INFLUENCE OF EXTREME EVENTS ON SEDIMENTATION PROCESSES IN DITCHES ENCLOSED BY BRUSHWOOD FENCES

by

Andreas Matheja[1] and Oliver Stoschek[2]

ABSTRACT

Climatic changes may result in an increase of mean high sea water levels, storm tides and related wave hights. To ensure the safety of coastal defense systems along the german wadden sea coast, sedimentation fields were used for many centuries as sedimentation traps to increase natural sedimentation, speed up foreland growth and thus realize sustainable foreland development.

To analyse sedimentation and erosion processes (i.e. velocities, sedimentation rates and distribution) from the approaching sea and inside the fields under varying conditions, two local areas have been surveyed over a period of three years. Selected data was used to calibrate a two-dimensional numerical hydrodynamic model, a wave model and a sediment transport model. Comparison with field recordings was used as a quality criterion for the applicability of the employed numerical methodology.

A numerical parameter study on the influence of currents, induced by tide and waves under mean longterm conditions, on sediment transport and erosion processes was performed. Simulations showed the effects of system geometry, dimension of the drainage system (ditches), construction of fences and permeability of the system (earth embankment). It could also be shown, that averaged input parameters (mean tide, characteristic wave heights and sediment characteristic under these conditions) are not sufficient to describe overall system behaviour.

So a second parameter study for extreme events was realized. It showed the effects of rising water levels and changing wave heights. The positive impact of brushwood fences to limit erosion during storm events in the protected area inside the fields could be shown. A comparison with system behavior under mean conditions cleared, that protection strongly depends on system geometry and permeable behavior of brushwood fences.

This parameter study was completed by an analysis about the influence of extreme events on sedimentation processes in ditches (part of the drainage system). This investigation showed significant differences between system behaviour under mean conditions and extreme events. Results showed also the effects of drainage system dimensions, number of ditches and incorporation of main ditches.

Overall results of the study and comparison with field measurements led to optimal design of sedimentation fields for foreland development, which can play a significant role in coastal protection and sustainable land reclamation.

[1] Dr.-Ing. Andreas Matheja, Research Assistant, University of Hannover, Franzius-Institute for Hydraulics, Waterways and Coastal Engineering, Nienburger Str. 4, 30167 Hannover, Germany,
email: am@fi.uni-hannover.de

[2] Dipl.-Ing. Oliver Stoschek, Research Engineer, University of Hannover, Franzius-Institute for Hydraulics, Waterways and Coastal Engineering, Nienburger Str. 4, 30167 Hannover, Germany

1. INTRODUCTION

At the German North Sea Coast forelands and salt marshes in front of sea dikes contribute significant to protection and safety of the artificial coastline. In this way forelands are a very important element of coastal protection systems. Salt marshes and forelying mud flats are formed by deposition of fine silts and sands due to tidal regime and wave attack.

Sea level rise and increased frequency/intensity of stormtides may endanger forelands resulting in losses of sediment or reduction thereby decreasing wave attenuation and thus increasing erosion.

Withhin a research program on the optimization of foreland management, field measurements in sedimentation fields, physical experiments, and numerical simulations have been carried out to analyse the interaction of waves, currents, sedimentation processed, maintenance techniques and field design. Numerical parameter studies highlighted the effects of system geometry, dimensions of the drainage system, construction of fences and permeability of the system in relation to boundary conditions (tides and wave heights) on mud and sand transport.

2. METHODOLOGY

2.1 Basic Procedure

To analyse sedimentation and erosion processes from the approaching sea and inside fields (Fig. 1) under varying conditions, two local areas have been surveyed over a period of three years.

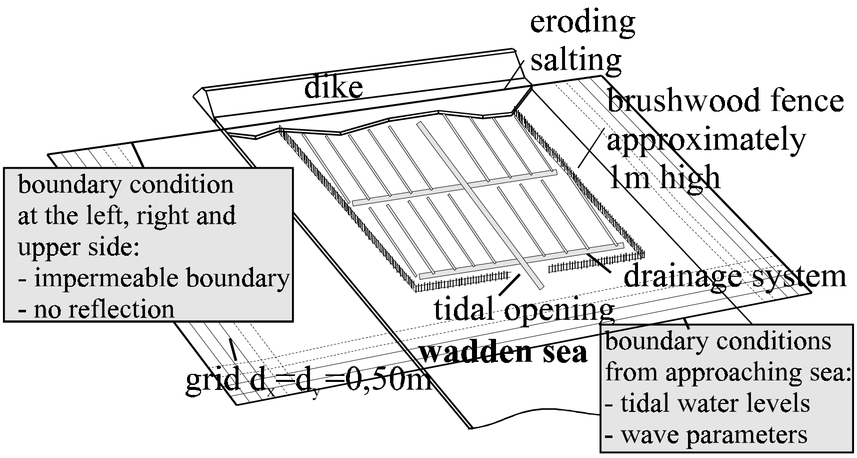

Figure 1. Sedimentation fields enclosed by brushwood fences used in the German Wadden Sea.

Data from these areas and data from physical experiments was used for parameter identification (friction parameter to simulate permeability of brushwood fences) and to calibrate a two-dimensional numerical hydrodynamic model (MIKE21 HD-module), including a wave model (EMS-module) and a sediment transport model (MT-module). Comparison with field recordings in the test area „Ockholm“ was used as a quality criterion for the applicability and efficiency of the employed numerical methodology (VON LIEBERMAN et al., 1997). Numerical problems with the applied simulation system MIKE21 indicated, that the implemented numerical methods have limitations in extreme shallow tidal waters (0 - 0.2 m). These limitations result from system parameters (minimal slope of bathymetrie, permeable behaviour of brushwood fences, geometric discription of drainage system) and from implementation characteristics of the applied numerical models (treatment of dried and flooded cells - chain problems and stability of the solver). However, these limitations have been overcome and results show satisfactory agreement.

