CHAPTER 200

INSTANTANEOUS SEDIMENT CONCENTRATION DUE TO WAVE ACTION AT PROTOTYPE SCALE

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1. INTRODUCTION

At sandy coasts the sediment transport due to wave action can cause beach erosion and loss of protecting dunes. In order to calculate the wave-induced sediment transport the physical parameter of wave height, wave-induced current, instantaneous sediment concentration and bottom elevation have to be known or measured. The following study was concerned with field measurements and extreme conditions (wave-induced sheet-flow transport), which were simulated at prototype scale in the Large Wave Flume (GWK) in Hannover.

2. MEASURING EQUIPMENT

From first investigations in the year 1987 with respect on wave-induced sediment concentration at velocities in the range up to 1.2 m/s followed the development of an electro-resistance- type-sediment-concentration-probe (ERSC) for prototype conditions. The idea arose from the small scale probe ERSC, used at wave tunnel experiments by HORIKAWA et al. (1982). The electric system enables the measurement of the bottom ($c/c' = 1.0$) and nearbottom concentrations at ripple as well as sheet-flow conditions.
The aim of the test series was, to get experience with the system. The probe ist still in development at the Leichtweiss-Institute in Braunschweig, and it has to be

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solved some structural problems. It will be presented, that the ERSC-probe is in principle prepared for measurements and that the results warrented the continuing development of the probe.

2.1 ERSC-PROBE IN FIELD TESTS

Since the GWK could be used only for a limited time for experiments with sand bottom, a prototype of the ERSC-probe, developed at the Leichtweiss-Institute of the Technical University of Braunscheig, was tested under field conditions at the island Norderney in the German Bight. The ERSC-probe had 6 electrodes in steps of 1 cm, connected to WHEATSTONE-half-bridges.

The ERSC-probe was positioned in the middle of an groyne field in the north-west part of the island. The water depth during the measurements was about 1.0 m, and the wave height about 0.5 m. The water temperature was T_w = 9°C. The sand near the test section had the mean diameter D_{50} of 220 µm and the geometric standard deviation was σ_g = 1.43.

The probe was installed after calibration under field conditions in the breaker zone during ebb tide, so that all electrodes were covered by sand. The assumption, that due to wave action the electrodes will be exposed, was verified by the electric signals. The reflection of waves from the groynes strongly influenced the measurements as seen from the current-vector during 40 s in Fig. 1. The wave-induced orbital velocity in on- and offshore direction could not be defined.

The time sequence of a measurement over 40 s is shown in Fig. 2. The upper part of Fig. 2 shows the measured wave induced velocity with a maximum of 1.38 m/s, registered about 0.1 m obove the bottom. Below are plotted the signals of 4 ERSC-electrodes, calculated from the extreme values of clear water and packed sand.

The correlation of the sediment concentration with the wave induced velocity is very difficult and the result cannot be used for basic research because of the current vector (see Fig. 1).

