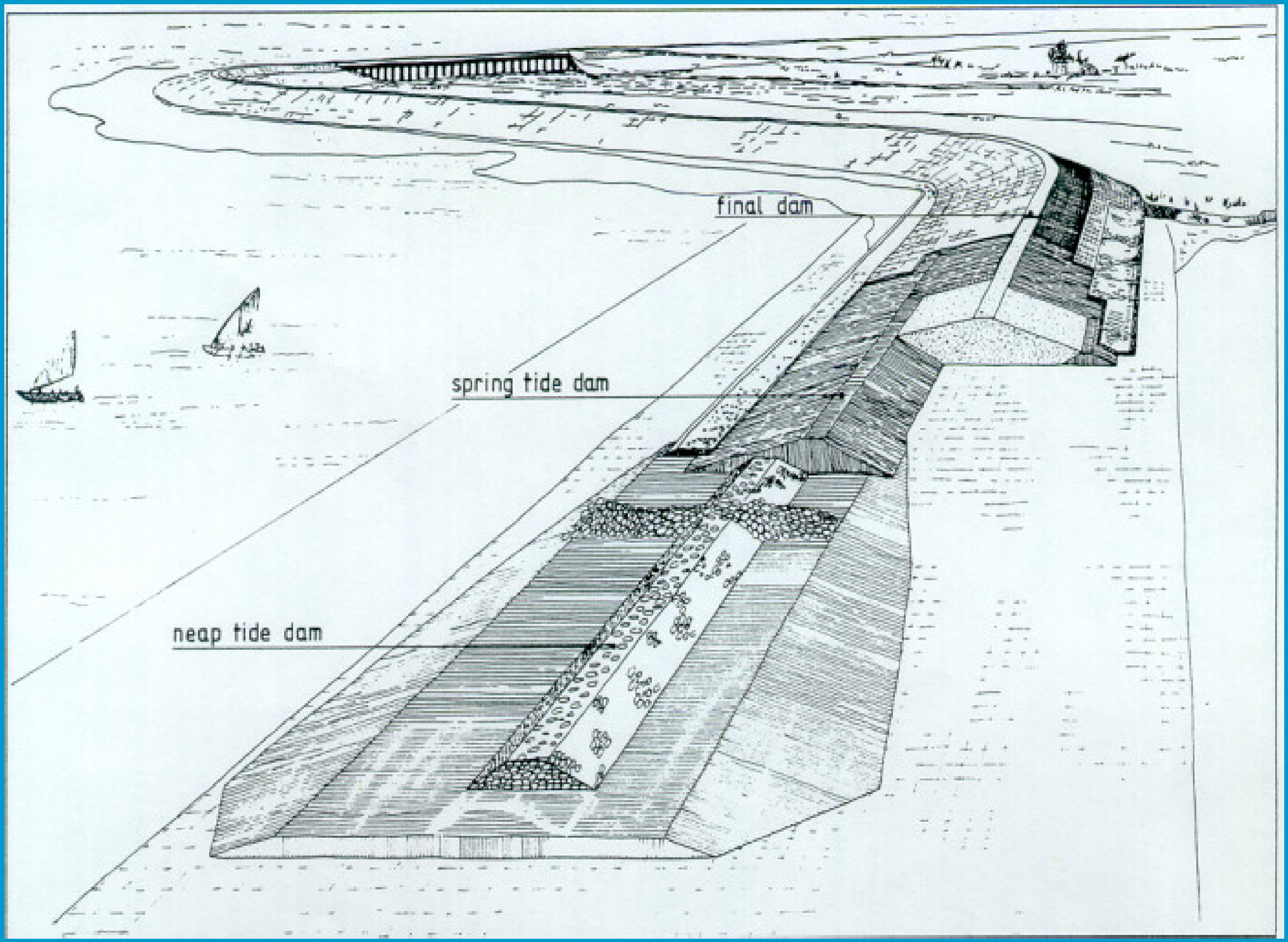
the feni-dam



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Closure of the Pluijmpot

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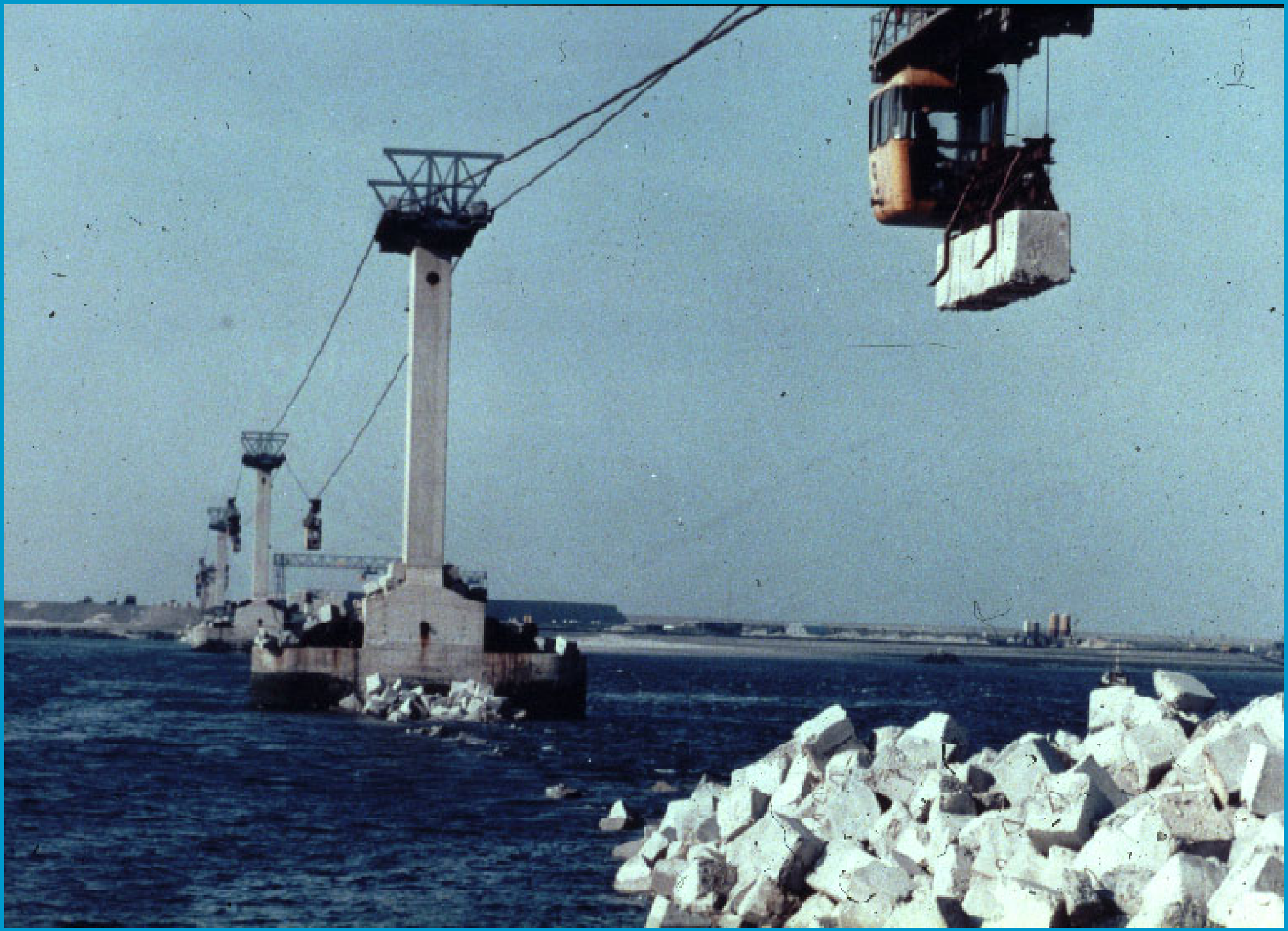
rock closure

cable car - vertical closure



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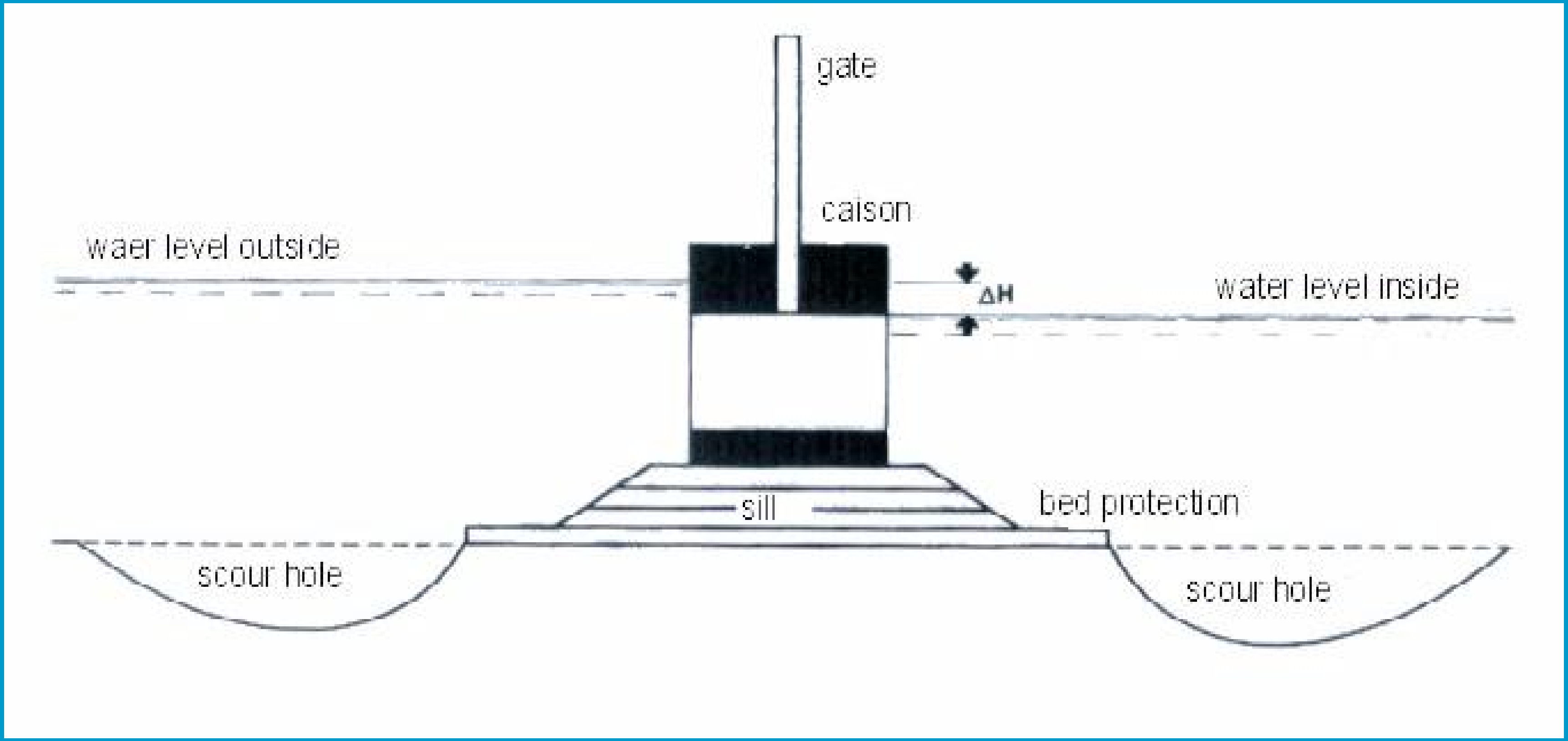
vertical closure, smooth current pattern

caissons

principle of a caisson



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some examples (1)

some examples (2)

