Coastal erosion in lee zone of structure; DIFSAND-model and LONGMOR-model

1. Introduction

A typical phenomenon in the lee zone of a shorenormal or shoreparallel structure is the regeneration of the longshore current and associated longshore sand transport, which are both blocked on the updrift of the structure. Basic questions are:
- what is the alongshore scale of the erosion zone?
- what is the maximum recession of the shoreline in the erosion zone?
To address this, it is necessary to schematize the wave diffraction process so that the wave heights at the breakerline in the diffraction zone can be determined and based on that the longshore sand transport rates, see **Figure 1.1**. This note presents a pragmatic solution to this problem.

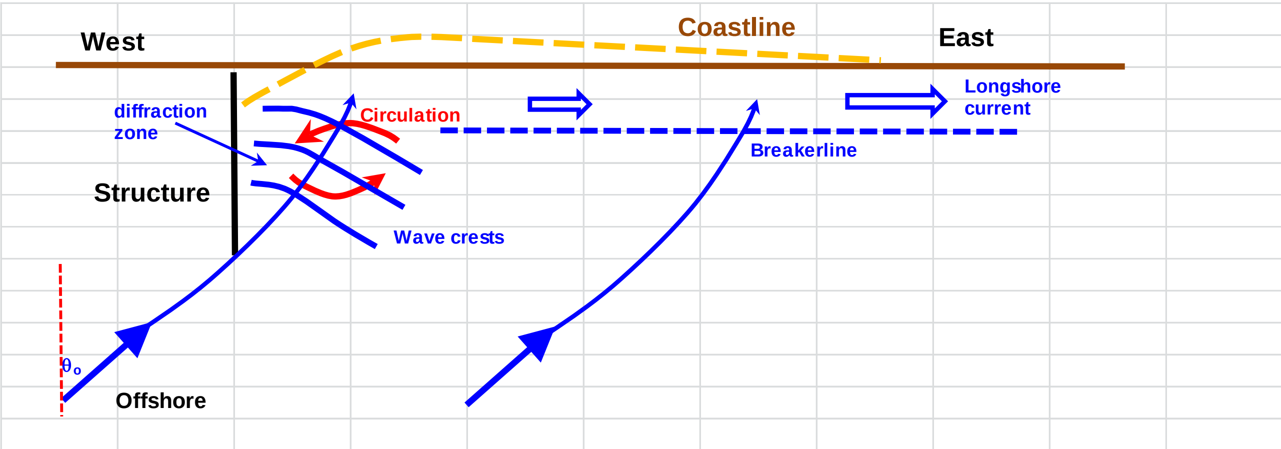

Figure 1.1 *Waves, currents, longshore sand transport and coastline changes in lee of structure*

2. Wave diffraction

2.1 Processes

Waves inside the diffraction zone in the lee of a shoreparallel or shorenormal structure are diffracted waves through the transfer of wave energy along the wave crest. The diffracted wave heights are significantly smaller than the incoming waves at the tip of the structure. Hence, the heights of the breaking waves in the diffraction zone are much smaller than the breaking waves further away from the diffraction zone. As a result, the wave-induced setup generated by the breaking waves inside the diffraction zone will be much smaller than the wave setup outside the diffraction zone. This alongshore difference in wave setup will generate a nearshore circulation current towards the structure (towards the diffraction zone). Assuming a setup difference of 0.05 m over 100 m (slope of S=0.0005) and a water depth of 3 m with Chezy value of 30 $m^{0.5}/s$, the current velocity will be of the order of $u = C(hS)^{0.5} \cong 1$ m/s. As the wave angle of the breaking waves inside the diffraction zone will be quite small (waves almost perpendicular to the shoreline), the strength of the wave-induced longshore current inside the diffraction zone will be much smaller than the nearshore circulation current. Outside the diffraction zone, the wave-induced longshore current will gradually increase to its full strength further away from the diffraction zone. The adjustment zone is of the order of length of the structure. Wave diffraction and associated longshore sand transport can be computed by the DIFSAND-model, which is described in this note. Coastal erosion values can be computed by the LONGMOR-model.

2.2 Kamphuis method

The wave diffraction process of the DIFSAND-model is based on the method of **Kamphuis (1962)** and **Goda et al. (1978)**. **Kamphuis (1992)** has presented an engineering method to represent the diffraction coefficients in the lee of a shorenormal structure (groin normal to shoreline). The K_d-coefficients for the diffraction zone with normal wave incidence have been parameterized, as follows (see also **Figure 2.1**):

$$K_d = 0.7 - 0.0077\,\delta \qquad \text{for} \quad 0 \leq \delta \leq 90^o \qquad (2.1a)$$
$$K_d = 0.7 - 0.37\,\sin\delta \qquad \text{for} \quad 0 \leq \delta \leq -40^o \qquad (2.1b)$$
$$K_d = 0.83 - 0.17\,\sin\delta \qquad \text{for} \quad -40^o \leq \delta \leq -90^o \qquad (2.1c)$$

with:
K_d = diffraction coefficient at wave rays from tip of breakwater;
δ = angle of wave ray from tip of structure with respect to the line of the incoming wave ray (+ clockwise and – anti-clockwise).

The K_d-values of Equation (2.1) for $-90^o \leq \delta \leq +90^o$ are also given in **Table 2.1**.