A numerical parameter study on the influence of currents, induced by tide and waves under **mean longterm conditions**, on sediment transport and thus sedimentation and erosion processes was performed. Simulations showed the effects of system geometry, dimension of the drainage system (ditches), construction of fences and permeability of the system (earth embankment). It could also be shown, that averaged input parameters (mean tide, characteristic wave heights and sediment characteristics under these conditions) are not always sufficient to describe overall system behaviour (MATHEJA et al., 1997). So a second parameter study for **extreme events** was realized. It showed the effects of rising water levels, changing wave heights (STOSCHEK & MATHEJA, 1998).

This parameter study was completed by the presented analysis about the influence of extreme events on sedimentation processes in ditches (part of the drainage system).

2.2 Numerical Approach

The equations for mass and momentum conservation are integrated over the vertical, describing flow and water level variations:

$$\frac{\partial \zeta}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial p}{\partial y}=0 \tag{1}$$

$$\begin{aligned}&\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\cdot\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\cdot\left(\frac{p\cdot q}{h}\right)+g\cdot h\cdot\frac{\partial \zeta}{\partial x}+\frac{g\cdot p\cdot\sqrt{p^2+q^2}}{C^2\cdot h^2}-\\&\frac{1}{\rho_w}\cdot\left[\frac{\partial}{\partial x}\cdot\left(h\cdot\tau_{xx}\right)+\frac{\partial}{\partial y}\cdot\left(h\cdot\tau_{xy}\right)\right]-\Omega\cdot q-c_d\cdot V\cdot V_x+\frac{h}{\rho_w}\cdot\frac{\partial p_a}{\partial x}=0\end{aligned} \tag{2}$$

$$\begin{aligned}&\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\cdot\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\cdot\left(\frac{p\cdot q}{h}\right)+g\cdot h\cdot\frac{\partial \zeta}{\partial y}+\frac{g\cdot q\cdot\sqrt{p^2+q^2}}{C^2\cdot h^2}\\&-\frac{1}{\rho_w}\cdot\left[\frac{\partial}{\partial y}\cdot\left(h\cdot\tau_{yy}\right)+\frac{\partial}{\partial x}\cdot\left(h\cdot\tau_{xy}\right)\right]-\Omega\cdot p-c_d\cdot V\cdot V_y+\frac{h}{\rho_w}\cdot\frac{\partial p_a}{\partial y}=0\end{aligned} \tag{3}$$

where

h (x,y,t)	water depth [m]
ζ (x,y,t)	surface elevation [m]
p,q (x,y,t)	flux density in x-/y-direction [m^3/s/m]
C (x,y)	Chezy resistance [$m^{0.5}$/s]
f(V)	wind friction factor [-]
V,V_x,V_y (x,y,t)	wind speed in x-/y-direction [m/s]
Ω (x,y)	Coriolis parameter [s^{-1}]
p_a (x,y,t)	atmospheric pressure [kg/m/s^2]
ρ_w	density of water [kg/m^3]
x,y	coordinates [m]
t	time [s]
$\tau_{xx}\tau_{xy}\tau_{yy}$	effective shear stresses [N/m^2]

The basic „mild-slope“ equation for time-harmonic problems is (BERKHOFF, 1972):

$$\nabla\,(C_g\,C\,\nabla\xi)=\frac{C_g}{C}\frac{\partial\,\xi}{\partial\,t^2} \tag{4}$$

where

C_g	group celerity [m/s]
C	wave celerity [m/s]
ξ	surface elevation [m]

By introducing pseudo fluxes and generalising the equations to include wave generation, sponge layer absorption, partial reflection, bed friction and wave breaking. Elliptic mild-slope results are introduced to (2) and (3) by radiation stresses. Time dependant variation (tidal water levels and wave parameters), i.e. radiation stresses, are reproduced here by splitting the hydrodynamic time scale into several parts. To describe sediment concentration at a given time and location for cohesive sediments and sand material (grain size larger than 60µm), the advection-dispersion equation for the two dimensional case has to be solved:

$$\frac{\partial \bar{c}}{\partial t}+u\frac{\partial \bar{c}}{\partial x}+v\frac{\partial \bar{c}}{\partial y}=\frac{1}{h}\frac{\partial}{\partial x}\left(h\,D_x\,\frac{\partial \bar{c}}{\partial x}\right)+\frac{1}{h}\frac{\partial}{\partial y}\left(h\,D_x\,\frac{\partial \bar{c}}{\partial y}\right)+Q_L C_L\,\frac{1}{h}-S \tag{5}$$

where

$\bar{c}$	depth averaged concentration [g/m^3]
u, v	depth averaged flow velocities [m/s]
D_x, D_y	dispersion coefficients [m^2/s]
h	water depth [m]
S	deposition/erosion term [g/m^3/s]
Q_L	disch. per unit horiz. area [m^3/s/m^2]
C_L	concentration of discharge [g/m^3]

The characteristics of mud and sand transport used to describe deposition and erosion are realized by different approaches for the deposition/erosion term *S* described in detail by VAN RIJN (1984) and ENGELUND & FREDSOE (1976).

3. PARAMETER STUDIES

3.1 Mean Conditions

The numerical parameter study included the parameters described in Table 1. Parameters used for the 48 test cases in the hydrodynamic, elliptic mild-slope and sediment transport modules are shown in Table 2, 3 and 4.

