# CHAPTER 60

# PREDICTION OF THE HEIGHT OF TIDAL DUNES IN ESTUARIES

by

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## ABSTRACT

In this paper prototype data of echo soundings of tidal dunes are analysed. A good relation between the fresh water discharge and the sand wave migration velocity in the upper part of a tidal river could be determined. The limitation of the dune heights as a function of the mean current velocities over the crests and the bed material characteristics is presented. States of equilibrium are described by dimensionless parameters and the latter compared with model tests.

## INTRODUCTION

In estuaries with beds of sand-sized material significant sand waves or tidal dunes can occur. These sand waves are very important for navigation, because the draft of vessels is limited by the crests of the bed forms.

A program of bottom soundings has been conducted on the Weser River (West Germany), downstream from km 18 to km 59 (Fig.1). Recently, a study was initiated at the Franzius Institut to analyse the resulting data of the soundings from 1966 to 1972 with the goal of gaining a better understanding of tidal dunes and the factors which influence their behaviour. The test reaches chosen for the investigation are presented in Fig. 1.

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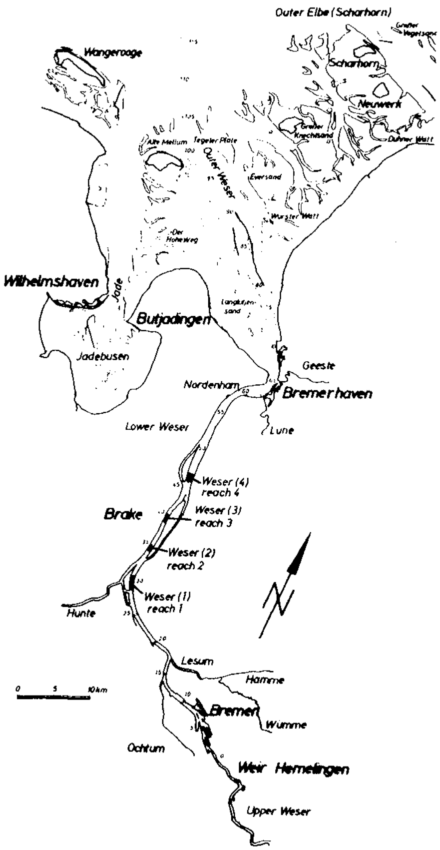

Fig. 1 Weser River with Test Fields

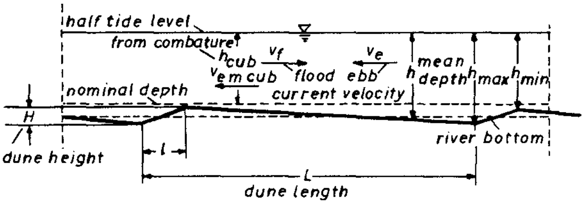

Fig. 2 Definition Sketch

## RESULTS OF THE MEASUREMENTS

In the upper part of a tidal region the mean current velocities are influenced by the fresh water discharge $Q_o$. The mean tidal range in the Weser varies from 3.35 m in reach 1 to 3.47 m in reach 4. The semi-diurnal tides in the Weser River are quite regular in range and duration of the flood and ebb currents. The four study reaches in the Weser are ebb predominant. The height and migration of the sand waves are influenced significantly by the long term change of the mean ebb current velocities $v_{em}$ as a consequence of the long term change of the fresh water discharge $Q_o$. As the mean tidal range does not vary much for a wide range of $Q_o$, the half tide level is nearly constant. By means of a cubature for a mean tide and different fresh water discharges $Q_o$, the current data in the navigation channel were calculated. They are presented as follows:

| $Q_o$ | Reach 1<br>$v_{em\ cub}$ | Reach 2<br>$v_{em\ cub}$ | Reach 3<br>$v_{em\ cub}$ | Reach 4<br>$v_{em\ cub}$ |
|---|---|---|---|---|
| $m^3/s$ | cm/s | cm/s | cm/s | cm/s |
| 100 | 82 | 92 | 81 | 83 |
| 282 | 88 | 97 | 86 | 87 |
| 600 | 94 | 100 | 89 | 92 |

In the cubature the calculated mean ebb current velocity $v_{em\ cub}$ is referred to a constant bottom level (nominal depth $h_{cub}$, Fig.2). In fact however, the level of the dune crests varies as a function of the mean ebb current velocities over the dune crests $v_{em\ max}$ ($h_{min} = f(v_{em\ max})$; $v_{em\ max} = f(Q_o)$). Only the mean values $\bar{H}$ of the dune heights and the mean level of the dune crests are treated.