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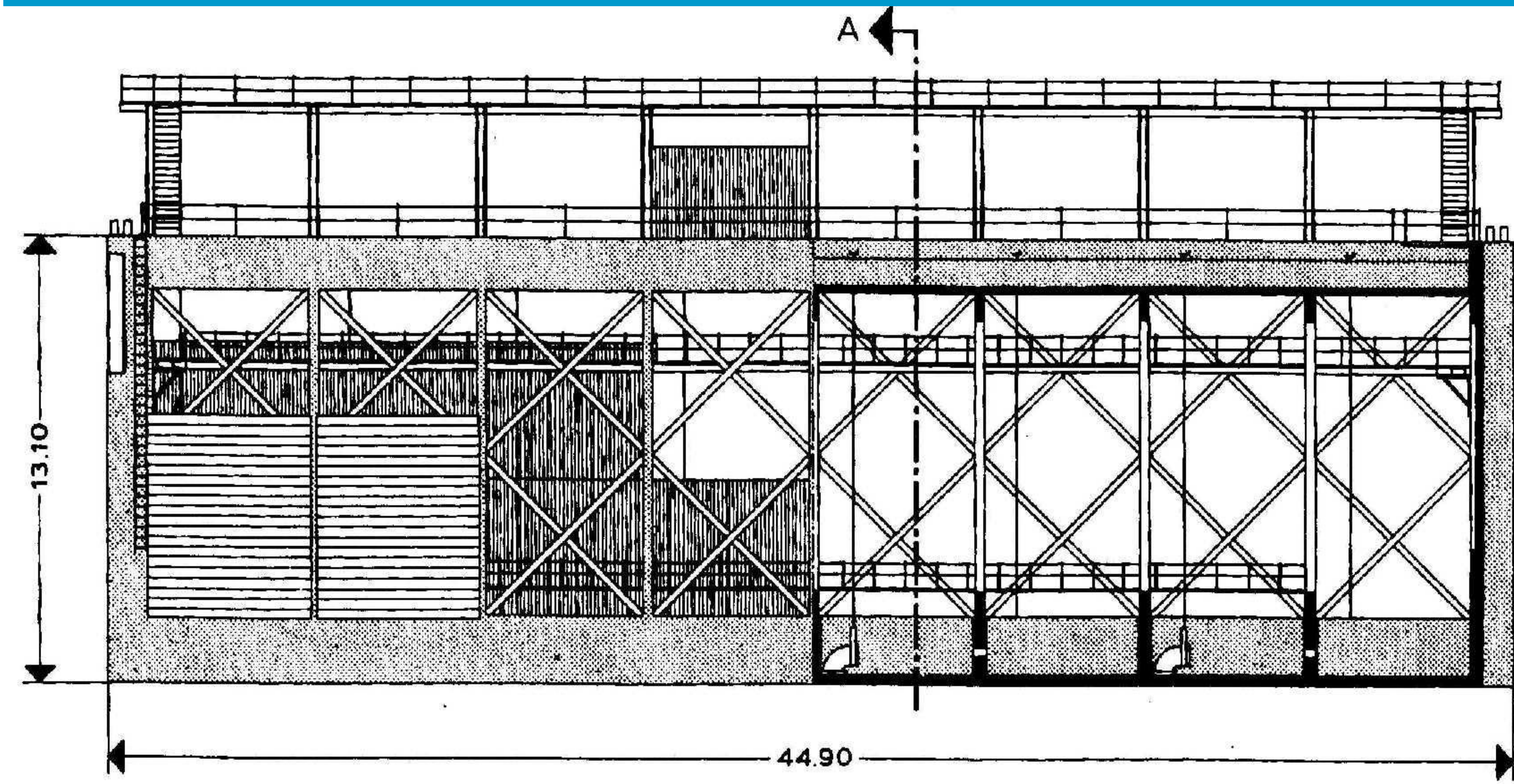
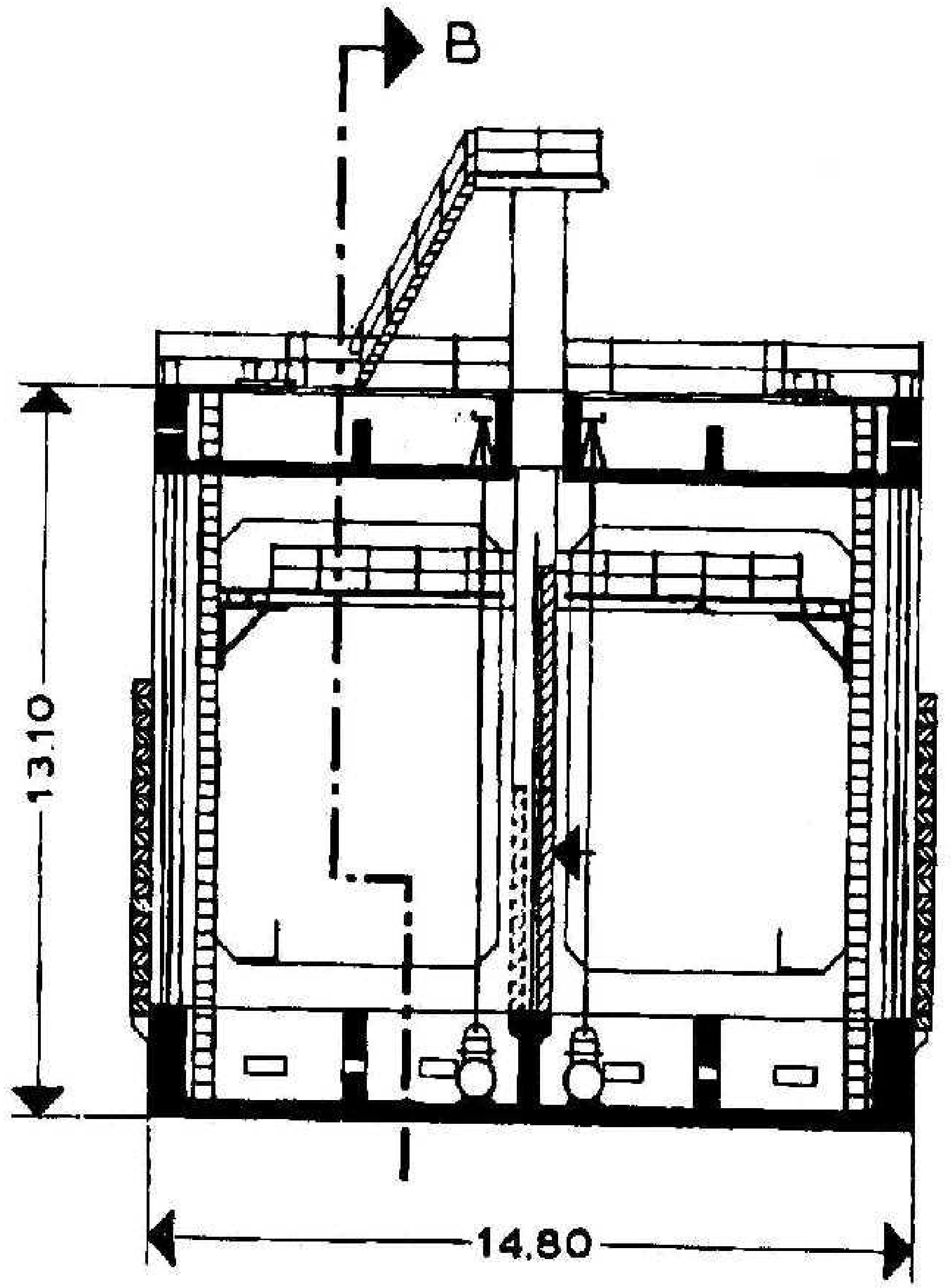
cross section (1)

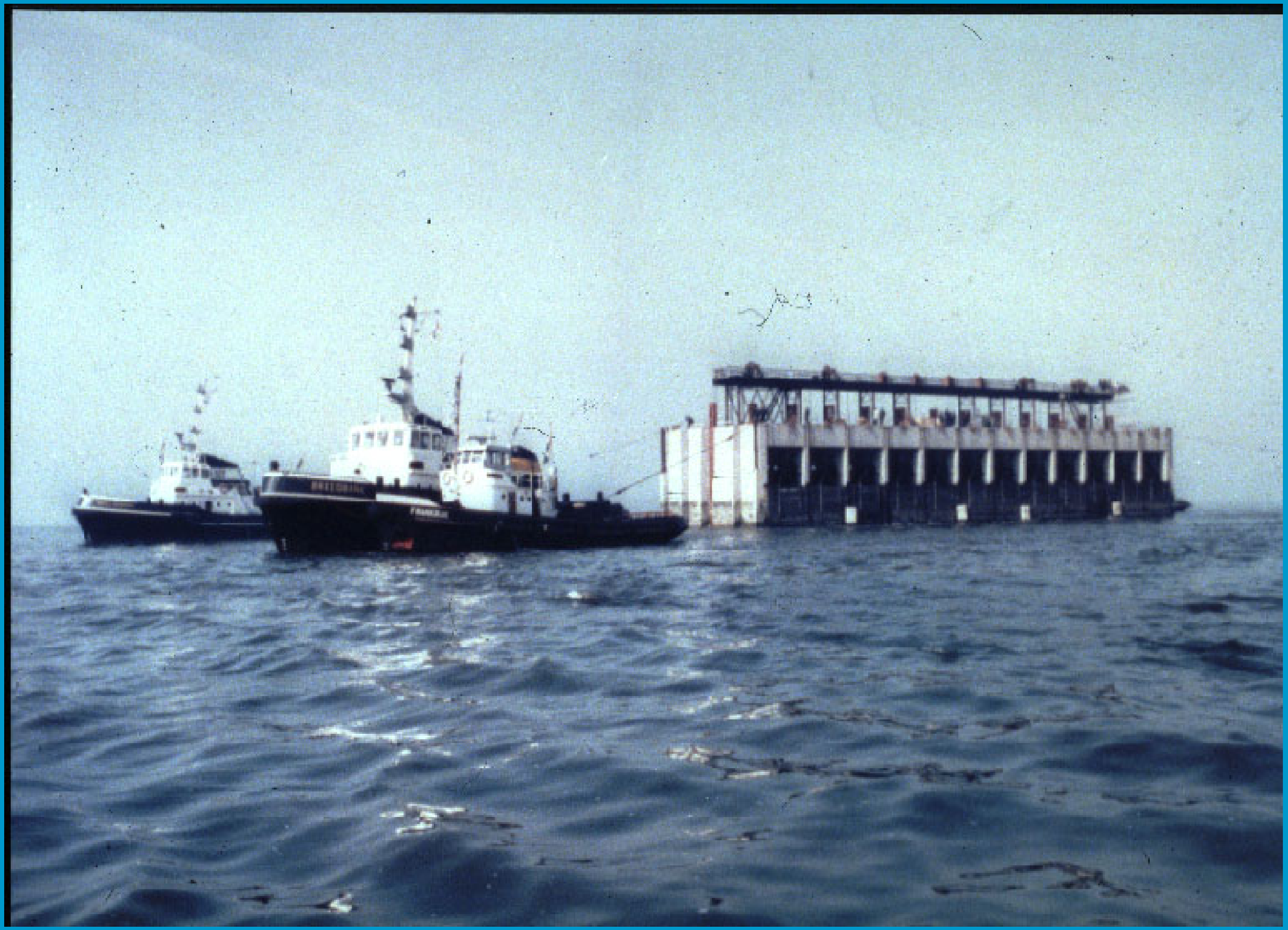


cross section (2)



some examples (3)

some examples (4)



some examples (5)

Caisson closure

	time before slack water	velocity above sill
- sailing in the caisson	-70 min	
- positioning caisson above sill	-55 min	
- connect caisson to already placed ones	-30 min	< 0.75 m/s
- sinking down of caisson	-15 min	< 0.30 m/s
- caisson on sill	- 5 min	
- moment of slack water	0 min	
- removal of wooden floating planks	+10 min	
- dumping of extra stone for ballast	+60 min	

