SITE INVESTIGATION ON SAND CONCENTRATION IN THE SHEET-FLOW LAYER

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ABSTRACT

Field measurements of sand concentration in the sheetflow layer have been carried out in the swash zone on a beach on the island of Norderney. Simultaneous registration of both sediment concentration at three levels and the velocity of wave induced water movement in the boundary layer gives an impression of the phenomenon sheetflow for prototype conditions.

1 INTRODUCTION

The development of sheetflow due to oscillating water movement for laboratory condititions was already reported 35 years ago by MANOHAR (1955). HORIKAWA et al. (1982) measured the vertical distribution of sand concentration and orbital velocities in the sheetflow layer in a wave tunnel. Meanwhile the observation of sheetflow in the

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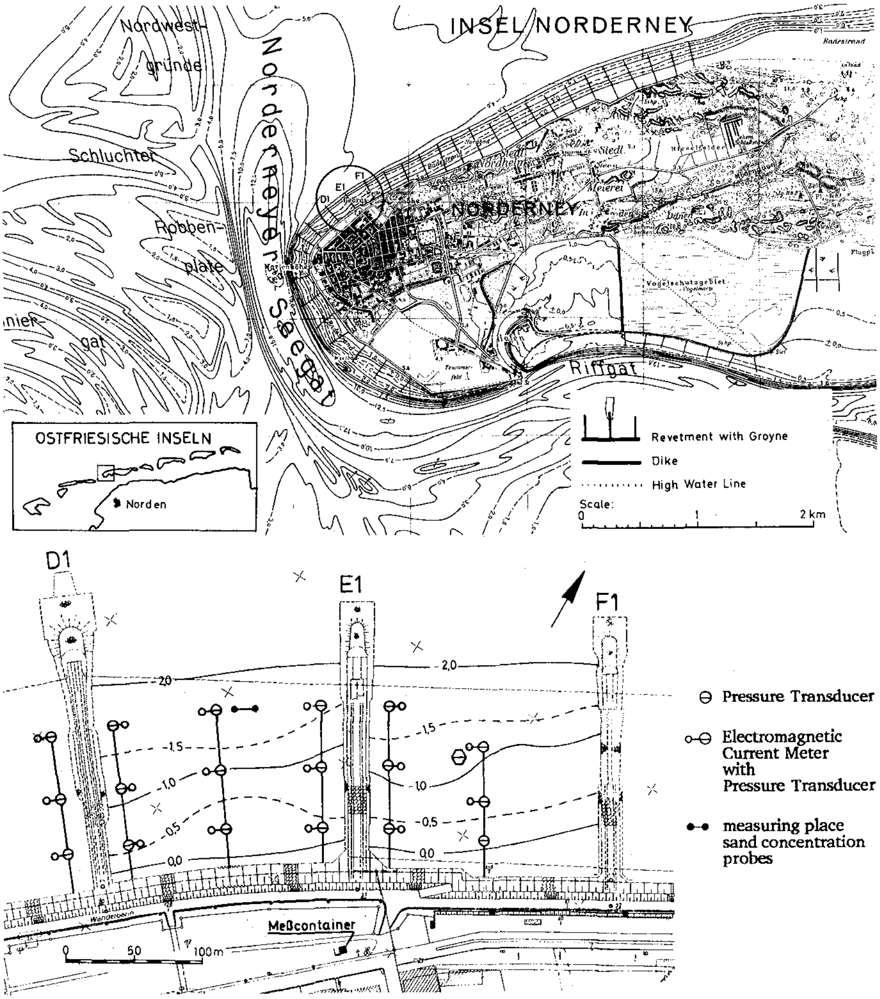


Fig. 1: Measuring site of the Forschungsstelle Küste at Norderney

prototype has also been mentioned and recently numerous theoretical studies and laboratory experiments have paid attention to the subject of sheetflow (BAKKER et. al 1989).

Under the umbrella of a Dutch-German cooperation site investigations on sheetflow has been started on the East Frisian island of Norderney, East Frisia, F.R. of Germany. Purposes of this study have been:

a. to obtain measured prototype data of sheetflow, which can provide some pictures of the reality of sheetflow,

b. to gain experience for future large scale field measurements.

