Design and Construction of Berm Breakwaters

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Contents

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- Classification of berm breakwaters
- Geometrical design guidance
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- Comparison with conventional rock design
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- Application in arctic area
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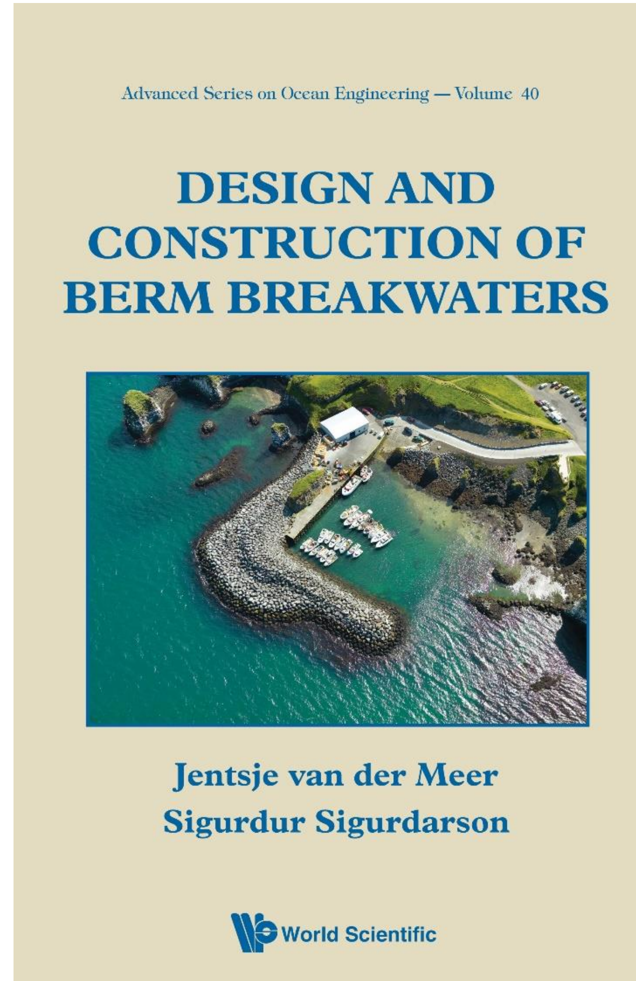


New book on Berm Breakwaters

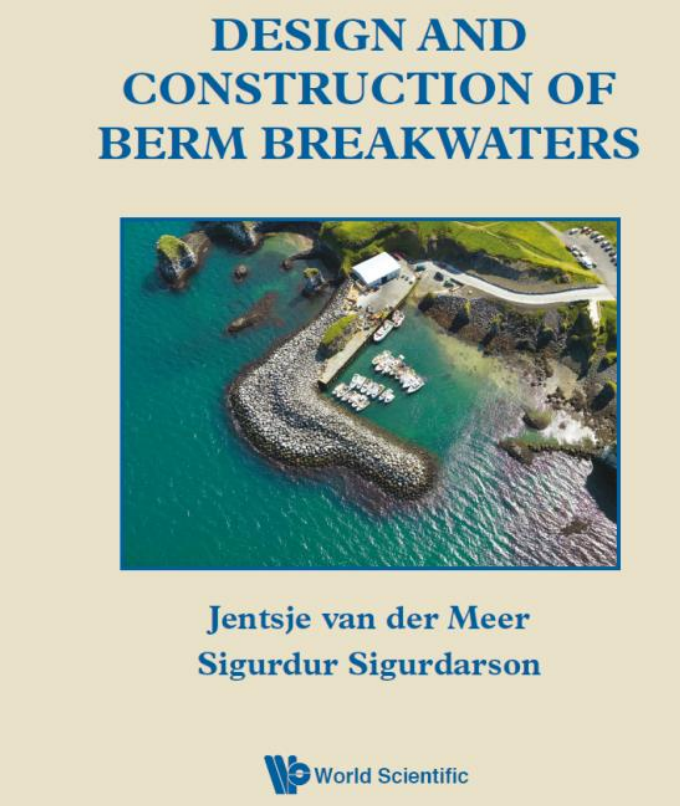
Design and Construction of Berm Breakwaters

Available since November 2016

Based on cooperative work, both in the scientific as well as in the practical field, with a number of papers presented

Chapters

1. History of Modern Berm Breakwaters
2. Classification and Types of Berm Breakwaters
3. Prediction on Stability and Reshaping
4. Functional Behaviour: Wave Overtopping, Reflection and Transmission
5. Geometrical Design of the Cross-section
6. Armourstone and Quarrying
7. Construction
8. Geometrical Design into Practice, Examples
9. Constructed Examples



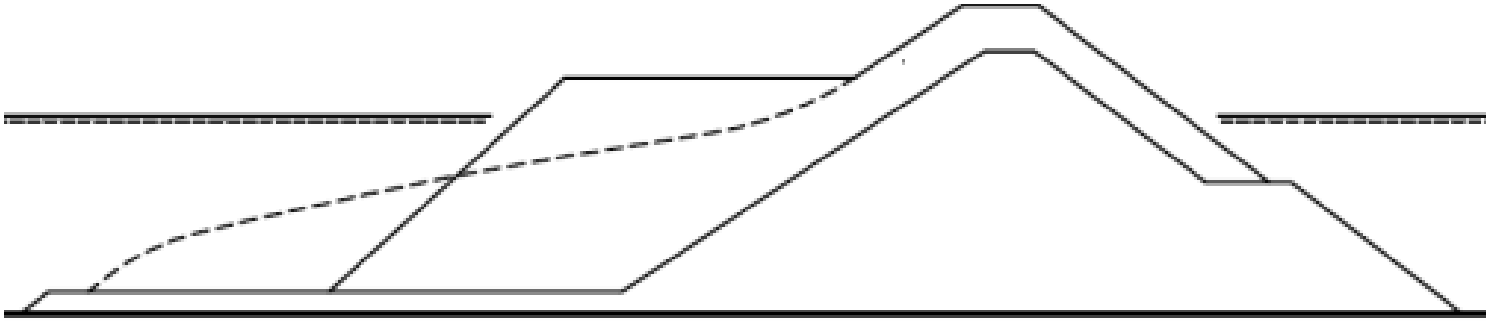
Iceland; berm breakwater

Sirevåg, Norway; berm breakwater

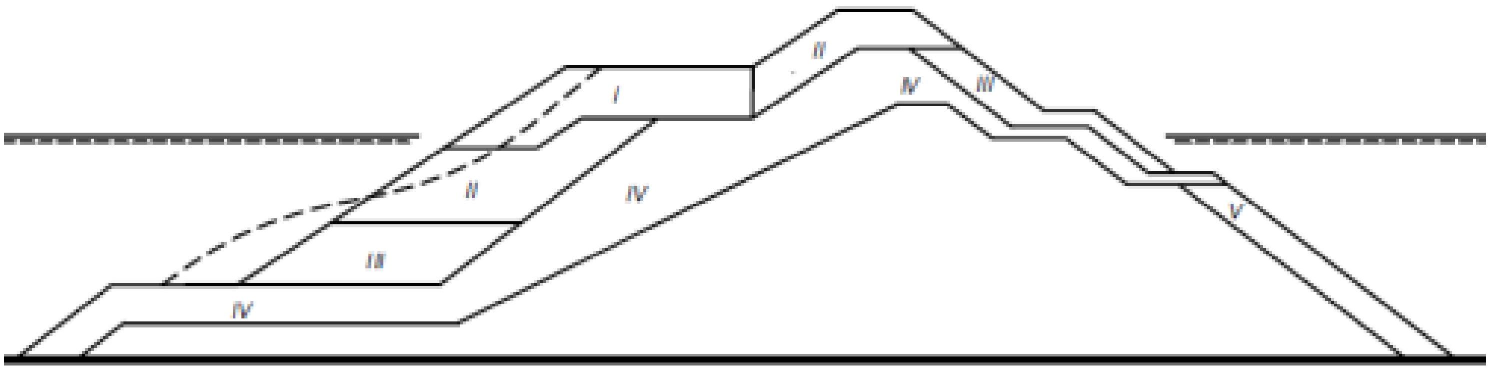
Sirevåg, Norway; berm breakwater after design storm