Table 1. Variation of input parameters (48 test cases).

tidal opening: 25m, 35m, 40m, 50m, 70m, 90m / number of fields: 1 or 2
ditches: yes / no (see also Table 3) / earth embankment: yes / no (see also Table 3)

Table 2. Parameters used for the elliptic mild-slope wave model.

wave direction perpendicular to the coast (wave period 3 s) / wind effects are ignored
grid spacing: $\Delta x = \Delta y = 0.50$ m / partial reflection coeff. at brushwood fences: 1.5 accuracy: 1.7%
water depth/wave height: 0.40m/0.08m, 0.50m/0.10m, 0.60m/0.15m, 0.80m/0.20m, 0.90m/0.23m, 1.25m/0.13m

Table 3: Parameters for the hydrodynamic model (see also Fig. 2).

tide: MThw (tidal curve in the project area „Ockholm", STOSCHEK & MATHEJA, 1998)
bathymetry: constant slope 1:800 / grid spacing: $\Delta x = \Delta y = 2.00$ m
height of brushwood fences: MThw, to prevent overtopping of brushwood fences
porosity of brushwood fence: 20 % / distance of brushwood fences: 3.00 m *
field dimensions: width = 200 m, lenght = 200 m / number of fields: 1 or 2
main ditch: width=3.00m*/depth=0.40 m cross ditch & 15m ditch: width=2.00 m/depth = 0.40 m
ditches: width = 2.50 m,** / depth = 0.40 m / distance = 10 m
flood/dry depth: 0.25 m / 0.10 m ditch adjacent to fences: width = 2.50 m / depth = 0.25 m
geometry of earth embankment: height = 0.60 m / slope 1:3.33

*modelled with two grid nodes ** modelled with one grid node

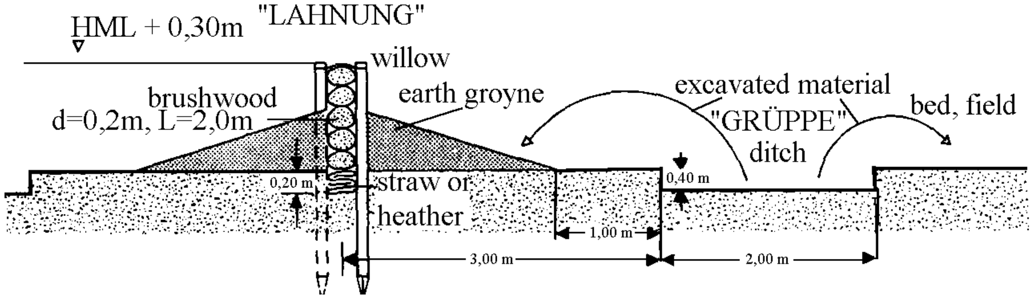

Figure 2: Construction of brushwood fences and excavation to build the drainage system (ditches).

Table 4. Parameters used for the sediment transport model.

	frac. 1 (1µm)	*frac. 2 (6µm)*	*frac. 3 (10µm)*
critical velocity for deposition/erosion [m/s]	0.05/0.30	0.06/0.30	0.07/0.30
mean settling velocity [m/s]	$7.3\cdot10^{-6}$	$2.6\cdot10^{-5}$	$7.3\cdot10^{-5}$
relative height of centroid [-]	0.3	0.3	0.3
erosion coefficient [kg/s/m²]	0.0005	0.0005	0.0005
initial bed composition [-]	6	13	1
dispersion coefficient in x/y-direction [m²/s]	0.1/0.1	0.1/0.1	0.1/0.1
initial concentration at boundary [g/m³]	105.0	227.5	17.5

A Manning number of 1.25 $m^{1/3}/s$ for brushwood fences was determined from physical experiments. For the rest of the model area values were obtained by calibration of the numeric model using data form the test site „Ockholm". „Sponge layers" were incorporated at the system boundaries to prevent wave reflection. The results of the Elliptic Mild-Slope Module where transferred to the hydrodynamic module for a tidal phase from which effects of waves on the hydrodynamic behavior of the system (i.e. velocity field) are calculated.

3.2 Extreme Events

For the numerical parameter studies of extreme events, two model tides were selected from field data (available data for a period from 1994 to 1995 in the test area „Ockholm", selected events in jan. and feb. 1995, Fig. 3) and transferred to datum.