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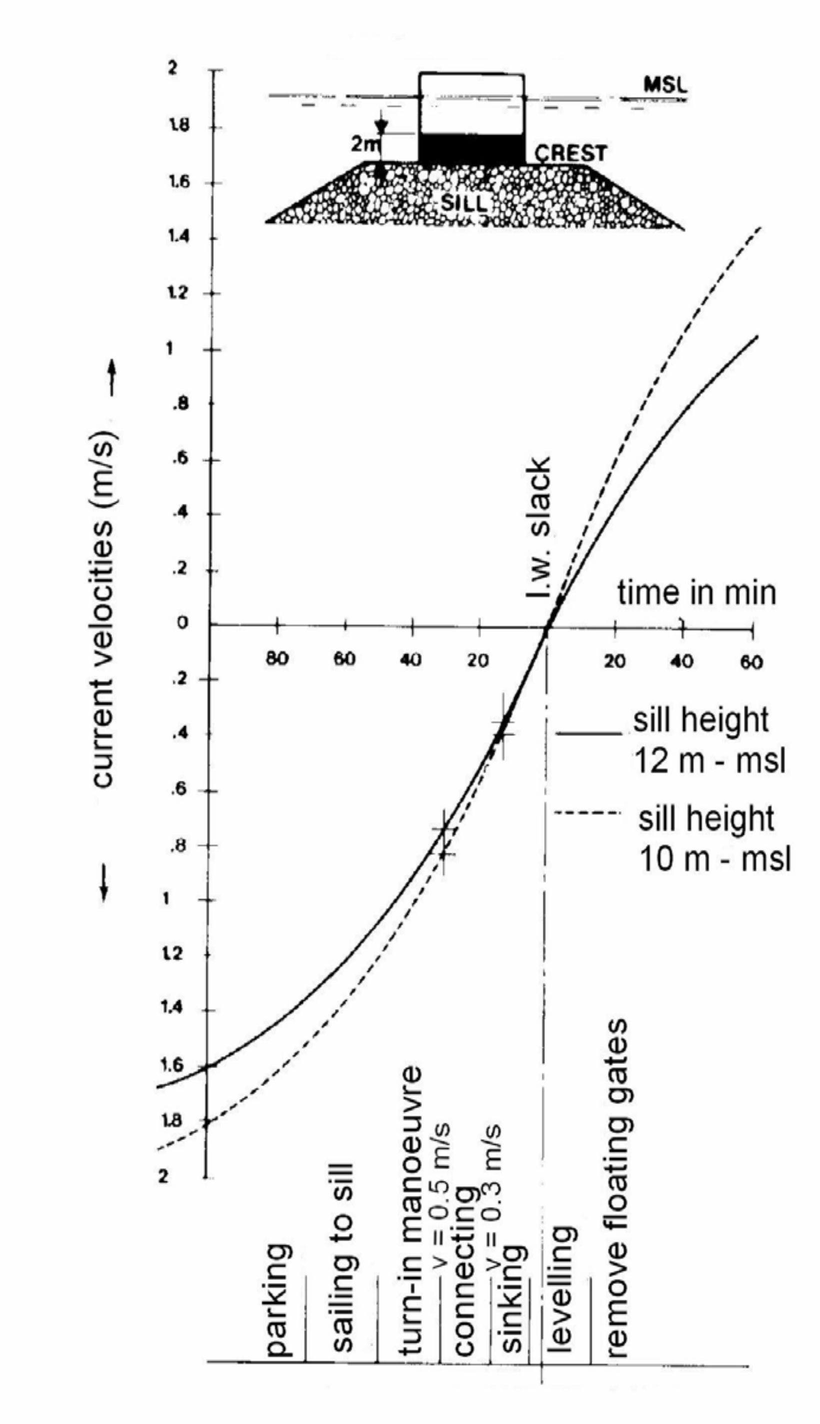
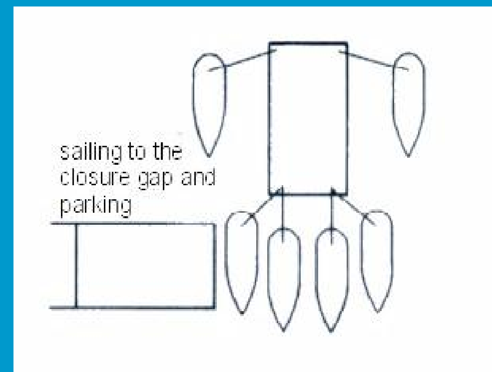
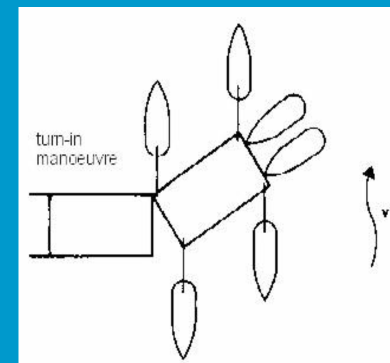
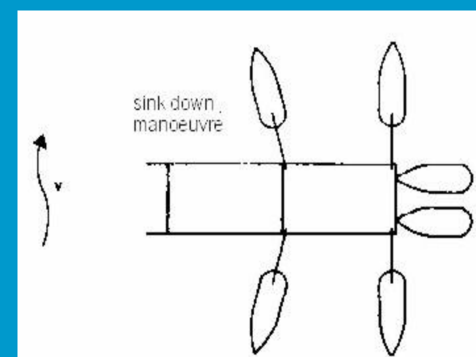
caisson placing procedure









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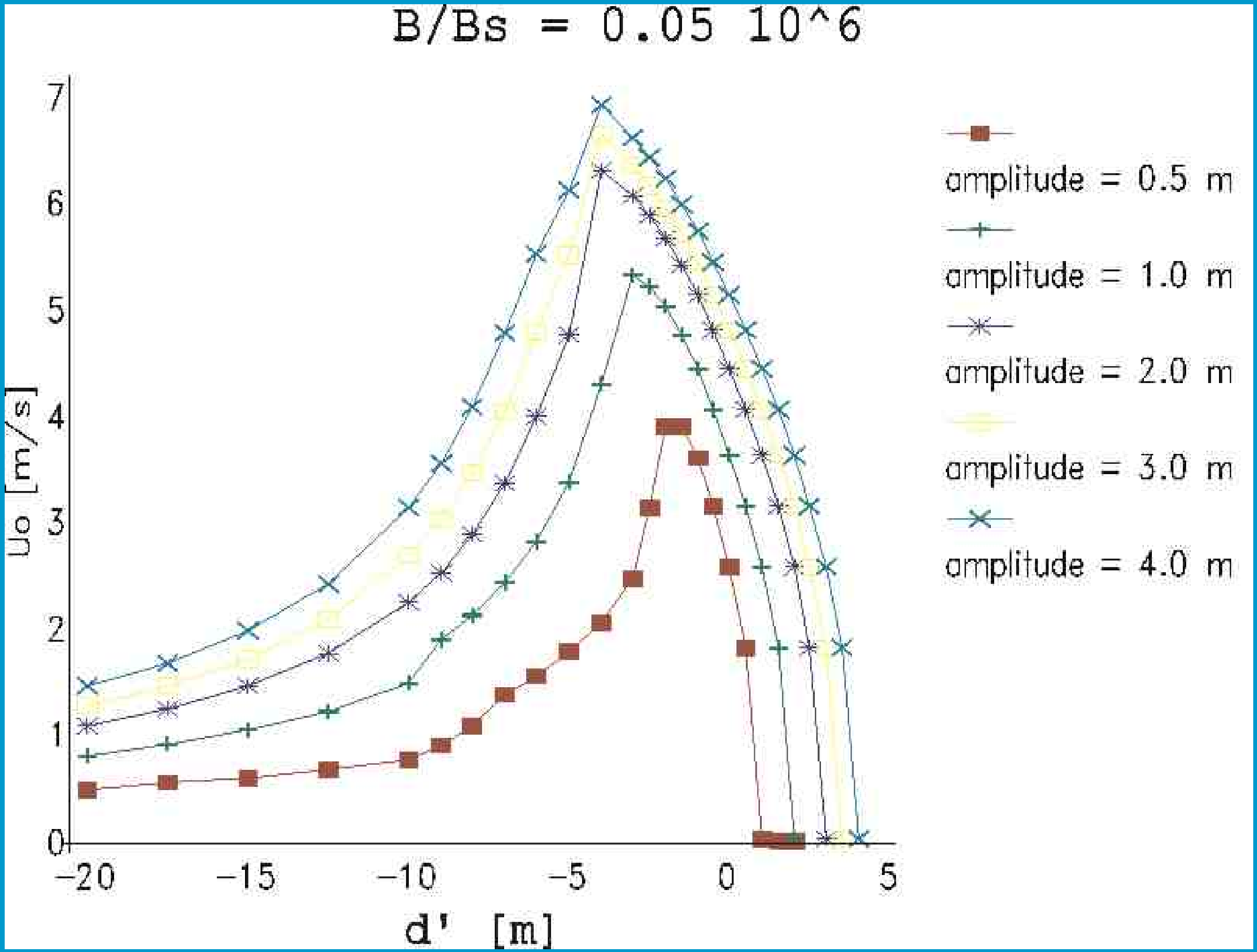
window for caisson closure (1)