The wave ray from the tip of the breakwater in the same line as the incoming wave ray has K_d = 0.7. The wave rays in the shadow zone of the breakwater have K_d-values < 0.7 and the wave rays outside the shadow zone have K_d-values between 0.7 and 1.
Basically, these K_d-values are only valid for waves with normal wave incidence to the structure (main wave direction $\theta = 90^o$). However, the K_d-coefficients are not very dependent on the wave incidence angle for multi-directional waves. Furthermore, the wave rays in the nearshore zone are rather perpendicular to the shoreline (wave angles <20^o).

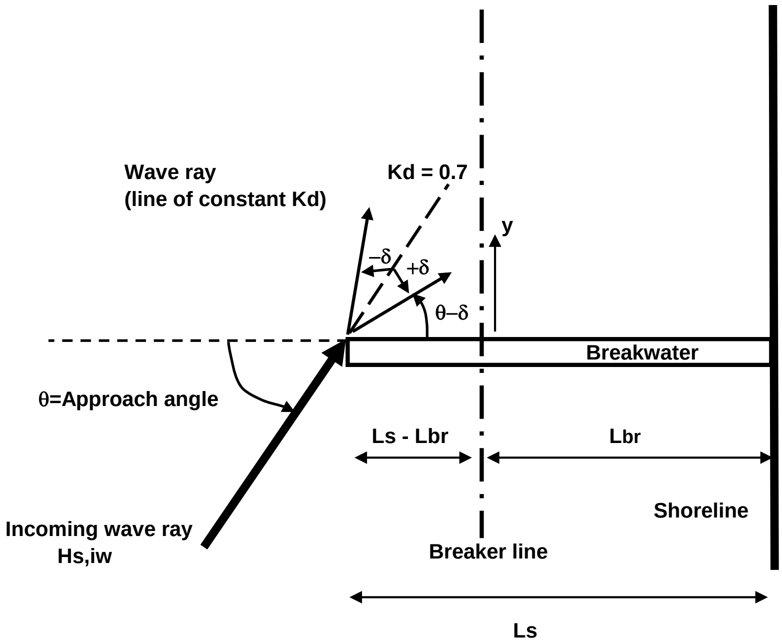

Figure 2.1 *Definition of wave diffraction around groin-type breakwater (normal to shore)*

Negative δ-values	K_d-coefficient	Positive δ-values	K_d-coefficient
-90^o	1.0	90^o	0
-80^o	1.0	80^o	0.08
-70^o	0.99	70^o	0.16
-60^o	0.98	60^o	0.24
-50^o	0.96	50^o	0.32
-40^o	0.94	40^o	0.39
-30^o	0.89	30^o	0.47
-20^o	0.83	20^o	0.55
-10^o	0.76	10^o	0.62
0^o	**0.70**	0^o	0.7

Table 2.1 *K_d-coefficients for wave rays from tip of structure in multi-directional waves*

The wave height at the breaker line in the diffraction zone (shadow zone) can be estimated as:

$$H_{s,br,d} \cong K_d H_{s,iw} \qquad (2.2a)$$

In the absence of a structure the wave height at the breaker line is approximately equal to the wave height at the position of the tip of the (virtual) structure.

Thus: $H_{s,br} \cong H_{s,iw}$ yielding:

$$H_{s,br,d} \cong K_d H_{s,br} \qquad (2.2b)$$

with:
$H_{s,br,d}$ = significant wave height at breaker line in diffraction zone,
$H_{s,iw}$ = significant wave height at tip of virtual structure (incoming wave height) and
$H_{s,br}$ = significant wave height at breaker line without structure.

Kamphuis (1992) has computed the diffracted waves in the lee of the structure for various conditions (varying θ, T_p, length of structure, beach slope, etc). Based on this, it was found that the angle of the diffracted waves at the breaker line in the lee of the structure can be approximated by:

$$\theta_{br,d} = (K_d)^{0.38}\,\theta_{br} \qquad (2.2c)$$

with:
$\theta_{br,d}$ = angle of diffracted wave ray (to shore normal) at the breaker line in the diffraction zone;
θ_{br} = angle of wave ray at the breaker line without structure.
Refraction effects of wave rays in the diffraction zone can also be taken into account.

2.3 Application

Given:
Diffraction around groin;
Length of groyne L_s = 160 m; Beach slope is 1 to 40;
Water depth at tip of groyne h_{tip} = 4 m;

Height of approaching waves at tip of groin $H_{s,iw}$ = 2 m; Peak wave period T_p = 8 s;
Wave angle at tip of breakwater $\theta = 45^o$ to shore normal,
Breaker line at L_{br} =120 m from shoreline;
Water depth at the breaker line h_{br} = 3 m;
Wave angle at breaker line without structure $\theta_{br} = 40^o$, see also **Figure 2.1.**

Compute: K_d-coefficients, wave heights $H_{s,br,d}$ and wave angles $\theta_{br,d}$ at the breaker line

Results: Computed results are given in **Table 2.2** and in **Figure 2.2**.

