SAND TRANSPORT UNDER THE ACTION OF WIND

by

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ABSTRACT

Field investigations on sand-transport by wind were carried out at German North-Sea coast. A special trap was constructed, which allows to measure bed load and suspended load seperated. In addition wind speed was measured up to 10 m over the bottom. The results of the field investigations were used to calibrate a transport-equation for sand-transport by wind.

1. INTRODUCTION

In coastal areas much sand is transported by the flow of wind. Hence wind generated sand movement on coasts can be a major factor in some areas, but very little is known about the basic meachnisms of the transport by wind yet. With growing use of artificial placement of sand for restoration and protection of beaches, wind generated sand movement shoreward of the waterline has become more and more a matter of interest.

In 1978 (4) the author presented a new transport equation which is valid for the calculation of bed load as well as suspended load in water flow, as it was demonstrated by many examples. Based on some results on the quantity of wind-generated sand transport given by KADIB (1964), O'BRIEN (1936) and EXNER (1928), the author demonstrated that the above mentioned equation is, in principle, also valid for wind generated sand transport. Either most of the earlier experimental results on wind transport were taken from tests in small wind tunnels and were carried out with sand-traps that did not seperate the bed load and the suspended load, or the particular results for the two types of transport have not been published.

Hence, field measurements on sand transport under the action of wind were carried out at the German North Sea coast (Island of Spiekeroog). Based on the results of these measurements, the transport equation was calibrated for the sediment transport by wind.

2. THEORY

The transport equation given by the author (4) is

$$q_b = a_1 \left(\frac{v_1^2 - v_{c1}^2}{w^2}\right)^2 D^{*4} \, \nu \frac{1}{p} \text{ for bed load} \qquad (1a)$$

$$q_s = a_2 \, f(h) \, \frac{(v_1 - v_{c1}^2) \, (v_1^2 - v_{\ell 1}^2)}{w^4} \, D^{*4} \, \nu \frac{1}{p} \, f(visc) \qquad (1b)$$

for suspended load.

Herein is

q	=	transported volume per unit width and unit time
v_1	=	actual bottom velocity in the reference level y_1 = 1 cm over the bottom
v_{c1}	=	critical velocity for start of bed load movement (in y_1 = 1 cm)
$v_{\ell 1}$	=	critical velocity for start of suspension
w	=	terminal settling velocity
D^*	=	$(\rho' g/\nu^2)^{1/3} d$
d	=	grain-size
g	=	coefficient of acceleration
h	=	flow depth
ρ'	=	$(\rho_s - \rho_F)/\rho_F$
ρ_s	=	density of sediment
ρ_F	=	density of fluid
ν	=	kinematic viscosity
p	≈	0,7; factor regarding the degree of compaction of natural sands
$f(h)$	=	$(h/h_1$ with h_1 = reference level y_1 = 1 cm, for water flow; 1 for flow
$f(visc)$	=	$(\nu/\nu_o - \nu)^{1/4}$ for water flow ($\nu_o = \nu$ at 0°C); 1 for air flow

The values of a_1 and a_2 are also different in the case of water or air flow probably because the turbulence structure, which is not directly included in Equ. (1), is different in both cases. (For water flow $a_1 = 10^{-7}$ and $a_2 = 10^{-8}$ (for air flow see 4. RESULTS).

The critical velocity v_{c1} in Equ. (1) is

$$v_{c1} = A + B - \sqrt{AB} \qquad (2)$$

$$A = C_1 \cdot 2{,}4 \cdot (\rho_s' \, gd)^{1/2} \qquad (2a)$$

$$B = C_1 \cdot 7{,}78 \cdot (\rho_s' \, g\nu)^{1/3} \qquad (2b)$$

C_1 = 1 for water flow / 0.5 for air flow

$$\rho_s' = \rho' + \rho_a/\rho_F \qquad (3)$$

where ρ_a is an "additional weight" effected by adhesion forces

$$\rho_a = \begin{cases} 9 \cdot 10^{-5}\ (cm^2)/d^2 \text{ for natural sand in water;} \\ \text{function of moisture content for sand in air} \\ \text{(see 4. RESULTS)} \end{cases}$$

The critical velocity $v_{\ell 1}$ in Equ. (1b) is given by the author (4)

$$v_{\ell 1} = C_1 \cdot 3{,}14\ w \qquad (4)$$

where

$$w = \frac{11\nu}{d} \left(\sqrt{1 + 0{,}01\ D^{*3}} - 1\right) \qquad (5)$$

3. EXPERIMENTAL TECHNICS

For the calibaration and test of the equation for wind flow, field measurements were carried out at the German North Sea coast over a duration of altogether 15 weeks in 1978 and 1979. During this time, wind-velocity profiles were measured up to 10 m over the bottom and sand-transport was measured seperately as bed-load and suspended load in two large traps. The inlets of the traps moved automatically into the direction of wind. The results were registrated continuously. In addition, air humidity, air temperature, air pressure and moisture content of the sand in the traps were measured. The following figures give an overview of the sand traps used during the field measurements. (The pictures were taken after heavy rainfall. Therefore the sand is wet).

Figure 1 is an overview of the test field: On a mast 5 wind-velocity-meters (variable hight) were installed. The apparatus in front of the mast is the suspended-load-trap.

Figure 2 is a view to the front inlet of the trap. Sand and air enter the trap and are seperated inside the trap. The wind-outlet is on the upper backside. The velocity-profile is not disturbed in front of the inlet. The sand in sampled inside the trap. The weight of the sampled sand is measured automatically and is plotted continuously.