From the diagrams in Fig. 3 it can be seen, that the dominant parameter for the change of the bottom pattern in the Weser River is the fresh water discharge, which influences directly the current data and indirectly the sand wave height $\bar{H}$ and the sand wave velocity $\bar{u}$. The variation of the wave height $\bar{H}$ with time is more significant than the variation of the wave length (dashed line in the upper diagram of Fig. 3).

There is no correlation between the sand wave characteristics and the temperature of the Weser River (Fig. 4). During the winters of 1970/1971 and 1971/1972 the dunes were as high as they were during the summer months of the previous years and the velocities showed a similar tendency, in spite of the low water temperature (Fig. 3). The reason must be seen in the low fresh water discharge, and as a consequence, in the low ebb-current velocities during the winter periods of 1970/1971 and 1971/1972. Consequently it can be stated, that water-temperature does not effect substantially the dune-height.

A strong correlation(r) and a nearly linear relation between sand wave velocity $\bar{u}$ and $\bar{Q}_o$ (mean fresh water discharge between the soundings) is apparent from the plotting in Fig. 5. The scattering of the points for reach 1 is similar to that for the other study reaches.

With increasing fresh water discharge the mean ebb-current velocity increases. The prototype data showed that - starting with equilibrium conditions - with increasing abb-current velocities $v_{em\ cub}$ the dune crests are eroded until a new state of equilibrium with flatter dunes is established. With decreasing $Q_o$ and $v_{em\ cub}$ the dune crests