Development in berm breakwater design

Originally: reshaping mass armoured

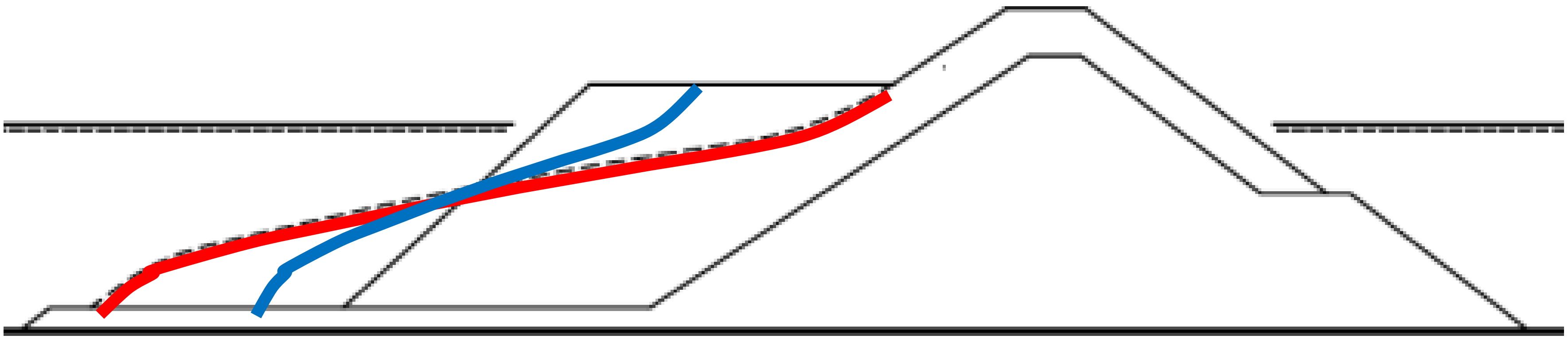


Developing to Icelandic-type



Mass armoured berm breakwater

For classification: design wave height = 100 years return period



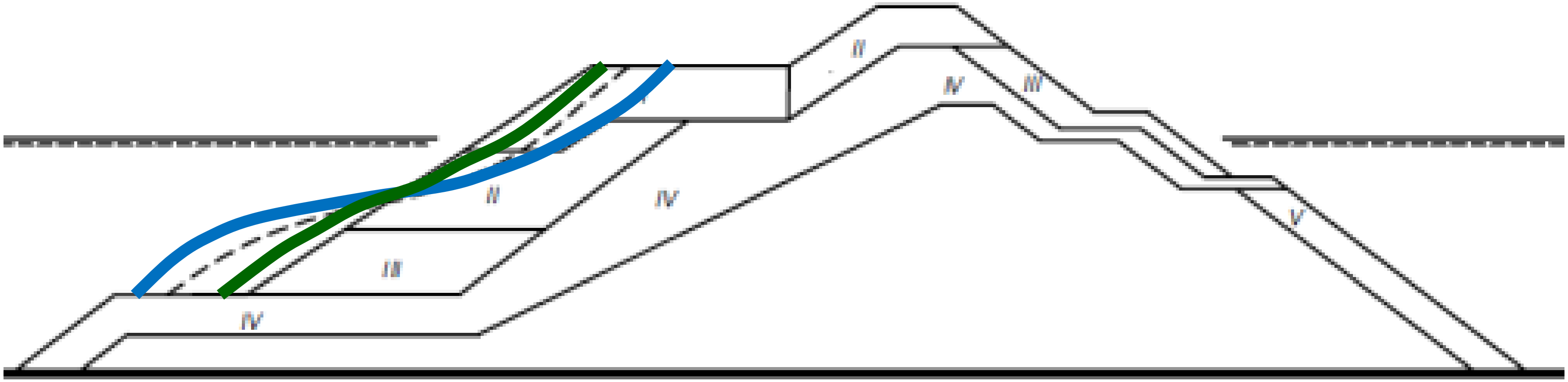
Fully reshaping berm breakwater (mass armoured)

Partly reshaping berm breakwater (mass armoured)

Mainly difference is stone size

Icelandic-type berm breakwater

For classification: design wave height = 100 years return period



Partly reshaping Icelandic-type berm breakwater

Hardly reshaping Icelandic-type berm breakwater

Mainly difference is stone size Class I

New classification

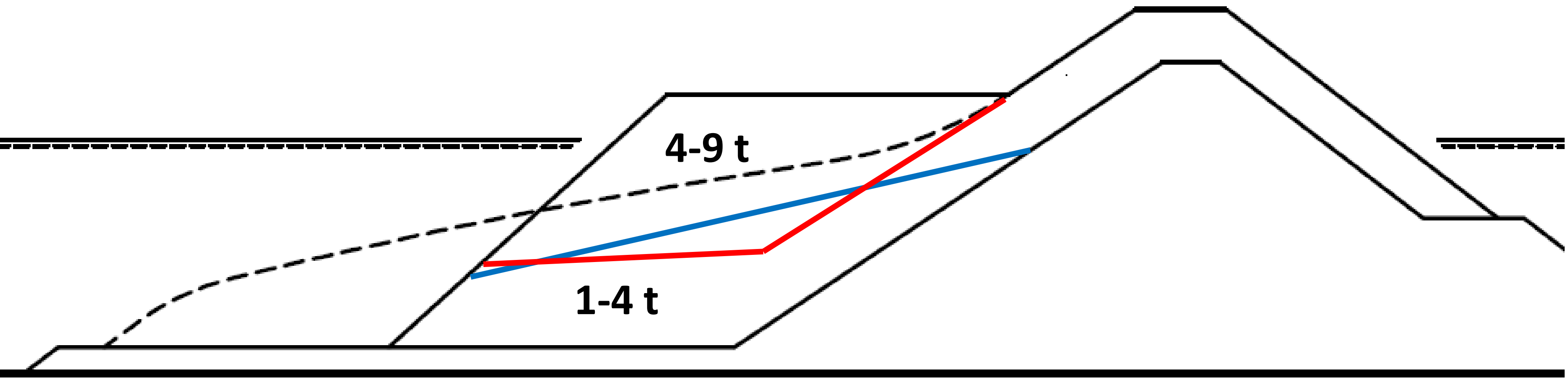
Breakwater	*Abbreviation*	$H_s/\Delta D_{n50}$	S_d	Rec/D_{n50}
Hardly reshaping berm breakwater (Icelandic-type)	**HR-IC**	1.7 - 2.0	2 - 8	0.5 - 2
Partly reshaping Icelandic-type berm breakwater	**PR-IC**	2.0 - 2.5	10 - 20	1 - 5
Partly reshaping mass armoured berm breakwater	**PR-MA**	2.0 - 2.5	10 - 20	1 - 5
Fully reshaping berm breakwater (mass armoured)	**FR-MA**	2.5 - 3.0	--	3 - 10

