FORELAND STABILISATION UNDER WAVES IN SHALLOW TIDAL WATERS

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ABSTRACT

At the German North Sea Coast forelands and salt marshes in front of the sea dikes contribute significantly to the protection and safety of the artificial coastline. In this way the forelands are an important element in the whole coastal protection system. The current state of scientific knowledge about the management of forelands is essentially based on experience acquired over generations. Therefore there is a need for research to determine the influence of the various parameters effecting accretion or erosion of forelands. Within a research programme on the optimization of foreland management, which is sponsored by the German Federal Ministry of Education, Science, Research, and Technology (BMBF), field measurements, physical, and numerical simulations have been carried out to analyse the interaction of waves, currents, sedimentation processes, and maintenance techniques of forelands at the german North Sea Coast.

INTRODUCTION

Salt marshes and their forelying mud flats are formed by the deposition of fine silts and sands in sheltered locations and colonised by specialized salt tolerant plants (see Fig. 1). The upper mud sediment layers of the tidal flats are very active containing biological production. Very quickly vegetation starts with single plants of the three main species as follows: For the settlement of glasswort or marsh samphire (*Salicornia herbacea L.*) the terrain must be of a certain height; at about mean tidal high water level (MHW) minus 40 cm or 50 cm. This plant is annual and its height does not exceed 20 cm. In october plants die off and seeds are released. The wooden parts of the stem often remains in place as a bare bush. Glasswort does not only promote sedimentation; according to Kamps (1962) its presence can also stir up the material already deposited as a result of the remaining dead bushes causing turbulence. The second pioneering plant is cordgrass (*Spartina Townsendii*), a coarse crop-like reed (*Phragmites communis L.*), which can reach a height of about 1 m. It develops at about 30 cm below MHW and its growing period starts later than that of glasswort. The third pioneering species is sea poa (*Puccinellia maritima Parl.*). It is a grass which settles above mean tidal high water level (Schulz and Zimmermann, 1994).

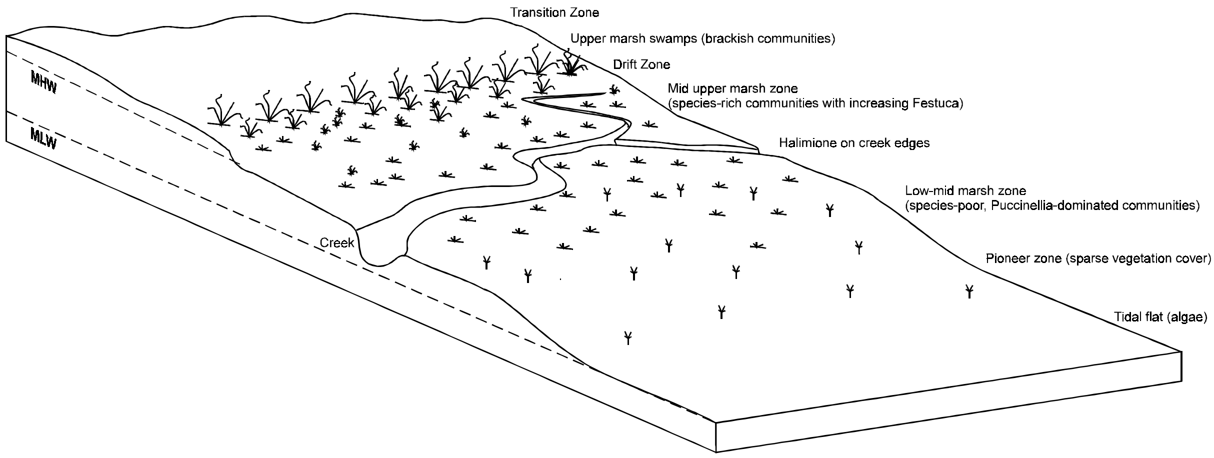


Fig. 1: Saltmarsh with Main Vegetation Zones at Tidal Levels
(after: MAFF, 1993)

These plants attenuate tidal currents and waves resulting in increased siltation. As these young marshes slowly raise in height the tidal currents form a network of drainage channels which act as transport routes for sediments and dissipators for the tidal currents.