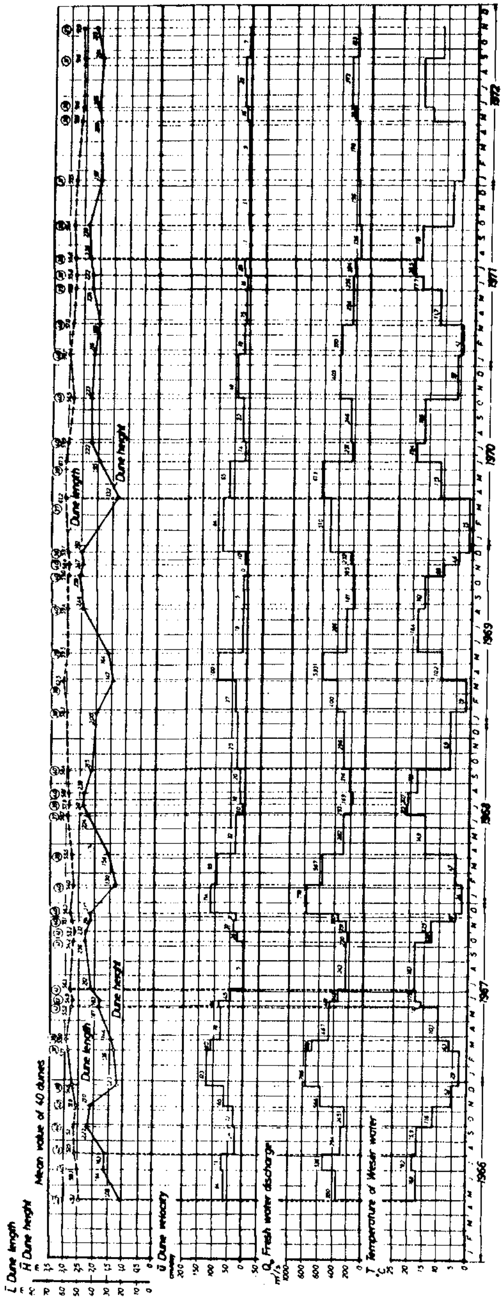

Fig. 3 Dune Characteristics of Test Field 1

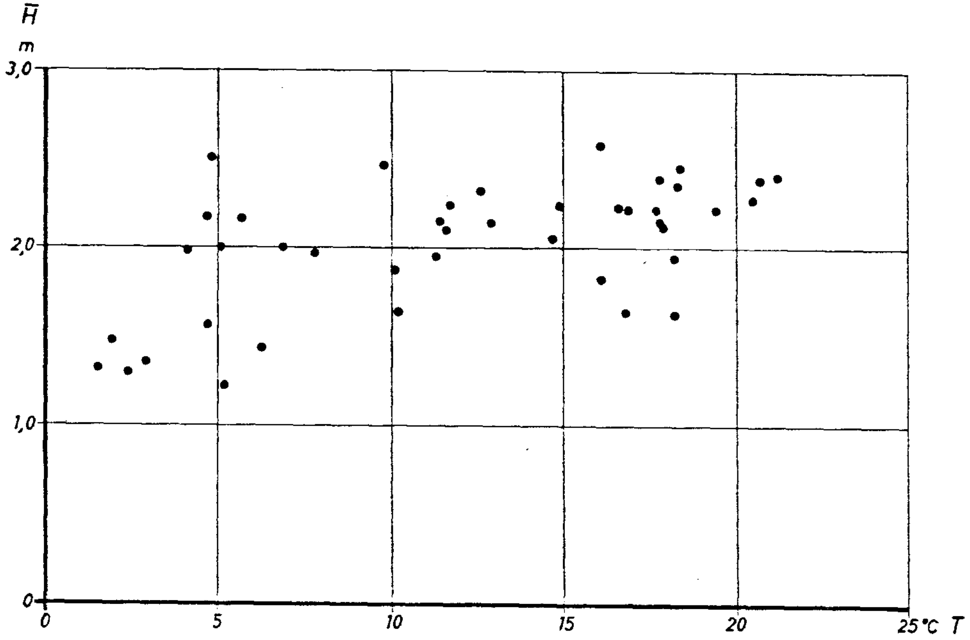

Fig. 4 Dune Height $\bar{H}$ and Temperature T of Weser Water (Reach 1)