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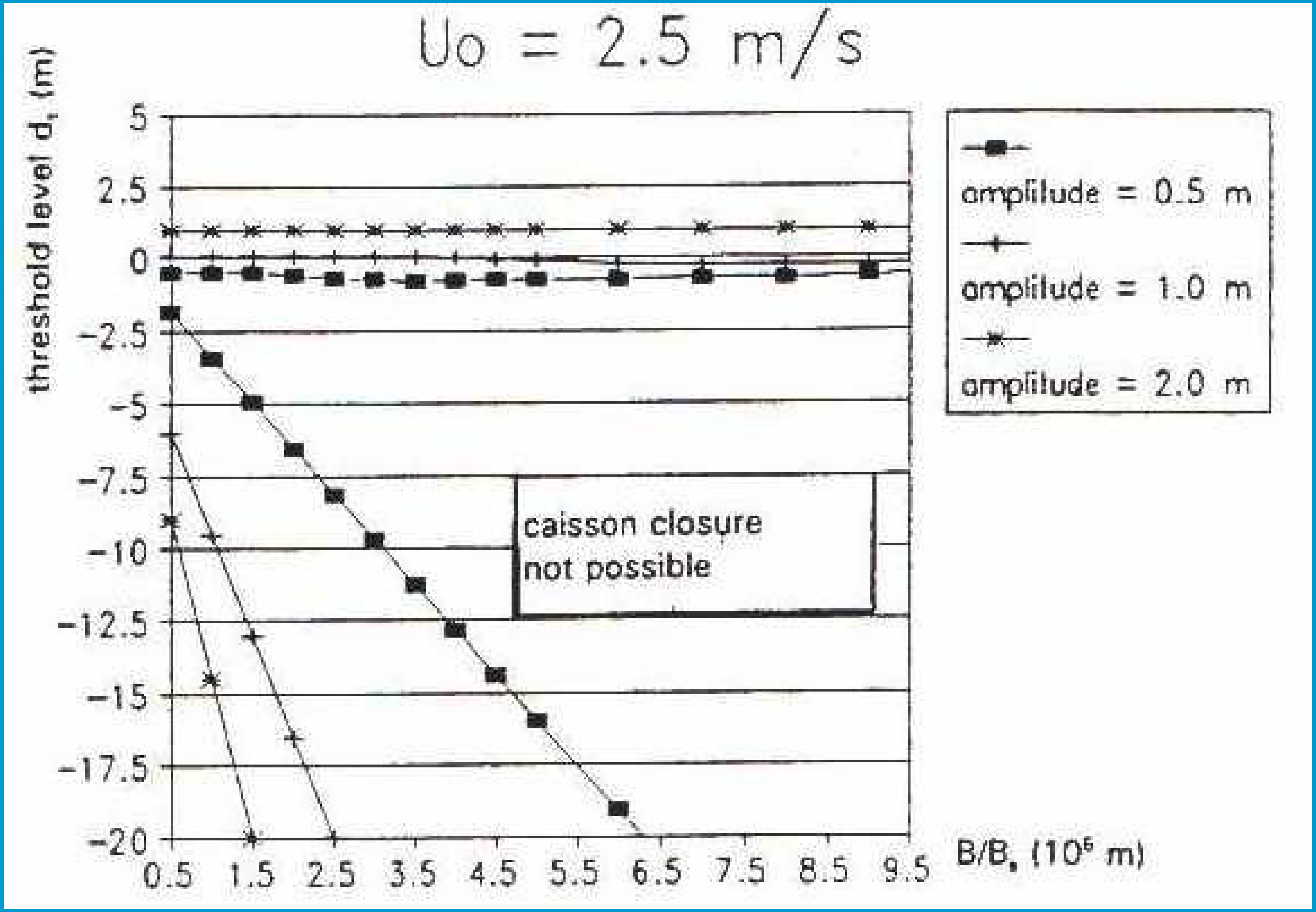
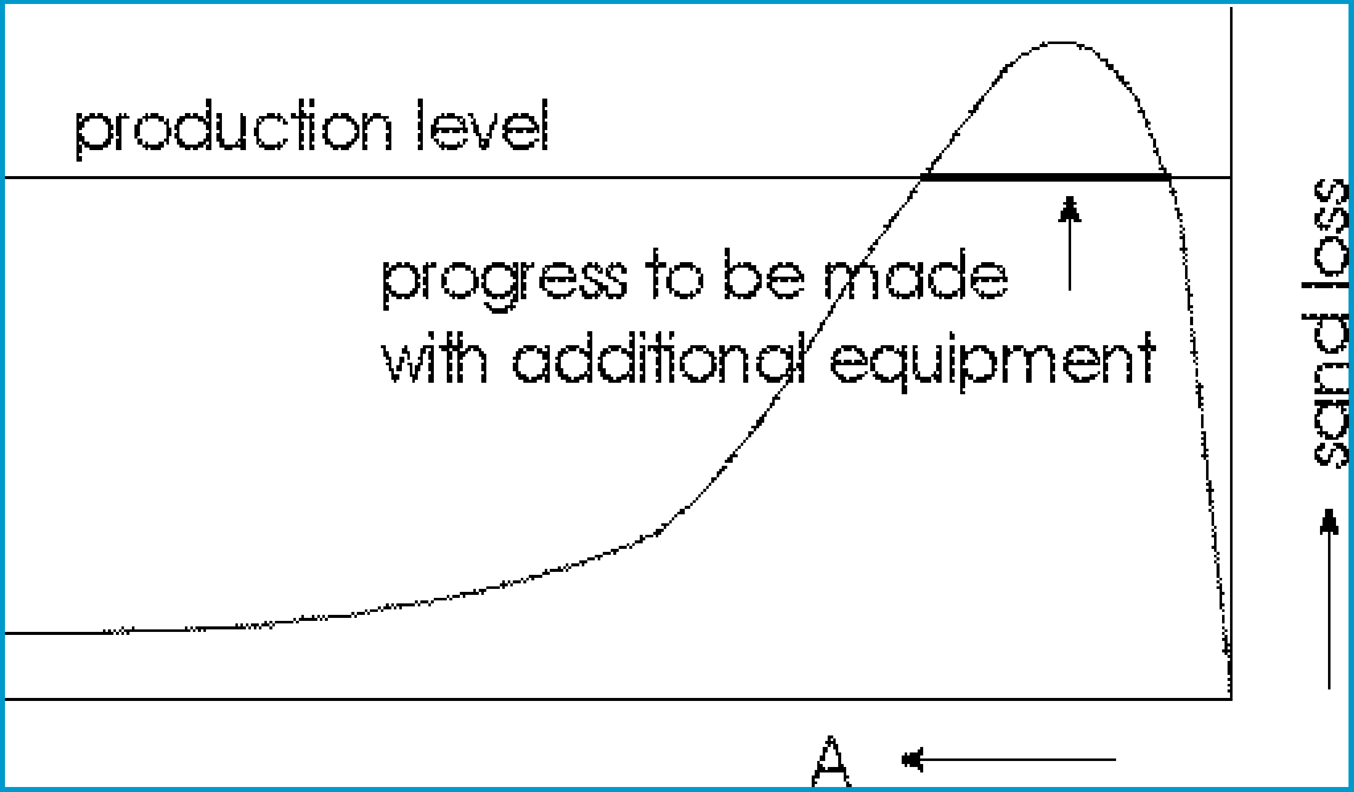
window for caisson closure (2)



sand closure

production vs. loss



equipment and borrow area

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dredges needed

number of dredges	crest width of the dam
1	less than 40 m
2	40 - 55 m
3	65 - 75 m
4	75 - 100 m

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slopes

under water	1:15 - 1: 30
intertidal area	1:50 - 1:100

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loss calculation

$$\Psi = u^2 / C^2 \Delta d_{50}$$

$$C = 18 \log(12h / k_s)$$

$$\Phi = s \Big/ \sqrt{g \Delta d_{50}^3}$$

$$\Delta = \frac{\rho_s - \rho_w}{\rho_w}$$

$$\Phi \frac{g}{C^2} = a \Psi^b$$

k_s roughness (0.1)
H waterdepth

b = 1.75 - 2.5

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loss calculation (2)

$$L^1 = \frac{s}{1-n} = \frac{a * C^2 \sqrt{\Delta D_{50}^3}}{(1-n)\sqrt{g}} \Psi^b$$

$$L_m^1 = \frac{0.06 u^5}{C^3 d_{50} \Delta^2 (1-n)\sqrt{g}}$$

$$L_v^1 = \frac{0.35 u^{3.5}}{C^{1.5} d_{50}^{1/4} \Delta^{1.25} (1-n)\sqrt{g}}$$

$$L = \frac{1}{T}\int_0^T \left\{ \int_0^{l_b} L_m^1 * dy \; + \; 0.3_{D_i} * L_{Vi}^1 \; + \; 0.3_{D_{ii}} * L_{Vii}^1 \right\} dt$$

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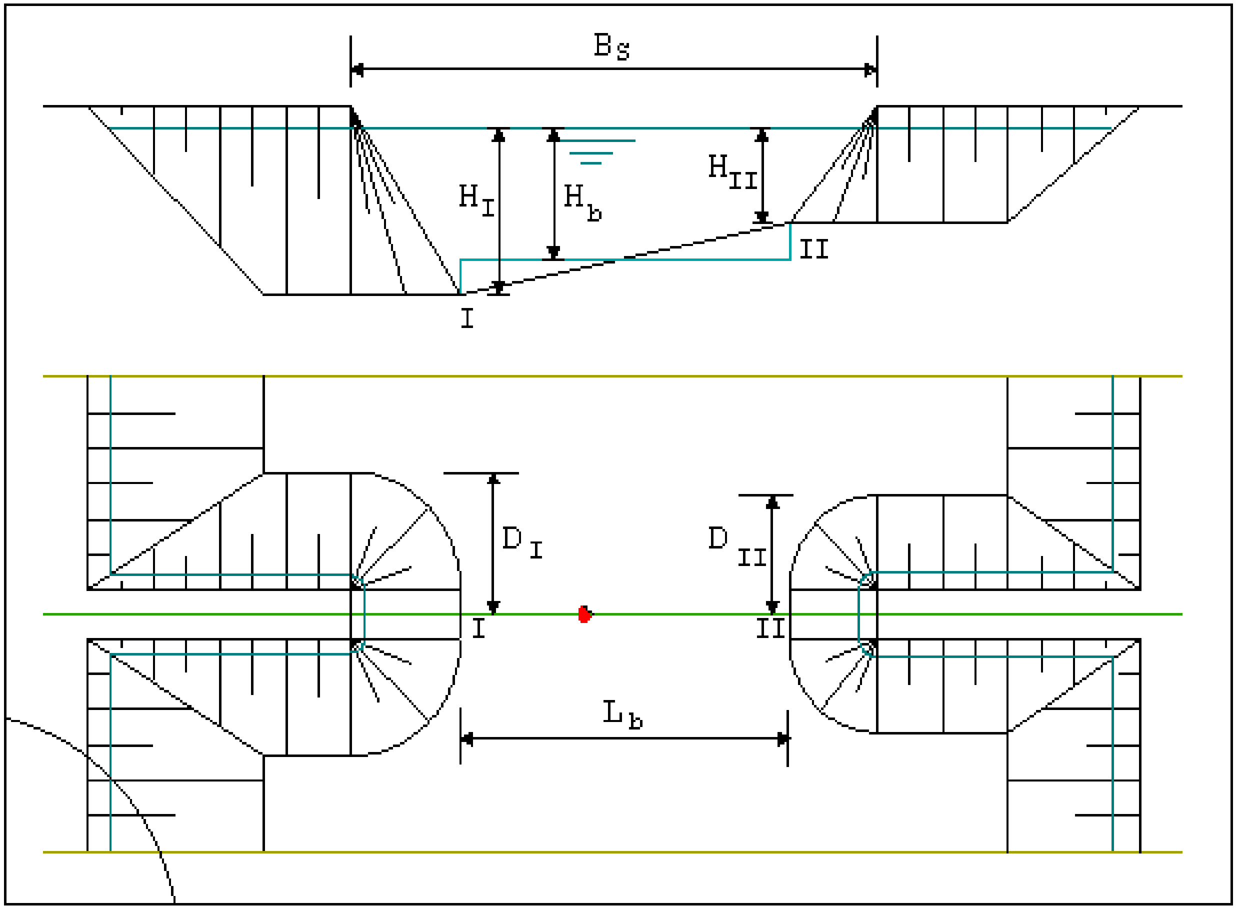
loss calculation (3)



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a more complicated example

- foreshore, 250 m wide, 0.5 m below msl
- gully of 200 m wide, depth of 4 m below msl
- tidal flat 300 m wide, at msl
- main gully, 250 m wide, 6.5 m below msl

- profile 4000 m^2 at high water and 1800 m^2 at low water
- tidal range 2x tidal amplitude) is 3 m
- storage area is 20 km^2 at high water and 5 km^2 at low water
- flow analysis is done with Duflow