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

FORELAND STABILISATION BY ARTIFICIAL SEDIMENTATION FIELDS

In order to counteract loss of sediment and to increase natural sedimentation artificial reclamation methods have been used for generations. At the German North Sea Coast this is by systematic installation of large-scale sedimentation fields using low brushwood fences in combination with a regular drainage system (see Fig. 2). Wooden stake and brushwood structures help to create areas with decreased wave heights and reduced currents resulting in enhanced sedimentation. However, there exist limitations from local boundary conditions where such techniques are less efficient with the need for increased and ongoing maintenance.

Supporting natural and artificial accumulation of the mud-flats with support of engineering techniques increase the potential for protection of the dikes and thus ensure the stability of the coastline against waves and storm tides due to shallow water effects on the tidal flats from shoaling or breaking of waves.

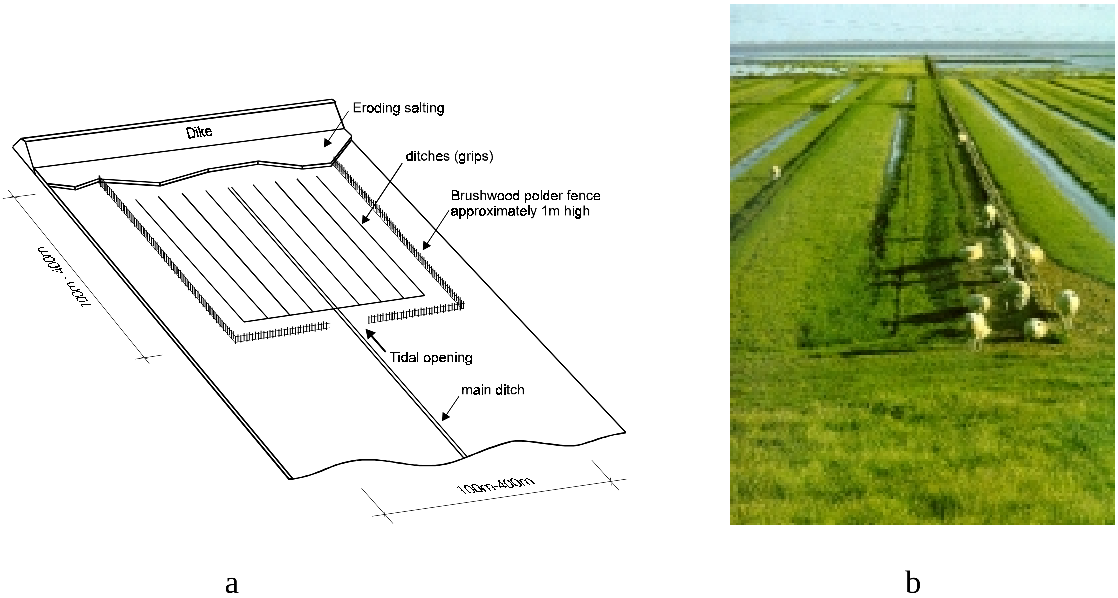


Fig. 2: Sedimentation Fields with Artificial Drainage System (a) and
Traditional Land Use after Several Decades of Continuing Maintenance (b)

The dimensions of the sedimentation fields, 100 m to 400 m in length and 100 m to 400 m in width, and of the drainage system are purely empirical so far. The design is based on traditional experience determined by local conditions. This also applies to the heights of the brushwood fences ("Lahnungen") above the ground, which vary between 0 and 30 cm above mean tidal high water level resulting in a total height of approximately 1.00 m. The materials that have been used are timber poles with bundled willow in between (see Fig. 3). These basically permeable structures become partly impermeable by a protective earth embankment, and from the fine sediments that settle within the brushwood.