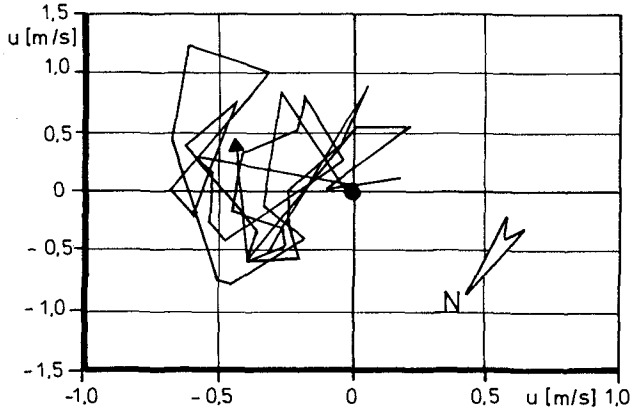

Figure 1. Current vector during 40 s of the measurement at the island Norderney

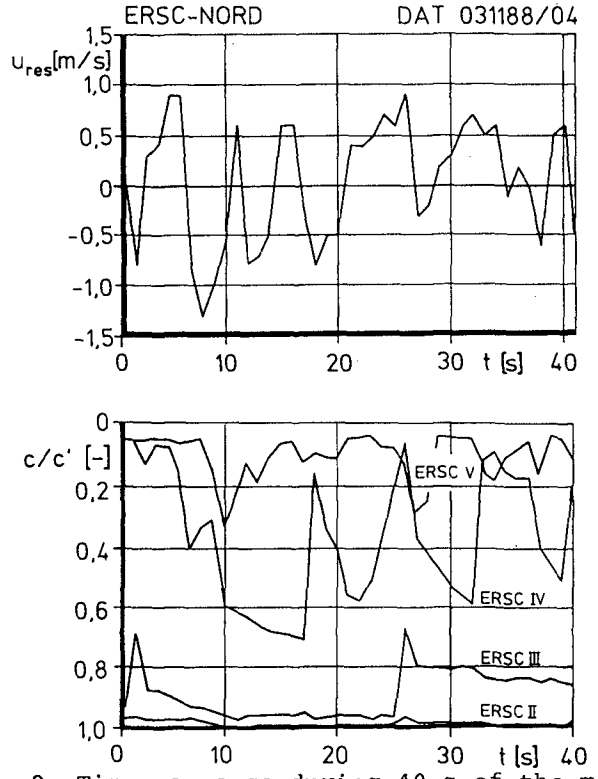

Figure 2. Time sequence during 40 s of the measurement at the island Norderney

Fig. 3 illustrates the variety of the vertical sediment concentration distribution during 40 s. The distance between the electrodes was 1 cm. The distribution between the measured values was plotted linear.

At the beginning of the measurement all wires were covered by sand and at the end the probe registered clear water, so that for the analysis the calibration values could be taken directly from the measurement. But, changing water temperature and conductivity has to be compensated in further developments. Scours due to vertical supports were assumed, but could not observed visually.

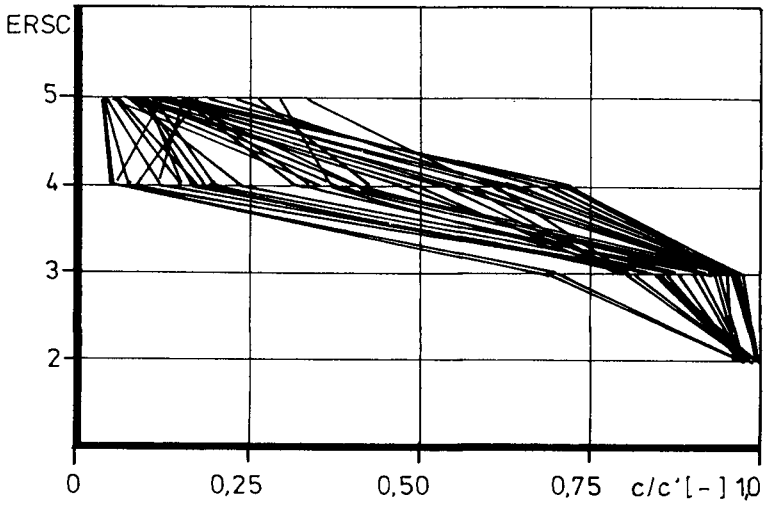

Figure 3. Sediment concentration distribution during 40 s of the measurement at the island Norderney

The results presented demonstrate the problems with informations gathering particularly on sediment concentration in the surf zone which can be used for basic research. The necessity of instantaneous data on wave induced sediment concentration and the possibillity to simulate high orbital velocities in the GWK in Hannover leaded to further investigations on the development of the ERSC-Probe.

2.2 THE ERSC-GWK-PROBE

The ERSC-GWK-probe (GWK: Large Wave Flume in Hannover) was developed at the Leichtweiss-Institute for large scale conditions. It recorded the instantaneous sediment concentration in the range of 7 cm (in steps of 1 cm) over the bed, and was steered by optical sensors, so that it should follow the bottom elevation as it changed due to hydraulic conditions.

The change of water temperature and conductivity was compensated with electrodes about 0.5 m above the bottom shielded against suspended material. These wires were connected parallel to the measuring electrodes within the WHEATSTONE-half-bridges. Consequently, only the sediment concentration was registered inside the electric field, of which 90 % were measured with a radius of 2.2 mm around each electrode. Starting from the principle, that an electric resistance has to be linear, the probe was calibrated for both extreme boundary conditions: clear water ($c/c'=0$) and wave-induced packed sand ($c/c'=1$). The scattering of both of these values yielded a measure of the accuracy.

The diameter of the wires was reduced from 1 mm (Norderney-probe) to 0.8 mm and the horizontal distance of the lateral supports was 8 cm.
The measuring section of 1 cm length on each wire was placed in the middle between the vertical supports.
Fig. 4 shows a sketch of the ERSC-GWK-probe.

