APPENDIX B – COMPUTATION OF DESIGN WAVE RUN-UP/ WAVE OVERTOPPING

I. Computation of Wave Run-up

Wave run-up is calculated by the following formula:

$$R_{up} / H_{m0p} = 1,75\,\gamma_\beta\,\gamma_b\,\gamma_f\,\xi_0 \qquad \text{if} \qquad 0,5 < \gamma_b\xi_0 < 1,8 \qquad (1)$$

$$R_{up} / H_{m0p} = \gamma_\beta\,\gamma_f\,(4,3 - \frac{1,6}{\sqrt{\xi_0}}) \qquad \text{if} \qquad 1,8 < \gamma_b\xi_0 < 8 \div 10 \qquad (2)$$

where, R_{slp} - Design wave run-up height (m);

H_{m0p} - Design wave height at the dike toe ($H_{sp} = H_{m0p}$) (m);

H_{sp} - See Appendix C.

I.1 Breaker parameter (ξ_0)

$$\xi_0 = \frac{\tan\alpha}{\sqrt{s_0}} \qquad (3)$$

where, α - inclination of dike slope;

In case the dike slope has two different inclinations, the following conversion formula can be used:

$$\tan\alpha = \frac{1,5H_{m0p} + R_{up}}{L - B} \qquad (4)$$

where, L, B – lengths, determined as per Figure 1.

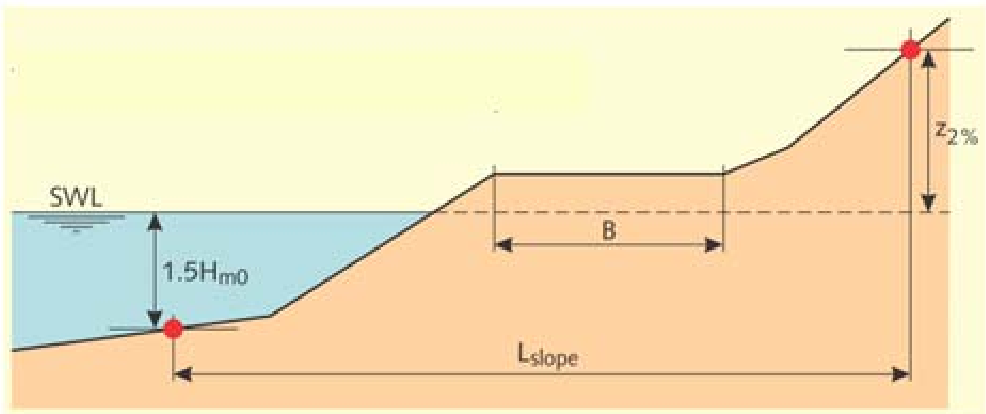

Figure B.1 *Converted slope for the computation of wave run-up*

(Courtesy of TAW, 2002: Technical Report – Wave Run-up and Wave Overtopping at Dikes)

s_0 - wave steepness;

$$s_0 = \frac{2\pi H_{m0p}}{g.T^2_{m-1,0,p}} \quad (5)$$

Spectral wave period: $T_{m-1.0,p} = T_p/\alpha$, $\alpha = 1{,}10 \sim 1{,}20$;

T_p - Peak period.

I.2 Reduction factor for oblique incident waves (γ_β)

$\gamma_\beta = 1 - 0{,}0022*|\beta|$ $(0^0 \leq |\beta| \leq 80^0)$ (6)

$\gamma_\beta = 1 - 0{,}0022*80$ $(|\beta| > 80^0)$

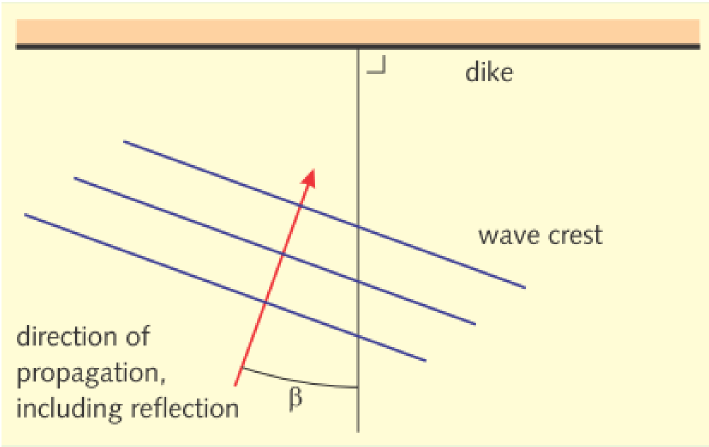

Figure B.2 *Angle of incident waves*

(Courtesy of TAW, 2002: Technical Report – Wave Run-up and Wave Overtopping at Dikes)

I.3 Reduction factor for a berm (γ_b)

$$\gamma_b = 1 - \frac{B}{L_b}\left(0{,}5 + 0{,}5.\cos\left(\pi\frac{d_h}{x}\right)\right) \quad \text{with } 0{,}6 \leq \gamma_b \leq 1{,}0 \quad (7)$$

where, B, L_b, d_h is determined as per Figure 3;

x is determined as follows:

$x = R_{up}$ khi $R_{up} > d_h > 0$ (berm located above design water level);

$x = 2.H_{m0p}$ khi $2.H_{m0p} > d_h \geq 0$ (berm located below design water level).