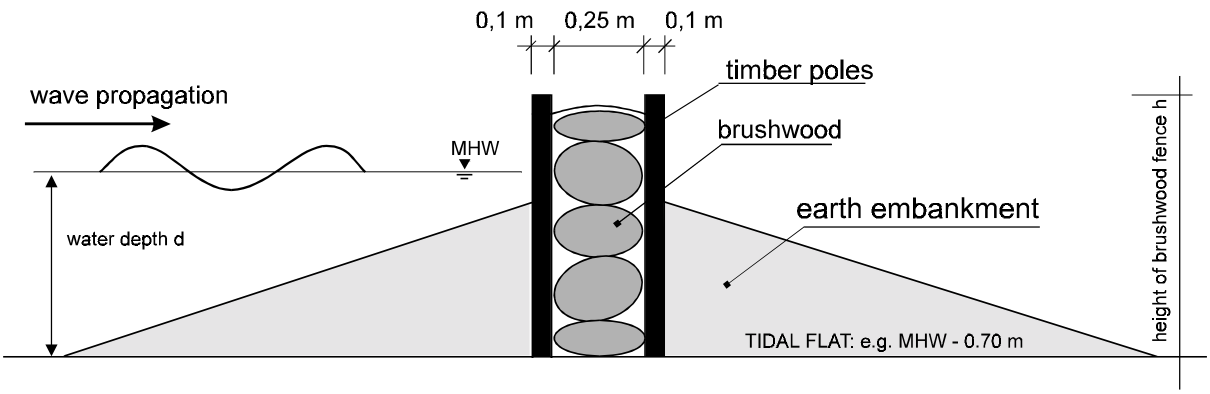


Fig. 3: Traditional Brushwood Fence ("Lahnung") with Earth Embankment

In some areas with heavy wave action and stronger tidal currents such fences were also constructed from prefabricated concrete, geotextiles filled with sand and rubblemound stones. Apart from the fact that they are impermeable, materials of this kind are today considered not in accordance with the environment, while timber and brushwood are natural materials and thus acceptable. In addition, the permeability of the brushwood fences allows the passage of water and sediment. To a certain extent, waves are damped out under mean tidal conditions (Schulz and Zimmermann, 1994).

Sediment consolidation and accelerated growth of the surface within the reclamation fields is achieved by digging small ditches about 2 m wide with a depth of approximately 40 cm. Excavated mud is placed on the areas between the ditches, thus leading to increased uploads and to further drainage of the material and of the soil underneath. The ditches, which regularly fill during rising tides, are resedimented. Repeated excavation increases the height of the fields above tidal high water levels so that the successive colonisation by glasswort, cordgrass and sea poa finally results in the salt marshes or forelands. So far, very few is known about the relationship between hydraulic parameters, boundary conditions and sedimentation. The same applies to the drainage system and its effect on consolidation. The optimum of spacing and the orientation of ditches, which should be a function of sediment, soil properties and hydraulic boundary conditions, has not so far been analysed (Schulz and Zimmermann, 1994).

RESEARCH PROGRAMME

In order to rationalize the discussion between engineers who feel responsible for the protection of the coast and the safety of the hinterland and the environmentalists who argue for a reduction in engineering work and maintenance, a research programme has been introduced to identify absolutely necessary protection work and minimize all man-made effects including maintenance (Schwarze and Schulz, 1995).

The research programme shall analyse and quantify

- hydraulic factors affecting mud flats and salt marshes under tides and waves
- effects of artificial works and interference on the sedimentation and erosion of forelands
- effects of the geometry of reclamation works and drainage system on waves, currents and sedimentation
- effects of reduced maintenance on foreland stability and coastal protection
  (aspects of grazing are not considered)

Analysis and conclusions are based on a combination of numerical simulations, hydraulic model tests, and field measurements. Field measurements were carried out in two test fields at the North-Sea coast of Schleswig-Holstein in Germany, which were installed by the local coast administrations. Tidal currents and wave parameters were also measured by these administrations. Physical model tests in a two-dimensional flume, in a wave channel and in a three-dimensional wave basin as well as a numerical simulation have been carried out by the Franzius-Institute of the University of Hannover. The field measurements and physical model tests were the basis for the numerical simulations.

