CHAPTER 131

ESTIMATES OF CROSS-SHORE BEDLOAD AND BED CHANGES

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ABSTRACT

Four series of tracer studies employing radioisotopic sand, tracked remotely from land, were carried out at the IBW PAN's coastal research station at Lubiatowo. Incipient motion of single grains with velocity v_{cr1} has agreed with Komar and Miller's (1974) formula, and has been 5...8 times smaller than v_{cr2}, the threshold velocity of water inducing bulk motion of sediment. The ratio of average nearbed water velocity, $\bar{v}$, to the effective speed of tracer sand, in the inshore zone, $\bar{v}_s$, is estimated about 100...1,000. The cross-shore sediment transport rates measured are ten times smaller than those predicted by Pruszak's (1987) energetics formula, the discrepancy being due to the real field phenomena of mixing and overburdening in a thick bed layer. Our wave flume and wave tank studies with movable bed point to the importance of initial slope in shore evolution. The laboratory findings on bed variability are extended by our 1987 field data obtained with an ultrasonic setup. Intensive cyclic depth changes are accompanied by varying transport rates computed from continuity equation.

1. INTRODUCTION

Sediment transport in the coastal zone, particularly in the bedload mode, still requires further analytical studies and experimental data. Field facilities of our Coastal Research Station at Lubiatowo and radiotracers were used to quantify sediment motion. An ultrasonic probe was devised and used at Kamchiya (or Shkorpilovtsy on the Bulgarian Black Sea) to measure short-term variability of bed topography. The latter provided a basis for cross-shore transport computations. The figures obtained are comparable with a theoretical prediction stemming from the

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energetics approach, which was earlier verified in a wave flume with movable bed. The three sets of the studies, together with various estimates of sediment motion measures, are discussed hereafter.

2. FIELD MEASUREMENTS OF SEDIMENT MOVEMENT

2.1. Apparatus and Environment

Four series of measurements with radioactive tracers of bed movement were conducted in 1984, 1986 and 1987 at Lubiatowo. Each series lasted several days and embodied continuous monitoring of waves, currents, bed topography and sand transport.

The instrumentation setup at Lubiatowo was installed on a steel framework , referred ta as a "Spider" , 10x10 m in plan view, with a system of three carriages and trolleys which allowed for accurate tracking,with a scintillation probe, of the movement of radioactive tracers within the area of Spider. In all experiments the latter was placed in a shallow nearshore zone on a depth of up to 1.5 m some 50-60 m offshore; Fig. 1 depicts the layout of Spider and bed topography in 1986 and 1987.

Iridium glass beads with quite uniform diameters of 0.2 mm (1984), 0.15...0.2 mm (1986), 0.088...0.15 mm (1986) and 0.2...0.25 mm (1987), in the range of the mean diameter of the Lubiatowo sand, D_{50} = 0.22 mm, were used as radiotracers. The composition of the glass was roughly 48 % SiO_2, 19 % Al_2,O_3, 17 % CaO, 6 % MgO, 5 % TiO_2, 5 % K_2O and 0.25 % IrO_2, which corresponded to the density of 2668 kg/m^{-3}. The radioisotope used, Ir-192, has the half-life period of 74.4 days. The principal radiation energy bands are 0.316 and 0.468 eV. Fifty-gram samples of radioactive sand were used in each experiment.

Waves were measured with a conductivity - type wire probe and a pressure transducer, water velocities with an electromagnetic current meter, and bed topography around Spider-manually by skin divers. The scintillation probe was moved and operated remotely from a land-based laboratory where all signals were collected and processed.