Angle δ	Angle $\theta-\delta$	$y = (L_s-L_{br})\tan(\theta-\delta)$	K_d	$H_{s,br,d} = K_d H_{s,iw}$	$\theta_{br,d} = (K_d)^{0.38}\theta_{br}$
-45^o	90^o	∞	0.95	1.90	39^o
-40^o	85^o	457.2	0.94	1.88	39^o
-30^o	75^o	149.3	0.89	1.78	38^o
-20^o	65^o	85.8	0.83	1.66	37^o
-10^o	55^o	57.1	0.76	1.54	36^o
0	45^o	40	0.70	1.40	35^o
10^o	35^o	28	0.62	1.24	33^o
20^o	25^o	18.7	0.55	1.10	32^o
30^o	15^o	10.7	0.47	0.94	30^o
40^o	5^o	3.5	0.39	0.78	28^o
45^o	0^o	0	0.35	0.70	27^o

Table 2.2 *Computed wave heights and wave angles at breakerline in lee of groin*

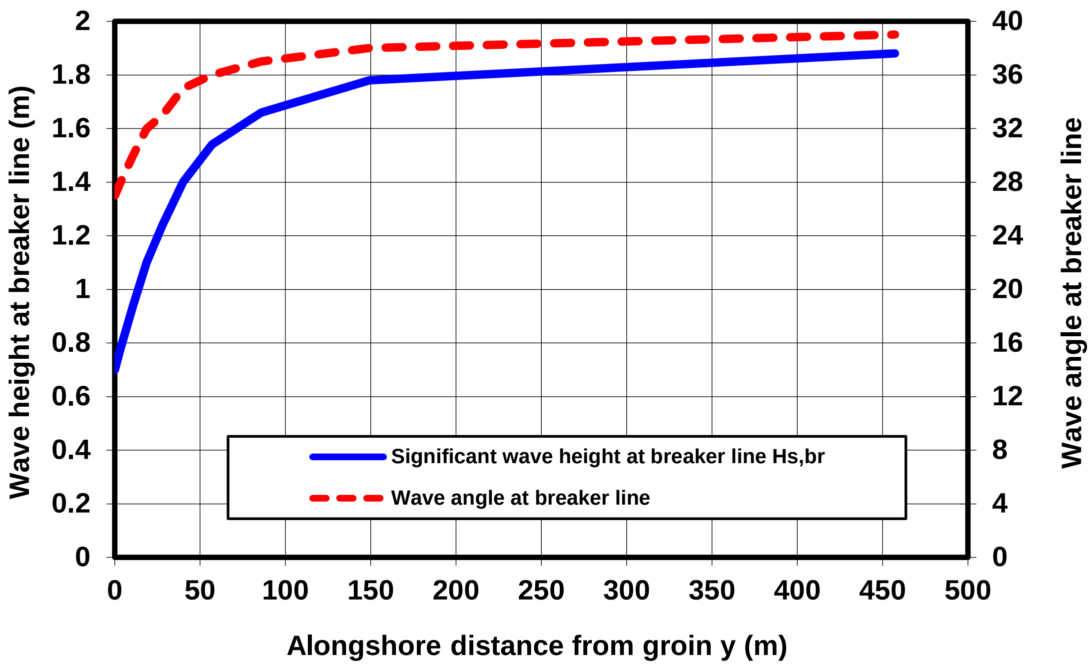

Figure 2.2 *Computed wave heights and wave angles at breaker line in lee of groin*

3. Longshore transport in diffraction zone

3.1 Longshore transport

Van Rijn (2014) has presented a simple general longshore transport expression, which reads as:

$$Q_{t,mass} = 0.00018\ K_{swell}\ \rho_s\ g^{0.5}\ (\tan\beta)^{0.4}\ (d_{50})^{-0.6}\ (H_{s,br})^{3.1}\ \sin(2\theta_{br}) \qquad (3.1)$$

with:
$Q_{t,mass}$ = total longshore sediment transport (in kg/s);
ρ_s = sediment density (kg/m^3), d_{50}= median grain size (m);
$H_{s,br}$ = significant wave height at breakerline (m);
θ_{br} = wave angle at breakerline (degrees);
$\tan\beta$ = slope of beach-surf zone;
d_{50} = median sand size (m);
K_{swell} = swell factor (default=1);
α = calibration coefficient = 0.00018.

Equation (3.1) can also be expressed, as:

$$Q_{t,mass} = 0.0006\ K_{swell}\ \rho_s\ (\tan\beta)^{0.4}\ (d_{50})^{-0.6}\ (H_{s,br})^{2.6}\ V_{wave} \qquad (3.2)$$

$$V_{wave} = 0.3\ (gH_{s,br})^{0.5}\ \sin(2\theta_{br}) \qquad (3.3)$$

with:
V_{wave} = wave-induced longshore current velocity (m/s) averaged over the cross-section of the surf zone.

Equation (3.2) is linear in velocity. Additional velocities in the surf zone due to tide and wind can be simply taken into account by schematizing the tidal period in two blocks, as follows:

$$V_{total} = V_{wave} + 0.01p_1\ V_1 + 0.01p_2V_2 \qquad (3.4)$$

With:
V_1= representative velocity in positive longshore direction due to wind and tide;
V_2= representative tidal velocity in negative longshore direction due to wind and tide;
p_1= percentage of time with positive flow (about 50%),
p_2= percentage of time with negative flow (about 50%).

The peak longshore velocities in the surf zone due to wind and tide are approximately in the range of 0.1 m/s for micro-tidal conditions to 0.5 m/s for macro-tidal conditions. Generally, there is a slight asymmetry in the wind-generated velocities in the main wave (wind) direction. Using this approach, a slight asymmetry in the velocities due to wind and tide (V_1 larger than V_2 or reversed) can be taken into account. The effect is zero for fully symmetric tidal flow (p_1=50%, p_2=50%, V_1=-V_2).

Similarly, nearshore circulation currents in the diffraction zone due to alongshore setup differences can be taken into account.