RESULTS

Field Measurements

Fig. 4 shows some wave characteristics, i.e. for the measured transmission coefficient at a brushwood fence in relation to the water depth. The transmission coefficient increases linear for water depths up to approximately 0.45 m above mean tidal high water level, which corresponds with h/d = 0.60 (h = height of the "Lahnung"; d = water depth) and above this remains more or less constant: The wave damping effect of a brushwood fence is of less importance for water levels above MHW.

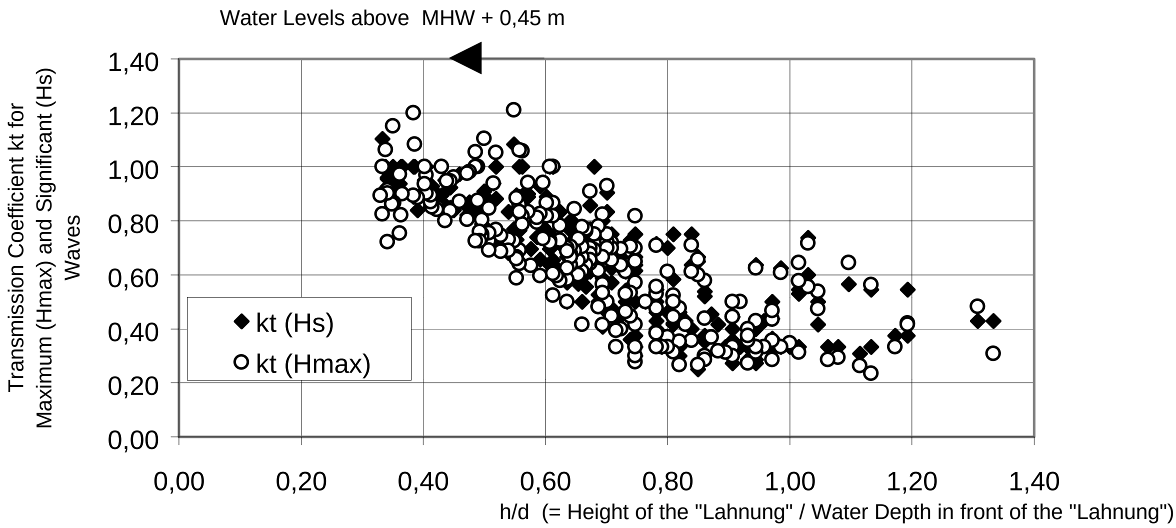


Fig. 4: Transmission Coefficient of a Brushwood Fence for varying Water Depth from Field Measurements

Physical Model Tests in a Wave Flume and in a Wave Basin

To analyse the effects of brushwood fences on waves under varying water levels one-dimensional model tests of different brushwood fences with varying heights and shapes were performed in a wave flume (110 m length, 2.20 m width and 2.00 m depth). Wave transmission coefficients of these fences were obtained with rectangular regular and irregular waves. The relationship between the wave transmission coefficient and the water depth in front of the brushwood fence – as determined by field measurements (see Fig. 4) – was confirmed (see Fig. 5). As shown in Fig. 5 the transmission coefficient is only slightly higher than calculated from field data. This behaviour can be attributed to fine sediments and algae which settle within the natural brushwood fences and reduce their permeability.