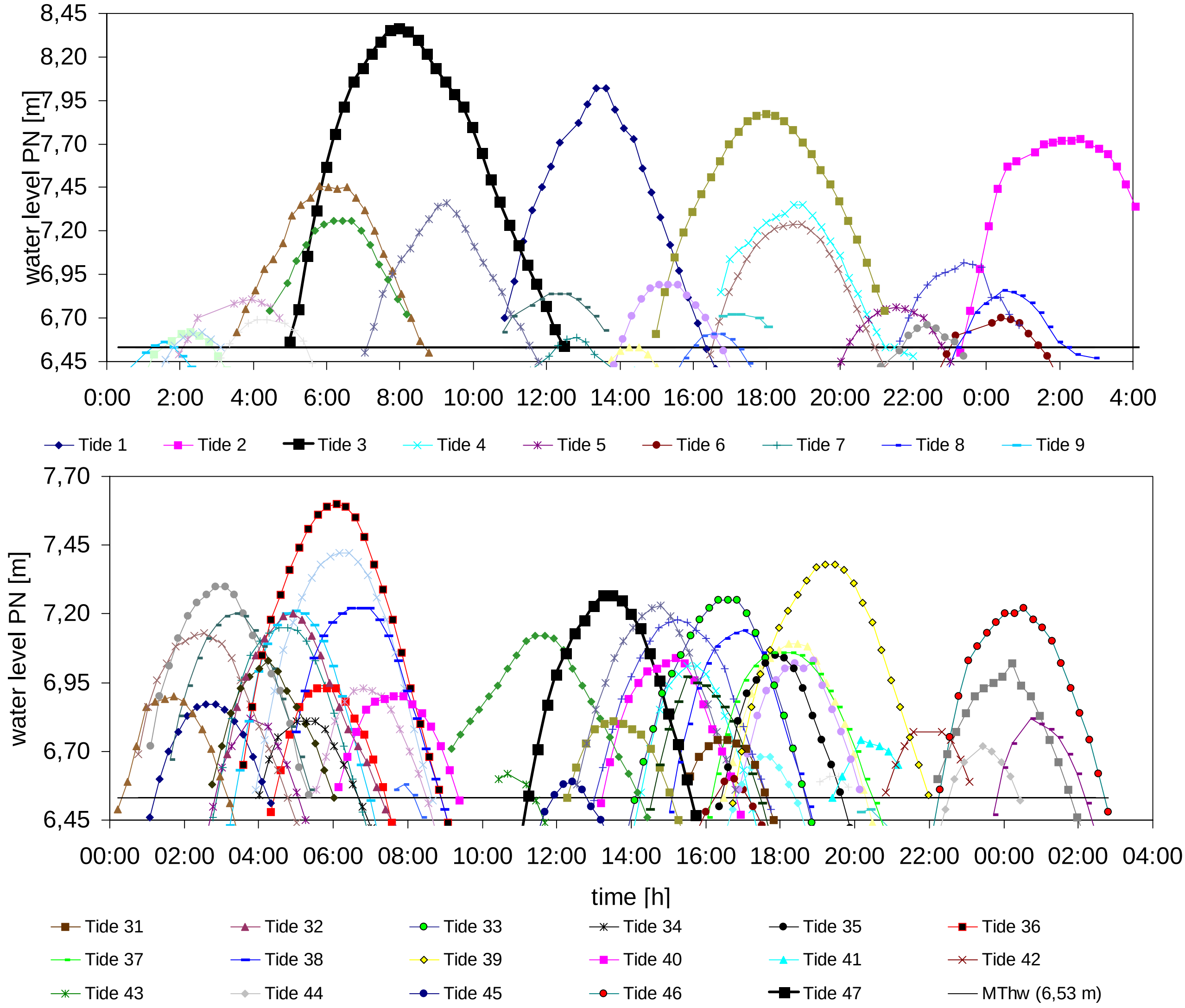

Figure 3. Field data (project area „Ockholm“) to identify extreme events (jan. 1995, tide 3 and feb. 1995, tide 47 selected).

Table 5. From field data selected wave parameters and calculated friction parameters.

Tide 3	case 1 (1./3. tidal phase)		case 1 (2. tidal phase)		case 2 (1./3. tidal phase)		case 2 (2. tidal phase)	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Hs [m]	0.22	0.22	0.22	0.22	0.31	0.31	0.31	0.31
Tp [s]	6.53	6.53	6.53	6.53	3.45	3.45	3.45	3.45
K_T [-]	0.99	0.87	0.99	0.87	0.92	0.85	0.92	0.85
friction [-]	0.20	0.70	0.20	0.70	0.20	0.70	0.20	0.70
Tide 47	case 3 (1./3. tidal phase)		case 3 (2. tidal phase)		case 4 (1./3. tidal phase)		case 2 (2. tidal phase)	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Hs [m]	0.12	0.12	0.12	0.12	0.18	0.18	0.18	0.18
Tp [s]	4.02	4.02	4.02	4.02	3.08	3.08	3.08	3.08
K_T [-]	0.95	0.89	0.95	0.89	0.91	0.88	0.91	0.88
friction [-]	0.20	0.30	0.20	0.30	0.20	0.30	0.20	0.30

(a) test cases without earth embankment; (b) test cases with earth embankment

Wave parameters (Tab. 5) were also selected for the according periods from field data. The friction parameter for modelling the permeable behaviour of brushwood fences was calculated with the MIKE21 „reflct“ subroutine. Transmission coefficients K_T [-] were selected from experiments as parameter input for this algorithm. All other parameters were taken from the parameter set for mean conditions. The influence of extreme events (case 1 and 2 for tide 3 and case 3 and 4 for tide 47, Tab. 5) were calculated for all 48 test cases described in Chpt. 3.1.

4. RESULTS

4.1 Mean Conditions

The overall behavior of the system under mean conditions is described in detail by MATHEJA et al. (1997) and MATHEJA & STOSCHEK (1998). Sedimentation results show the influence of tidal opening width, earth embankment, permeability of the system and ditches (Fig. 4, Fig. 5).

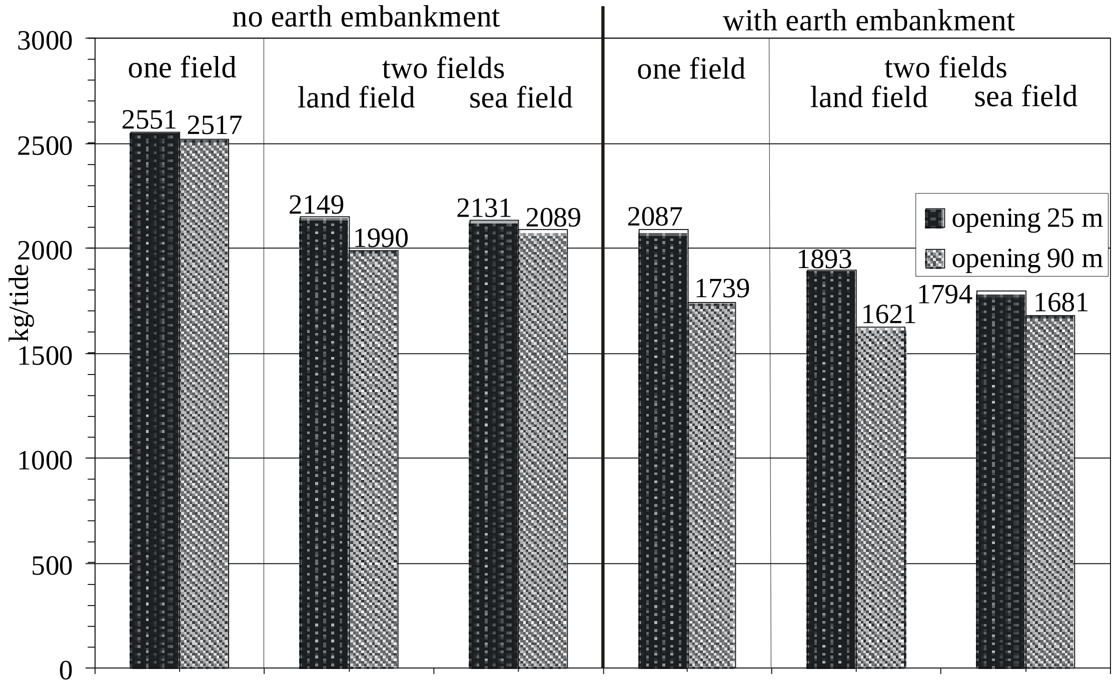

Figure 4. Sedimentation [kg] for systems without ditches after one tide under mean conditions.