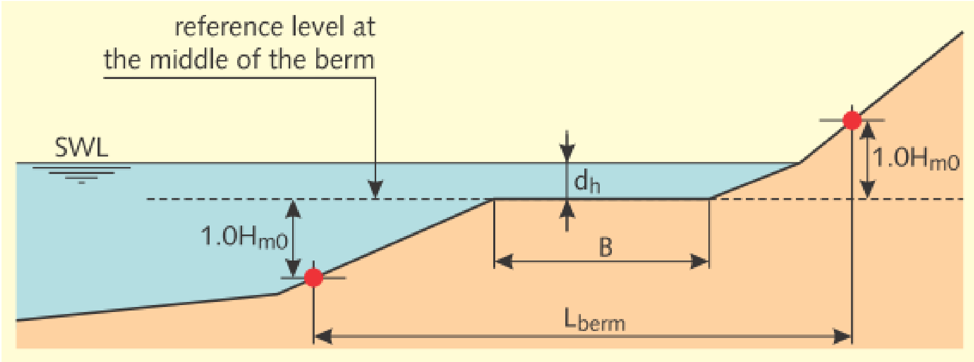

Figure B.3 *Parameters used for the determination of a berm*

(Courtesy of TAW, 2002: Technical Report – Wave Run-up and Wave Overtopping at Dikes)

Optimum width of a berm is B_{opt} = 0,4.L_b, in case it is introduced at the design water level for the maximum reduction of wave run-up and wave overtopping γ_b = 0,60.

I.4 Reduction factor for roughness elements on slope (γ_f)

The reduction factors are given in Table 1.

Table 1. *Reduction factor for roughness elements on slope*

Types of structural elements on slope	Reduction factor γ_f
Asphaltic concrete, concrete, smooth structural concrete elements, grass, asphaltic sand	1,00
Horizontally joined structural concrete elements, structural elements with grass	0,95
Special structural elements: Basalt, Basalton, Hydroblock, Haringman, Fixstone, Armorflex	0,90
¼ of block revetment 10cm higher	0,90
Lessinische and Vilvoordse, structural elements with low roughness	0,85
Small blocks over 1/25 of surface	0,85
Tsc elements (Vietnam)	0,85
Small blocks over 1/9 of surface	0,80
Armour rock – single layer	0,70
Armour rock – two layers thick	0,55

I.5 Calculation procedure for wave run-up on dike slope

- Assume R_{slp} ;
- Calculate tanα, ξ_0 ;
- Calculate γ_b, γ_f, γ_β ;
- Re-calculate R_{slp};
- Compare the assumed value with the calculated value of R_{slp}

Example 1: Given the design wave height at the dike toe H_{sp} = 2m, wave period T_p= 8s, angle of incident wave $\beta = 10^0$.

Ratio $T_p/T_{m-1,0,p} = 1,1 \rightarrow T_{m-1,0,p} = 7,27$s

Select the geometrical characteristics and the revetment protecting structures for the cross section of a dike as follow:

- A berm is placed on seaward side, with a width of 6m;
- Berm is located at the design water level;
- Inclination of slope sections below a berm: m = 4;
- Inclination of slope sections above a berm: m = 3;
- Outer slope is protected by precast concrete elements TSc.

Answer:

Assume the wave run-up R_{slp}= 3,8m

$$\tan\alpha = \frac{1,5\times 2+3,8}{29,4-6} = 0,29\ ; \qquad s_0 = \frac{2\times 3,14\times 2}{9,81\times 7,27^2} = 0,0242$$

$$\xi_0 = \frac{\tan\alpha}{\sqrt{s_0}} = 1,86\ ; \qquad \gamma_b = 1-\frac{B}{L_{berm}} = 1-\frac{6}{20} = 0,7$$

From the given table: $\gamma_f = 0,85$

$\gamma_\beta = 1 - 0,0022\times 10 = 0,978$

$\gamma_b\xi_0 = 0,7\times 1,86 = 1,302$, which is in the range $0,5 < \gamma_b\xi_0 < 1,8$; formula (1) is selected then:

$R_{slp} = 1,75\times 0,978\times 0,7\times 0,85\times 1,86\times 2 = 3,79\,(m)$, which approximates to the assumed value R_{up}