Wave parameters and water velocities measured in the

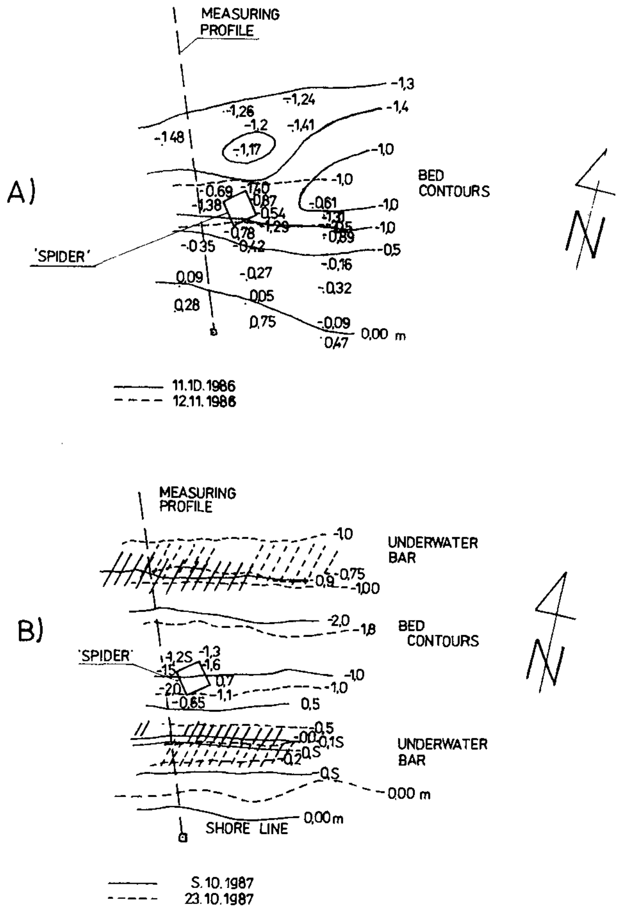

Fig.1 Bed Topography : (A) Lubiatowo '86 ; 11 th Oct ... 12 th Nov '86
(B) Lubiatowo '87 ; 5 th Oct ... 23 d Oct '87

1986 and 1987 experiments are shown in Fig. 2 and Fig. 3, respectively. Wave crests were approximately parallel to the seaward side of Spider. In both series the prevailing longshore current was eastward.

2.2. Sediment Transport

Systematic tracking of the radiotracers within Spider has provided a background for the evaluation of various modes of sediment movement, cf. examples for 1986 and 1987 in Fig. 4, where the areas in different shades depict tracer activity, in pulses per second. Advection and dis-

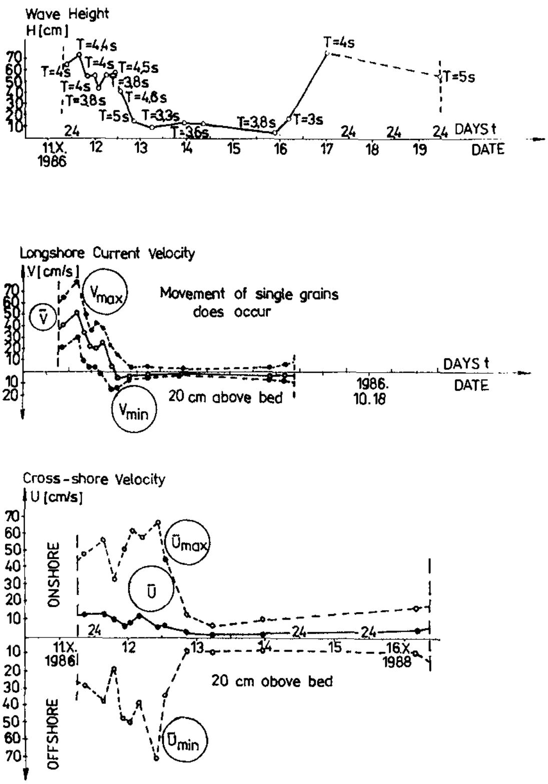

Fig. 2 Waves and Water Velocities in 1986

persion of the radiotracer provide estimates for incipient motion and bulk transport of sand.