Overall sedimentation after one model tide (linear behaviour between the cases in tab. 6 for varied tidal opening width) decreases as the width of tidal opening increases. It is found that systems with earth embankment hinder sedimentation, i.e. suppress sediment transport across brushwood fences. Ditches in systems with earth embankment give higher sedimentation rates.

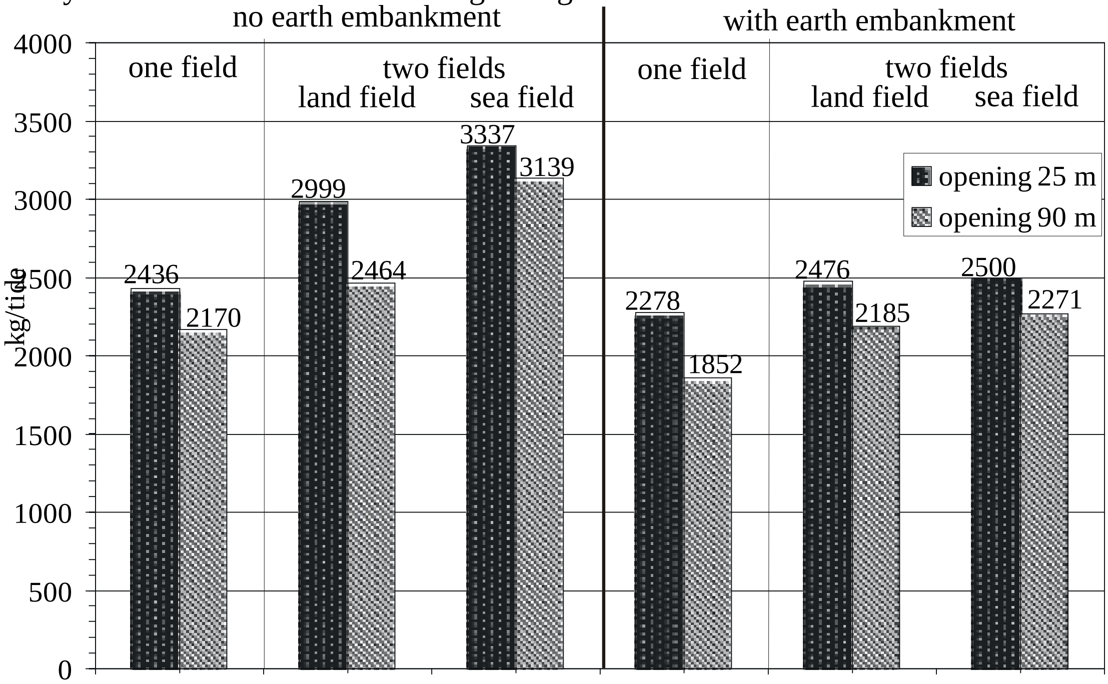

Figure 5. Sedimentation [kg] for systems with ditches after one tide under mean conditions.

4.2 Extreme Events for Systems without Ditches

Increase of sedimentation is immense (Fig. 6). In all test cases eroded areas near tidal openings become smaller as opening width increase for case 1 and 2 (as also visible under mean conditions).