Design is a choice of availability of rock and wanted reshaping

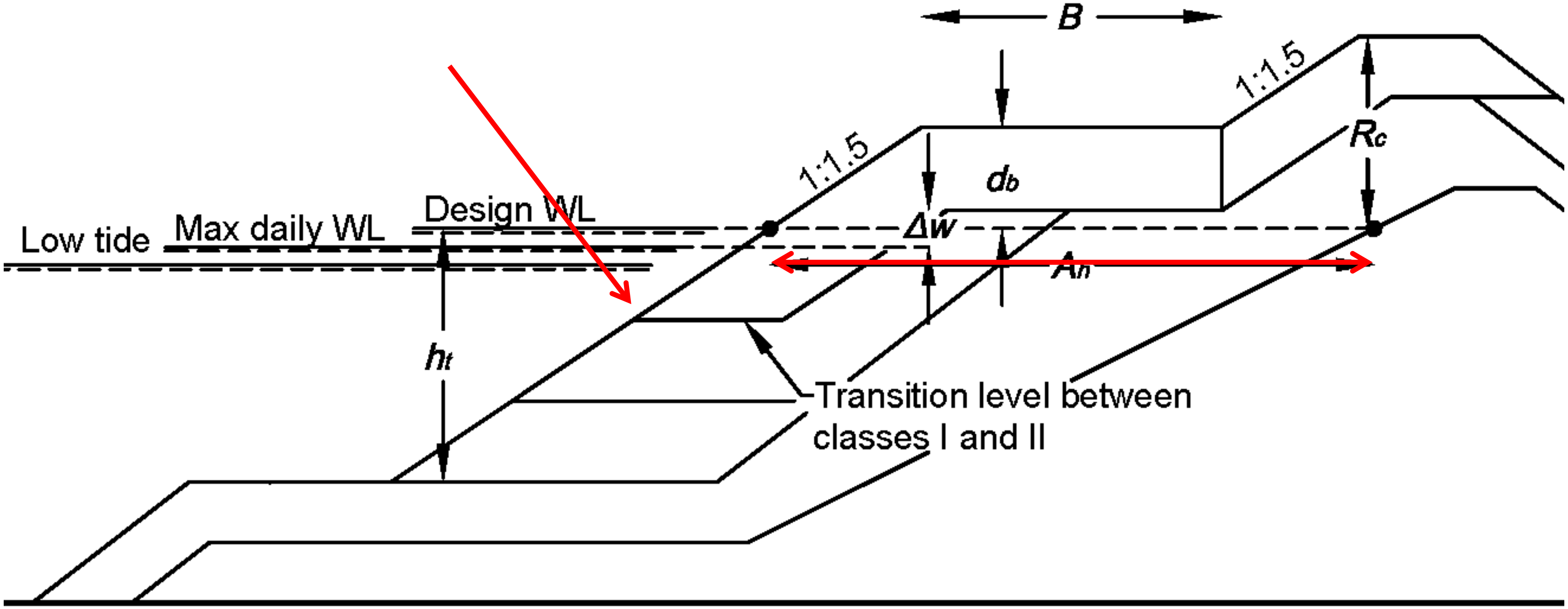
Proposal for new fully reshaping berm breakwater

Do not allow one wide graded rock class (1-9 t),
but divide in two narrower classes (1-4 t and 4-9 t)
No extra costs, but larger stability!

Quite some fully reshaping berm breakwaters needed maintenance over 15-25 years.



Geometrical design guidance



- berm width B (recession, resiliency)
- berm level d_b
- crest level R_c (overtopping)
- horizontal armour height A_h
- transition to Class II
- toe depth h_t

Berm width and resiliency

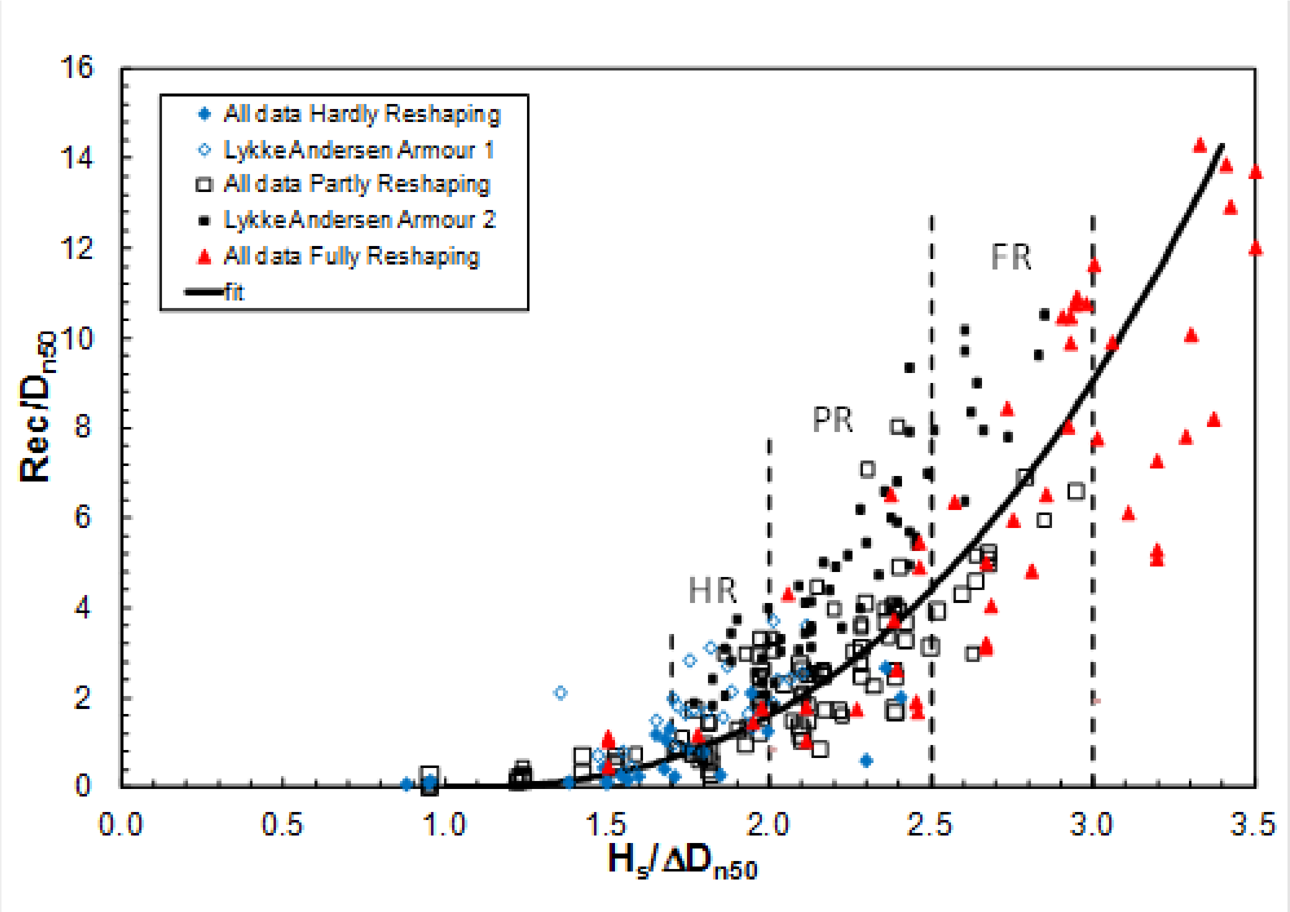
Resiliency: a percentage, $P_{\%}$, of the berm width, B, that may erode under the design condition H_{sD}.

Very resilient, hardly reshaping, IC HR	$P_{\%}$ = 10-20%
Good resiliency, partly reshaping, IC PR or MA PR	$P_{\%}$ = 20-40%
Minimum resiliency, fully reshaping, MA FR	$P_{\%} \leq$ 70%

Berm width B = Rec/($P_{\%}$/100)

Example
Rec = 4 m; P% = 30%
B = 4/0.3 = 13.3 m

New recession formula – average trend



$$Rec/D_{n50} = 1.6\ (H_s/\Delta D_{n50} - 1.0)^{2.5}$$

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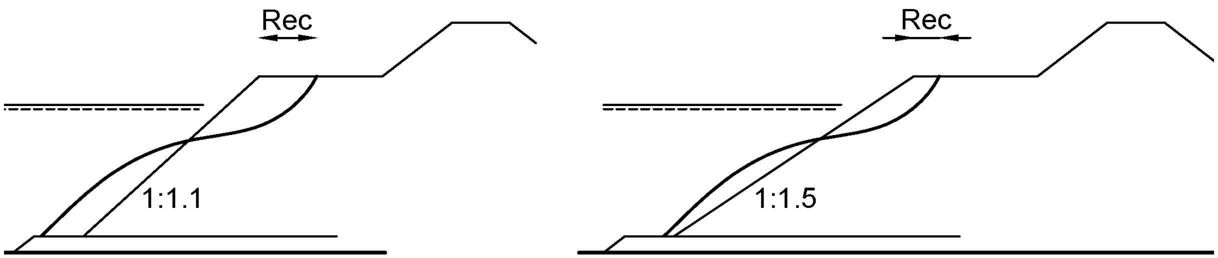
Front Slope Stability - Influences