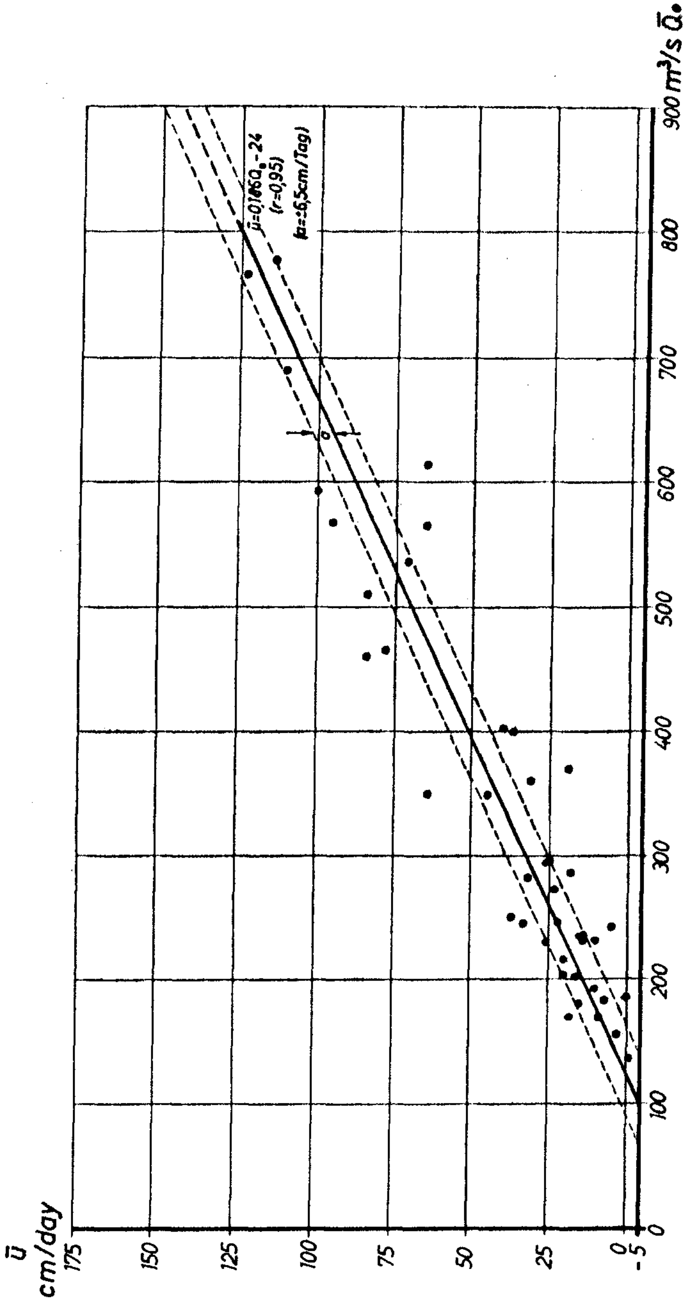

Fig. 5 Relation between Dune Velocity ū (cm/day) and Fresh Water Discharge $Q_o$ (Reach 1)

rise due to sedimentation until another new state of equilibrium is reached (Fig. 6).

There is a certain phase-lag between the change of $Q_o$ and the change of the sand wave height $\bar{H}$. In a first approach, a state of equilibrium is reached when there is a quasi-steady freshwater discharge for about 30 days, $Q_{o\ 30}$. Each state of equilibrium is characterised by a certain limiting mean ebb current velocity over the dune crests $v_{em\ max} = v_g$, which is a function of the sediment characteristics. The results for $v_g = f(\bar{D}_m, \frac{D_{90}}{D_{10}})$ are as follows:

| Reach | $\bar{D}_m$ mm | $\frac{D_{90}}{D_{10}}$ | $v_g$ cm/s |
|---|---|---|---|
| 1 | 0,54 | 3,40 | 100 |
| 2 | 0,55 | 3,48 | 104 |
| 3 | 0,36 | 2,08 | 93 |
| 4 | 0,47 | 3,04 | 96 |

$$\text{with} \quad \bar{D}_m = \sum_{D_{10}}^{D_{90}} \frac{D}{9}$$

$\bar{D}_m$ is the mean value of some samples taken in September 1972 in the different dune fields of the Weser River. Samples taken in 1969 show the same general tendency of grain sizes in the different study reaches. It is therefore assumed that the grain diameter $\bar{D}_m$ does not change much with time.

By means of the diagram of Fig. 6 a prediction of the average

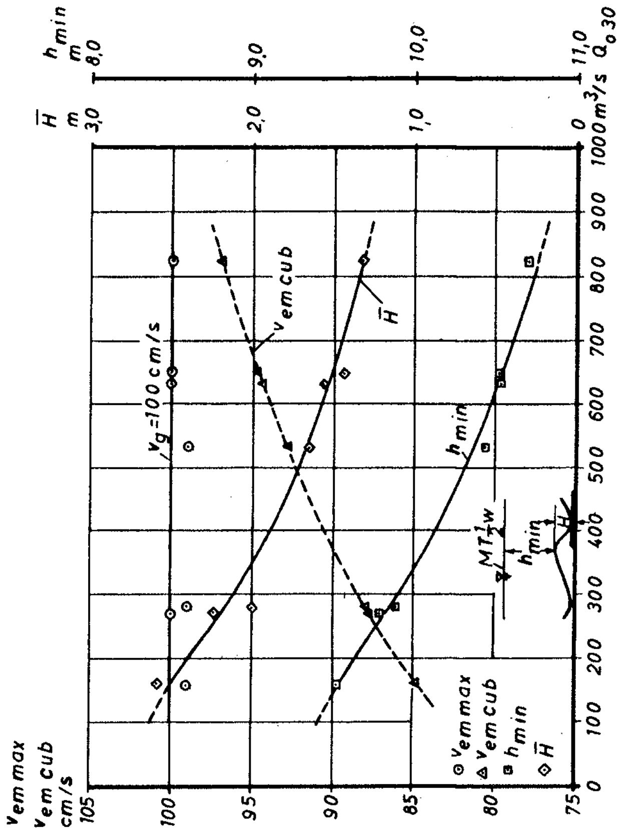

Fig. 6 Equilibrium values for different fresh water discharges (Reach 1)