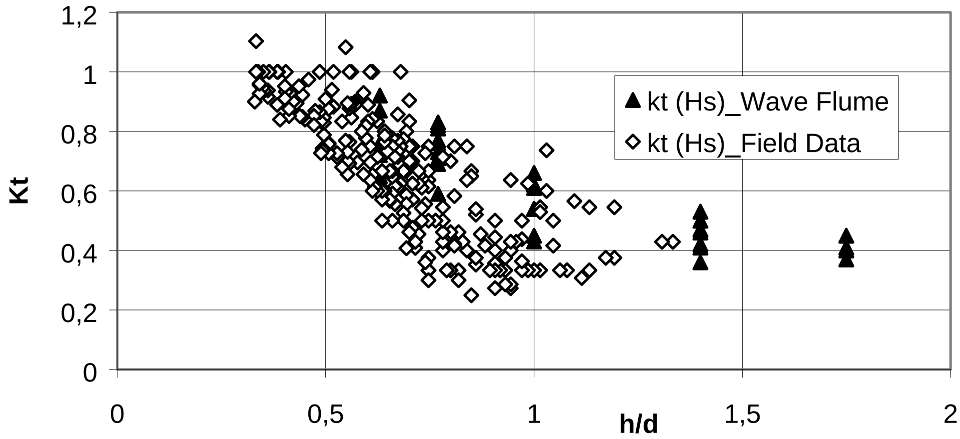


Fig. 5: Results for Irregular Wave Transmission for a Typical Brushwood Fence (Height = 0.70 m) with a Porosity of about 20% without a Side Earth Embankment, Results compared with Field Data

To analyse and verify three-dimensional wave induced currents, hydraulic model tests with waves were carried out in a three-dimensional wave basin. The maximum water depth was 0.60 m. Waves up to approximately 0.25 m were generated. All tests were carried out with a brushwood fence with prototype scale as for the investigations in the wave flume (see Fig. 6). During the tests, video recordings of surface floats were made and current velocities were calculated.

The results compared with the numerical simulations showed satisfactory agreement for diffraction and attenuation due to the "Lahnung". Thus the numerically modelled brushwood fence is a good approximation to the prototype (see Fig. 7).

Physical model tests and numerical simulation show that the sediment-laden waters enter the reclamation fields also through the brushwood fences while thus leave the fields through the tidal opening. This behaviour has been observed also at permeable rubble mound breakwaters (see e.g. Pilarczyk and Zeidler, 1996).