Other parameters influence berm recession

Three geometrical parameters identified

Down slope

Gentle slope less recession



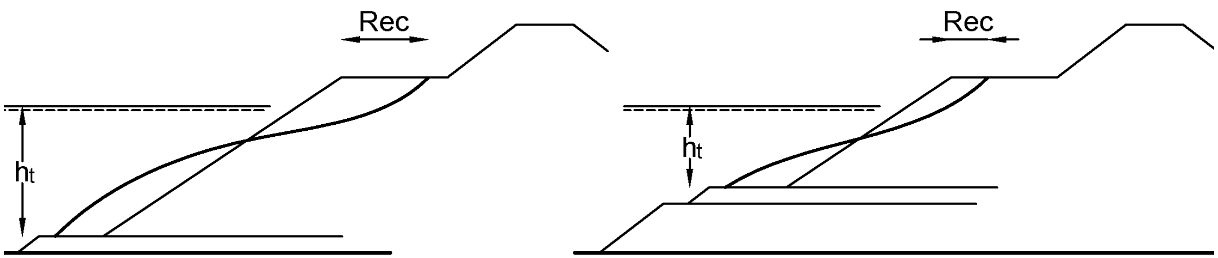
Berm level and width

High berm less recession

Large berm width reduces recession

Toe depth

High toe reduces recession



Wave overtopping at berm breakwaters

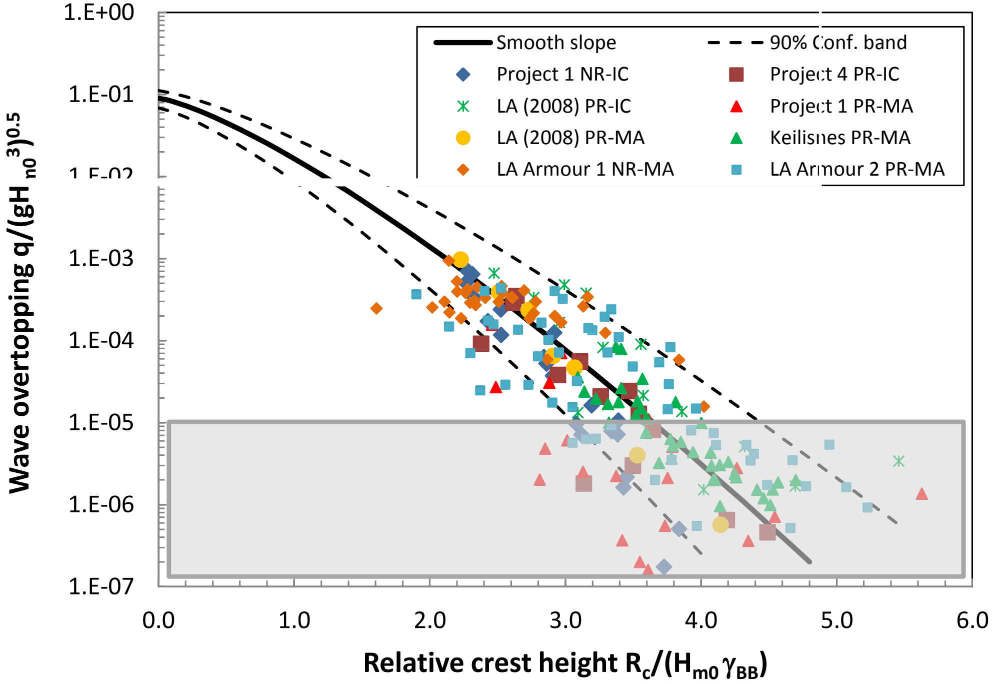
$$\frac{q}{\sqrt{g \cdot H_{m0}^{3}}} = 0.09 \cdot \exp\left[-\left(1.5 \frac{R_c}{H_{m0} \cdot \gamma_{BB} \cdot \gamma_{\beta}} \right)^{1.3} \right]$$

with:

$\gamma_{BB} = 0.68 - 4.5 s_{op} - 0.05 B/H_{sD}$ for HR and PR

$\gamma_{BB} = 0.70 - 9.0 s_{op}$ for FR

and B/H_{sD} is given by the design wave height.