Incipient motion has been linked to dispersion without any advection, i.e. any displacement of the centre of mass. Single grains with $D_{50} = 0.2$ mm begin to move under waves about $H \simeq 15$ cm $T \simeq 3.5...4$s, in water with the longshore and cross-shore velocity components of 5 and 8...10 cm s^{-1}, respectively (13th to 16th Oct '86). Similar results were obtained in 1984 and 1987. Hence the threshold velocity of water for grains with $D_{50} = 0.15...0.25$ mm can be given as $V_{cr1} = 8...10$ cm/s. These findings roughly coincide with the field data by Davis (1980) who observed no movement of 1.4-mm grains for water velocities lower than 8 cm/s, along with the incipient motion for the range of 8...22 cm/s, the number of

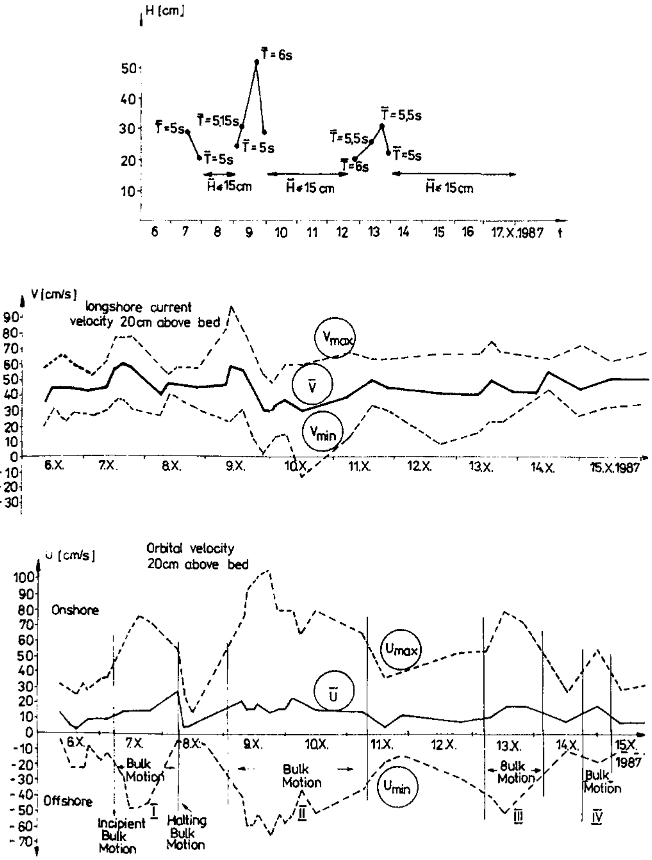

Fig. 3 Waves and Water Velocities in 1987

moving grains increasing with water velocity. Our estimates are also in line with the prediction by Komar and Miller (1974), which is worth noting as our waves were irregular.

B u l k t r a n s p o r t, attributed to displacement of the centre of mass, has been observed for water velocities about 50...60 cm/s, cf. Figures 3 and 4. All studies of 1984, 1986 and 1987 point to the same critical velocity of water V_{cr2} = 50...60 cm/s for sand grains with D_{50} = 0.15...0.25 mm.

The ratio of water velocity near bed to the effective sediment velocity i.e. the average velocity of the centre of mass is estimated about $10^3...10^4$. Some characteristic

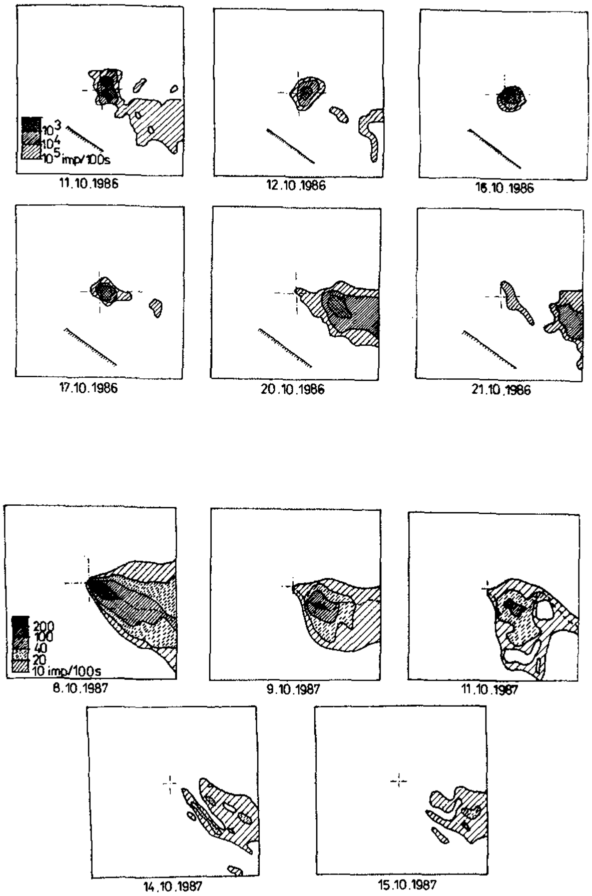

Fig.4 Plumes of Radioactive Sand Recorded within SPIOER

figures are given in Tab. 1.