2 MEASURING SITE AND INSTRUMENTATION

The measurements have been carried out in the measuring array (Fig. 1) of the Coastal Research Station Norderney (CRS), where a matrix of wave and current meters is installed on the beach (NIEMEYER 1991). Additionally electrical resistance probes for measurements of sand concentration are used during the experiments, which have originally been developped and manufactured by DELFT HYDRAULICS for laboratory investigations. Due to limited financial resources only three probes have been avaible for this pilot study.

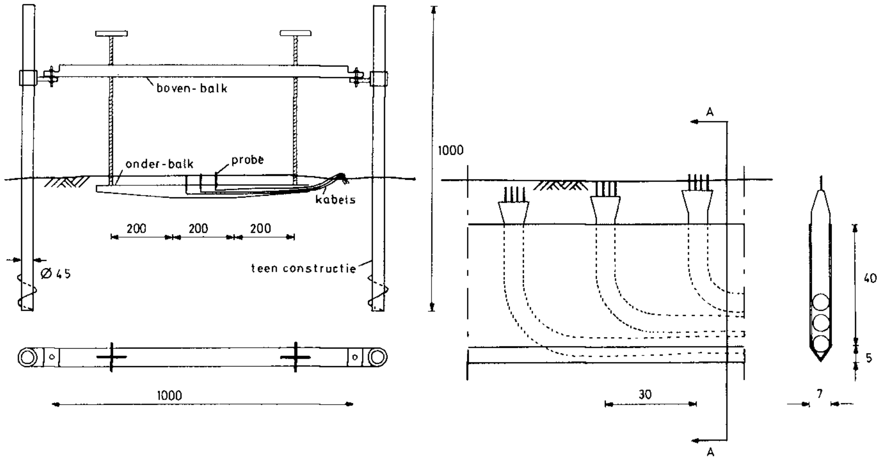


Fig. 2: Measuring set-up, **right:** front- and top-view of the set-up, **left:** detail position of probes on the lower bar of the frame

In the first stage of the study trials have been carried out to get a suitable frame construction (Fig. 2). The basic conception, which had been developped at Delft University of Technology had to be improved step by step due to prototype experience. Design and manufacturing was carried out at the Coastal Research Station. This construction meets the following requirements:

a: limited disturbance of water and sediment movements which should be unaffected in the area around the probes, b: flexible, exact adjustable vertical level for each probe.

This instrumentation was already described by BAKKER et al. (1989).

3 CALIBRATION

The probes had only been used at DELFT HYDRAULICS for freshwater. For prototype measurements in salt water it was therefore necessary to adapt their measuring range and to carry out a corresponding calibration. Its final goal is to get a general function

$$U = f\ (\text{field parameters}) \tag{1}$$

where U is the output of the probe [V].

The calibration procedure was carried out in consideration of the following four parameters with respect to the output signal of the probes:

1. characteristics of sediment particles
2. sand concentration
3. temperature
4. salinity

The first parameter was taken into account by using sand from the measuring site. This allows the simplification of formula (1) to

$$U = f\ (\ c,\ S,\ T\ ) \tag{2}$$

with c: volumic sand concentration [%]
S: salinity [ppt]
T: temperature [°C].

A suitable experiment set-up was installed in the soil mechanics laboratory of the CRS. Sand-water mixtures with variable 'composition' (c, S, T,) were created by use of a mixer to simulate conditions according to prototype boundary conditions:

- uniform suspension in the entire water column for sand concentrations from 0 to 45 %

- variation of salinity between 20 and 35 ppt

- controlled water temperature for a range of 2 - 20 °C

The treatment of calibration data was done by multiple regression analysis. As a result the following calibration function was established:

$$U = \sum_{j=1}^{3} \sum_{i=1}^{3} a_{ij} \, x_i^{b_{ij}} \, x_j^{b_{ji}} \tag{3}$$

where: a_{ij}, b_{ij}, b_{ji} are constants derived from the regression-analysis and