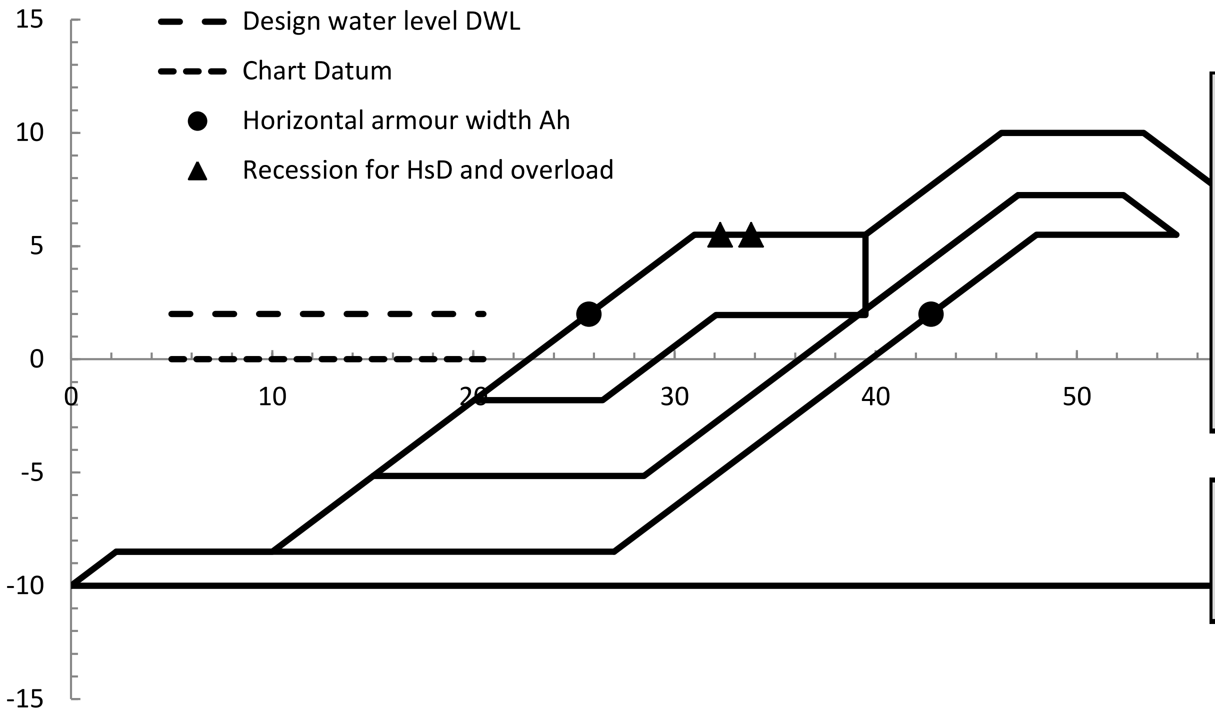


Conceptual design spreadsheet www.vdm-c.nl

General conditions			**Outcome main parameters**			**Minimum transition level to class II**		
Design wave height H_{sD}	3	m	Wave steepness s_{op}	0.020	-	For H_{sD} at lowest level	-0.2	m CD
Peak period T_p	9.8	s	Relative mass density Δ	1.54	-	For lowest level with according H_s	-1.2	m CD
Overload H_s	3.5	m	Median mass Class I M_{50}	2.5	t	Design choice of transition for IC (3 rock classes	-1.8	m CD
Design water level DWL	1	m CD	Nominal diameter Class I D_{n50}	0.99	m	Transition lower class for MA (2 rock classes)	-1.8	m CD
Lowest water level with H_{sD}	1	m CD	Stability number $H_{sD}/\Delta D_{n50}$	1.98	-			
Lowest storm level	0	m CD	**Type of berm breakwater**	**Hardly reshaping**		**Crest level (γ_β = 1)**		
H_s at lowest storm level	3	m	Number of rock classes for berm	2		If no overtopping criteria, $R_{c\,min}$	4.6	m CD
Mean High Water Spring	1	m CD	Basic recession for H_{sD} (no adaptation)	1.49	m	If no overtopping criteria, $R_{c\,max}$	5.2	m CD
Bottom level of foreshore at toe of structu	-9	m CD	Recession for overload (no adaptation)	2.28	m	For given allowable overtopping, q, γ_{BB}	0.46	
Allowable overtopping q for H_{sD}	5	l/s per m	Nominal diameter Class II, D_{n50}	0.61	m	Required crest level for design conditions	4.93	m CD
Allowable overtopping q for overload	20	l/s per m	Nominal diameter Class III, D_{n50}	No Class		Required crest level for overload	4.87	m CD
Mass density water	1025	kg/m^3				Design choice of crest level	4.80	m CD
Mass density rock	2600	kg/m^3	**Resiliency, berm width and level**					
			Wanted resiliency	20	%	**Check possibility of toe berm at level h_t**		
Choice of rock classes			Resulting Berm width B from resiliency	7.47	m	**Lowest** possible toe level (two layers)	-6.27	m CD
Rock Class I: minimum mass (0-15%)	1	t	Minimum berm width B_{min} from geomet	2.96	m	*Design conditions*		
Rock Class I: maximum mass (85-100%)	4	t	Berm level 0.6 H_{sD}	2.8	m CD	Allowable damage level for H_{sD}, N_{od}	2	-
Rock Class II: minimum mass (0-15%)	0.2	t	Δw for waves during construction	1	m	*Highest* level of toe for H_{sD} with chosen N_{od}	-3.83	m CD
Rock Class II: maximum mass (85-100%)	1	t	MHWS plus Δw = working level	2	m CD	Check validity range h_t/D_{n50}	7.9	ok
Rock Class III: M_{min} (leave open for MA)		t	Minimum berm level from construction	3.97	m CD	Check validity range h_t/h	0.48	ok
Rock Class III: M_{max} (leave open for MA)		t	Design choice of berm width	8.00	m	*Overload conditions*		
			Design choice of berm level	4.00	m CD	Allowable damage level for overload, N_{od}	4	-
						Highest level of toe for overload with chosen N	-4.12	m CD
			Required horizontal armour width A_h	11.9	m	Check validity range h_t/D_{n50}	8.3	ok
			Design choice of A_h	12.0	m	Check validity range h_t/h	0.51	ok
						Design choice of toe berm level (0 if no berm)	0	m CD
						Design choice cotα core below A_h	1.5	-

Design spreadsheet result

H_{sD} = 5 m; Class I 10-20 t



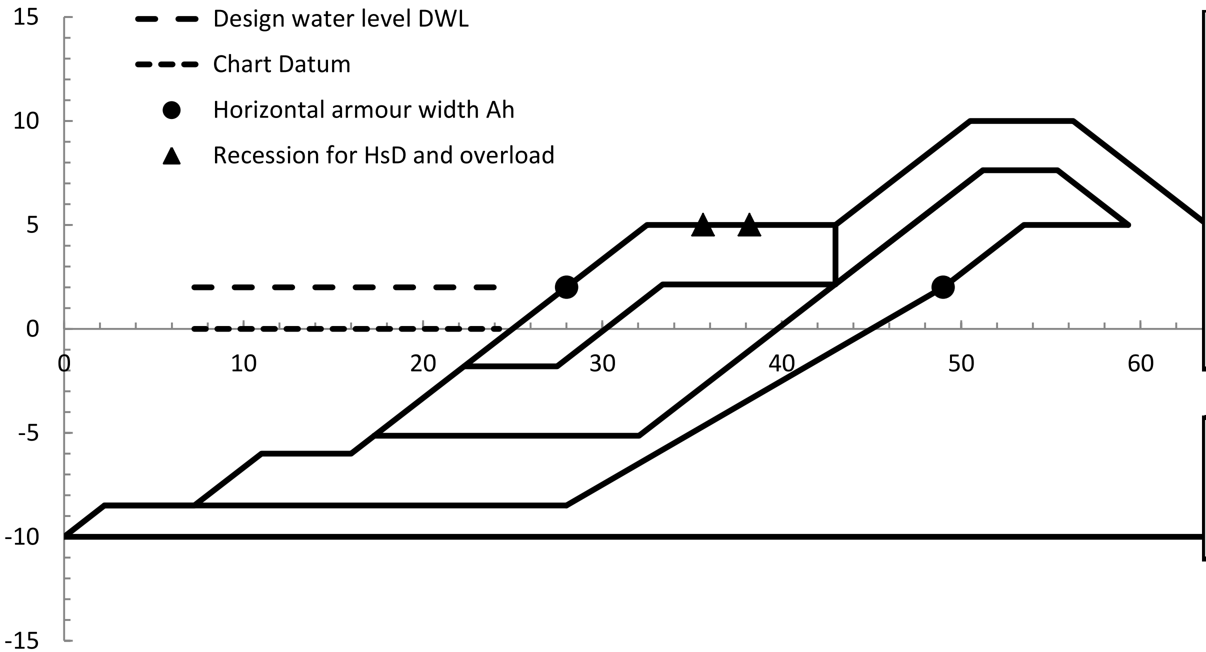
Summary of design choices	
Design of berm width	8.50 m
Design of berm level	5.50 m CD
Design of A_h	17.0 m
Design of transition class I to class I	-1.8 m CD
Design of crest level	10.00 m CD
Design of toe berm level	0 m CD
Design choice cotα core below A_h	1.5 -

Rock Class	10	-	20	t
Rock Class	4	-	10	t
Rock Class	1	-	4	t

Rock classes versus stability numbers

		Stability number $H_{sD}/\Delta D_{n50}$		
Dedicated quarry	**M_{50} (t)**	**H_{sD} = 3 m**	**H_{sD} = 5 m**	**H_{sD} = 7 m**
Class 20-35 t	25.0	0.87	1.46	**2.04**
Class 10-20 t	15.0	1.04	**1.73**	**2.42**
Class 4-10 t	7.0	1.34	**2.23**	3.12
Class 1-4 t	2.5	**1.88**	3.14	4.39
Class 0.2-1 t	under layer			
Class 2-6 t	4.0	1.61	**2.68**	3.76
Class 0.5-2 t	1.2	**2.41**	4.01	5.61
Standard gradings				
Class 10-15 t	12.5	1.10	**1.84**	**2.57**
Class 6-10 t	8.0	1.28	**2.13**	**2.98**
Class 3-6 t	4.5	1.55	**2.58**	3.61
Class 1-3 t	2.0	**2.03**	3.38	4.73
Class 0.3-1 t	under layer			