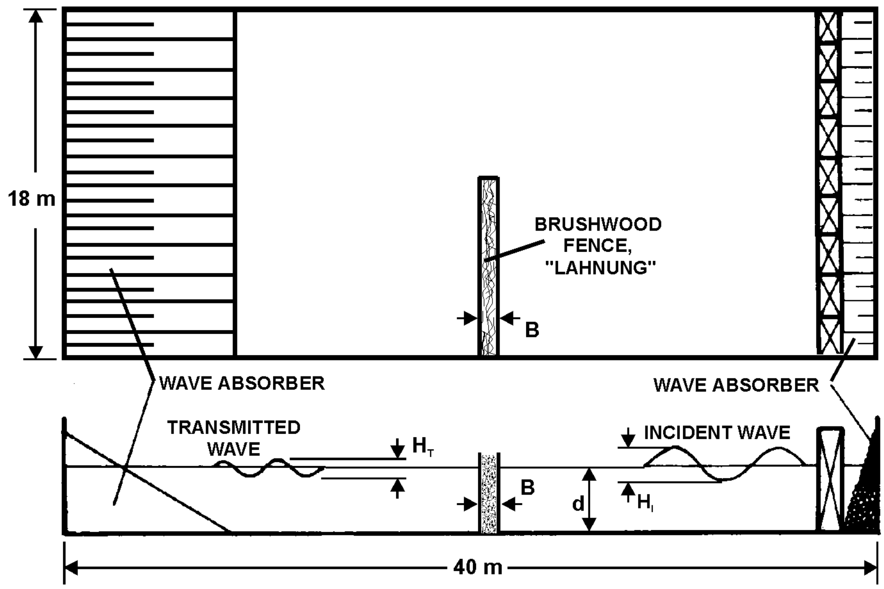


Fig. 6: Wave Basin with Brushwood Fence

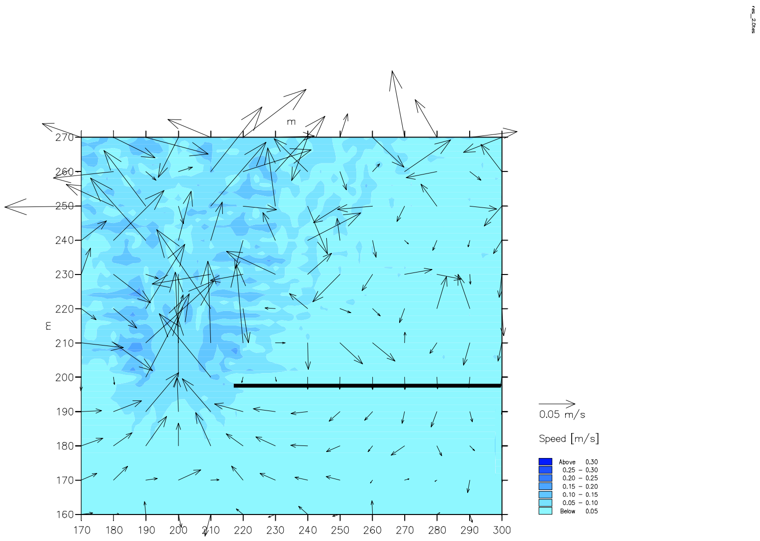
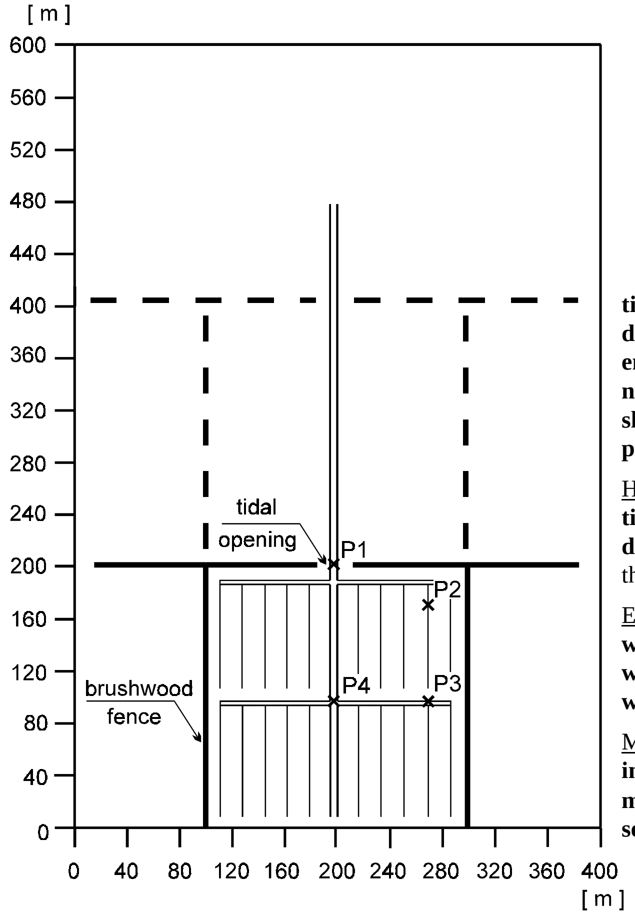


Fig. 7: Wave induced Currents computed at the Tidal Opening
and across a Typical Brushwood Fence

Numerical Simulations

To analyse longterm effects of waves and currents on sedimentation and erosion, two-dimensional numerical simulations were carried out for varying boundary conditions, i.e. waves, tides, sediment concentrations. Boundary conditions were obtained from the field measurements and from the physical models. For the simulation the **H**ydro**D**ynamic module, a wave module (**E**liptic **M**ild **S**lope), and the **M**ud **T**ransport module of the software system

MIKE 21 of the Danish Hydraulic Institute is applied. The parameter study on the influence of currents, induced by tide and waves, on sediment transport and thus sedimentation and erosion processes, showed effects of the system geometry, dimensions of the drainage system, brushwood fences and permeability of the system. The reliability of the obtained results has been confirmed via comparison with field data.