Two optical sensors, one in vertical, the other in horizontal direction at the tip of one support recorded the distance of the lowest ERSC-wire to the sand bed. The sensitivity of the optical sensors was tuned in the laboratory in such a way, that the vertical sensor had all the time to register sediment concentration greater than about 1,000 g/l. The horizontal sensor had to measure clear water. The distance between both sensors was 1 cm. The hydraulic power steering, by means of on/off connections, should keep the probe near the bottom, so that the lowest wire, ERSC I, should register the near bottom concentration.

Under prototype conditions in the GWK the sensitivity of the optical sensors had to be tuned new before each test series. Therefore a constant distance was not kept for all test series. As the sensitivity was to less,

the lowest wires were covered by sand.
The time-analysis of the vertical movements yielded the order of magnitude of the bottom elevation changes even during a single wave.

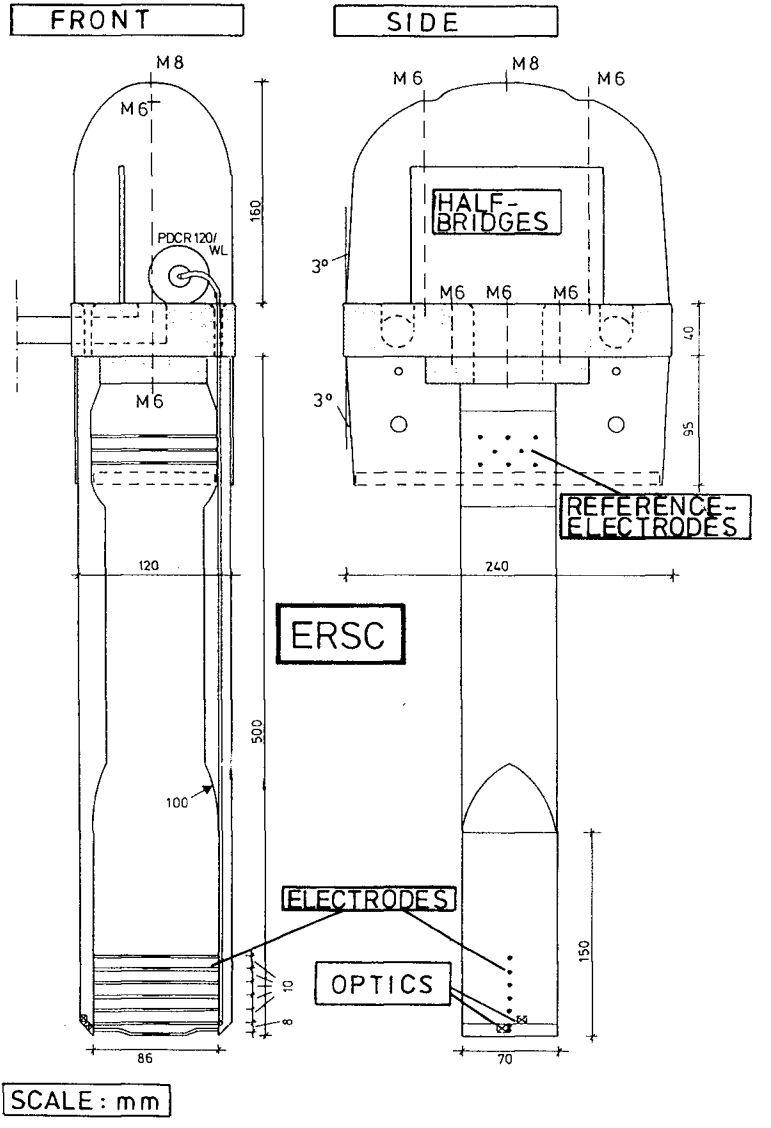

Figure 4. Sketch of the ERSC-GWK-probe

3. INVESTIGATION IN PROTOTYPE SCALE

3.1 TEST SECTION IN THE GWK

The investigations in August and September 1989 were carried out in the GWK in Hannover, in which waves of the size up to 1.8 m were generated.

A sand bed of 0.5 m thickness was installed in the flume extending 40 m in both directions of the test section (110 m from the wave generator). The transition to the concrete of the wave flume floor was at an initial slope of 1 to 40 (Fig. 5).