H_{sD} = 5 m; Class I 6-10 t

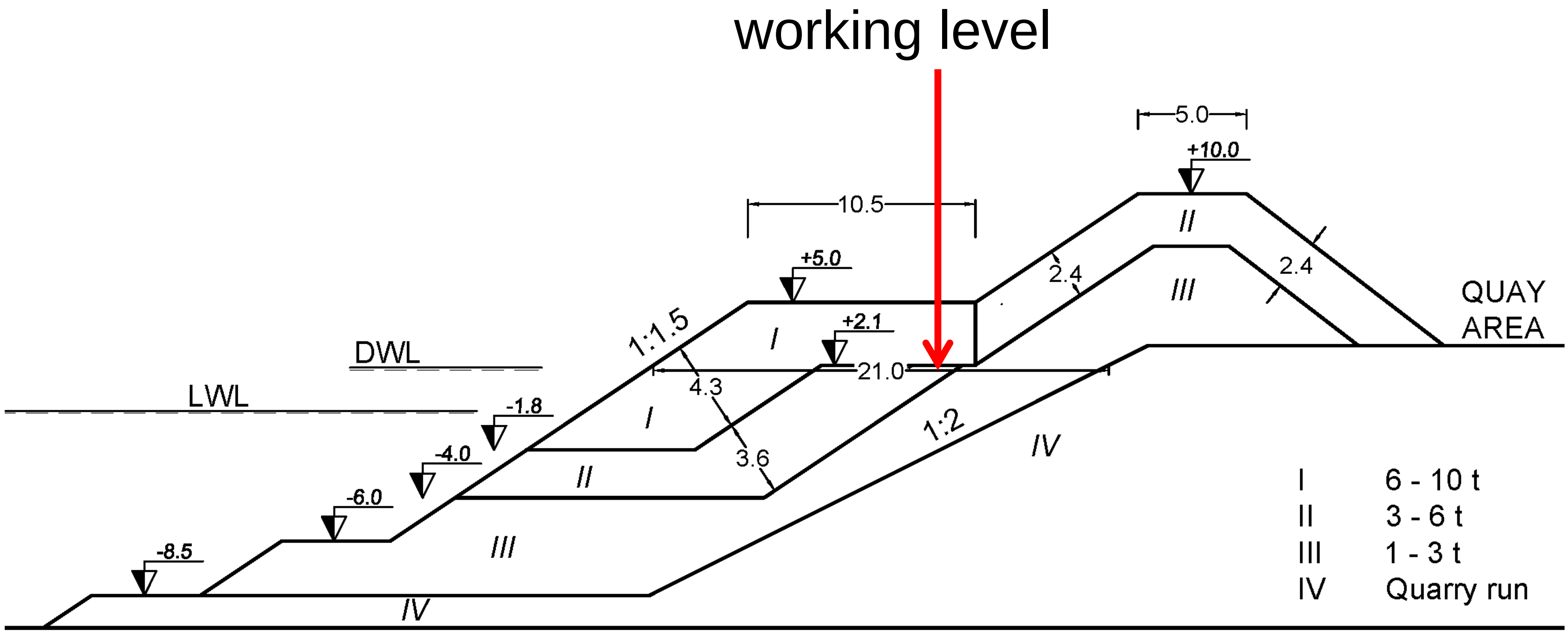


Summary of design choices	
Design of berm width	10.50 m
Design of berm level	5.00 m CD
Design of A_h	21.0 m
Design of transition class I to class I	-1.8 m CD
Design of crest level	10.00 m CD
Design of toe berm level	-6 m CD
Design choice cotα core below A_h	2 -

Rock Class	6	-	10	t
Rock Class	3	-	6	t
Rock Class	1	-	3	t

H_{sD} = 5 m; Class I 6-10 t

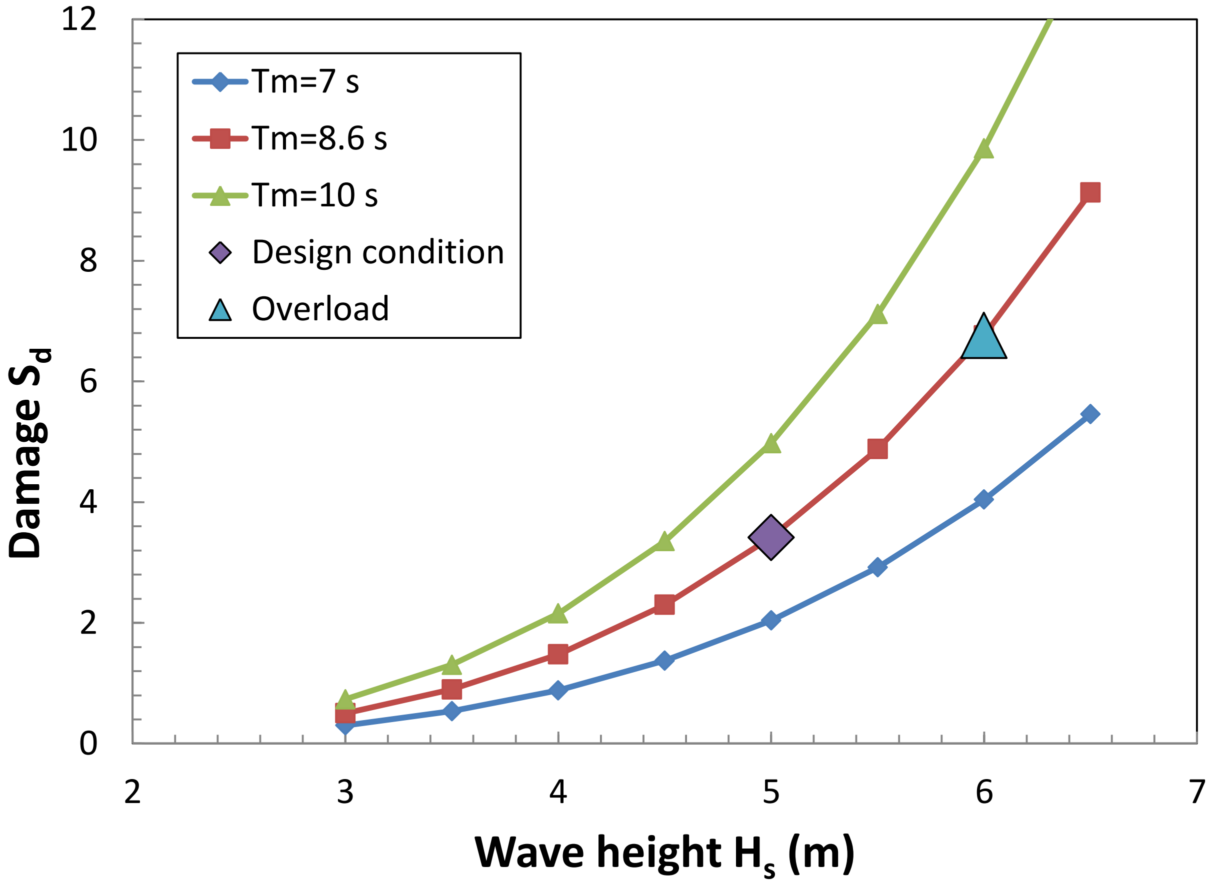
Drawing for tender



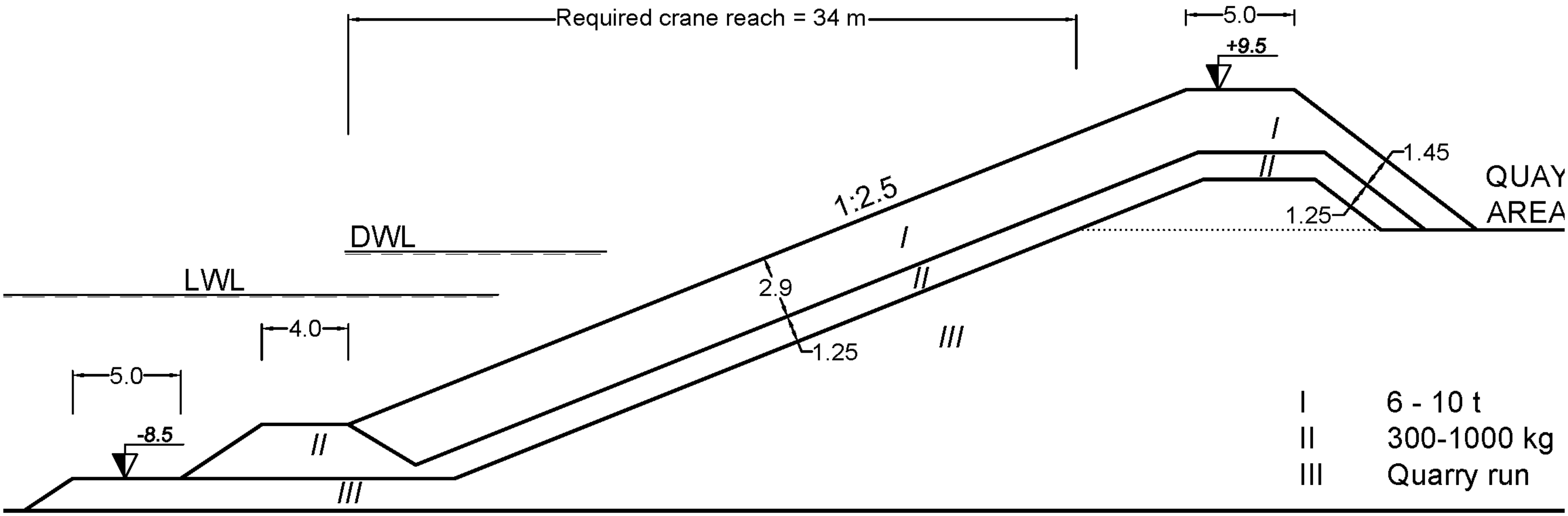
Placing Class I rock from top of Class II