Boundary Conditions
for Results presented in Fig. 9 and 10:

tidal opening: 25 to 90 m
ditches: main ditch; with or without small ditches
embankment: with or without earth embankment
number of fields: one or two
slope of bottom: 1:800
permeability of brushwood fence: 20%

<u>HD-Module:</u>
tidal curve: mean tidal curve of the test fields
direction of currents: perpendicular to the coast

<u>EMS-Module:</u>
wave heigths: 10 to 23 cm
wave period: 3 s
wave direction: perpendicular to the coast

<u>MT-Module:</u>
initial concentration: 17.5 to 227.5 g/m³
mean settling velocity: $7.3 \cdot 10^{-6}$ to $7.3 \cdot 10^{-5}$ m/s
sediment fraction: referring to test fields

Fig. 7: Numerical Model Area and Boundary Conditions

Fig. 9 and 10 show the effects on sedimentation at points P2 and P4 of a sedimentation field for different combinations of parameters. In all test cases that include ditches sedimentation starts immediately at the beginning of the tidal period. The highest sedimentation rates occur during the high tide period (Matheja et al., 1997).

The width of the tidal opening (results for tidal openings of 25 m and 90 m are shown in Fig. 8 and 9) seems not to be significant for the sedimentation in the fields. Only a small increase in the sedimentation rate is indicated for a tidal opening of 90 m.

For brushwood fences with earth embankments, sedimentation decreases at both points, P2 and P4. Earth embankments combined with a regular drainage system lead to an increased sedimentaton at point P2, while this combination does not show significant effects for a sedimentation in the field centre around point P4. The conclusion is, that ditches dissipate the sediment-laden waters into sheltered areas of the sedimentation fields (e.g. at point P2), but they do not have significant influence on the sedimentation in the centre of the fields.