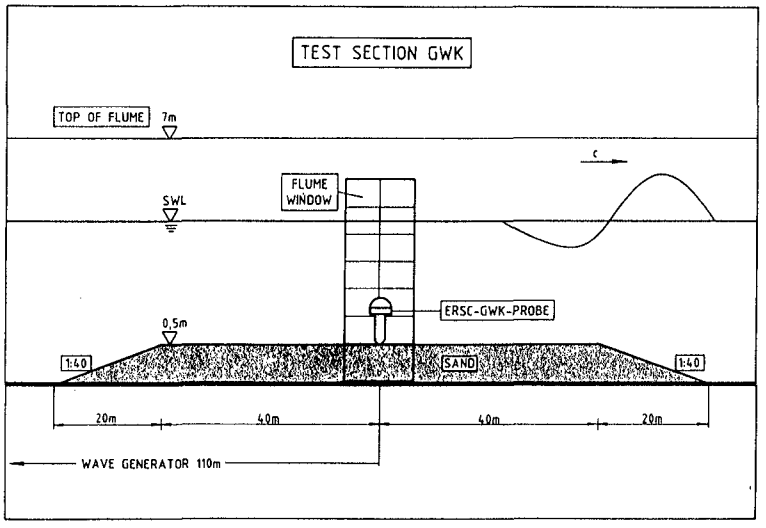

Figure 5. Test section in the GWK (not scaled)

3.2 USED SAND

About 250 m³ of sand was used, originating from the west coast of the island Norderney. It had the following parameters:

$$D_{50} = 220\ \mu m,\ \sigma_g = 1.48,\ w = 0.0284\ m/s$$

where σ_g is the geometric standard deviation and w the mean fall velocity of sand at 18 °C.

The wave-induced packed sand below water had the mean dry density of 1708 g/l. With this value the relative concentration was calculated in g/l. The band width of error from five density samples was about ± 1 %.

3.3 CALIBRATION

The ERSC-Probe was calibrated for the limiting conditions: clear water and wave-induced packed sand. The signals from the ERSC-Probe were registered before each test series first in clear water. Then the probe was covered with sand and consolidated by 100 monochromatic waves of 0.3 m wave height. This procedure was repeated three times and results were compared.

The mean scatter from one calibration of ERSC II, III and IV yielded 0.5 % for the water and 2.6 % for the sand in terms of the full measuring-range of each electrode.
The mean standard deviation of the water values yielded 21 mV (mean value: 171 mV; deviation: 12 %), the standard deviation of the sand values yielded 97 mV (mean value: 6111 mV; deviation: 2 %).

Since at times at control after an experiment the water value changed from test to test, the assumption was made, that the thin wires were deformed by larger shells or stones, enclosed in the natural sand. Therefore only a limited number of tests could be analysed for sediment concentration, those for which also the limiting conditions were registered and the band width of error could be decreased.

3.4 ANALYSIS OF TIME SEQUENCES

The analysis of orbital velocity, near-bottom sediment concentration and bottom elevation was aimed at the interaction during single waves as well as a sequence of waves.
The experiments were run with monochromatic waves as well as wave-spectra. The water depth was varied from $d = 4.5$ m to $d = 3.5$ m above the horizontal sand bottom. The oscillating velocity 0.1 m above the initial sand bed was measured up to $u_{max} = 1.3$ m/s. In the following some selected results are presented.

Fig. 6 illustrates a 20 s sequence of waves showing instantaneous wave height, orbital velocity and sediment concentration from the test at the GWK.