Table 1.

Sand and Water Velocities

Year	D_{50} mm	V_{cr2} cm/s	V_s cm/hr	$V/\bar{V}_s$	Remarks
1984	0.2	60	12	10^4	1/curvilinear tracer trajectories 2/bulk transport is depth-averaged
1986/1	0.15..0.25	50	12	10^3	
1986/2	0.088..0.15	20	8...9	10^3	
1987	0.2...0.25	55	10	$10^3..10^4$	

It should be remembered that our bulk transport is depth-averaged, so that the uppermost bed grains may move faster even by one order of magnitude. If this is so then our estimates for $V/\bar{V}_s$ are close to 10^2 obtained by Katoh and Tanaka 1986 . The velocity $\bar{V}_s$ = 75 cm/hr given by Drapeau and Long (1984) for D - 0.2...0.4 mm might be higher due to persistent tidal flows.

The depth of penetration has been assessed by measuring the radioactivity in 2-cm layers cut of core samples. Six examples of the vertical distribution of moving sediment are shown in Fig. 5. Although the tracer was detected as deep as 15 cm below sea bed, this thick layer must not be identified with the bedload layer, as irregular restructuring of sea bed took place in various stages of the experiments.

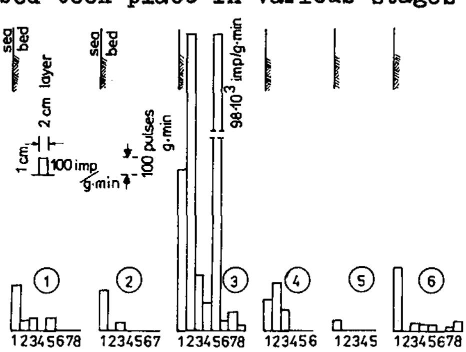

Fig. 5 Vertical Distributions of Radiotracers in 1987

Generally, the vertical distribution varies from rectangular through parabolic (with a maximum at the sea bed) to Gaussian (with a maximum below bed), and seems to reflect a variety of sedimentation patterns encountered, from sheet flow through rapid overburdening to random mixing.

The absolute magnitude of the unit bedload rate at Lubiatowo was of the order of 2.5×10^{-3} kg/m·s, or 9 kg/m·hr. This value corresponds to the average effective thickness of bedload layer of 5 cm, $\bar{V}_s$ - 10...12 cm/h, and to the concentration of sand increasing sharply to about 1700 kg m^{-3} (dry weight) a few grain diameters below the mud line. If $\bar{V}_s$ is increased to 50 cm/hr due to the aforementioned reasons then the transport rate can be estimated as 40 kg/m·hr. It should be remembered that all experiments were conducted in fairly calm situations. Some other estimates of. Drapeau and Long (1984), Lavelle et al. (1978) include higher figures, up to 60 kg/m hr, but pertain to more dynamic environments with stronger waves, currents and tides.

The critical bulk transport velocity V_{cr2} is about 5...6 times greater than the incipient motion velocity V_{cr1}. The regression analysis undertaken shows that V_{cr1} and small bedload rates are best correlated with $^{H}/T$ while V_{cr2} and higher bedload rates may be linked better to the mean velocity of water.