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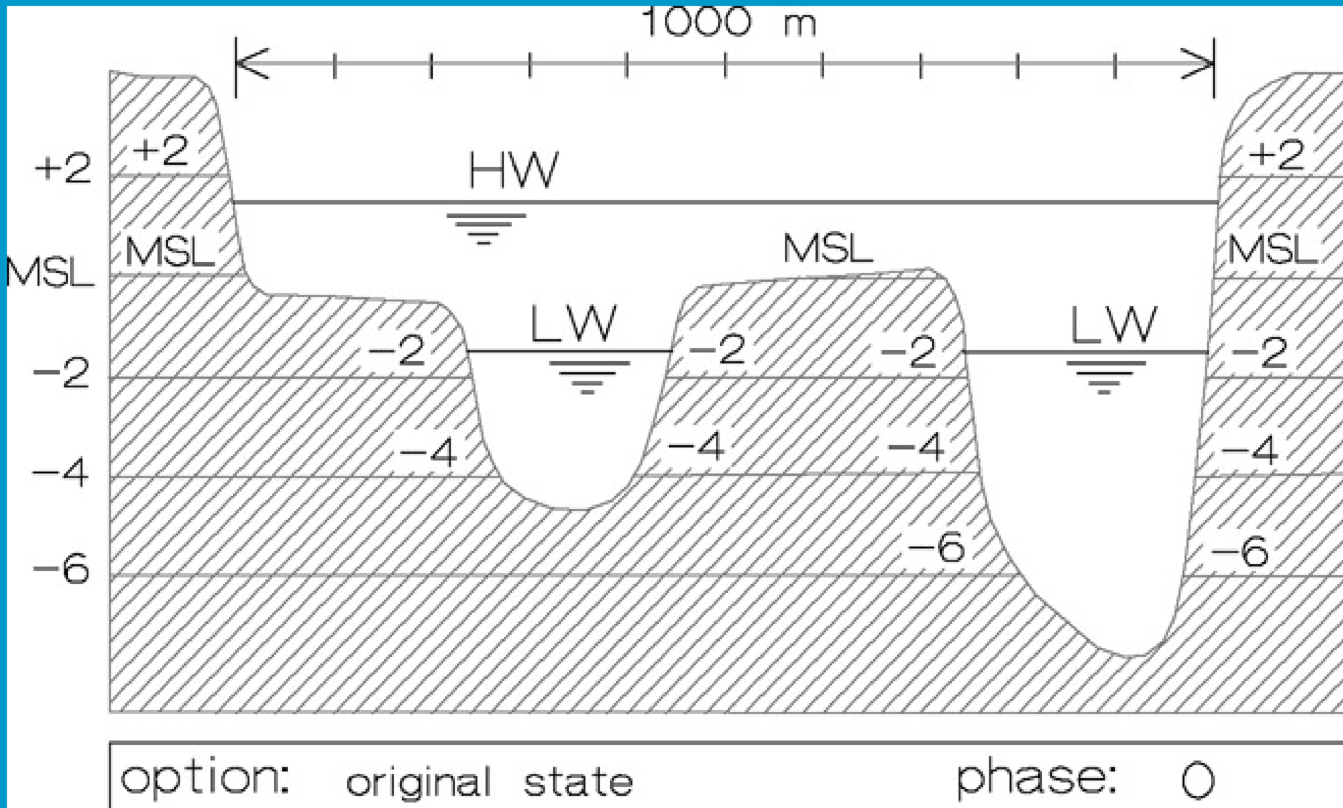
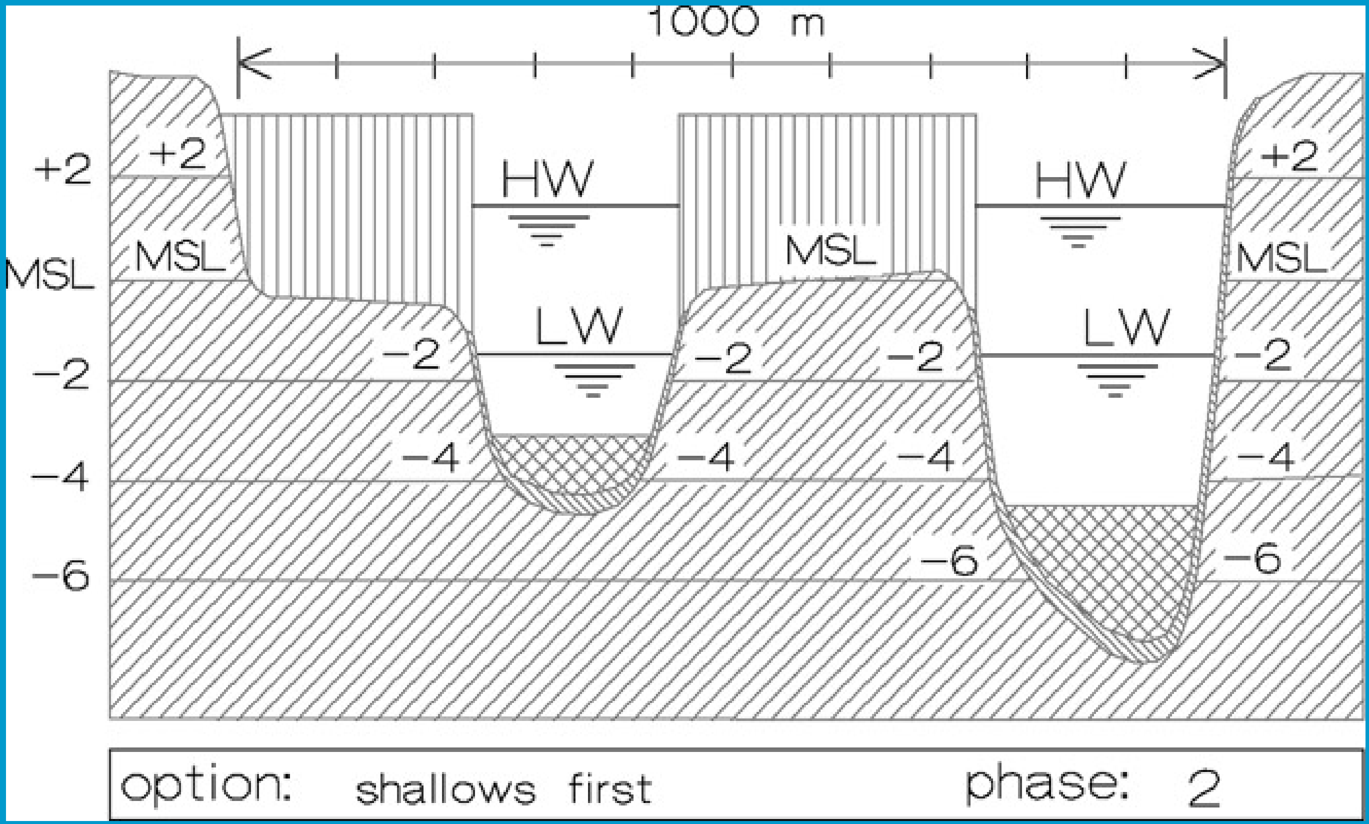
original state, phase 0



Blocking the shallows first

phase	action	foreshore	sec. gully	tidal flat	main gully
0	original state	250 m; -0.5	200m; -4	300m; msl	250m; -6.5
1	bottom protection + shallows	dammed	200m; -3.5	dammed	250m; -6
2	partial sills in both gaps	dammed	200m; -3	dammed	250m; -4.5
3	final sill, abutments	dammed	200m; -2.5	dammed	190m; -4.5
4	first caisson in place	dammed	200m; -2.5	dammed	128m; -4.5
5	sec. caisson in place	dammed	200m; -2.5	dammed	66m; -4.5
6	third caisson in place	dammed	200m; -2.5	dammed	closed
7	narrowing on sec. sill	dammed	100m; -2.5	dammed	closed
8	further narrowing	dammed	50m; -2.5	dammed	closed
9	last gap	dammed	10m; -2.5	dammed	closed

original state, phase 2



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Check on velocities

U in m/s Q in m^3/s		secondary gap				main gap			
		during ebb		during flood		during ebb		during flood	
phase	situation	U_{max}	Q_{max}	U_{max}	Q_{max}	U_{max}	Q_{max}	U_{max}	Q_{max}
0	original	1.09	915	1.07	940	1.09	1810	1.07	1825
1	bp+dams	1.33	1010	1.27	1045	1.33	2070	1.27	2085
2	sills	1.67	1065	1.57	1135	1.67	1935	1.57	1995
3	abutment	2.12	1090	1.94	1215	2.12	1790	1.94	1865
4	1 placed	2.71	1305	2.39	1505	2.57	1385	2.26	1470
5	2 placed	3.57	1550	3.00	1875	3.19	820	2.69	895

U_{max} becomes too high for closed caissons

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closing steps using sluice caissons

phase	action	foreshore	sec. gully	tidal flat	main gully	sluice gate
4	first placed, opened	dammed	200m; -2.5	dammed	128m; -4.5	56m; -3.5
5	sec. placed, opened	dammed	200m; -2.5	dammed	66m; -4.5	112m; -3.5
6	third caisson placed	dammed	200m; -2.5	dammed	0m	112m; -3.5
7	narrowing on sill	dammed	100m; -2.5	dammed	0m	112m; -3.5
8	further narrowing	dammed	50m; -2.5	dammed	0m	112m; -3.5
9	last gap in sec.	dammed	10m; -2.5	dammed	0m	112m; -3.5
10	close sluice gates	dammed	dammed	dammed	0m	closed

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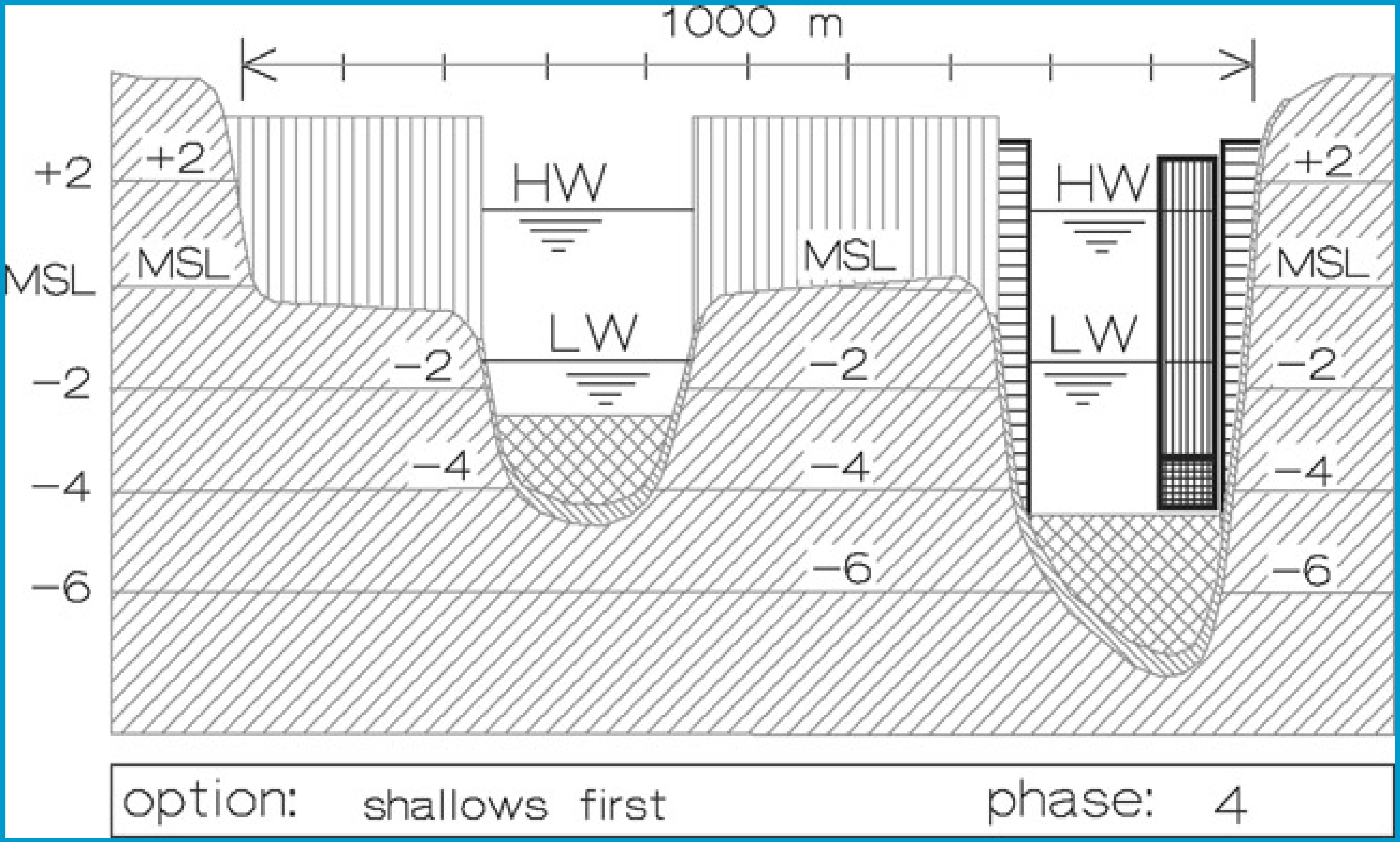
shallows first, phase 4



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velocities with sluice caissons (velocities in the caissons)