Next, Figure 3, shows the entry of the bed-load trap. The sand moving near the bottom falls into an underground-trap. The axis of the inlet for the bed-load-material is always directed to the wind by the suspended-load-trap. Thus the area of the inlet is well defined every time. The weight of sand sampled in the bed-load-trap is also plotted continuously.

Fig. 1

Fig. 2

Fig. 3

4. RESULTS

Based on the measurements the following results were obtained:

1. ρ_a in Equation (3) can be approximated by

$$\rho_a = \frac{0{,}116 \ \ln \ (W^{1/2} + 1)}{d^2} \quad \frac{(cm^2)}{(cm^2)} \quad \text{for } W > 0{,}0025 \qquad (5a)$$

or

$$\rho_a = \frac{2{,}28 \ \ln \ (W + 1)}{d^2} \quad \frac{(cm^2)}{(cm^2)} \quad \text{for } W < 0{,}0025 \qquad (5b)$$

or

$$\rho_a = \frac{8 \cdot 10^{-3} \ \ln \ (H + 1)}{d^2} \quad \frac{(cm^2)}{(cm^2)} \qquad (5c)$$

where $W = \dfrac{\text{weight of wet sample - weight of dry sample}}{\text{weight of dry sample}}$

H = relative humidity of air

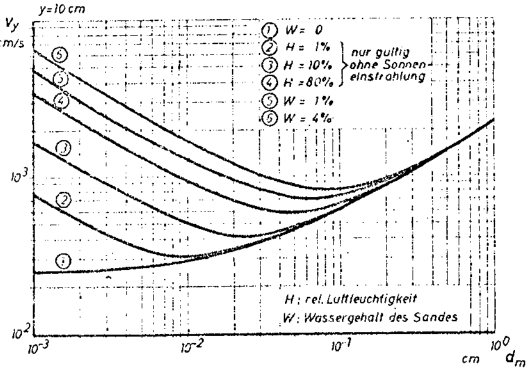

Fig. 4
Threshold velocities under wind action

Fig. 4 illustrated the dependence of threshold velocity on moisture content. Equations (5a) and (5b) are only valid for a short time after a rainfall. Then the sand is dried by the flow of wind and the critical velocity decreases. Nevertheless it is still impossible to set up a formula to calculate this decrease for each practical case, because in the nature sunshine, rainfall and wind speed can change rapidly. Moreover, some time after a rainfall, a layer of comparatively dry sand moves over a layer of more wet sand.

Equation (5c) is only valid, if there is no sunshine and if the moisture content is only effected by air humidity.

As a result of the measurements, calculations for practical use should at present therefore be carried out taking

$\rho_a \approx 0$ to $5 \cdot 10^{-4}/d^2$ for comparatively dry sand
$\rho_a \approx 2 \cdot 10^{-3}$ to $4 \cdot 10^{-3}/d^2$ for moved wet sand
(d in cm)

2. The values of a_1 and a_2 in Equations (1a, 1b) could be determined to be $a_1 \approx a_2 \approx 1.5 \cdot 10^{-6}$ in the case of sand-transport by wind.

3. For calculations of the quantity of wind generated sand transport in the nature the wind speed is, in general, only given for one level. Thus, to set the actual velocity in this given level in relation to the reference level of $y_1 = 1$ cm in Equs. (1), (2), (4), the velocity profile must be known. The investigations on the velocity profile gave the result that the velocity profile in the nature can be calculated by the Prandtl - Equation for rough boundary conditions with good agreement.

$$\frac{v_{y1}}{v_{y2}} = \frac{\ln \frac{30 \cdot y_1}{d}}{\ln \frac{30 \cdot y_2}{d}} \qquad (6)$$

Equation (6) could be shown to be valid up to 10 m over the bottom for a velocity range between threshold and 20 ms^{-1} although the sand in the test field was comparatively fine (d = 0.24 mm) (see Fig. 5). Effected by the irregularities of a natural sand bed in opposite to laboratory tests, a velocity distribution according to smooth conditions was never registrated.

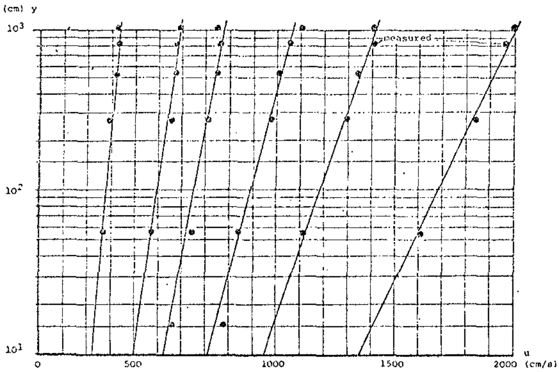

Fig. 5
Some examples of observed velocity profiles

5. SUMMARY AND CONCLUSIONS

A method for the calculation of the rate of wind generated sand-transport was developed in a half-empirical way. It could be demonstrated, that the critical velocity, v_c, increases rapidly if the sand becomes wet. Subsequently, depending on the duration and strength of wind, air humidity and rate of sunshine the layer of sand becomes drier and v_c decreases. On the functional coherences of these effects further research is needed.

For practical purpose an approximation for the calculation of v_c is given in this paper based on a great number of field investigations.

6. ACKNOWLEDGEMENTS

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