3.2 Wave shoaling and refraction for uniform coasts

Equation (3.1 or 3.2) depends on the basic wave parameters at the breakerline. If only the offshore wave parameters are known, the values at the breakerline can be determined from shoaling-refraction theory **(Van Rijn, 1990/2011)**.
Assuming a straight uniform coast with parallel depth contours, the water depth at the breakerline (location where 5% of the waves are breaking) can be estimated from:

$$h_{br}= [(H_{s,o}{}^2\ c_o \cos\theta_o)/(\alpha\ \gamma_{br}{}^2\ g^{0.5})]^{0.4} \tag{3.5}$$

The wave heights can be computed by:

$$H_{s,x}= K_{s,x}\ K_{r,x}\ K_{f,x}\ H_{s,o} \tag{3.6}$$

$$H_{s,br}= \gamma_{br}\ h_{br} \tag{3.7}$$

with:
$K_{s,x}$ = $[(n_o/n_x)(C_o/C_x)]^{0.5}$ = shoaling factor;
$K_{r,x}$ = $[\cos\theta_o/\cos\theta_x]^{0.5}$= refraction factor;
$K_{f,x}$ = $[1/(1+\alpha H_{s,o}\ x]^{0.3}$= friction factor;
n_x = 0.5[1+2kh/sin(2kh)]=coefficient;
α_x = $f_w\ \omega^3/[3\ \pi\ g\ n\ C\ \{\sinh(kh)\}^3]$= coefficient;
ω = $2\pi/T_p$; $k=2\pi/L_{wave}$;
f_w = friction coefficient (≅ 0.01);
h = water depth at location x;
L_{wave}= wave length;
C_x = wave speed= L_{wave}/T_p;
x = coordinate with respect to deep water location.

The wave incidence angle at the breakerline (θ_{br}) can be determined from:

$$\sin\theta_x = (C_x/C_o)\sin\theta_o \tag{3.8}$$

$$\sin\theta_{br} = (C_{br}/C_o)\sin\theta_o \tag{3.9}$$

with:
$H_{s,o}$ = significant wave height at deep water;
h_{br} = water depth at breakerline;
C_o, C_{br} = wave propagation speed at deep water and at breakerline;
θ_o, θ_{br} = wave incidence angle (to shore normal) at deep water and at breakerline;
γ_{br} = $H_{s,br}/h_{br}$= breaking coefficient based on 5% breaking= 0.6 to 0.8;
α = 1.8= calibration coefficient based on Egmond beach data (The Netherlands);
L_o = wave length in deep water (h_o);
C_o = L_o/T_p, T_p= peak wave period.

3.3 Diffraction zone

Equation (3.2) can also be used in the wave diffraction zone with some adjustments, see also **Figure 3.1**. The longshore current is computed as:

$$V_{Longshore} = r\, V_{wave} - V_{circ} \quad (3.10)$$

with:

V_{wave} = wave-induced longshore current velocity;
r = (y/L_{tip})= adjustment factor factor (-), r=0 for y<0 and r= 1 for y > y_{null};
V_{circ} = nearshore circulation velocity (input value in m/s);
L_{tip} = distance between tip of structure and shoreline (m);
y = $(L_{tip}-L_{br}) \tan(\theta-\delta)$= alongshore distance from structure;
y_{null} = null point where circulation velocity$\cong$0, null point is intersection of K_d=0.7 line and breakerline;
L_{tip} = distance between tip of structure and shoreline (m);
L_{br} =$h_{br}/\tan\beta_{surf}$ = distance between breakerline and shoreline;
h_{br} = water depth at breakerline;
$\tan\beta_{surf}$ = slope of surf zone.

3.4 Application

Given:
Diffraction around long harbour breakwater, see **Figure 3.1**; basic data are given in **Table 3.1**.
Offshore wave height $H_{s,o}$ = 3 m; Peak wave T_p = 10 s, offshore wave angle = 30^o to shore normal,
Offshore water depth= 30 m at 6000 m from the shore;
Length of breakwater L_{tip} = 2800 m;
Surf zone slope is 1 to 100 ($\tan\beta_{surf}$=0.01);
Water depth at tip of breakwater h_{tip} = 7 m;
Breaker coefficient = 0.8.