U in m/s Q in m³/s		secondary gap				main gap **			
		during ebb		during flood		during ebb		during flood	
phase	situation	U_{max}	Q_{max}	U_{max}	Q_{max}	U_{max}	Q_{max}	U_{max}	Q_{max}
5	1+2 open	2.60	1260	2.30	1445	2.32	1460	2.06	1580
6	3 placed	3.35	1480	2.85	1775	2.82	965	2.40	1095
7	100m gap	3.87*	830	3.40	1040	3.67	1155	3.03	1360
8	50 m gap	3.78*	410	3.57	535	3.95*	1220	3.36	1485
9	10 m gap	3.62*	80	3.58	105	4.05*	1245	3.58	1560

* means critical flow ** via the sluice gates

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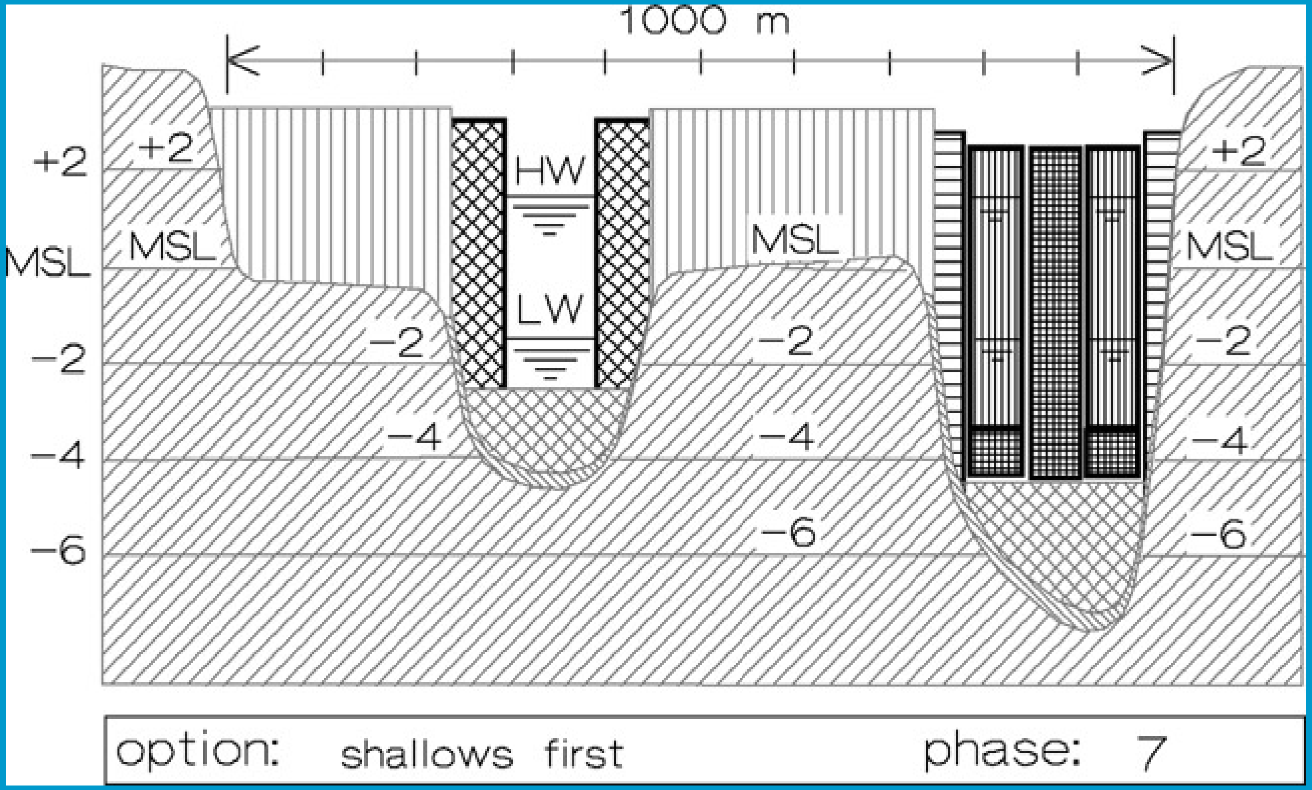
shallows first, phase 7



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velocities in case of three sluice caissons

U in m/s, Q in m^3/s		secondary gap				main gap **			
		during ebb		during flood		during ebb		during flood	
phase	situation	U_{max}	Q_{max}	U_{max}	Q_{max}	U_{max}	Q_{max}	U_{max}	Q_{max}
7	100m gap	3.35*	720	2.80	875	3.14	1570	2.63	1805
8	50 m gap	3.55*	385	3.09	480	3.51	1695	2.91	1980
9	10 m gap	3.49*	80	3.15	100	3.81*	1780	3.15	2120

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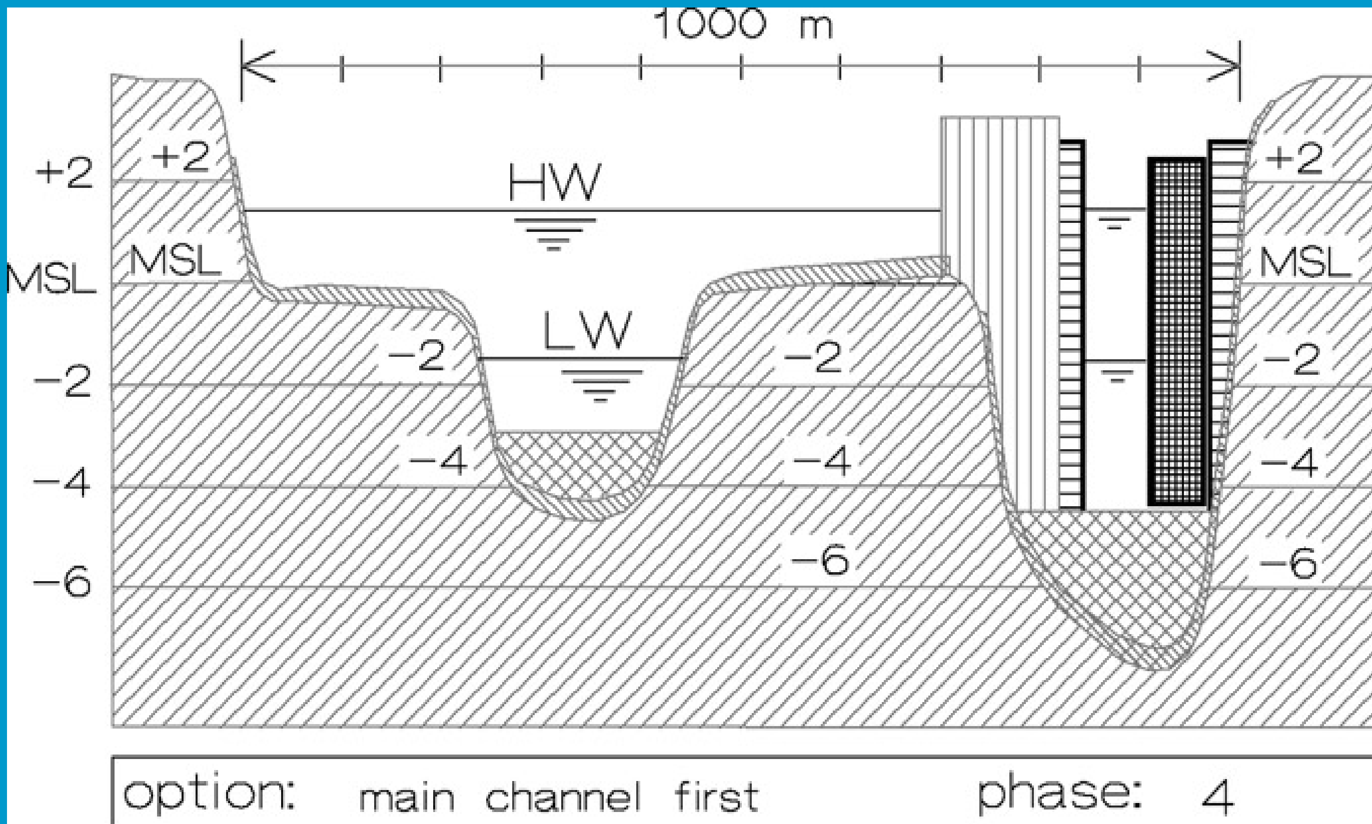
Blocking the main channel first

- raise sills in both channels somewhat (to the maximum allowed)
- place caissons in main channel
- close secondary channel and tidal flats by dumping rock
- keep a small gully open

main channel first, phase 4



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sequence of closing (main channel first)

phase	action	foreshore	sec. gully	tidal flat	island	main gully
0	original state	250m; -0.5	200m; –4	300m; MSL	none	250m; –6.5
1	bottom prot. + island	250m; MSL	200m; –3.5	250m; +0.5	125m	175m; –6
2	sills in both gaps	250m; MSL	200m; –3	250m; +0.5	125m	175m; –4.5
3	sill, abutments	250m; MSL	200m; –3	250m; +0.5	150m	125m; –4.5
4	first caisson placed	250m; MSL	200m; –3	250m; +0.5	150m	65m; –.5
5	sec. caisson placed	250m; MSL	200m; –3	250m; +0.5	-	closed

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velocities (main channel first)

U in m/s, Q in m^3/s		secondary gap **				main gap			
		during ebb		during flood		during ebb		during flood	
phase	situation	U_{max}	Q_{max}	U_{max}	Q_{max}	U_{max}	Q_{max}	U_{max}	Q_{max}
0	original	1.09	915	1.07	940	1.09	1810	1.07	1825
1	bott. prot. + island	1.61	1155	1.52	1215	1.61	1695	1.52	1720
2	sills	2.01	1175	1.85	1295	2.01	1525	1.85	1600
3	abutment	2.42	1355	2.19	1525	2.29	1205	2.07	1285
4	after 1st	3.06	1585	2.68	1860	2.73	705	2.40	770
5	after 2nd	3.98*	1860	3.37	2310	closed	0	closed	0