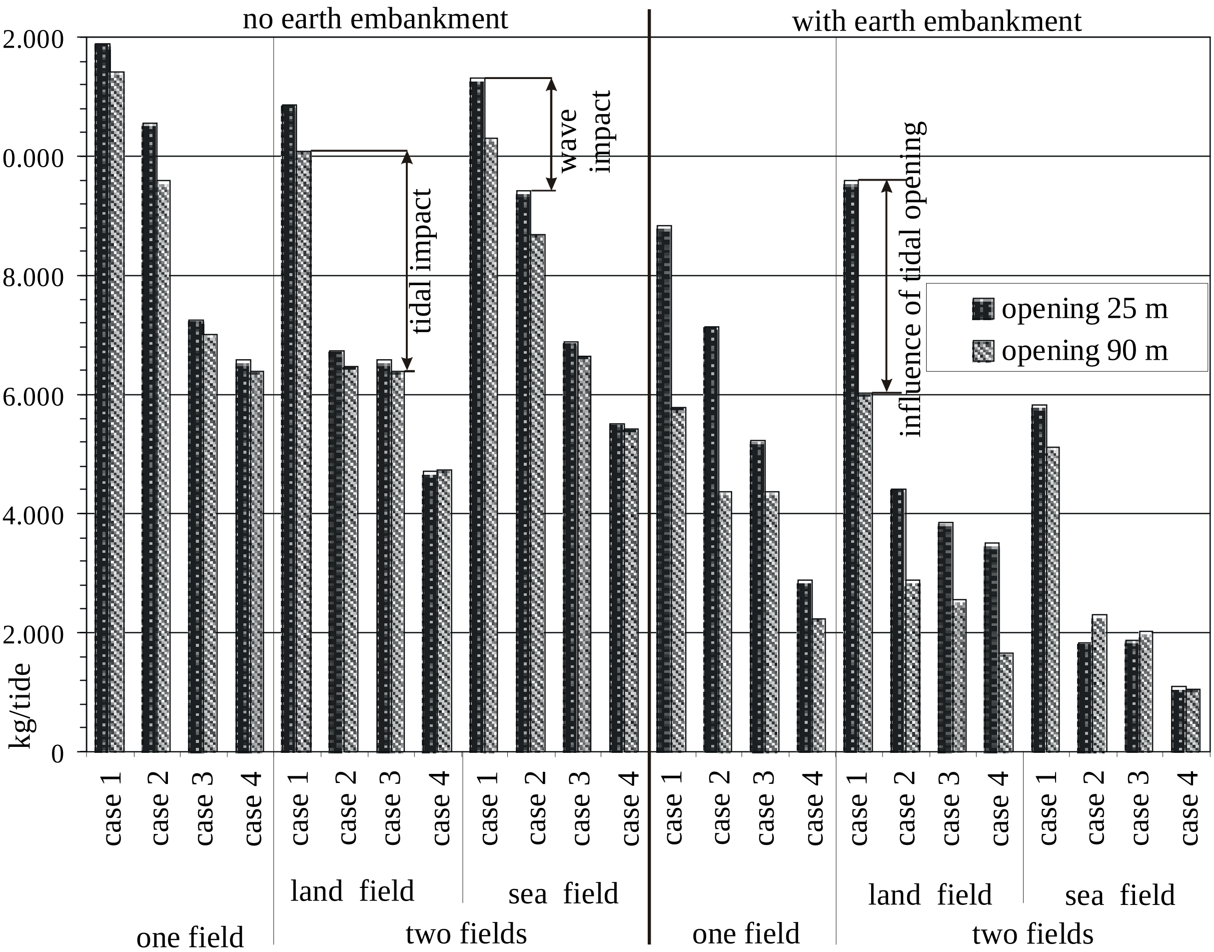

Figure 6. Sedimentation [kg] for systems without ditches after one tide under extreme conditions. With earth embankment transport across fences ist limited due to impermeability of the structure (up to 60 cm above the bottom). Overall sedimentation decreases in all test cases (up to 400%). Maximum decrease is observed for larger tidal openings.

From comparison of case 1/2 and 3/4 follows a decrease of sedimentation for higher waves (Fig. 6, wave impact). The effect of waves becomes evident in the „land fields" of two-field cases. In all cases the influence of wave characteristics stands behind the influence of flooding period (7.5 h for tide 3, 4,45 h for tide 47, compare Fig. 6), maximal flooding depth (1.8 m for tide 3, 0.92 m for tide 47), and thus corresponding tidal water volume entering the fields (Fig. 6, Fig. 3).

In two-field cases, areas with lower sedimentation in the middle of the „sea field" become larger (Fig. 7 and compare MATHEJA & STOSCHEK, 1998). Two-field cases with earth embankment show a significant decrease.

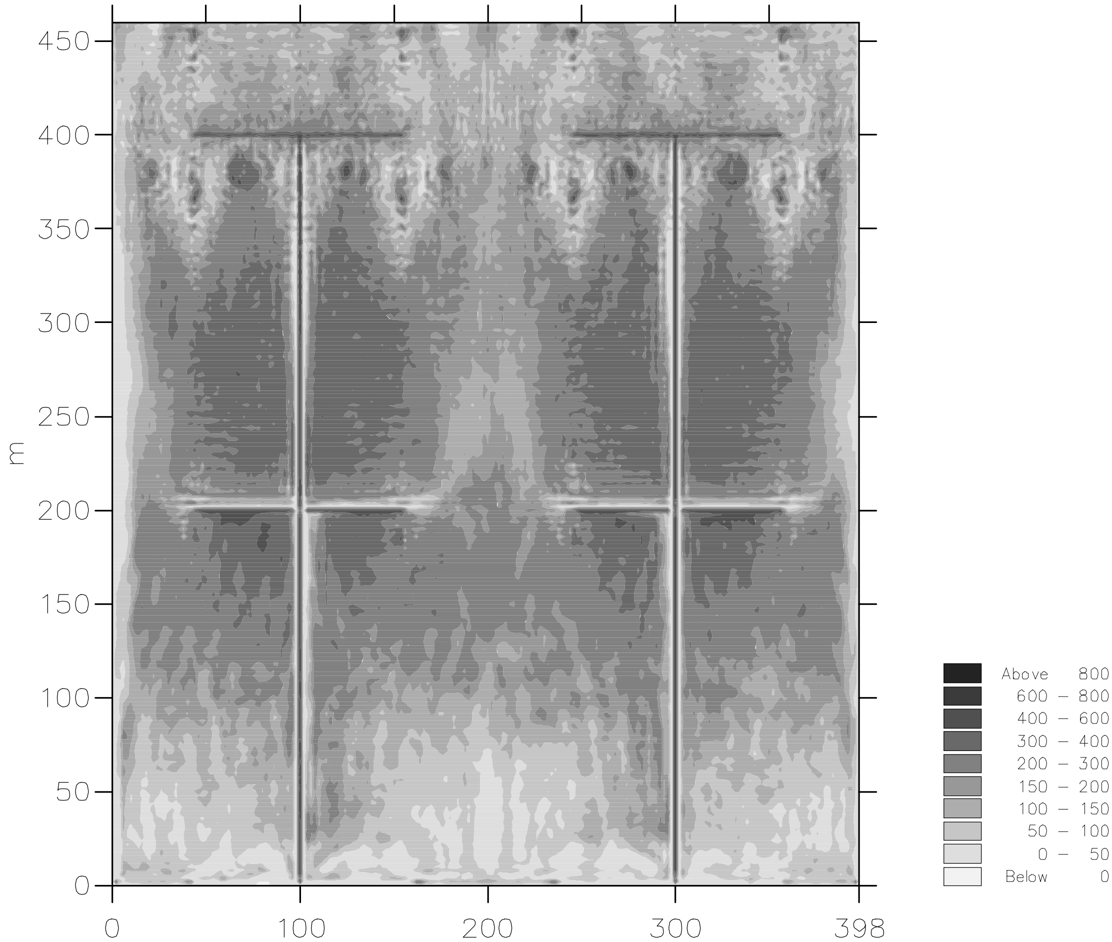

Figure 7. Sedimentation/Erosion after one model tide [g/m2] (test case m_12, case 2: two fields, no ditches, no earth embankment, tidal opening = 90m, levels: Below 0; 0 - 50; 50 - 100; 100 - 150; 150 - 200; 200 - 300; 300 - 400; 400 - 600; Above 600; from light to dark [kg].