Conventional rock armour 6-10 t

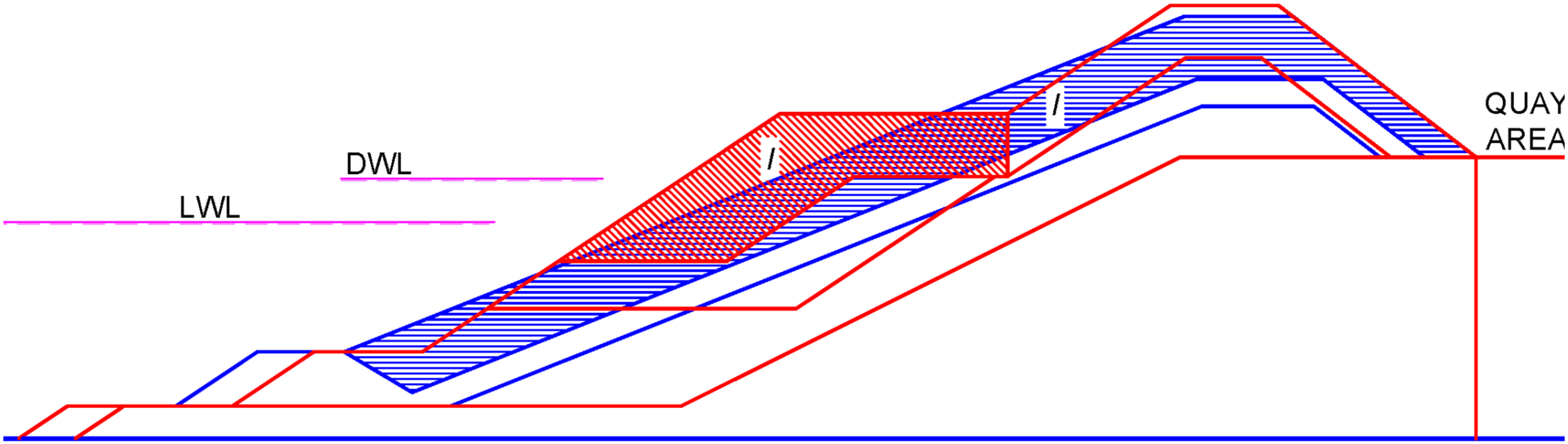
Breakwat: damage curves for performance based design
cotα = 2.5; P = 0.4; N = 3000



Conventional rock armour 6-10 t



Comparison



Conventional: two times more 6-10 t rock
Total volume of rock similar
Berm breakwater: construction by excavator only

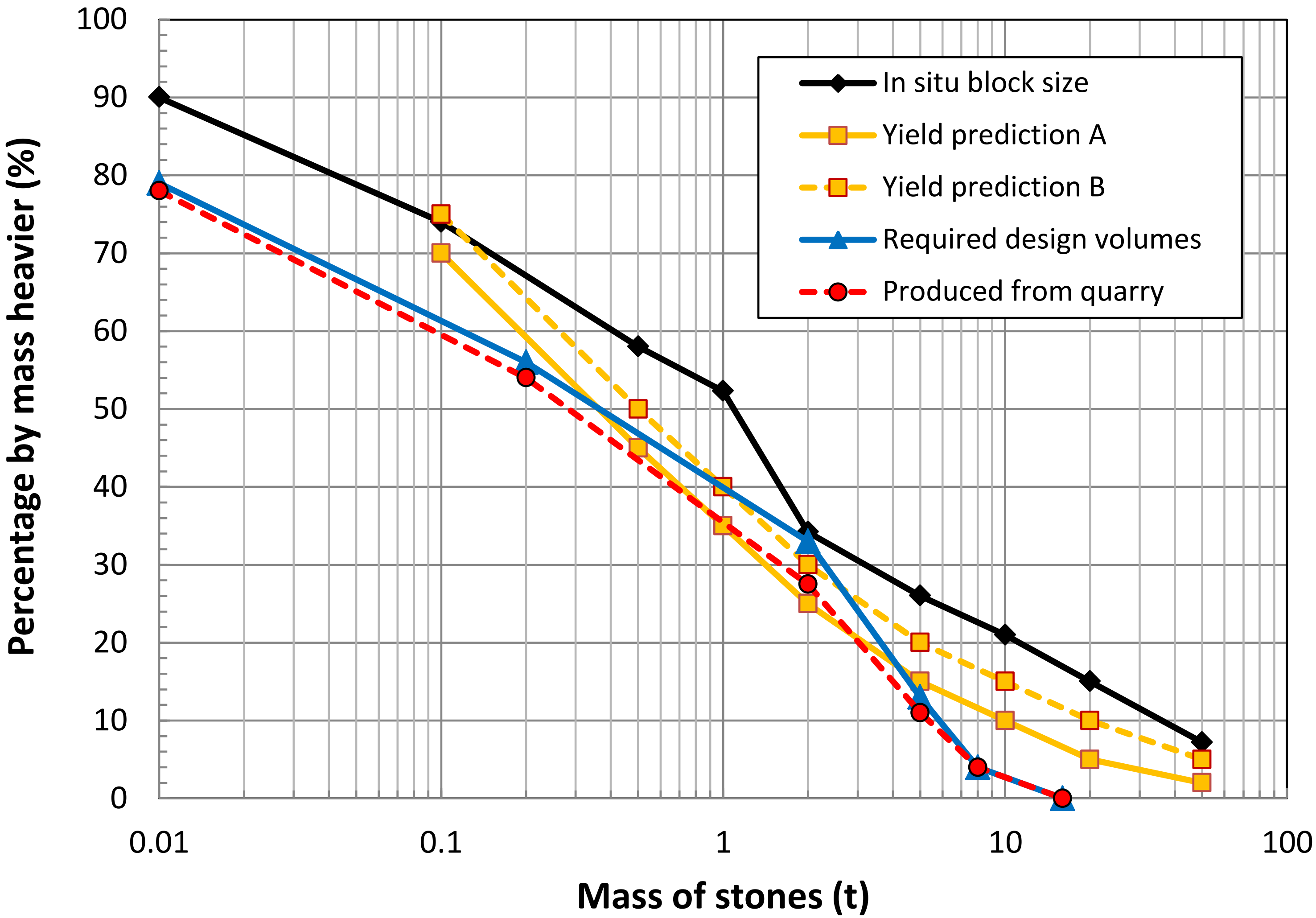
Construction – quarry. Getting the large rock!