** the central 200 m section only (the shallows falling dry during low tide).

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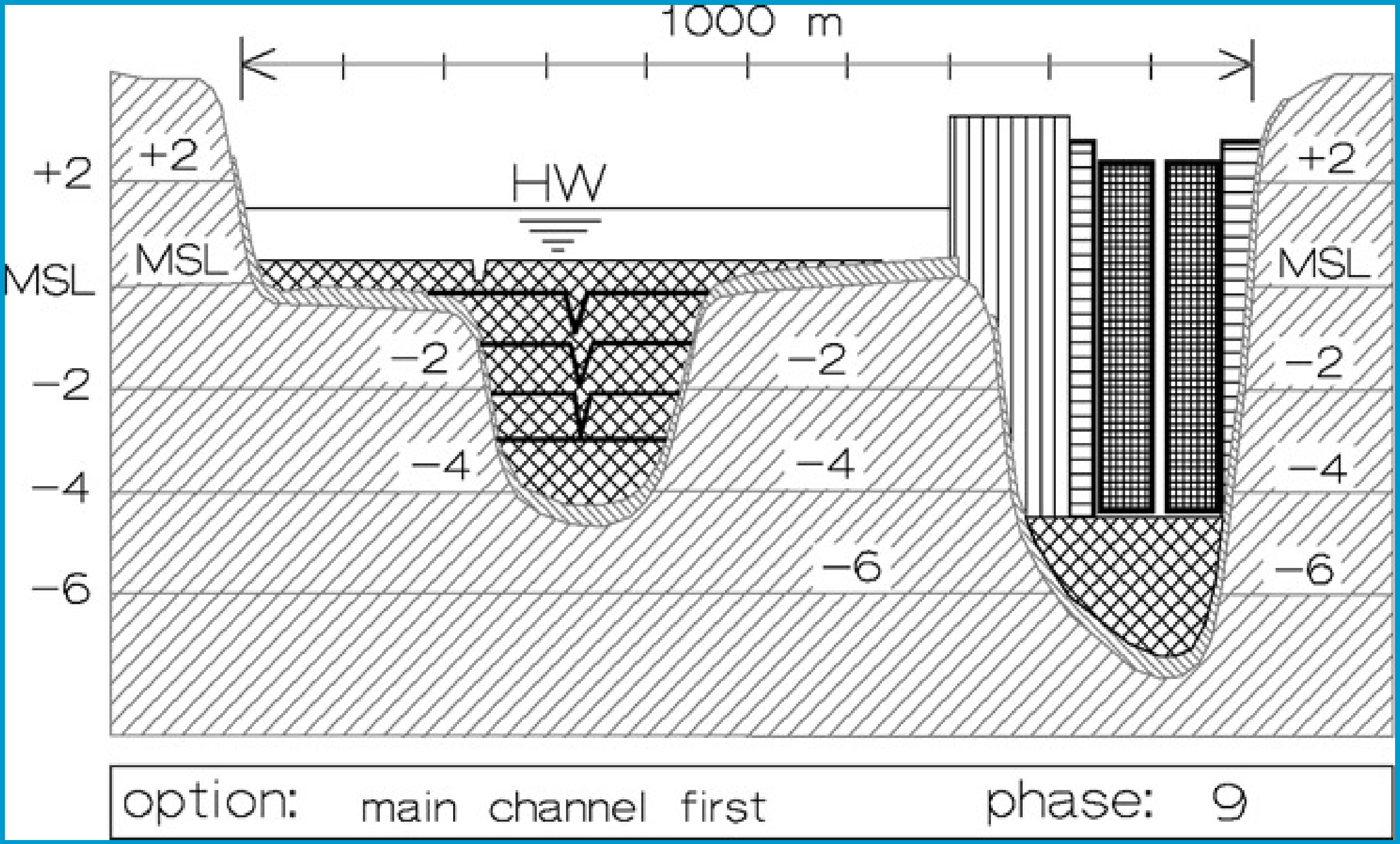
main channel first, phase 9



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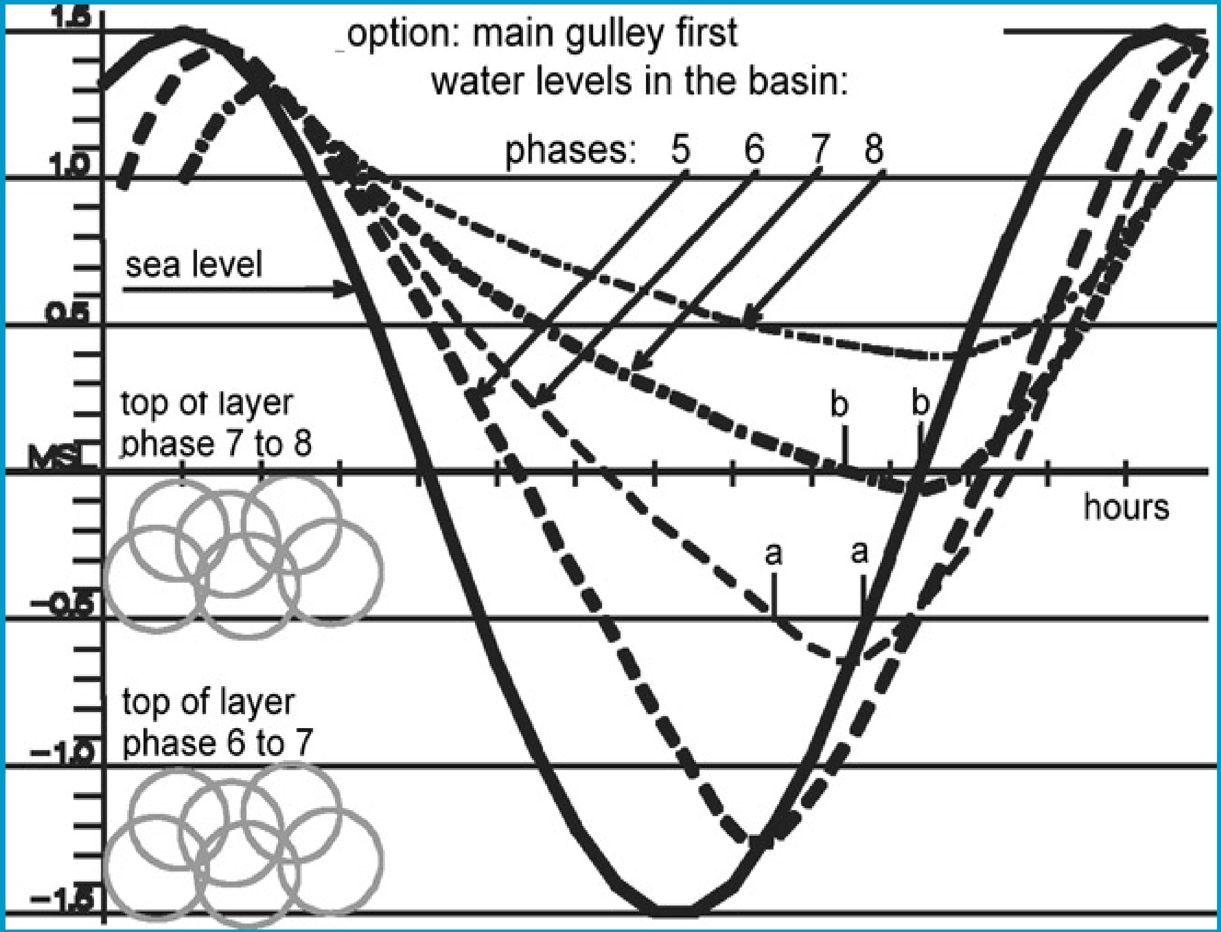
main channel first, water levels in basin



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closing steps secondary gully

phase	action	foreshore	sec. gully			tidal flat
6	first layer	250m; MSL	97m; -2	6m;-2	97m; -2	250m; +0.5
7	first layer	250m; MSL	97m; -1	6m; -2	97m; -1	250m; +0.5
8	level foreshore	250m; MSL	97m; MSL	6m; -1	97m; MSL	250m; +0.5
9	level tidal flat	222m; +0.5		6m; MSL	222m; +0.5	250m; +0.5
10	level + 1	347m +1		6m; +0.5		347m; +1
11	final layer	dammed		6m; +1		dammed

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flow velocities in several stages

U_{max} in m/s		deepest part		deepest but one		deepest but two		deepest but three	
phase	situation	ebb	flood	ebb	flood	ebb	flood	ebb	flood
5	after 2nd	3.98*	3.37	2.34*	2.85*	1.80*	2.50*		
6	up to -2	4.22*	3.43	3.81*	3.84	2.28*	3.03*	1.94*	2.32*
7	up to -1	3.82*	3.38	3.28*	2.68*	2.38*	3.15*	2.02*	2.32*
8	up to MSL	3.27*	2.92	2.50*	2.91*	2.06*	2.32*	not applicable	
9	up to 0.5	2.32*	2.67	1.98*	2.32*	not applicable			
10	up to + 1	1.86*	2.18*	1.05*	1.55*				
11	up to HW	0.88*	1.55*	high water free					

* means limited by critical flow condition.

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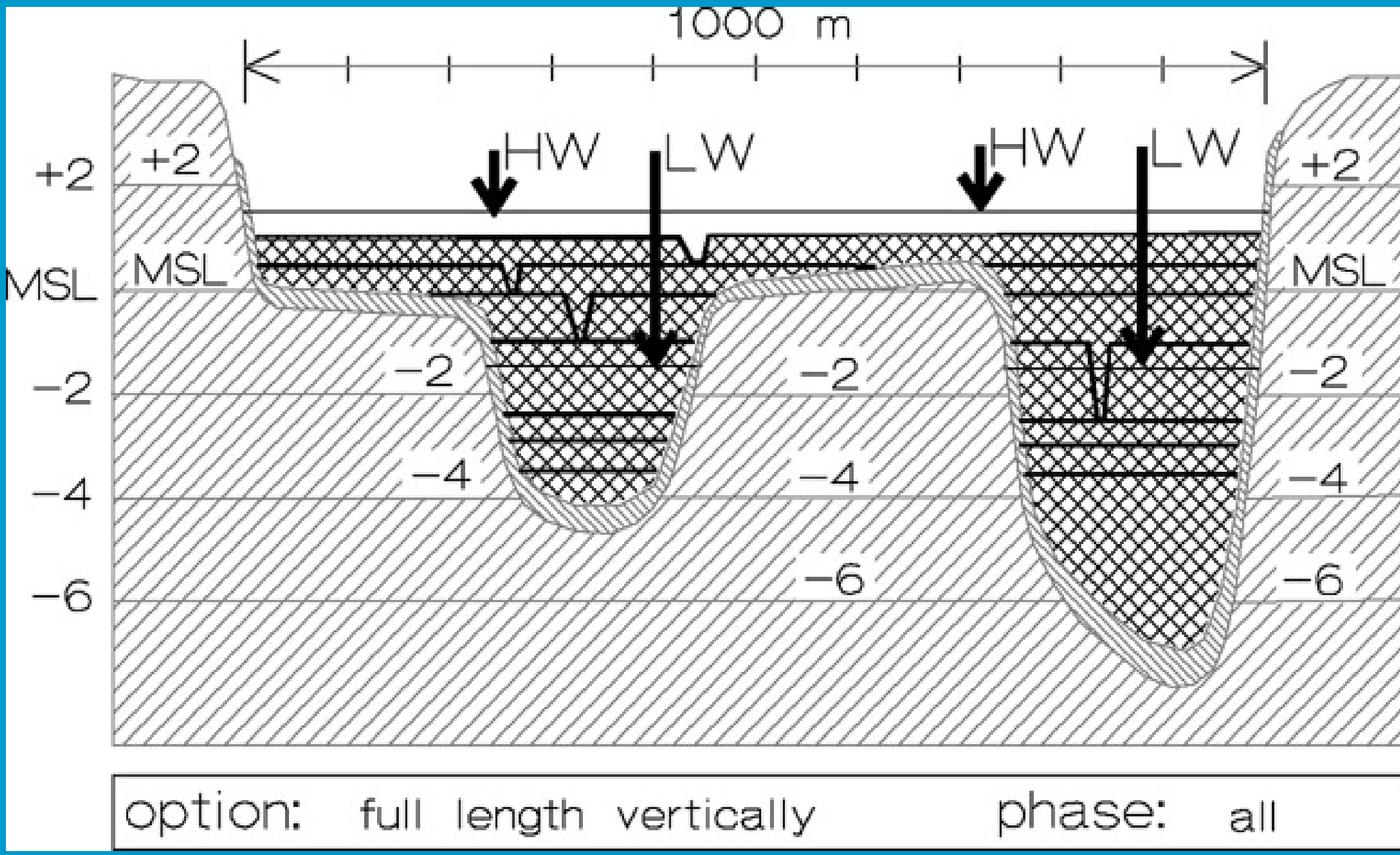
pure vertical closure (both channels simultaneously)

- raising the level simultaneously in all channels

full length vertically, phase: all



steps in the vertical closure

phase	action	foreshore	sec. gully	tidal flat	main gully
0	original state	250m; -0.5	200m; -4	300m; MSL	250m; -6.5
1	bottom prot. + sill (-3.5)	250m; MSL	200m; -3.5	300m; +0.5	250m; -3.5
2	sills dumped (-3)	250m; MSL	200m; -3	300m; +0.5	250m; -3
3	sills dumped (-2.5)	250m; MSL	200m; -2.5	300m; +0.5	250m; -2.5
4	sill by trucks (-1)	250m; MSL	200m; -1	300m; +0.5	245m; -1
5	up to MSL	445m; MSL	5m; -1	300m; +0.5	250m; MSL
6	up to +0.5	445m; +0.5	5m; MSL	300m; +0.5	250m; +0.5
7	up to +1	445m; +1	5m; +0.5	300m; +1	250m; +1
8	up to HW	445m; +1.5	5m; +1	300m; +1.5	250m; +1.5

velocities in the vertical closure (phase 1-4)