$$x_1 = 1 - c$$

$$x_2 = S$$

$$x_3 = T$$

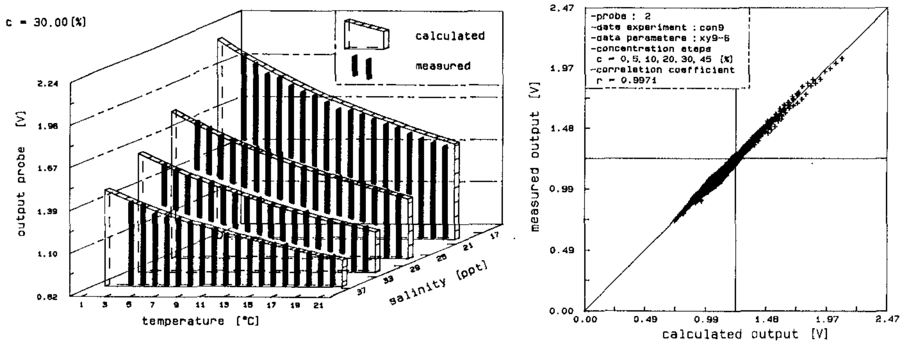


Fig. 3: left: Fitting of calibration function to data for variations of temperatur and salinity,
right: Fitting of calibration function for variations in sand concentration

Scatter diagramms for calibration data in comparison to the calibration function for variations of sand concentration, salinity and temperature demonstrate its applicability and soundness (Fig. 3).

4 EXECUTION OF FIELD MEASUREMENTS AND DATA ANALYSIS

The installation of the probes with the frame (Fig. 1 and 2) took always place at low tide close to one current meter of the existing measuring array (NIEMEYER 1991). The probes had a cable connection to a data acquisition system which was established in a container close to the beach (Fig. 1). For the performance of the system two cooperating crews are acting: one at the measuring site and the other one in the container.

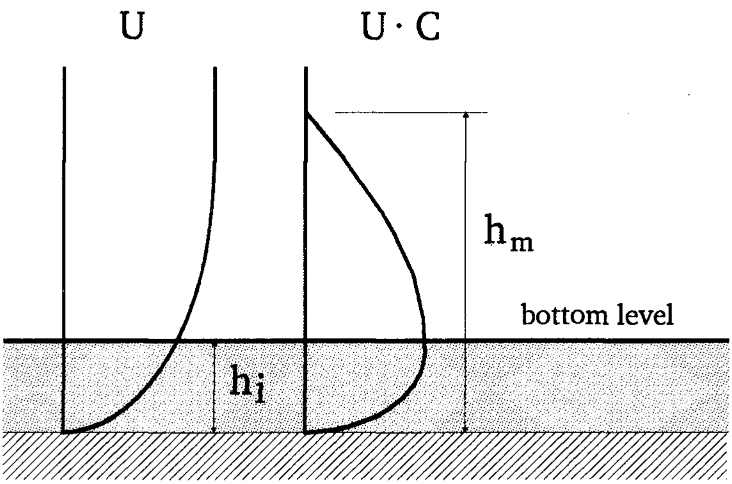


Fig. 4: Definition of intrusion depth and thickness of moving layer

The measuring procedure was started, when the sea bed near the probes was covered by water of the rising tide. It is very important to ensure that the probes 'stay' in the moving layer (definition: Fig. 4). The crew in the container acts therefore as steering group. By observation of the measuring signals on a strip chart recorder the current position of the probes and necessary readjustments could be evaluated:

- the probe is in water ($c = 0$)
- the probe is in sand ($c = co$, co: maximum concentration)
- in the moving layer ($0 < c < co$, variable in time)

The measuring strategy is to keep the lowest probe at the level where sand particles will just move or not. This is necessary for the estimation of the intrusion depth h_i and guarantees that the two higher placed probes will catch the moving layer. If a readjustment of the probes is required due to erosion or sedimentation, orders will be given from the container crew by radio to the beach crew in order to follow the moving layer by heightening or lowering the frame. The measurements could be continued in this manner until rising water level and increasing wave heights force the crew to leave the beach.

Additionally temperature T and salinity S are measured in order to establish proper data sets. For this case function (3) may be reduced to

$$g(c) = 0 \qquad (4)$$

which allows the derivation of c by iteration.

5 RESULTS OF THE MEASUREMENTS

Several measurements have been performed in the swash zone on the beach of Norderney. As the electromannetic current meters must keep within a certain distance from the sea bed, velocity registrations show many distrubances at begin of each time series, because the sensor head is not continuously covered by water. If the sensor head falls dry, it measures wind speed. Data of one time series will be discussed here concerning the following aspects:

- concentration in the moving layer h_m,
- intrusion depth of the sheetflow h_i,
- local morphological change during the measurement.

