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, to-
gether 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 diame-
ter 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_2O_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 radio-
active 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 labora-
tory where all signals were collected and processed.

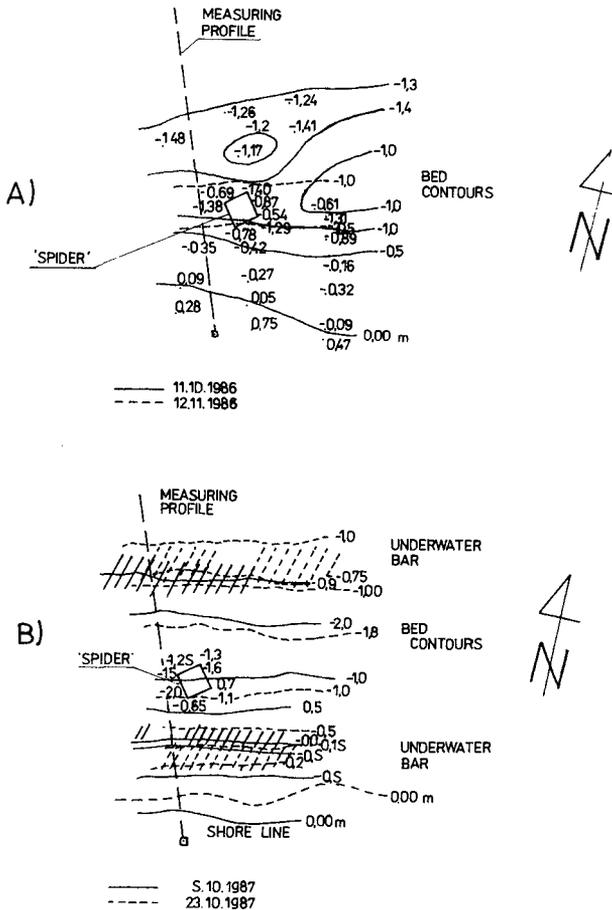Wave parameters and water velocities measured in the

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-
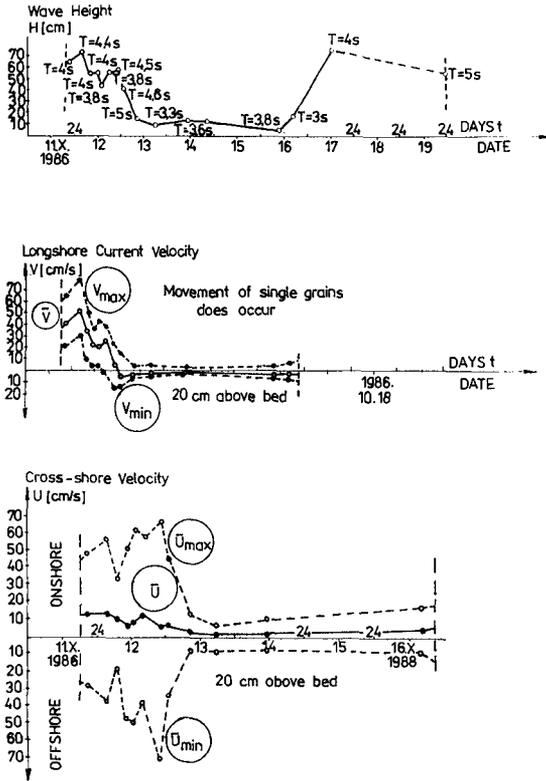
Fig. 2 Waves and Water Velocities in 1986