U in m/s Q in m^3/s		secondary gap				main gap			
		during ebb		during flood		during ebb		during flood	
phase	action	U_{max}	Q_{max}	U_{max}	Q_{max}	U_{max}	Q_{max}	U_{max}	Q_{max}
0	original	1.09	915	1.07	940	1.09	1810	1.07	1825
1	protect. + sill	1.78	1230	1.66	1310	1.78	1535	1.66	1635
2	sills -3	2.06	1180	1.90	1310	2.06	1475	1.90	1635
3	sills -2.5	2.48	1110	2.23	1305	2.48	1385	2.23	1630
4	sill -1	2.99*	710	3.49*	1135	2.99*	870	3.49*	1390

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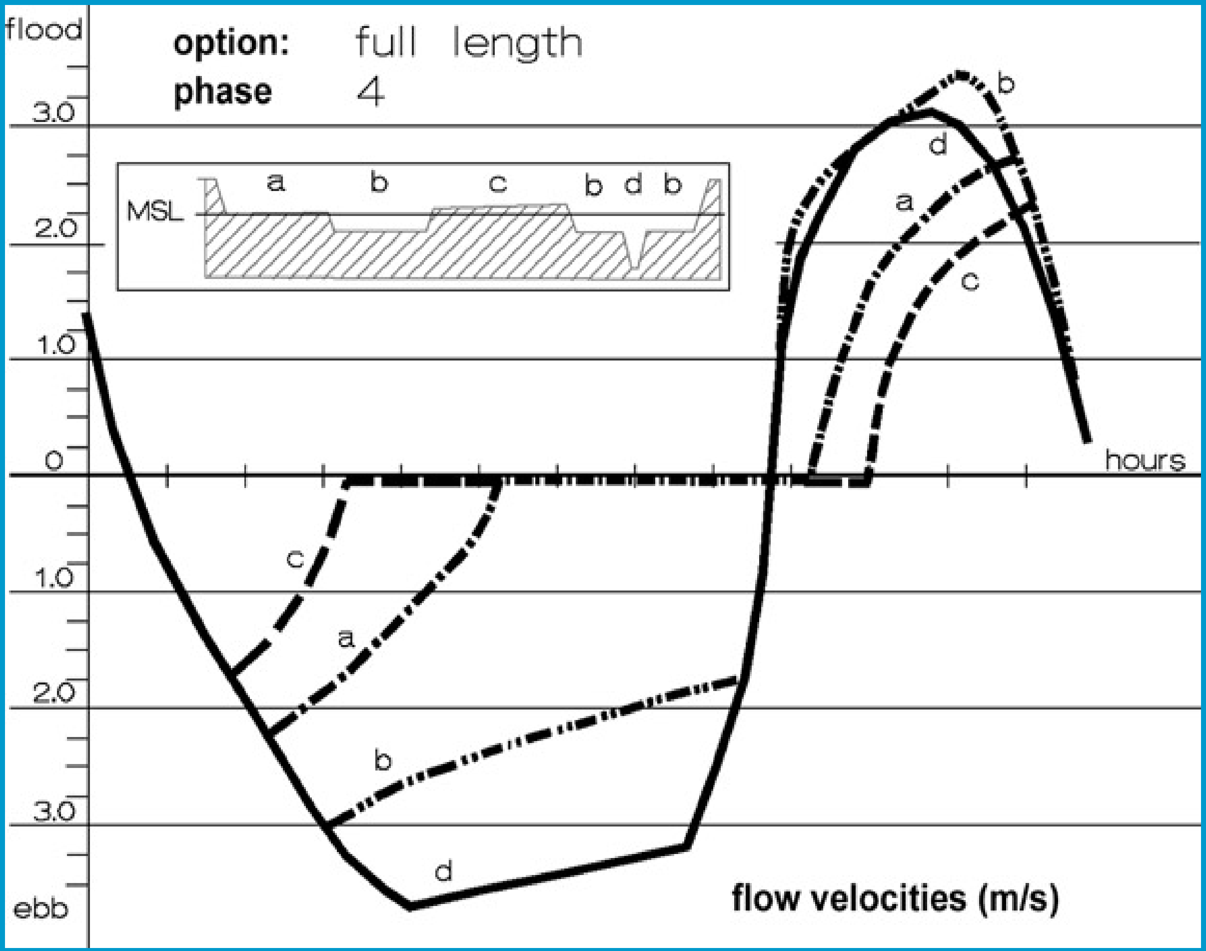
full length vertically, phase 4



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velocities in the vertical closure (phase 1-4)

U_{max} in m/s		deepest part		deepest but one		deepest but two		deepest but three	
phase	situation	ebb	flood	ebb	flood	ebb	flood	ebb	flood
4	sill -1	3.62*	3.09	2.99*	3.49*	2.24*	2.74*	1.68*	2.27*
5	up to MSL	2.97*	2.87	2.33*	3.05*	1.98*	2.32*	not applicable	
6	up to 0.5	2.32*	2.64*	1.95*	2.41*	not applicable			
7	up to +1	1.90*	2.05	1.11*	1.55*				
8	up to HW	0.88*	1.55*	high water free					

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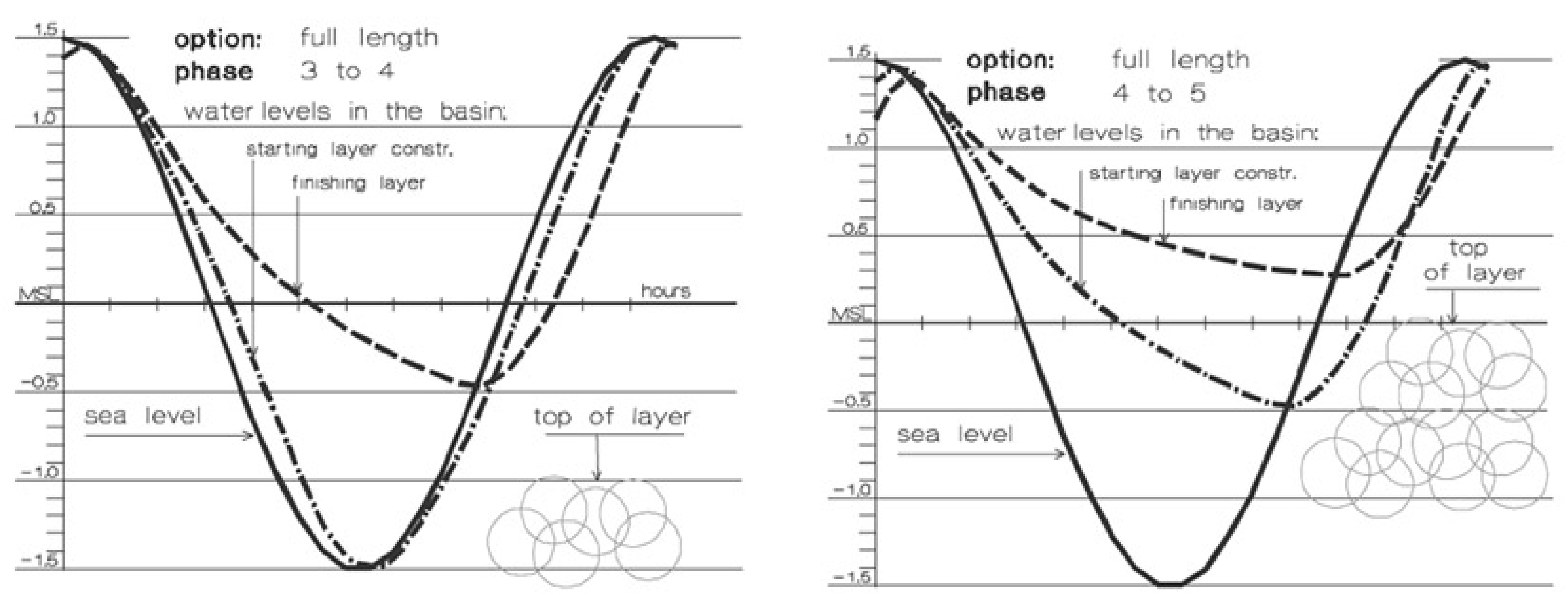
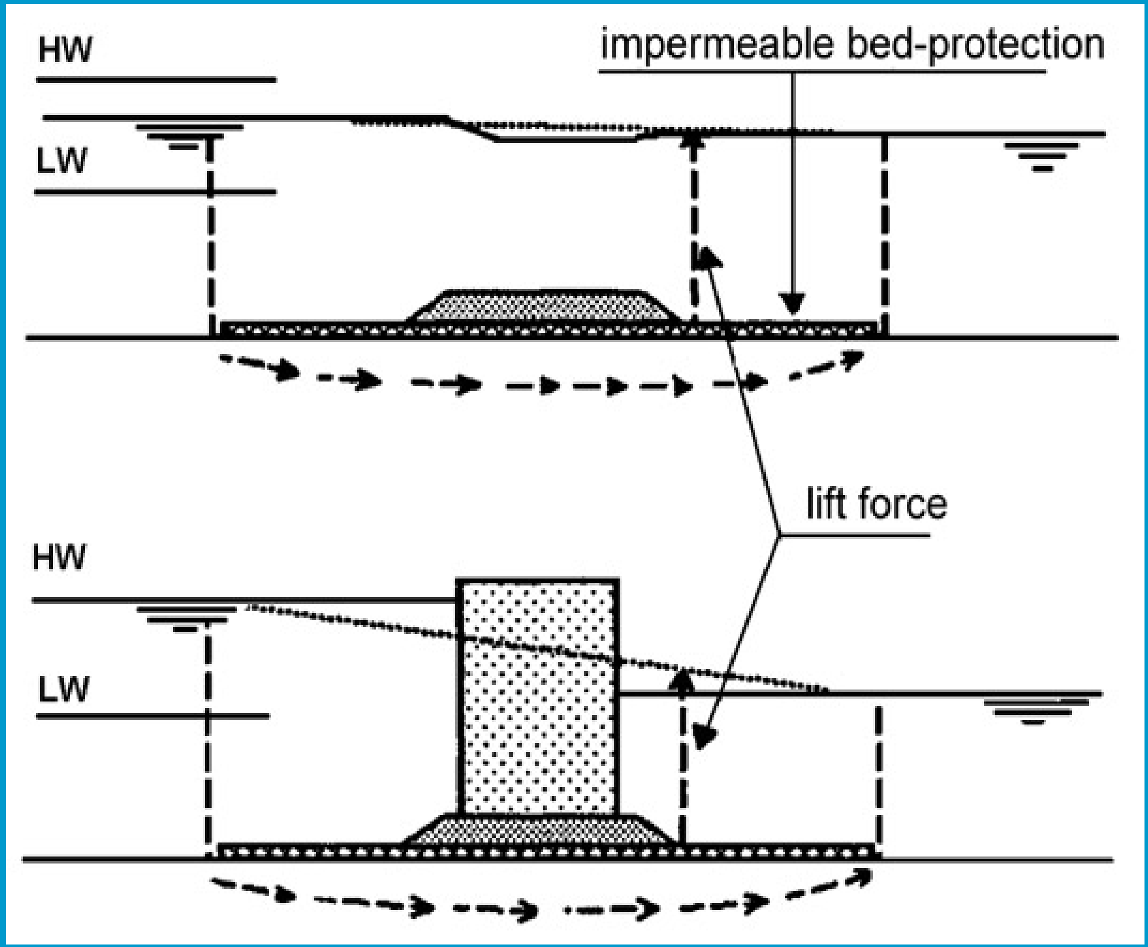
full length, phase 3 to 4 and 4 to 5



TUDelft

uplift of impermeable bed protection



TU Delft