3. CROSS-SHORE SEDIMENT TRANSPORT

From among the numerous cross-shore bedload models available the one put forward by Pruszak (1987) has been taken for comparison against the field data presented above. The model is based on the assumption that the asymmetric oscillatory motion of water at seabed dominates the cross-shore bedload, and was originally tested against Pruszak's laboratory data. The formula proposed for the time - averaged cross-shore bedload rate reads

$$< q_b(x) > = \sum_{i=1}^{2} \alpha_i \frac{A_i [\rho f_w < u^3 > - < u > \tau_{cr}]}{T_i g (\rho_s - \rho)[\tan\phi + \frac{u}{|u|}\tan\beta]} \qquad 1$$

$$u_s = 0.25 \left(\frac{z}{D_{50}} + 4\right) A_i < u(x) > ; \quad -4D_{50} \leq z \leq 2D_{50} \qquad 2$$

in which

$$A_i = 1 - \frac{u_{cr}}{u_{cr} + \int_{T_i} [u(x,t) - u_{cr}]dt} \qquad 3$$

$\alpha_1 =$ 1 for the wave crest phase i=1
$\alpha_1 =$ -1 for the wave trough i=2
T_i = duration of the respective phase
ϕ = internal friction angle
β = bed slope angle
u_s = speed of sand grains

Obviously, the onshore transport is assumed in the crest phase, while offshore movement for wave trough.

The laboratory findings for the bedload measured in special traps are illustrated in Fig. 6. The experiments

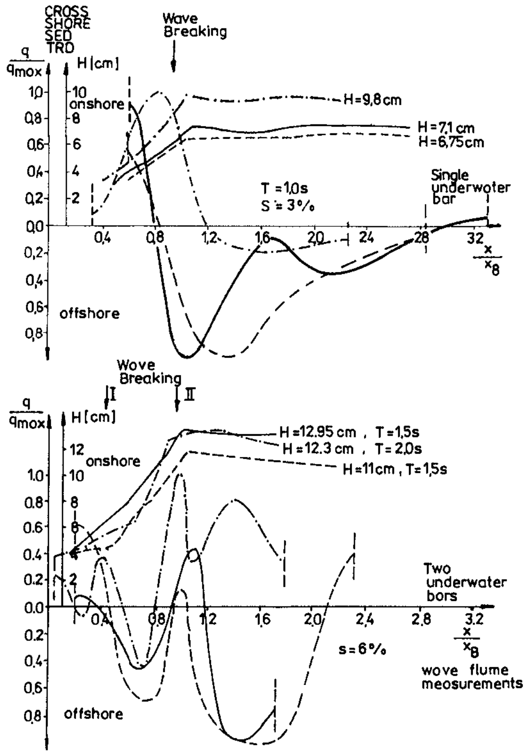

Fig. 6 Cross-Shore Transport Rate Measured in IBW PAN Wave Flume

were carried out in a 25-m long wave flume with movable bed (quartz sand with D_{50} = 0.22 mm). One or two bars were generated on initial bed slopes varying from 0 to 6 %. Offshore transport prevailed seawards of the breaking point $x=x_b$. The clearcut transition to the landward transport behind the single bar $x < x_b$ is not confirmed on the profiles with two bars.

The values computed by Eq. 1 for the reported prototype situations at Lubiatowo are of the order of 1.0...0.5 kg/m·s, hence about 10 times greater than those measured. Since Eq. 1 has been verified under laboratory conditions it must be inferred that the discrepancy is caused by different mechanics of sediment motion. Indeed, the figures given in Sec. 2 refer to bulk motion of the entire bedload layer, as judged from displacements of the radioactive plumes monitored whereas the computed quantities stem from measurements in the wave flume in which either individual grains or at most thin laminae of sand were set in motion and tracked subsequently.

The disparity of prototype and laboratory is now being compromised through an elaborate analysis of the physical factors shaping the sediment transport in both environments, followed by inclusion of all relevant quantities into the eventual version of our bedload model.

4. SHORT-TERM BED VARIABILITY

4.1. Laboratory and Field Measurements

Extensive tests in the IBW PAN wave tank with movable bed have exposed the dominance of bed slope, and not the angle of wave incidence, among the important factors of shore evolution (cf. Fig. 7). Wave-generated currents have been found to give rise to the instability of some bed features. Under oblique waves the bars migrate with meandering littoral drift.