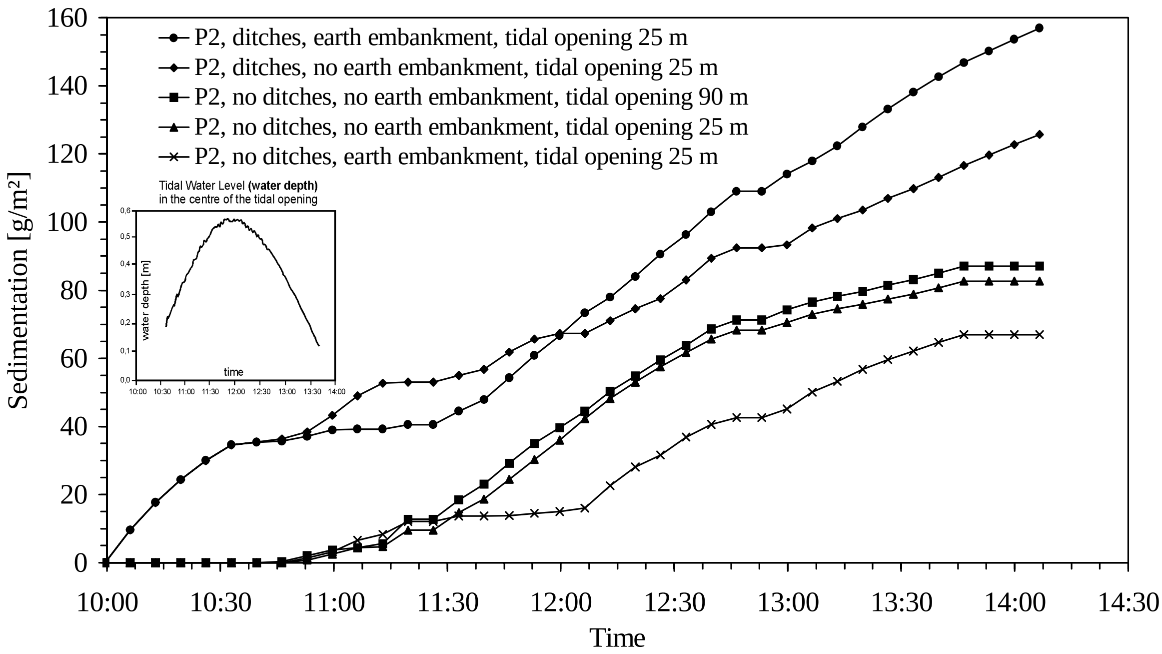


Fig. 8: Sedimentation and Erosion [g/m^2] during one Tidal Period at Point P2

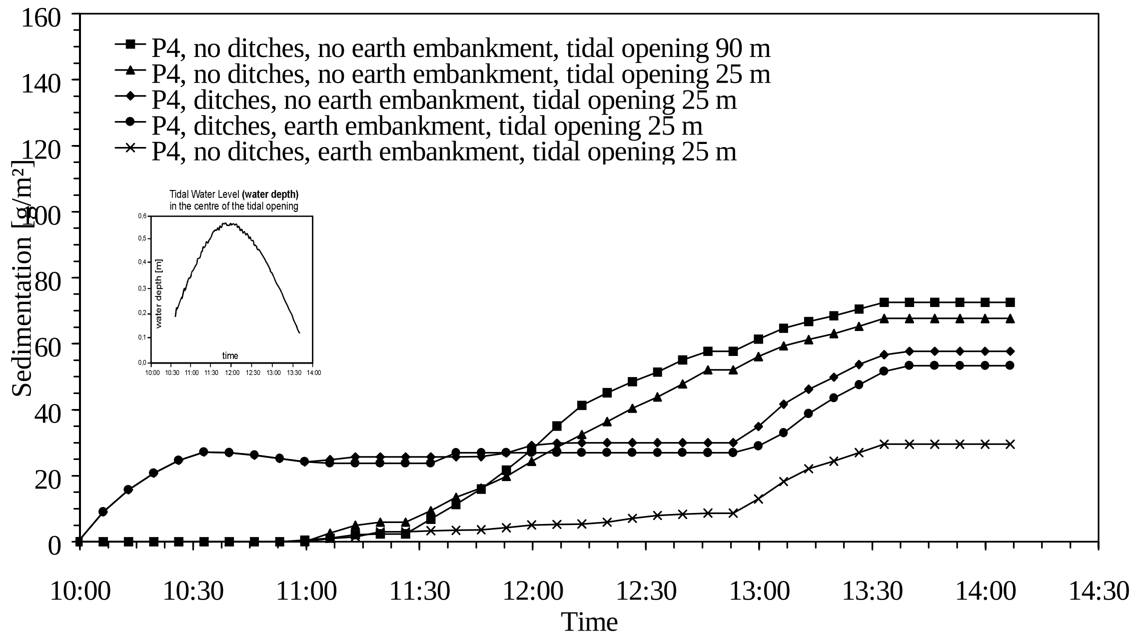


Fig. 9: Sedimentation and Erosion [g/m^2] during one Tidal Period at Point P4

SUMMARY

Increase of the level of certain areas of the Wadden Sea through enforced sedimentation in front of the main dikes by introducing sedimentation fields surrounded with brushwood fences („Lahnungen“) is confirmed from physical and numerical simulations with the verification from field measurements. Effects of oblique waves and tidal currents and extreme water levels (storm tides) are subject of ongoing research.

Acknowledgements

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