Additional boundary conditions of the measuring set-up and initial beach geometry are:

- height of current meter sensor head above sea bed: 70 mm
- beach slope: ~ 1 / 60
- vertical difference between probe levels:
  3 mm between 1 (highest) and 2 (center);
  2 mm between 2 and 3 (lowest)

Measured concentrations at three levels and the cross- and longschore components of wave induced currents are plotted in Fig. 5. At the beginning (mark A) probe 3 is just at the lower boundary of the moving layer (level of the intrusion depth) and probe 1 is above the sea bed. It only measures sand concentrations, if high velocities occur. The intrusion depth h_i of the sheetflow should be about 2 mm and the total moving layer h_m might have a thickness of nearly 7 mm at mark A and B. The current meter is from time to time exposed to air, especially in the final stage of backwashes. Between the marks C and D a layer with a thickness of 2 mm or more is eroded, but is afterwards again restored by sedimentation.

The continuation of this registration is shown in Fig. 6: At mark E there is an intrusion depth of less than 2 mm and a moving layer of about 4 mm. Responding to large velocities as well higher concentrations occur as the layer thickness increases (mark F: h_i ~ 3 mm, h_m ~ 8 mm). Noteworthy is also the rapid change of onshore-offshore current directions. This specific feature of wave induced currents in the swash zone is totally different from the orbital motions which are reproduced in wave tunnels in order to generate sheetflow conditions there, as e. g. done by HORIKAWA et al. (1982) or BAKKER et al. (1988).

The maximum intrusion depth occurs often in coincidence with flow direction changes (long backwash followed by large uprush) which is obviously the case at mark F and again at mark G. At mark F both probe 2 and 3 are still covered with sand (c=co). But then both are subsequently eroded and the resedimentation is only sufficient to recover probe 3 which is finally eroded at mark G. This resulting step by step erosion does occur in the final stage of long backwash movements with increasing offshore directed velocities. Even the comparable high onshore directed velocities of the uprush do not have the same effectiveness with respect to resedimentation, as the uprush duration is remarkably lesser than that of the backwash.

This causes a continuous erosion during the first stage of the rising tide. At the measuring point an erosion of about 5 mm has taken place some 30 minutes after the start of the registration. During the following 10 minutes a layer of another 4 mm sand has additionally been washed away. As documented in Fig. 7 the erosion process could even accelerate: the frame is lowered at mark H to a level which is 4 mm lower than before. But within less than three minutes this layer is again eroded (mark I).

Another 10 minutes later the probes are already 24 mm lower than at the beginning (Fig. 8). This tendency remains stable for the whole measuring period: After an hour plus a few minutes a total erosion of about 55 mm has taken place.

With respect to the development of sheetflow conditions it seems noteworthy that a thickness of 2 mm does often occur and in some cases (e. g. mark F; Fig. 6) a thickness of 5 mm with concentrations of more than 5 mm. This is about twenty times of mean local sediment diameter.