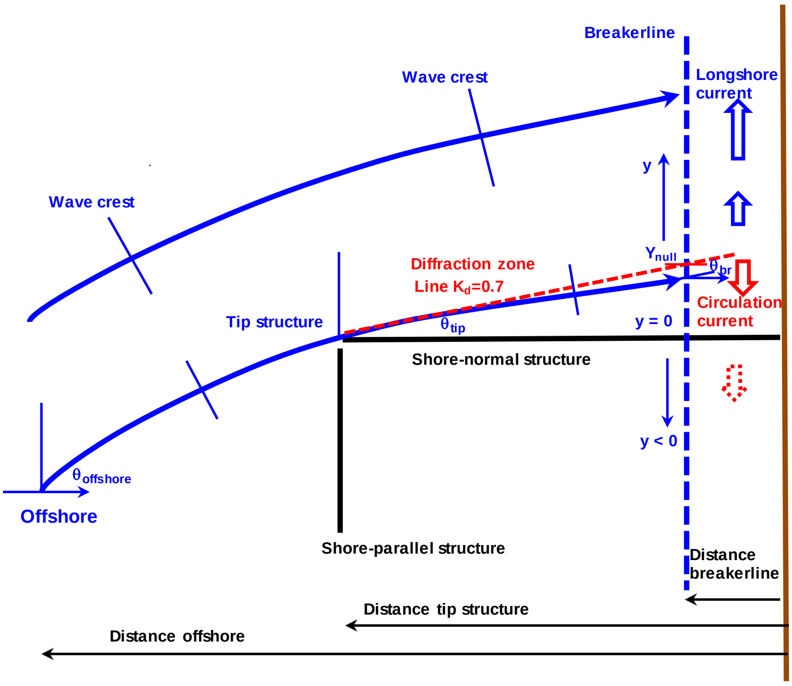

Figure 3.1 *Schematization of wave diffraction zone*

INPUT DATA in red; computed values in blue and black		
Offhore water depth (ho)	30	(m
Offshore wave angle (Teta,o; += longsh current away from structure))	30	(degrees)
Offshore wave height (Hs,o)	3	(m)
Wave period (Tp)	10	(s)
Water depth near tip of structure (htip)	7	m
Slope surf zone (tan beta) used to compute breakerline position from shore	0.01	(-)
Distance of tip of structure from the shoreline (Ltip)	2800	(m)
Distance of offshore depth from shoreline Loffshore)	6000	(m)
Breaker coefficient (gamma-br)	0.8	(-)
Friction factor (f)	0.01	(-)
Sediment size (d50)	0.0005	(m)
Sediment density (rhos)	2650	(kg/m3)
Bulk density sand	1600	(kg/m3)
Beach slope (tanβ) used to compute longshore transport	0.03	(-)
Nearshore circulation current towards structure in diffraction zone (y<ynull; Kd<0.7)	0.3	(m/s)
Tidal longshore velocity away from srtucture far downdrift	0.1	(m/s)
Calibration factor longshore transport	1	(-)
Swell factor	1	(-)
Number of days	30	(-)

Table 3.1 *Input data DIFSAND-model*

Results:

The results of the DIFSAND-model are:

Significant wave height at tip of structure based on shoaling-refraction approach $H_{s,tip}$= 3.09 m,

Wave angle at tip of structure θ_{tip} =16.7°,

Water depth at breakerline far away from structure = 3.9 m,

Significant wave height at breakerline far away from structure (outside diffraction zone)= 2.9 m,
Wave angle at breakerline θ_{br}=12.6°.

Figure 3.2 shows the computed significant wave height and the wave angle along the depth contour (=3.9 m) at the breakerline (outside diffraction zone). The wave height varies between 1.4 m near the structure and 2.9 m far away (at 7 km) from the structure. The wave angle at this depth contour of 3.9 m varies between 2° near the structure and 12.6° further away.

The waves inside the diffraction zone donot break at a depth of 3.9 m, but will move further inshore until they break at a depth of $H_{s,dif}/\gamma_{br}$ with $H_{s,dif}$= nearshore wave height inside diffraction zone. The wave height $H_{s,dif}$ will not change much over the distance between the tip of the breakwater and the breakerline.

Figure 3.3 shows the computed longshore sand transport (in m^3 per day) for a storm event with $H_{s,o}$= 3 m. Two values of the nearshore circulation current have been used: 0.5 m/s and 0.3 m/s over an alongshore distance of about 1400 m. The longshore sand transport is negative (towards the structure) in the circulation zone. Outiside this zone, the longshore sand transport gradually increases to the value of about 25,000 m^3/day far away (≅ 20 km) from the structure, where the coast is assumed to straight and uniform. The adjustment length of the longshore transport is of the order of two times the length of the structure.

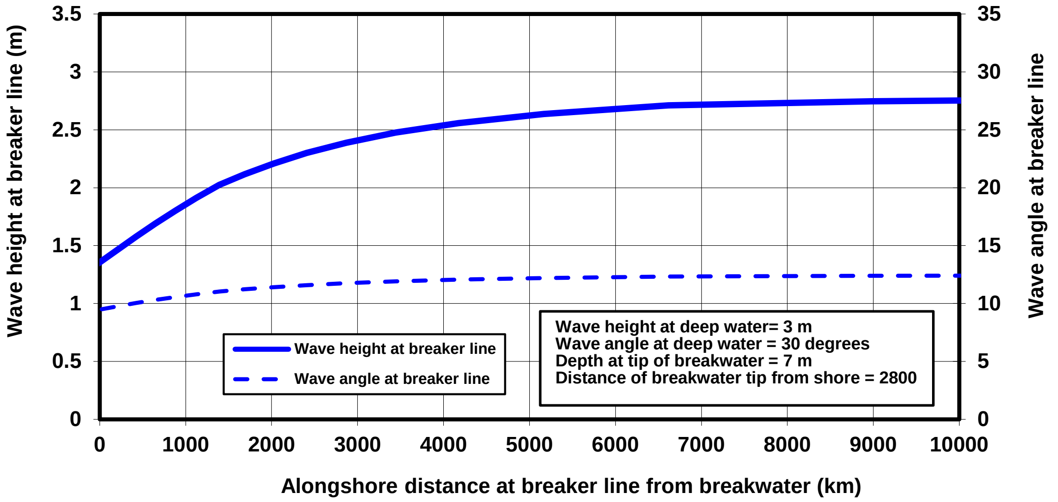

Figure 3.2 *Computed significant wave height and wave angle at water depth of 3.9 m*