4.3 Extreme Events for Systems with Ditches

In comparison with mean conditions increase of sedimentation is also considerable (Fig. 8), but smaller than for systems under extreme conditions without ditches (Fig. 6 and Fig. 8). A concentration of sedimentation to ditches is visible (Fig. 7 and Fig. 9). It is mainly related to collection ditches (compare sedimentation lines in Fig. 9 - middle of the „land field" - perpendicular to the main drainage channel, which accumulates drainage and ends outside the „sea field" crossing tidal opening), who act as main drainage for the smallest ditches (responsable for area drainage in the fields). In proportion the main drainage channel has lower sedimentation due to higher velocities and wave heights entering the fields in his direction.

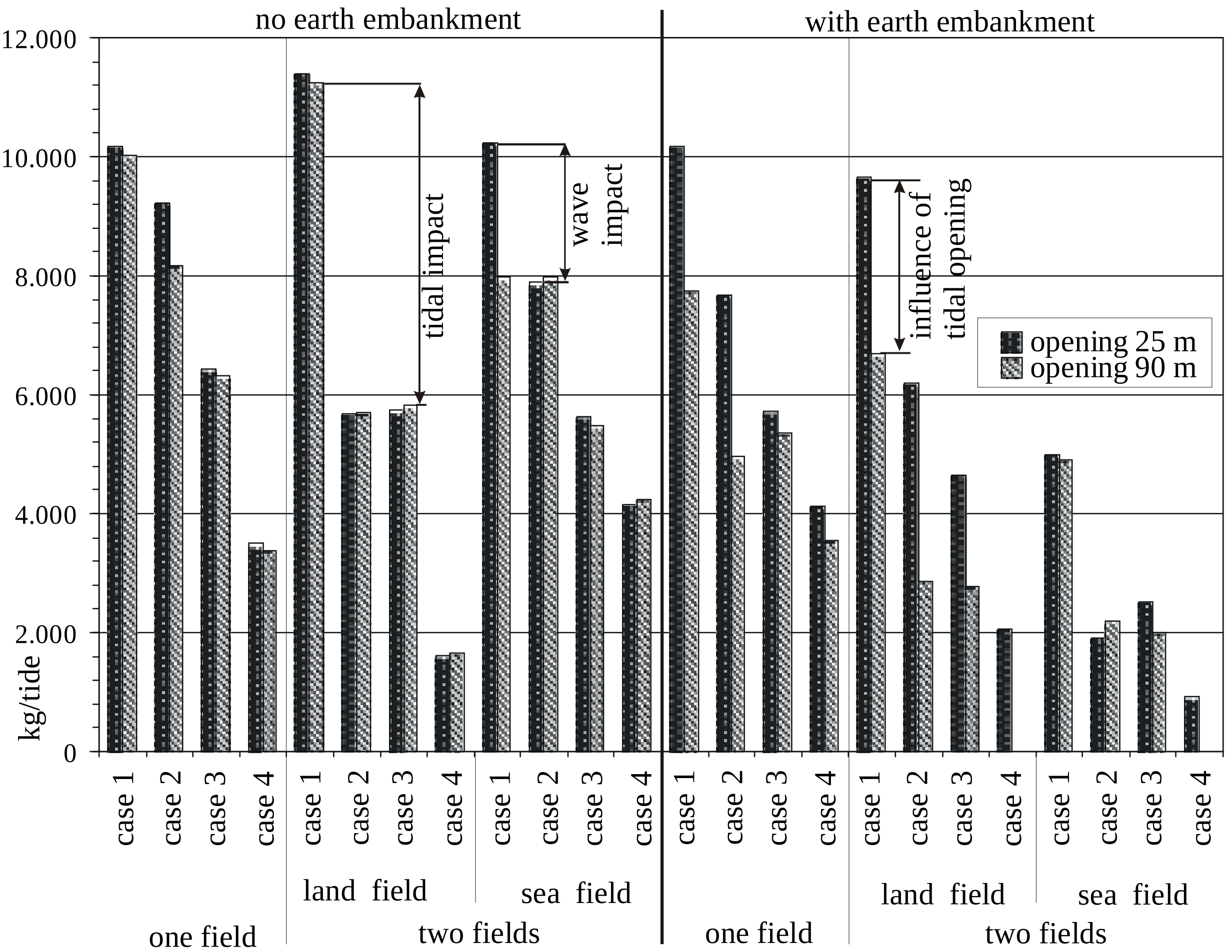

Figure 8. Sedimentation [kg] for systems with ditches after one tide under extreme conditions.