Field Measurement of Sand Concentration in Sheetflow Layer

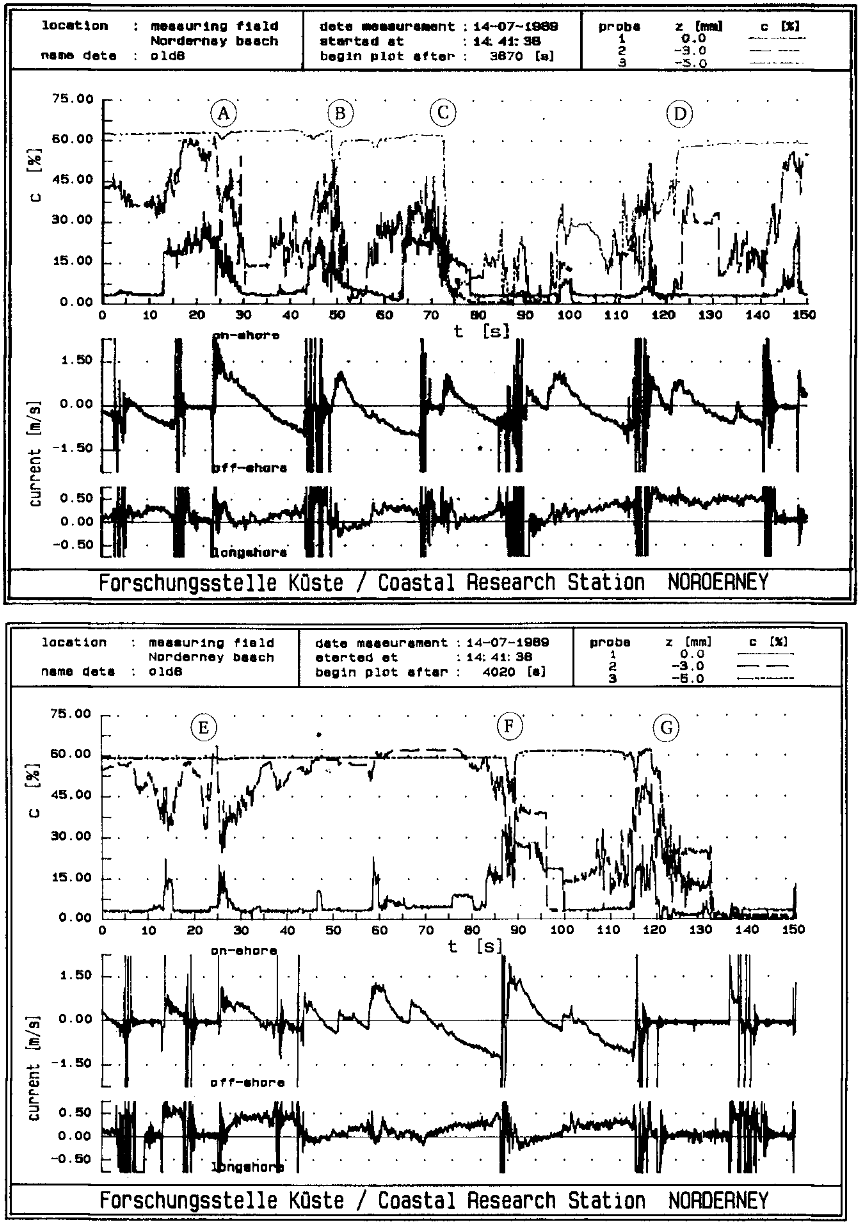
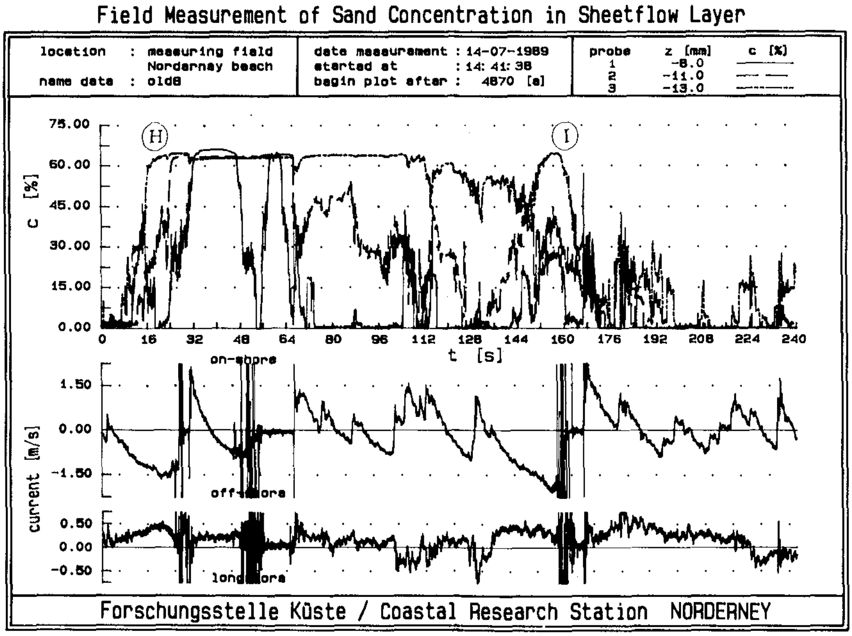


Fig. 5+6: Time series of sand concentration on three levels with cross-shore and longshore current components. - Example 1+2