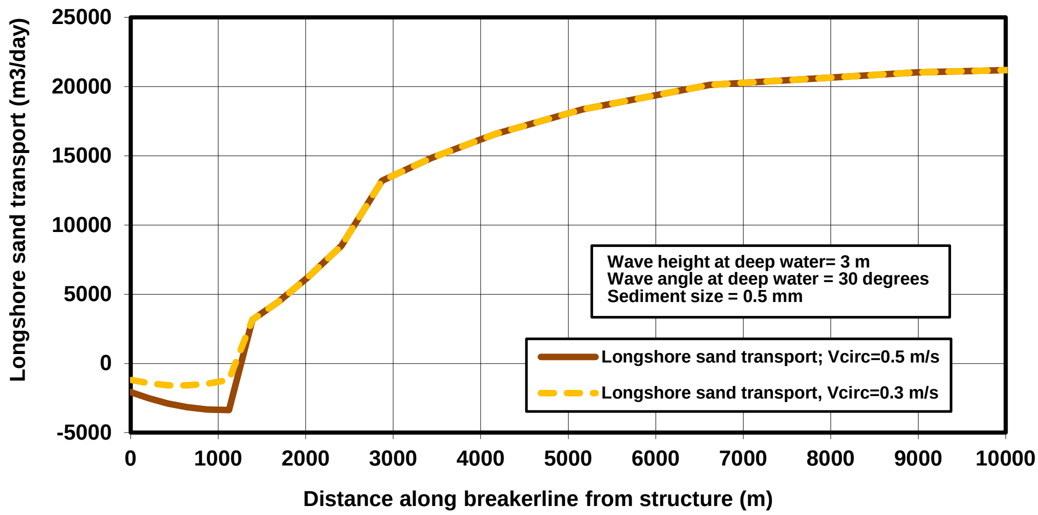

Figure 3.3 *Computed Longshore sand transport in surf zone*

4. Coastline changes based on LONGMOR-model

4.1 Basic equations

Coastline changes can be computed (LONGMOR-model) from the mass balance Equation (4.1), which reads as:

$$h_a \, \Delta y_s/\Delta t + \Delta Q_{LS}/\Delta x - q_s = 0 \qquad (4.1)$$

$$\Delta y_s = [\Delta x \, q_s - \Delta Q_{LS}] \, [\Delta t/(h_a \, \Delta x)]$$

with:
Δy_s = coastline change in cross-shore direction (m);
Δt = time step (s);
Δx = alongshore space step (m);
h_a = thickness active layer (5 to 10 m);
q_s = source/sink term (nourishment or sand mining) per unit coastline (in $m^3/(ms)$);
Q_{LS} = longshore sand transport including pores (in m^3/s).

Deposition if $\Delta Q_{LS}/\Delta x < 0$ and if $q_s > 0$ (nourishment).
Erosion if $\Delta Q_{LS}/\Delta x > 0$ and if $q_s < 0$ (sand mining).

4.2 Application

Given:
Diffraction around long harbour breakwater, see **Figure 4.1**; annual offshore wave climate given in **Table 4.1**.
Basic data are similar to that of **Section 3.4**;
Offshore water depth= 30 m at 6000 m from the shore;
Water depth at tip of breakwater h_{tip} = 7 m;
Length of breakwater L_{tip} = 2800 m; Breaker coefficient = 0.8;
Beach slope is $\tan\beta_{beach}$=0.03; Surf zone slope $\tan\beta_{surf}$=0.01;
Sediment size d_{50}=0.0005 m; d_{90}=0.001 m; active layer thickness= 10 m;
Nearshore circulation velocity = 0.5 m/s; tidal velocity outside diffraction zone= 0.1 m/s away from structure;