Therefore, R_{up} = 3,8m

* In case of no berm, the slope coefficient m = 4:

- $\xi_0 = \dfrac{\tan\alpha}{\sqrt{s_0}} = 1,61$;
- Reduction factor for a berm: $\gamma_b = 1$;
- $\gamma_b\xi_0 = 1,0\times 1,61 = 1,61$, which is in the range $0,5 < \gamma_b\xi_0 < 1,8$; formula (1) is used then.
- Wave run-up : $R_{slp} = 1,75\times 0,978\times 1,0\times 0,85\times 1,61\times 2 = 4,68$ (m)

II. Computation of wave overtopping

Formulae used for the computation of wave overtopping are as follows:

$$\frac{q}{\sqrt{gH_{m0p}^3}} = \frac{0,067}{\sqrt{\tan\alpha}}\gamma_b\xi_0.\exp\left(-4,3\frac{R_{cp}}{H_{m0p}}\frac{1}{\xi_0\gamma_b\gamma_f\gamma_\beta}\right) \quad \text{if} \quad \gamma_b\xi_0 \le 2 \quad (8)$$

$$\frac{q}{\sqrt{gH_{m0p}^3}} = 0,2.\exp\left(-2,3\frac{R_{cp}}{H_{m0p}}\frac{1}{\gamma_f\gamma_\beta}\right) \quad \text{if} \quad \gamma_b\xi_0 > 2 \quad (9)$$

$$\frac{q}{\sqrt{gH_{m0p}^3}} = 0,21.\exp\left(-\frac{R_{cp}}{\gamma_f\gamma_\beta H_{m0p}(0,33+0,022.\xi_0)}\right) \quad \text{if} \quad \xi_0 > 7 \quad (10)$$

where, q - Allowable average unit discharge of wave overtopping (l/s/m);
R_{cp} – Crest freeboard above the design water level (m);

II.1 Unit discharge of wave overtopping (q)

The unit discharge of wave overtopping (q) is determined on the basis of the quality of protecting elements of dike crest and inner slope, as well as the requirements of flood control in the area behind the dike (see Table 2 and Figure 4).

Table 2. *Unit discharge of wave overtopping corresponding to requirements of inner slope protection*

Average unit discharge of wave overtopping q (l/s/m)	*Requirements of inner slope protection*
≤ 0,1	Normal grass
1,0 < q < 10,0	Concrete is laid on the surface of dike crest, extended by 1m down the dike slope; for the next sections, normal grass or Vetiver grass is grown reaching the dike toe; methods for protecting against slope sliding and grass on slope are adopted; water intake works, storage area for overtopping water and drainage works are designed if necessary;
q > 10,0	Inner slope is protected by concrete; designed structural elements for the protection of dike toe; designed water intake works, storage area and drainage works for the overtopping water after the storm.

II.2 Reduction factor for oblique incident waves (γ_β)

$\gamma_\beta = 1 - 0,0033\times|\beta|$ $\quad (0^0 \le |\beta| \le 80^0)$ $\quad$ (11)

$\gamma_\beta = 1 - 0,0033\times 80$ $\quad (|\beta| > 80^0)$

With $80^0 < |\beta| \le 110^0$: $\quad H_{m0p} = H_{m0p} \times \frac{110-|\beta|}{30}$

$$T_{m-1,0,p} = T_{m-1,0,p} \times \sqrt{\frac{110-|\beta|}{30}}$$

With $110^0 < |\beta| \leq 180^0$ then $H_{m0p}=0$ and therefore $R_{up} = 0$ and wave overtopping $q = 0$.