crest height, $h_{min}$, below the mean tide level is possible for a wide range of fresh water discharges $Q_o$. If the current velocity $V_{em\ cub}$, the nominal depth $h_{cub}$ and $v_g = f(\bar{D}_m, \frac{D_{90}}{D_{10}})$ is known, the average crest height can be determined by means of the following equation

$$h_{min} = \frac{v_{em\ cub}}{v_g} \cdot h_{cub}.$$

For every reach, all states of equilibrium are characterised by two constant dimensionless parameters which are defined as follows

$$\alpha_{MIN} = \frac{\bar{w}}{v_g} \qquad (1)$$

where $\bar{w}$ is the fall velocity of the sediment particles (after WIEDENROTH, 1967,(5))

$$\bar{w} = \frac{11,15}{d} \left(\sqrt{1 + 9,7\,(\gamma_s - 1)\cdot g \cdot d^3} - 1\right)$$

and $v_g = v_{em\ max}$.

The second dimensionless parameter is given by:

$$f_{MAX} = \frac{v_g}{g \cdot \bar{D}m} \qquad (2)$$

with g = acceleration due to gravity.

The results obtained for the 4 test reaches in the Weser River are as follows:

| Reach | $\alpha_{MIN}$ | $f_{MAX}$ | $\bar{D}_m$ mm | $v_g$ cm/s | $\bar{w}_m$ cm/s |
|---|---|---|---|---|---|
| 1 | 0,080 | 189 | 0,54 | 100 | 8,0 |
| 2 | 0,079 | 200 | 0,55 | 104 | 8,2 |
| 3 | 0,061 | 245 | 0,36 | 93 | 5,7 |
| 4 | 0,075 | 200 | 0,47 | 96 | 7,2 |

## COMPARISON WITH RESULTS OF MODEL TESTS

In a first step, the results of the prototype measurements are compared with model tests where the water depths in the flume was between 0,25 m and 1,0 m. (DILLO, 1960; FRANZIUS-INSTITUT, 1960, (1), (2)).

The bottom pattern in the model tests changed at certain mean current velocities $v_m$ from ripples to sand waves with ratios H/L similar to those observed in prototype with water depths of about 10 m. The mean diameter $D_m$ of the sands used in the model tests were:

$D_m$ = 0,3 mm ("Syltsand")
$D_m$ = 0,2 mm ("Norderneysand")
$D_m$ = 0,36 mm ("Huntesand")

The mean flow velocities at which sand waves in the model started forming were:

$v_m$ = 90 cm/s ("Syltsand")
$v_m$ = 82 cm/s ("Norderneysand")
and $v_m > 85$ cm/s ("Huntesand")

The dimensionless values $\alpha$ and f were calculated in the same way as $\alpha_{MIN}$ and $f_{MAX}$ for the prototype data