Compute: *Coastline changes after 1 and 5 years*

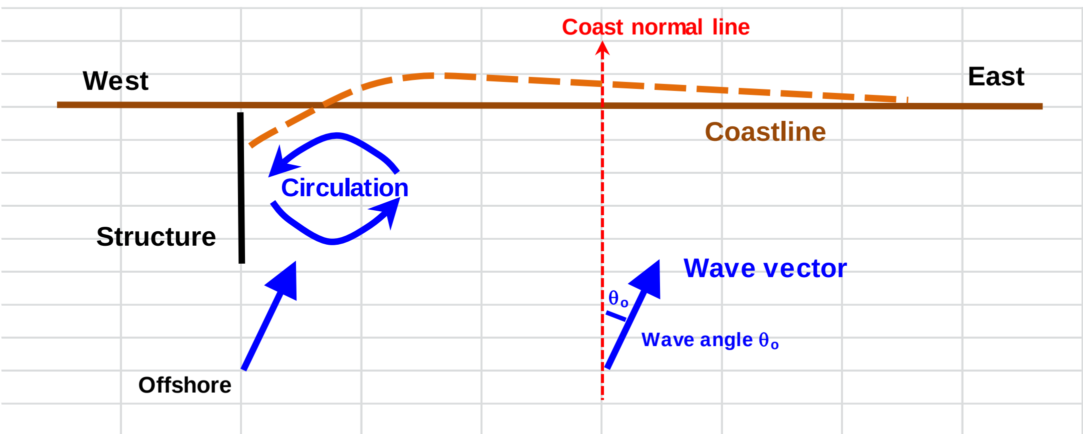

Figure 4.1 *Definition sketch*

Significant wave height H_s (m)	Peak wave period T_p (s)	Angle of wave vector to north and to coast normal (°)	Number of days	Significant wave height H_s (m)	Peak wave period T_p (s)	Angle of wave vector to north and to coast normal (°)	Number of days
0.75	8.6	352.5; -7.5	3.3	1.75	10.5	352.5; -7.5	2.5
0.75	9.8	7.5; 7.5	9.7	1.75	12.0	7.5; 7.5	48.1
0.75	11.0	22.5; 22.5	22.2	1.75	12.6	22.5; 22.5	48.5
0.75	9.5	37.5; 37.5	1.7	1.75	5.6	37.5; 37.5	2.3
1.25	9.5	352.5; -7.5	8.8	1.75	5.1	52.5; 52.5	3.0
1.25	10.9	7.5; 7.5	76	1.75	4.9	67.5; 67.5	0.4
1.25	11.8	22.5; 22.5	112.2	2.25	12.9	352.5; -7.5	0.3
1.25	6.5	37.5; 37.5	7.2	2.25	12.8	7.5; 7.5	7.6
1.25	4.6	52.5; 52.5	3.0	2.25	12.9	22.5; 22.5	5.7
1.25	4.3	67.5; 67.5	0.9	2.25	5.8	37.5; 37.5	0.6
				2.25	5.5	52.5; 52.5	0.37
				2.75	12.9	7.5; 7.5	0.51
				2.75	13.7	22.5; 22.5	0.04
Total			245 days				120 days

Table 4.1 *Annual wave climate for offshore conditions (depth 30 m); coast normal shore = 0° to North*

PARAMETER	VALUES	
Wave conditions - Wave height at deep water - Wave angle at deep water (to coastnormal) - Peak wave period - Duration	**Case 1** $H_{s,o}$= 3 m θ_o= 30° T_p= 10 s 30 days (1 year), 150 days (5 years)	**Case 2** $H_{s,o}$= 1.5 m θ_o= 30° T_p= 8 s 240 days (1 year) 1200 days (5 years)
Grid size and traject length	20 m; 6000 m	
Time step and grid-'smoothing'	0.01 day; 0.01	
Sand d_{50}, d_{90}	0.5 mm; 1 mm	
Slope beach zone ($\tan\beta_{beach}$)	0.03	
Breaker coefficient	0.8	
Layer thickness of active zone	10 m (between -6 m and +4 m MSL)	
Longshore transport formula; Calibration coefficient	Van Rijn 2014; 0.87	
Angle of coastnormal to North	0 degrees	
Tidal currents in surf zone	V_1= 0.1 m/s (away from structure); V_2= 0 m/s (towards structure)	
Beach nourishment volumes	0 m³/m/day	
Input files	niger1.inp (straight coastline)	

Table 4.2 *Input data of LONGMOR-model*

Three models have been used, as follows:

1. LITTORAL-model to compute the net annual longshore transport based on the detailed annual wave climate (**Table 4.1**);
2. DIFSAND-model to compute the diffracted wave heights and the longshore sand transport rates inside and outside the diffraction zone of the structure for schematized wave conditions (**Table 3.1**);
3. LONGMOR-model to compute the coastline changes for schematized wave conditions (**Table 4.2**).

Based on the detailed annual wave climate (**Table 4.1**), the net annual longshpore transport far away from the structure is determined to be 750,000 m^3/year (**Littoral.xls**).
This annual longshore transport can be represented by one wave condition (Case 1) with offshore significant wave height $H_{s,o}$= 3 m, peak wave period T_p= 10 s, offshore wave incidence angle θ_o= 30^o resulting in a longshore sand transport rate of 25,000 m^3/day with duration 750,000/25,000= 30 days per year.
Another condition (Case 2) which has been used is: $H_{s,o}$= 1.5 m, peak wave period T_p= 8 s, offshore wave incidence angle θ_o= 30^o resulting in a longshore sand transport rate of 3115 m^3/day with duration 750,000/3115= 240 days per year.
Both conditions have been used in the LONGMOR-model to compute the coastline changes.
The model settings of the LONGMOR-model are given in **Table 4.2**.
The input data of DIFSAND-model are given in **Table 3.1**.

Results:
Figure 4.2 (lower) shows the computed longshore sand transport (LONGMOR-model) averaged over 5 years in the lee of the breakwater for condition (Case 1) $H_{s,o}$= 3 m, θ_o= 30^o, T_p= 10 s and duration 30 days per year. Far away from the structure the longshore transport is calibrated to be 25,000 m^3/day. In the nearshore circulation zone close to the structure the longshore transport is determined by the DIFSAND-model (see **Section 3**). Based on this, the longshore transport of the LONGMOR-model has been calibrated to give similar results with a maximum negative transport rate of -5000 m^3/day towards the structure, see **Figure 4.2**. The longshore transport gradually increases to the faraway-value of 25,000 m^3/day over a distance of about 8 km.

Figure 4.2 (upper) shows the computed coastline changes after 1 and 5 years. The maximum coastline recession is about 120 m at a distance of about 2 km from the structure. The total erosion volume after 5 years is about 4 million m^3 (layer thickness of 10 m), which corresponds to the summation of the sand transport values: 25000 m^3/day x 30 days x 5 years= 3.75 million m^3. The accretion volume close to the structure after 5 years is about 0.35 million m^3. This latter value corresponds to the summation of the sand transport values: 5000 m^3/day x 0.5 x 5 years x 30 days=0.35 million m^3.

Figure 4.3 shows the computed coastline changes after 5 years for two Cases:
Case 1: $H_{s,o}$= 3 m, θ_o= 30^o, T_p= 10 s with duration 30 days per year and
Case 2: $H_{s,o}$= 1.5 m, θ_o= 30^o, T_p= 8 s with duration 240 days per year.
Both conditions yield the same coastline changes as the net annual transport rate is the same (750,000 m^3/year).