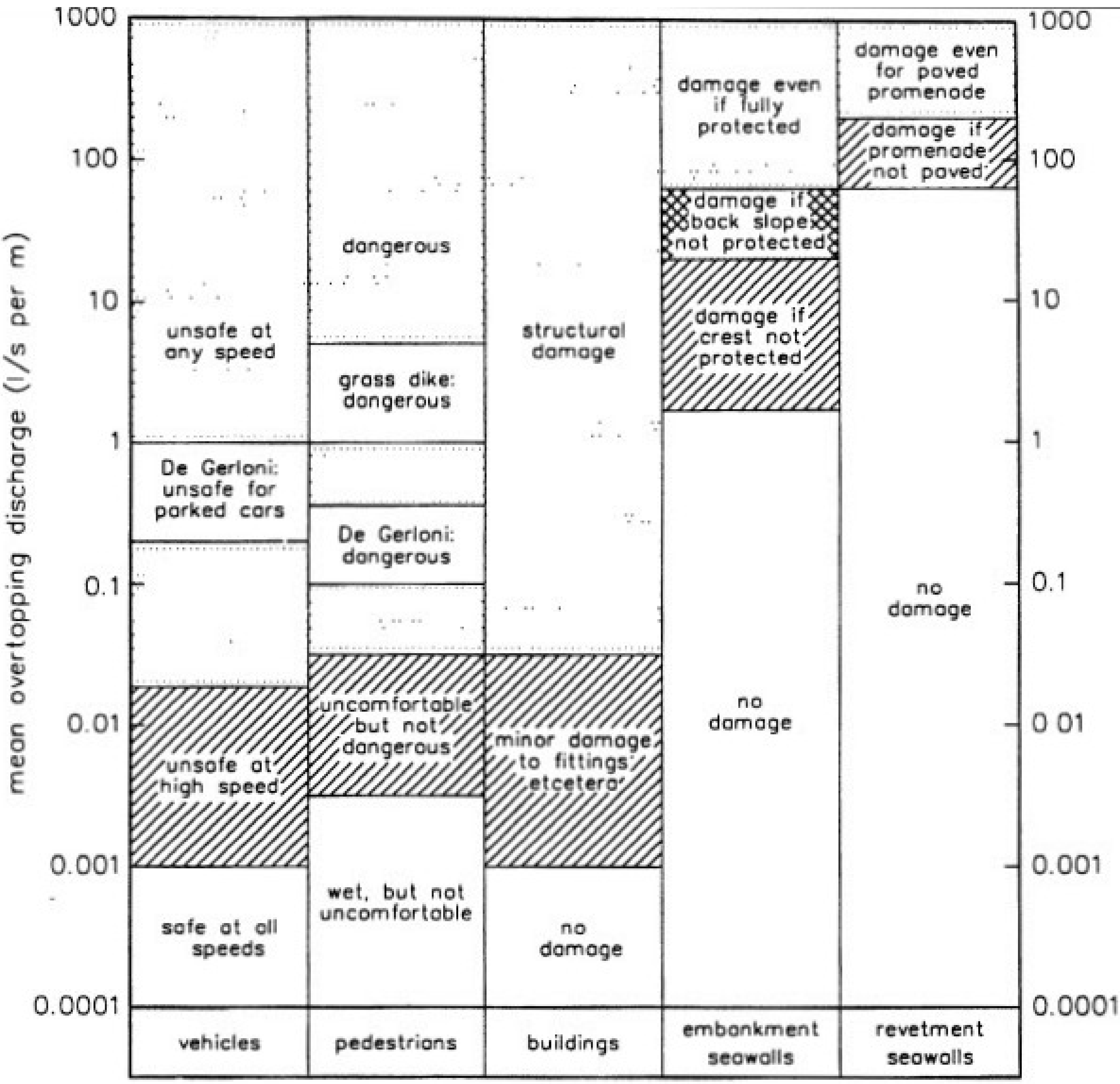

Figure 4. *Allowable average unit discharge of wave overtopping (CEM-2002)*

Other factors are calculated in the same way as done in wave run-up computation section.

Example 2: With the same wave parameters and geometrical characteristics as given in Example 1 in case of berm. Determine the unit discharge of wave overtopping q_{tt} with the crest freeboard above the design water level R_{cp} = 2,5m.

$\gamma_\beta = 1 - 0{,}0033 \times 10 = 0{,}967$

$$\frac{q}{\sqrt{9{,}81\times 2^3}} = \frac{0{,}067}{\sqrt{0{,}29}} 0{,}7\times 1{,}86.\exp\left(-4{,}3\times\frac{2{,}5}{2}\times\frac{1}{1{,}86\times 0{,}7\times 0{,}85\times 0{,}97}\right)$$

q_{tt} = 9,69 (l/s/m)

Notes:

1. In case of existing sea dikes, it is necessary to check the dike quality and to propose solutions for guaranteeing the safety of sea dikes.

- Dike crest level (or crown wall level), which has been determined;
- Design water level, determined as per the given appendix;
- R_{cp} is determined by subtracting the design water level from the dike crest elevation (or crown wall level);
- By means of the substitution in the formulae for wave overtopping discharge computation, q (l/s/m) can then be determined;
- Compare with the given requirements in Table 2 to check if the quality of sea dike is guaranteed. If it is not guaranteed, it is necessary to take the solutions for strengthening the sea dike and for the drainage of overtopping water into consideration.

2. In case of new sea dike systems

- The design parameters including cross sections, dike berm, dike slope, protection material and allowable wave overtopping discharge (q) are proposed;
- By means of the substitution in the formulae for wave overtopping discharge computation, R_{cp} (m) can then be determined;

3. Crown wall is usually used in sea dike design, however its height is only in the order of 0,5 ÷ 0,7 m (approximately 10% of dike height) with no significant impacts on the wave overtopping discharge; therefore the formulae from (8) to (10) can be used directly.