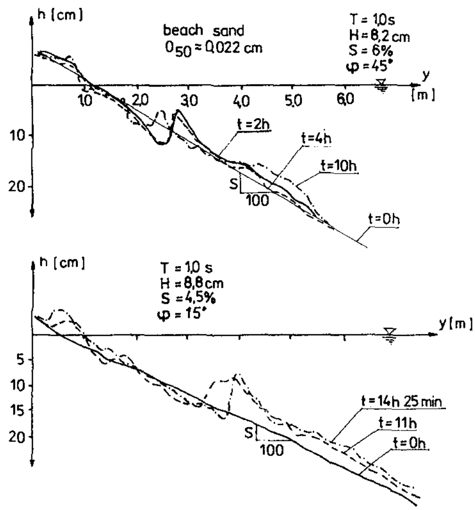

Fig. 7 Bed Profiles Generated in IBW PAN Wave Tank Experiments under Oblique Waves (φ=15°;45°)

The type of shore profile is reached rather quickly but the ultimate equilibrium requires a fairly long duration of experiments (i.e. coastal processes). In other words, the bed reacts fast to changing wave climate but adjusts slowly to the equilibrium profile. It is interesting to investigate this variability in the prototype.

Field studies on short-term variability of bed profiles were undertaken at Lubiatowo and Shkorpilovtsy. Special 210-kHz 20-W ultrasonic probes were arranged along the measuring profile to record bed changes. The absolute error is now 1 cm for 0.2...1 m elevation of the oscillators above bed. The advantages of the technique include ideal repeatibility of depth measurements, small relative error, flexibility of measurements during storms, and nondestructibility. Further improvements (40-W power, 5^o-beam in lieu of 20^o etc.) are under way.

The tests at Lubiatowo were primarily technological. The measurements at Shkorpilovtsy were carried out from 23d to 27th October 1987. Waves with the parameters shown in Fig. 8 (top) were normal to shore. First breaking occurred on the sand bar (between probes 17 and 19), and was usually accompanied by collapsing at the shoreline.

Although preliminary, the following findings can be singled out:

I/ bed changes are particularly intensive in the ultimate breaking zone

II/ maximum hourly bed changes under the waves experienced were 10 cm, versus several centimetres over a few hours

III/ bed changes are cyclic, and seem to oscillate about a certain long-term equilibrium profile

IV/ the amplitude of bed changes decreases in the offshore direction; for the examples shown in Fig. 8 (bottom) the range of changes at station 21 has been about 20...25% of those encountered some 20 m from shoreline (station 5).

4.2. Sediment Transport Rate Estimates

The cross-shore sediment transport rate q_x may be computed from the continuity equation

$$\frac{\partial h}{\partial t} = \frac{1}{1-p}\left(\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y}\right) \qquad 4$$

in which p = porosity of bed sediment.

The bed changes have been measured, and the longshore transport q_y is neglected due to the normal wave

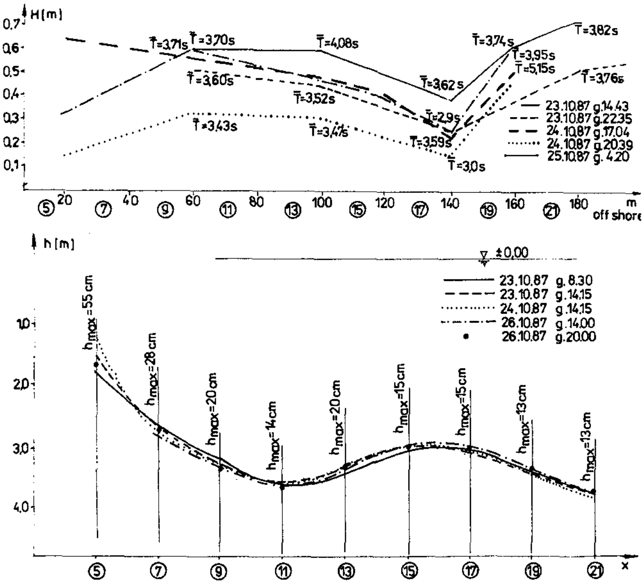

Fig. 8 Examples of Waves (top) and Bed Topography (bottom) Measured at Shkorpilovtsy

incidence. Results of the computations are illustrated in Fig. 9.