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 $H \cong 15$ cm $T \cong 3.5...4s$, in
water with the longshore and cross-shore velocity compo-
nents 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 inci-
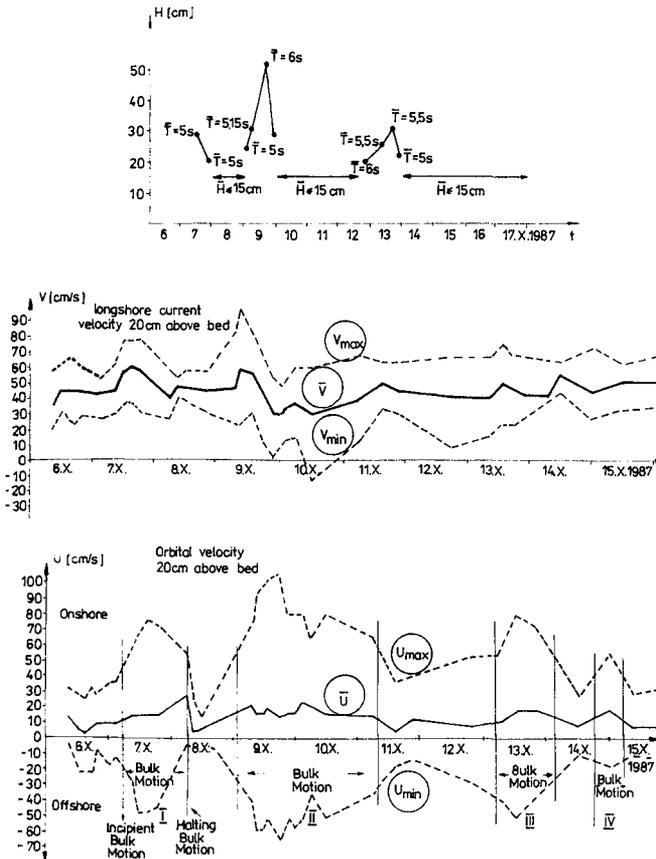pient motion for the range of 8...22 cm/s, the number of

Fig. 3 Waves and Water Velocities in 1987

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

Bulk transport, attributed to displa-
cement 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
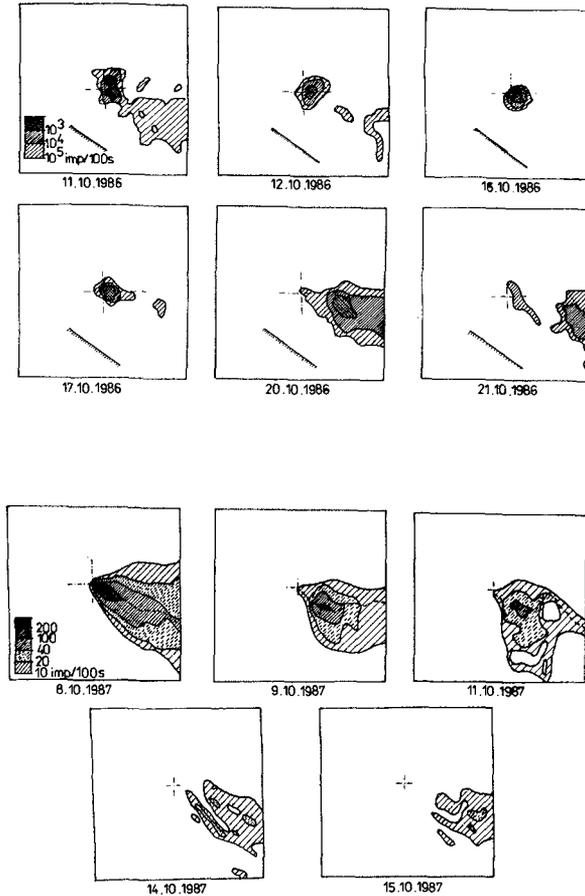of mass is estimated about $10^3...10^4$. Some characteristic

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
1986/1	0.15..0.25	50	12	10^3	2/bulk transport is depth-averaged
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 mea-
suring the radioactivity in 2-cm layers cut of core samples.
Six examples of the vertical distribution of moving sedi-
ment 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 restruc-
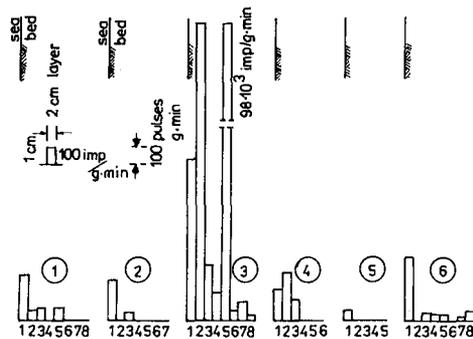turing of sea bed took place in various stages of the   ex-

Fig. 5 Vertical Distributions of Radiotracers in 1987

periments. 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 x 10^{-3} kg/m·s, or 9 kg/m·
·hr. This value corresponds to the average effective thick-
ness 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 afore-
mentioned reasons then the transport rate can be estimated
as 40 kg/m·hr. It should be remembered that all experi-
ments were conducted in fairly calm situations. Some other

estimates cf. 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 asy-
mmetric 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