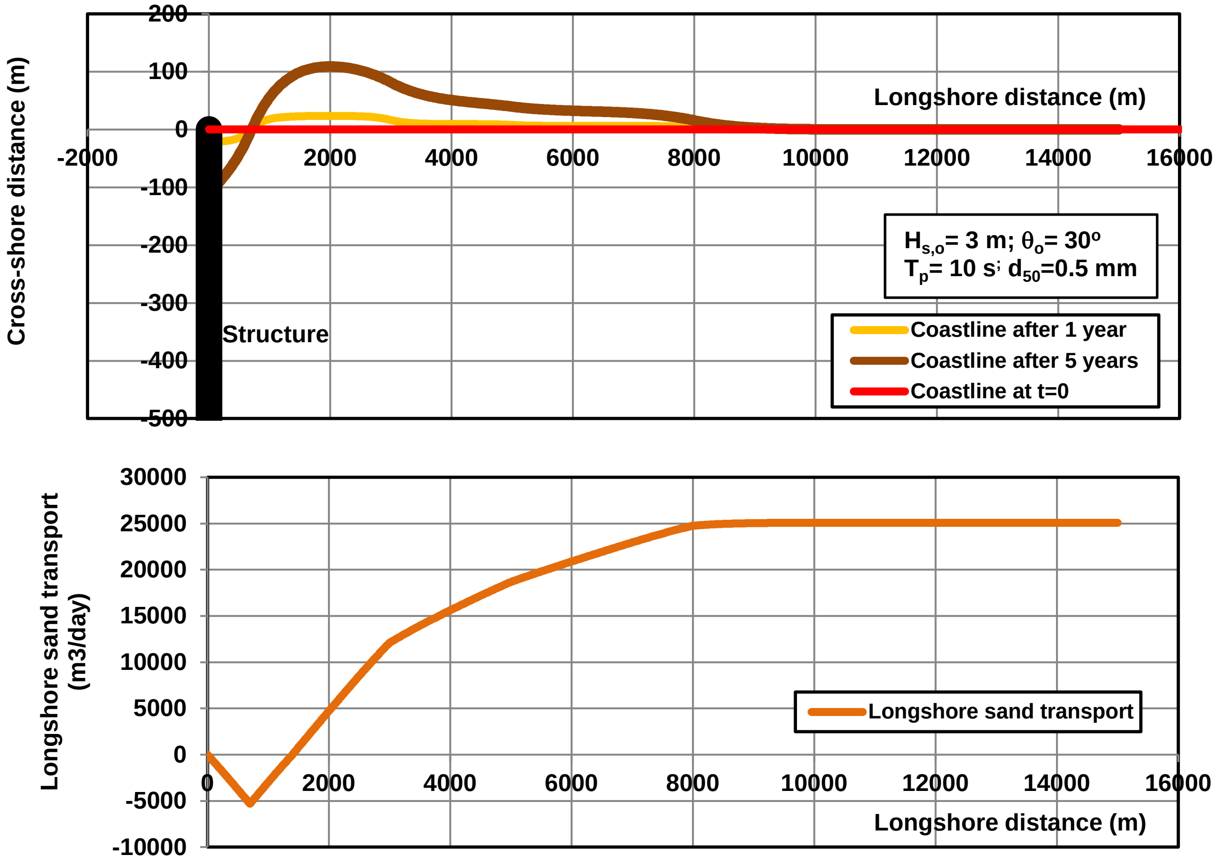

Figure 4.2 *Longshore sand transport (lower) and coastline changes (upper) in lee of structure*

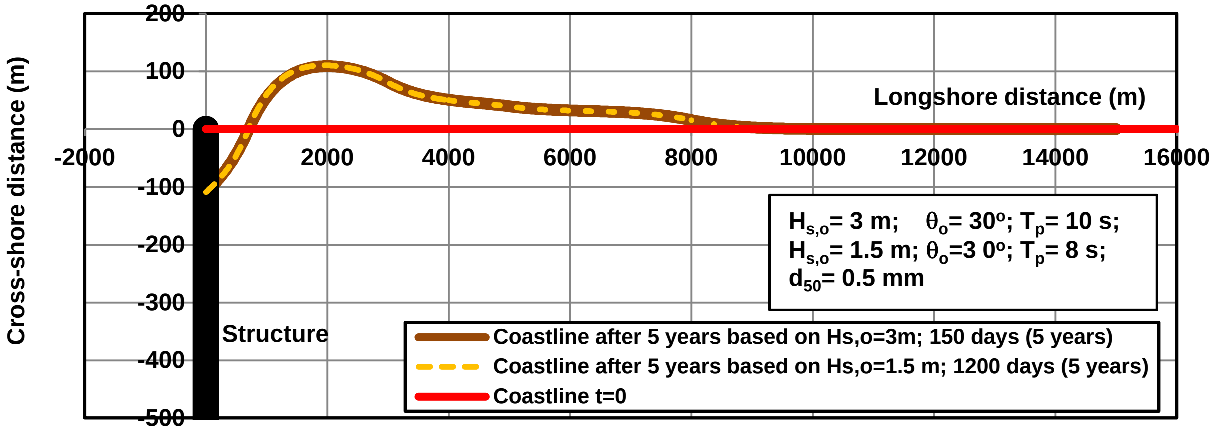

Figure 4.3 *Coastline changes in lee of structure*

5. References

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