The highest transport rates have been found for the area of breaking, in agreement with our wave flume experiments. The direction of cross-shore sediment transport varies with time, and seems to depend on the actual stage of shore evolution. Further studies, including those carried on at Shkorpilovtsy in 1988, are to shed more light on this important question of cross-shore evolution.

SUMMARY and CONCLUSIONS

Field studies with radioisotopic sand tracers were carried out at IBW PAN's coastal research station at Lubiatowo in 1984, 1986 and 1987. In the conditions outlined in Figures 1...4, two critical nearbed water velocities, v_{cr1} and v_{cr2}, have been found as respective estimates for incipient motion of single grains and bulk motion of sediment. The figures measured are 8...10 cm s^{-1} and 50...60 cm s^{-1}, the first of them being in rough agreement with Komar and Miller's (1974) formula. The ratio of

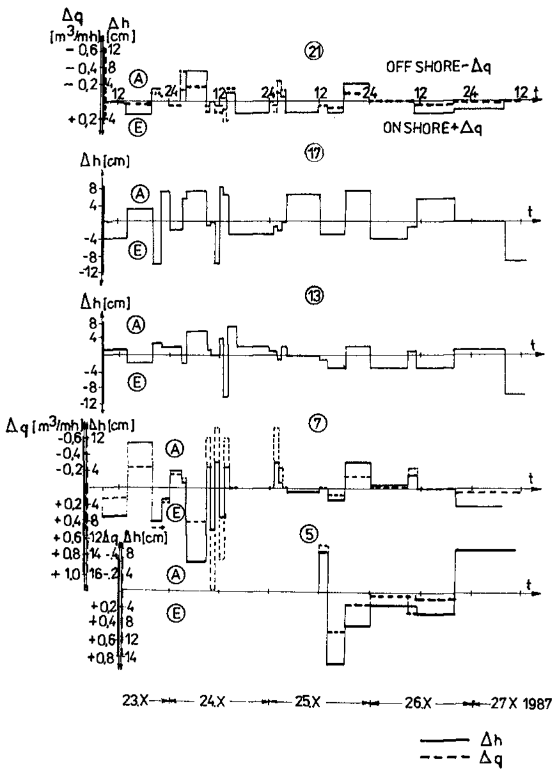

Fig. 9 Depth Increments Measured vs Sediment Transport Rates Computed

average nearbed water velocity $\bar{V}$, to the effective speed of tracer sand in the inshore zone $\bar{V}_s$, is estimated about 100...1,000, the figures in Tab.1 being divided by ten due to the noted curvilinearity of tracer trajectories. The order of magnitude of the speed $\bar{V}_s$ itself is estimated as 1 m/hr.

The cross-shore transport rates measured, 0.01... 0.015 kg/m.s for the climate encountered, are ten times smaller than the figures computed by Pruszak's (1987) formula. The latter stems from the energetics approach, and has been calibrated against wave flume data for bedload in thin seabed laminae. The discrepancy is due to the real bulk motion of the entire bedload layer in the field, subject to the mixing and overburdening effects noted.

The reported wave flume and wave tank studies with movable bed point to the importance of initial bed slope in the evolution of shore profiles. Single-bar profiles wi ness a clear-cut transition from the offshore transport seawards of the bar to the onshore transport on the opposite side, while for double-bar profiles the transitions are multiple.

The bed variability observed in the wave flume and wave tank was further explored in field studies employing special 210-kHz 20-W ultrasonic probes. The findings confirm intensive short-term bed changes in the ultimate breaker zone about 10 cm per one hour of a weak storm (cf. Fig. 8). Their amplitude decreases in the offshore direction. The short-term bed changes are cyclic, and seem to oscillate about a certain long-term equilibrium profile.

The first estimates of the cross-shore sediment transport rate obtained from the field measurements of bed changes agree with our wave flume experiments as to the occurrence of the highest rates about the breaking line. Further studies with our ultrasonic setup are expected to yield more precise data on cross-shore evolution and transport.

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