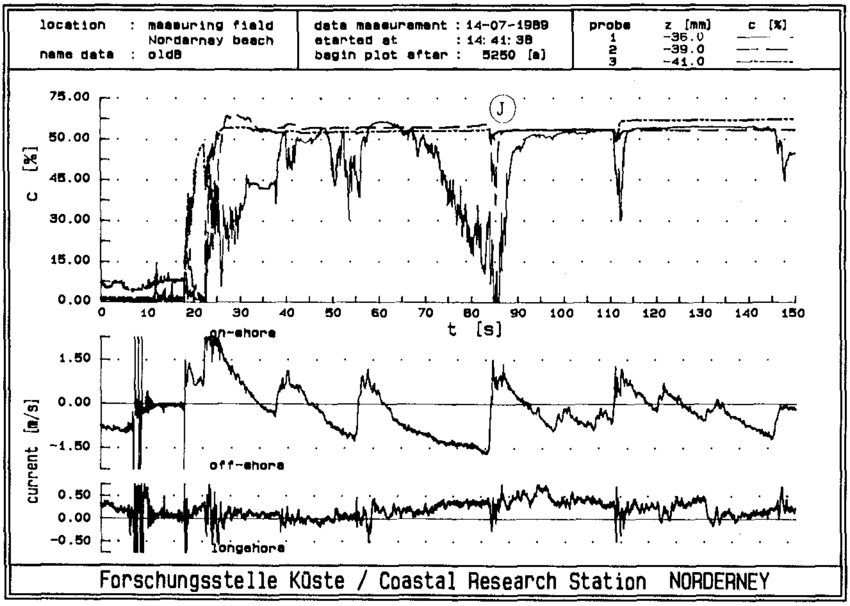


Fig. 7+8: Time series of sand concentration on three levels with cross-shore and longshore current components. - Example 3+4

6 CONCLUSIONS

6.1 INSTRUMENTATION

1. The measuring set-up is suitable (up to a water depth of about 1 m) for sheetflow measurements in the swash zone. However for measurements in the surf zone the system must be remote controlled in order to adjust the position of the probes with respect to bottom level fluctuations.

2. Measurements with three probes provide a quite good impression of the reality of sheetflow in field. Detailed studies will require more probes, because the large vertical gradients in sheetflow demand for distances of not more than 1 mm. In order to overcover the moving layer h_m with an expected maximum thickness of about 8 mm a measuring height of 10 mm is recommended.

3. The distance of the current meter of 70 to 100 mm to the sea bed causes disturbances due to measurements of wind speed when it falls dry. A lower position might effect scouring, especially for the occurence of high velocities and intensive sediment transport. The use of a finer shaped current meter might reduce this handicap.

6.2 Sheetflow and Beach Erosion

1. The measured maximal intusion depth h_i of sheetflow is about 2 to 5 mm and the maximal moving layer h_m is about 8 mm.

2. A moving layer can be observed if the near bottom velocity in the boundary layer exceeds a value of about 1.3 m/s. This takes mostly place in the final stage of the backwash.

3. At the measuring point a 55 mm thick sand layer was eroded within an hour and an average erosion rate of 1.5 mm/min does occur during the last 30 minutes of the measurement.

4. There is a certain correlation between erosion and backwash with long periods.

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REFERENCES

BAKKER, W.T., VAN KESTEREN, W.G.M. & YU, Z.H. (1989): Grain-Grain interaction in oscilating sheetflow. Proc. 21st Int. Conf. o. Coast. Eng. Costa del Sol - Malaga, ASCE, New York

BASINSKI, T. (1989): Field studies on sand movement in the coastal zone. Prace Instytutu Budownictwa Wodnego PAN, Nr 16 (Institute of Hydroengineering-Polish Academy of Sciences, Gdansk)

HORIKAWA, K., WATANABE, A. & KATORI, S. (1983): Sediment transport under sheetflow condition. Proc. 18th. Int. Conf. o. Coast. Eng. Capetown, ASCE, New York

MANOHAR, M. (1955): Mechanics of bottom sediment movement due to wave action. U.S. Army, Corps of Engineers, Beach Erosion Board, Tech. Memo. No.75

NIEMEYER, H.D. (1991): Field measurements and analysis of wave induced nearshore currents. Proc. 22nd Int. Conf. o. Coast. Eng. Delft, ASCE, New York