Sirevåg berm breakwater, Norway

The rocks in quarry A

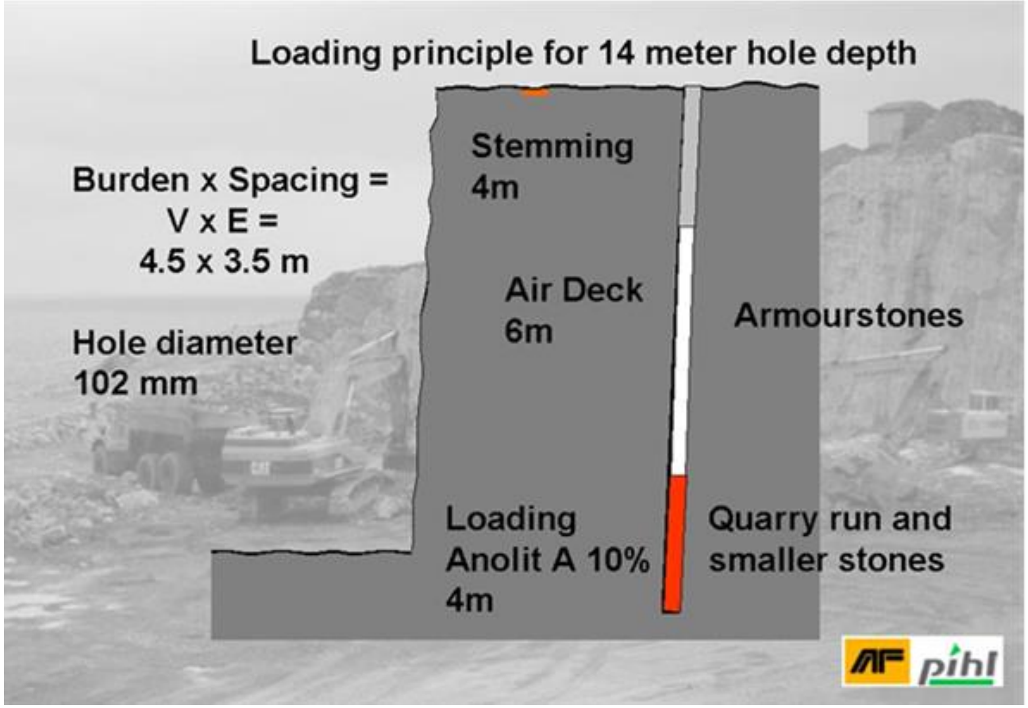
Drilled borehole cores

Quarry Yield Prediction, very important for dedicated quarry



From Smarason *et al.* (2000)

Blasting for very large rock



Blasting design Hammerfest for 20-35 t rock

Low charge of explosives

Bottom charges

One row at the time

Optimum spacings

Hambantota Artificial Island Revetment

Application of the geometrical design rules

Potential project in arctic conditions

Conceptual design for a road crossing a small bay, sheltered for ocean waves

This area is difficult to reach

Icefree only for few months each summer

Initially there was no information on rock

- Initial design conditions:
- H_s = 4.4 m
- T_p = 7.9 s
- Spring tide +1.2 m CD
- Design water level +2.0 m CD
- No information on available rock

Parameters and volume of different design

Initial design wave height: H_s = 4.4 m T_p = 7.9 s

Applying the geometrical design rules different desings can be suggested

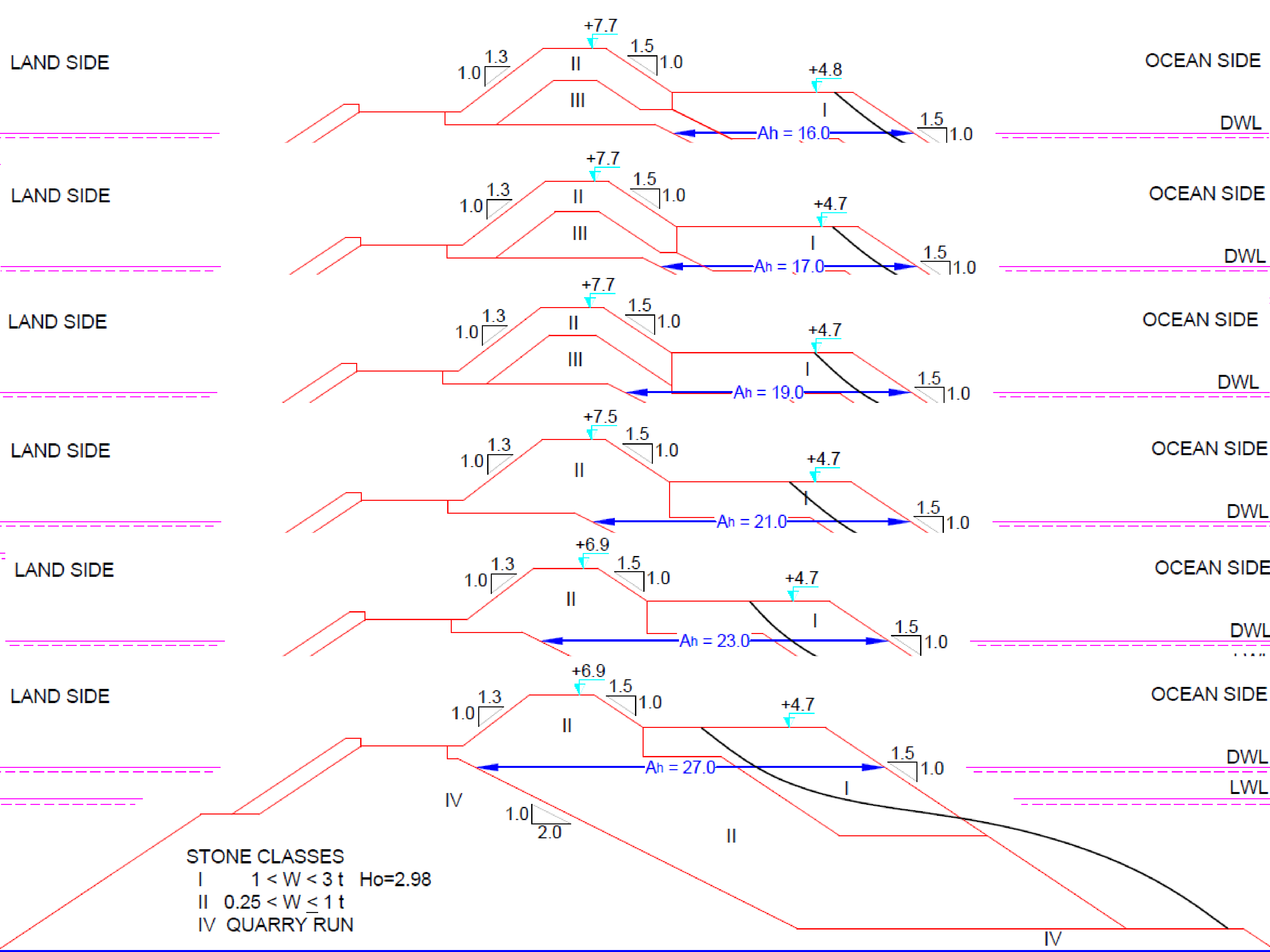
Heavy Class I rock with low stability number on top of the table

Lighter Class I rock withe higher stability parameter further down

Crest height and berm width determine the total volume

Armour width increases with higher stability number

Class I	$H_s/\Delta D_{n50}$	**Armour width** A_h (m)	Resi-liency (%)	**Berm width** B (m)	**Berm level** B_l (m)	**Crest level** C_l (m)	**Large rock** (m^3/m)	**Core** (m^3/m)	**Total** (m^3/m)
5-15 t	1.74	16	10%	12	4.8	7.7	240	610	850
4-12 t	1.87	17	14%	12	4.7	7.7	250	600	850
3-9 t	2.06	19	21%	12	4.7	7.7	270	580	850
2-6 t	2.36	21	34%	12	4.7	7.5	290	550	840
1.5-4.5 t	2.60	23	46%	12	4.7	6.9	310	500	810
1-3 t	2.98	27	69%	12	4.7	6.9	350	460	810


LAND SIDE
OCEAN SIDE
+7.7
1.3
1.0
1.5
1.0
+4.8
II
III
I
DWL
Ah = 16.0
Ah = 17.0
+4.7
Ah = 19.0
+7.5
Ah = 21.0
+6.9
Ah = 23.0
Ah = 27.0
LWL
IV
2.0
STONE CLASSES
I 1 < W < 3 t Ho=2.98
II 0.25 < W ≤ 1 t
IV QUARRY RUN

Photos only information on possible rock sizes

But no scale!

Conclusions on design of berm breakwaters

- Full guidance in the book
- Most guidance in papers (free download)
- Guidance on construction mainly in the book
- New classification: HR, PR and FR
  MA or IC
- Conceptual design spreadsheet available
- Design depends on: the rock you can get
  design wave height
  wanted resiliency
- Berm breakwater designs possible for 3 m to 7 m


Thank you!