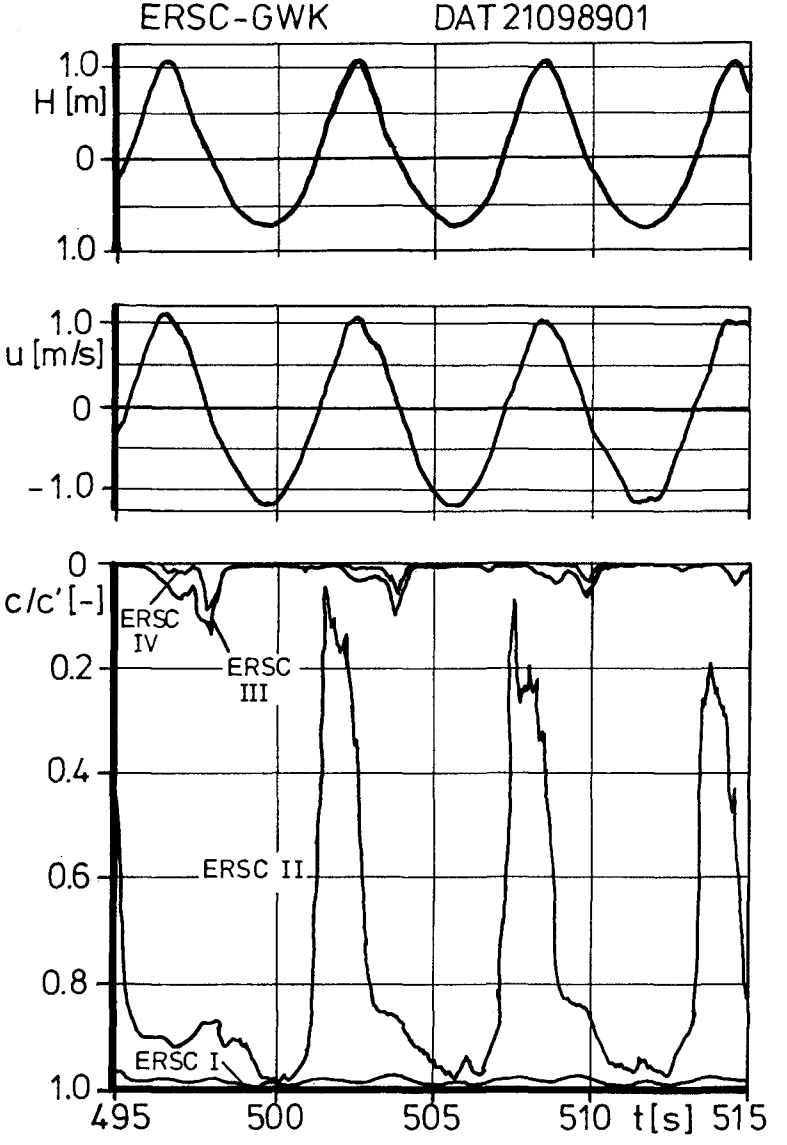

Figure 6. Wave sequence of the ERSC-GWK-probe at large scale conditions (21.09.89/01, 495 s to 515 s)

The ERSC-GWK-probe shows concentration signals from 4 electrodes ranging from high concentration near the bottom electrode and clear water (c/c'=0) at the electrode 4 cm above. The wave conditions were:

Monochromatic waves, H = 1.8 m, T = 6 s, d = 4.5 m

at water temperature Tw = 19.1 °C.
The results illustrate the highly time-dependent sediment concentration about 1 cm above the sand bed (from c/c'=0.05 to 0.95) and the phase-shift between the concentration maxima at different levels (about 2.5 s) as well as orbital velocity 10 cm above the bed (u_{max} = 1.25 m/s at wave trough).
The orbital velocities measured were in the range of sheet-flow-conditions indicated for the sand used and an horizontal bed. The actual bed showed formations with mean / -values of about 0.05 (= 0.1 m, = 1.9 m). This could be the reason why the sediment concentration has not the same phase as the oszillating velocity.

The wave conditions for the measurement, shown in Fig. 7, were:

Monochromatic waves, H = 1.15 m, T = 6 s, d = 4.0 m

The maximum orbital velocity was recorded at u_{max} = 1.0 m/s and T_w = 19.2 °C.
Noticeable during this sequence was the stepwise up and down movement of the probe. From observations at the window of the flume the position of the probe before test run was on the face (Luff) of a flat dune (= 0.14 m, = 1.1 m); additionally sheet-flow conditions were possible (ALLEN, 1984). The upwards movement of about 1 mm was recorded 0.7 s after the start of the return current at u_{mean} = 0.5 m/s . The downwards movements were in the range of 1 to 4 mm, mean value 2.4 mm, at return current of u_{mean}= 0.9 m/s, at t_{mean} = 1.7 s after the maximum velocity below the wave trough.

The maximum of the sediment concentration was measured about 0.5 s after the wave crest, about 0.4 s after the maximum of orbital velocity. A phase shift between the recorded signals of the three wires is not indicated at every wave.