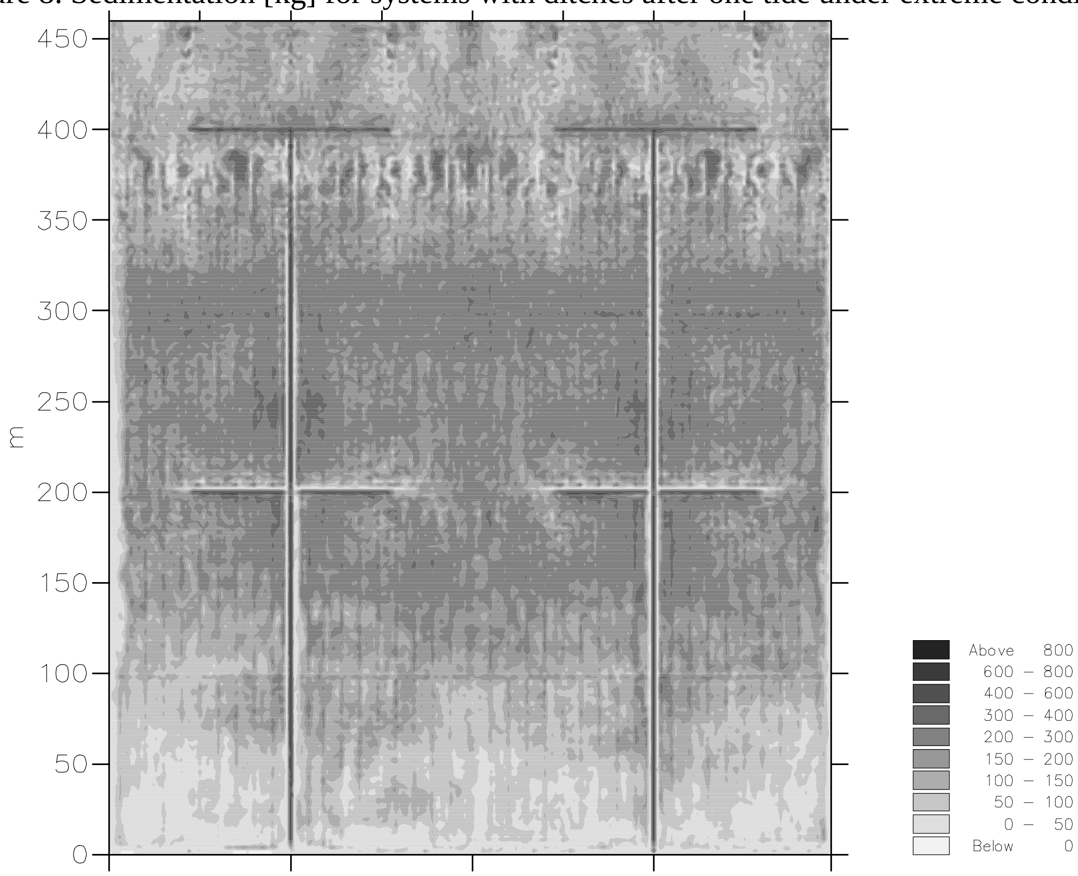

Figure 9. Sedimentation/Erosion after one model tide [g/m2] (test case m_36, case 2: two fields, with ditches, no earth embankment, tidal opening = 90m, levels: see fig. 7.

Tidal impact is larger than wave impact for all system. In two-field systems wave impact in the „sea field“ increases in comparison to one-field systems. For systems with earth embankment the difference between tidal impact and wave impact becomes smaller.

The influence of wave attack varies most significantly in „sea fields“ of two-field systems. With earth embankment transport across fences ist limited due to impermeability of the structure (impermeable up to 60 cm above the bottom).

Overall sedimentation decreases in all test cases (up to 300%), accept for one-field systems with earth embankment. Maximum decrease is observed for larger tidal openings. The influence of tidal opening is greater for systems with earth embankment.

5. CONCLUSIONS

Presented parameter studies are restricted due to iedealised conditions (i.e. numerical models, presentation of system parameters). Beside idealisation results are applicable and transferrable to other coastal regions and scenarios, because used parameter sets are based on field data and physical experiments. Model results are also compared with reality (project area „Ockholm“) to ensure applicability.

System behaviour under mean conditions show, that efficiency of this protection system strongly depends on system geometry (height of the fences, width of tidal opening and field dimensions), permeability of brushwood fences (applied material and earth embankment) and dimensions of the drainage system (number of ditches, incorporation of main ditches).

It could be shown that the influence of extreme events is uncritical for applied parameter sets (e.g. wave heights, wave periods and tides). Sedimentation under these conditions is extremely higher (up to 400%) due to higher water exchange (tidal volume) and longer flooding (effective tidal period).

These global tendencies are also visible for sedimentation fields with drainage system (ditches). Especially for systems with earth embankment ditches are an efficient measure to speed up sedimentation during extreme events.

Numerical simulation of longterm system behaviour of a natural system (projekt area „Ockholm“), comparison of 2D/3D model results for modelling permeability of brushwood fences (high resolution model in the surrounding of brushwood fences) and the influence of ice periods will be research topics in the future.

REFERENCES

BERKHOFF, J.C.W. (1972). Computation of combined refraction-diffraction. Proc. 13th Coastal Eng. Conf., Vancouver, 1972: Vol. 1, 471-490. New York: ASCE.

ENGELUND, F. and J. FREDSOE (1976). A sediment transport model for straight alluvial channels. Nordic Hydrology, Vol. 7, 293-306.

MATHEJA, A.; VON LIEBERMAN, N. and C. ZIMMERMANN 1997. Land reclamation and coastal protection in shallow tidal waters - A numerical case study in the german wadden sea area. In: Proc. of the 1st International Conf. Port, Coast, Environment, Varna, 30 June - 4 July 1997: Vol. 1, 62-72.

MATHEJA, A. and O. STOSCHEK (1998). Influence of extreme events on sedimentation in sedimentation fields enclosed by brushwood fences. In: Babovic, V. and L.C. Larsen (Eds.): Proc. 3th Int. Conf. on Hydroinformatics, Copenhagen, 24-26 Aug. 1998: Vol. 2, 1411-1418.

VAN RIJN, L.C. (1984). Sediment Transport, Part I: Bed Load Transport, Part II: Suspended Load Transport. Journal of Hydraulic Engineering, 110 (10).

VON LIEBERMAN, N.; A. MATHEJA and C. ZIMMERMANN (1997). Foreland stabilisation under waves in shallow tidal waters. In: Proc. of the 2nd Indian National Conference on Harbour and Ocean Engineering, Thiruvananthapuram, 7-10 Dec. 1997, Vol. 2, 1236-1245.