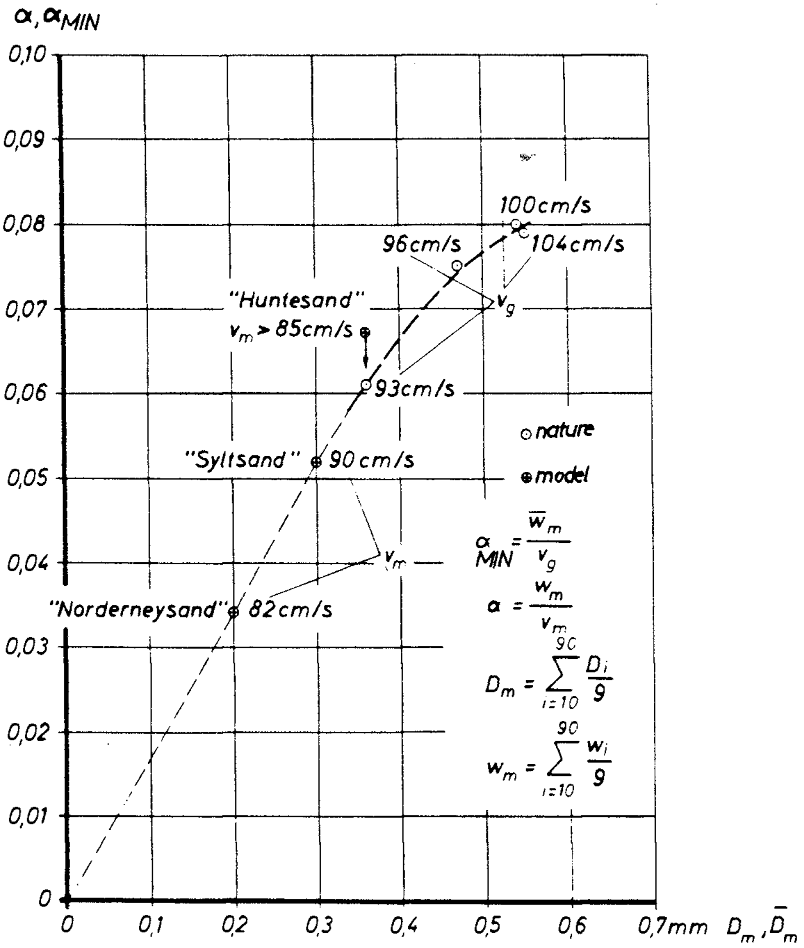

Fig. 7 Relation between α and $D_m$ in prototype and model

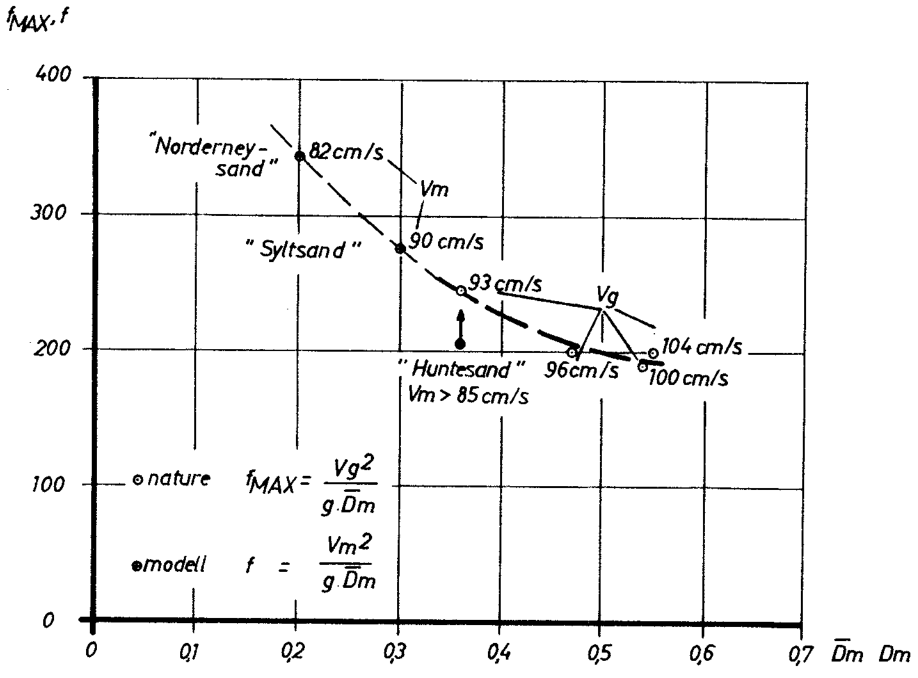

Fig. 8 Relation between f and $D_m$ in prototype and model

and are plotted in Fig. 7 and 8. It can clearly be seen that model and prototype data show the same tendency.

## CONCLUDING REMARK

It should be the goal of further investigations in the prototype and in the model to gain a functional relationship between the sediment data and both α and f.

## ACKNOWLEDGEMENT

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