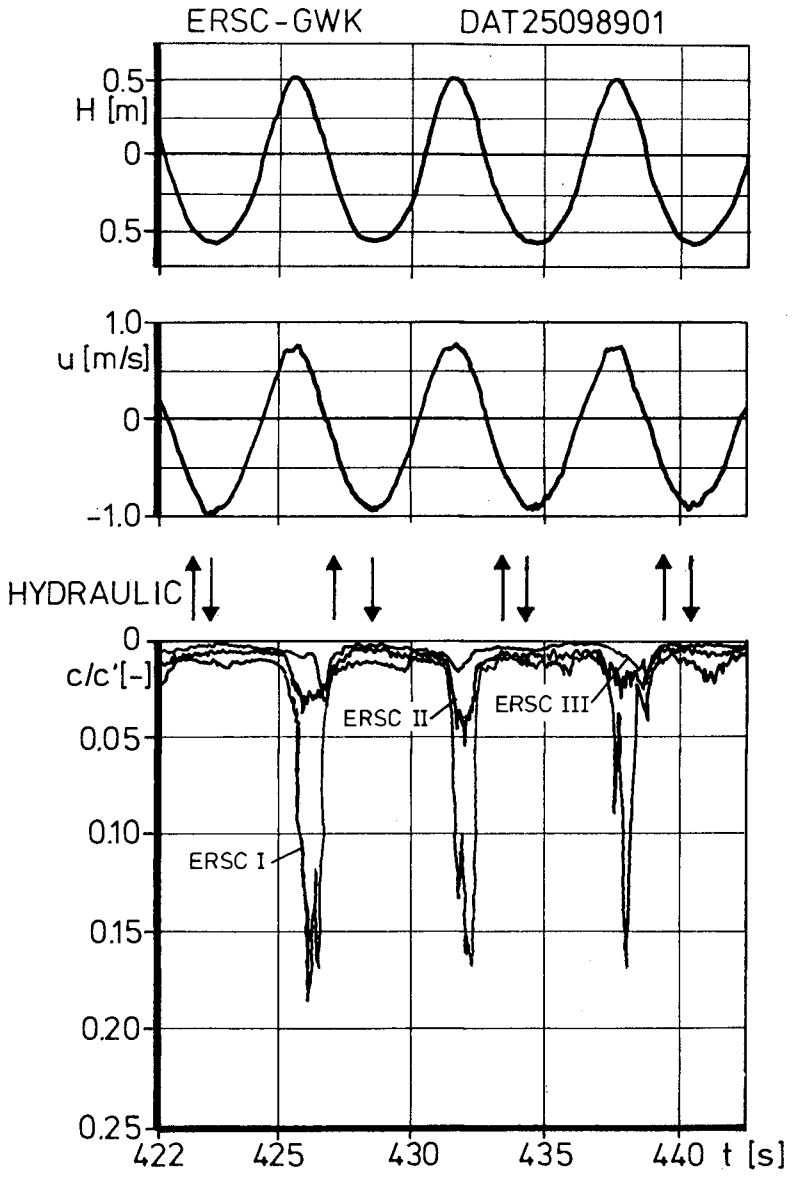

Figure 7. Wave sequence of the ERSC-GWK-probe at large scale conditions (25.09.89/01, 422 s to 442 s)

3.5 SINGLE WAVE ANALYSIS

One single wave will be presented from the monochromatic wave series. The wave was devided in 9 steps, corresponded with $\pi/4$.
Fig. 8 shows the phase dependent sediment transport after about 0.8 s due to:

Monochromatic waves, H = 1.8 m, T = 6 s, d = 4.5 m.

At the right top corner the instantaneous phase - here phase 1 - was plotted. Below from left the measured orbital velocity, the sediment concentration and the calculated sediment transport is shown. The minus values of the orbital velocity stand for return current below the wave trough.
The near bottom orbital velocity was calculated from a simple parabolic distribution from the lowest current meter down to the instantaneous bed. The instantaneous sediment transport was calculated from the time dependent orbital velocity times the instantaneous sediment concentration.
Fig. 9 demonstrates the phase dependent sediment transport during this single wave.

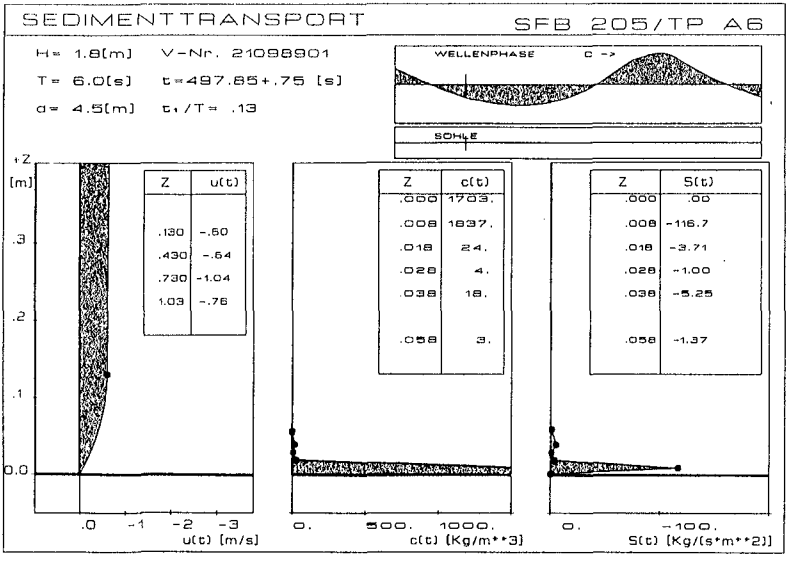

Figure 8. Example of phase dependent sediment transport after about 0.8 s (H= 1.8 m, T= 6 s, d= 4.5 m)

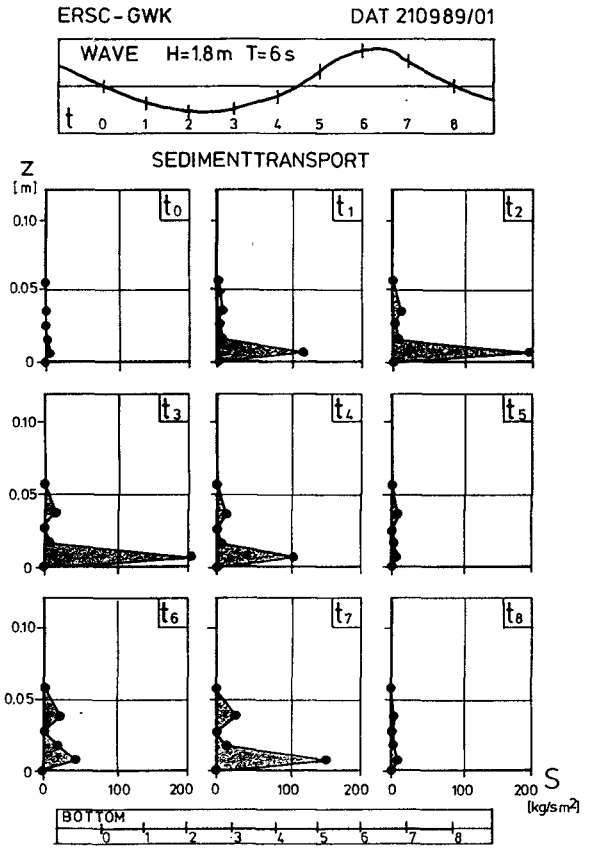

Figure 9. Phase dependent sediment transport due to wave action (Monochromatic waves, H= 1.8 m, T= 6 s, d= 4.5 m)

During this wave no vertical movement of the ERSC-probe was recorded. The maximum sediment transport rate was calculated to about 200 kg/s*m² at phase no.3, 2.2 s after wave start. About 10 cm above the bed the orbital velocity was 1 m/s. These should be sheet-flow-conditions.

It is open to discussion, whether the very high sediment transport was affected by sheet-flow or resulted from the multiplication of the sediment concentration with the assumed parabolic distribution of the velocity. After 0.8 s , phase no.4, the velocity as well as the sediment transport was reduced to half.

The zigzag distribution above ERSC III points to sediment transport in clouds and whirls.

4. CONCLUSIONS

Experiments were run in the Large Wave Flume (GWK) in Hannover with the aim of obtaining data on wave-induced instantaneous sediment concentrations. The measurements were made with an electro-resistance-type-sediment-concentration-probe (ERSC-GWK-probe). The data presented illustrate features of time dependent sediment concentrations under waves, particularly the instantaneous values and their phase dependency. Likewise problems which arose during the calibration, the measurement as well as the analysis have been indicated. The results were sufficiently encouraging and warrented the continuing development of the ERSC-probe as a means of measurement of instantaneous sediment concentrations under wave actions. The probe is still under development at the Leichtweiss-Institute in Braunschweig.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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