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

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

in which

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

$\alpha_1 = 1$ for the wave crest phase   i=1
$\alpha_1 = -1$ for the wave trough i=2
$T_i =$ duration of the respective phase
$\phi =$ internal friction angle
$\beta =$ 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
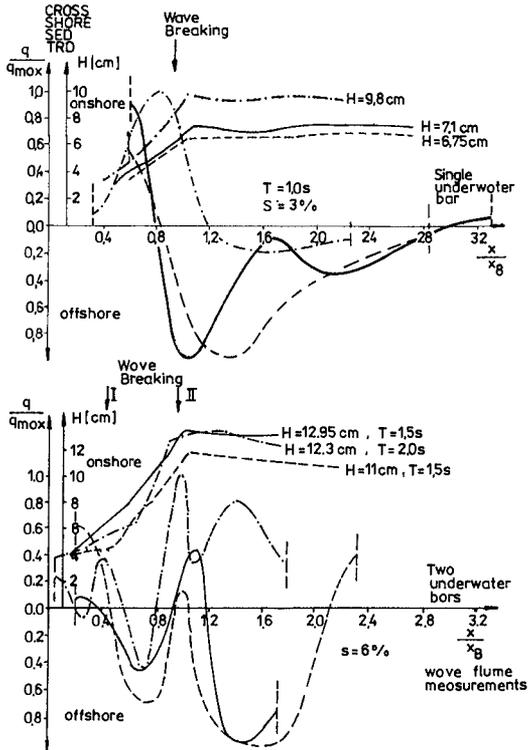special traps are illustrated in Fig. 6. The experiments

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 po-
int $x=x_b$. The clearcut transition to the landward tran-
sport 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 proto-
type 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 dif-
ferent 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 quan-
tities 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 mova-
ble 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
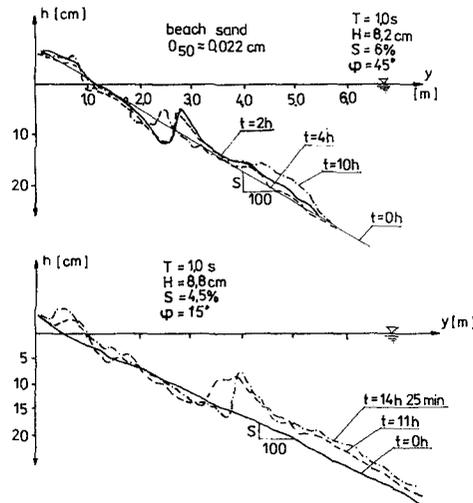bed features. Under oblique waves the bars migrate with
meandering littoral drift.

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

The type of shore profile is reached rather quickly
but the ultimate equilibrium requires a fairly long dura-
tion 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 intere-
sting to investigate this variability in the prototype.

Field studies on short-term variability of bed pro-
files 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 oscil-
lators 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° 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 oc-
curred 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

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

in which p = porosity of bed sediment.

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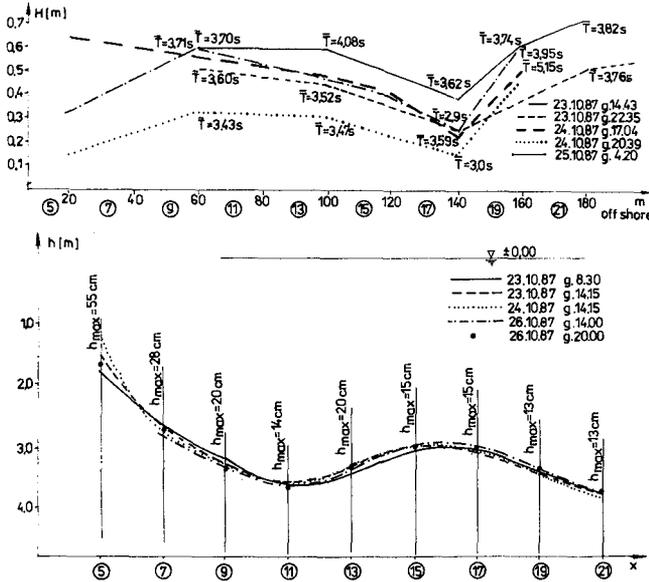hore transport q_y is neglected due to the normal wave

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 experi-
ments. 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 car-
ried 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 Lu-
biatowo in 1984, 1986 and 1987. In the conditions outli-
ned in Figures 1...4, two critical nearbed water veloci-
ties, v_{cr1} and v_{cr2}, have been found as respective es-
timates for incipient motion of single grains and bulk mo-
tion of sediment. The figures measured are 8...10 cm s^{-1}
and 50...60 cm s^{-1}, the first of them being in rough agree-
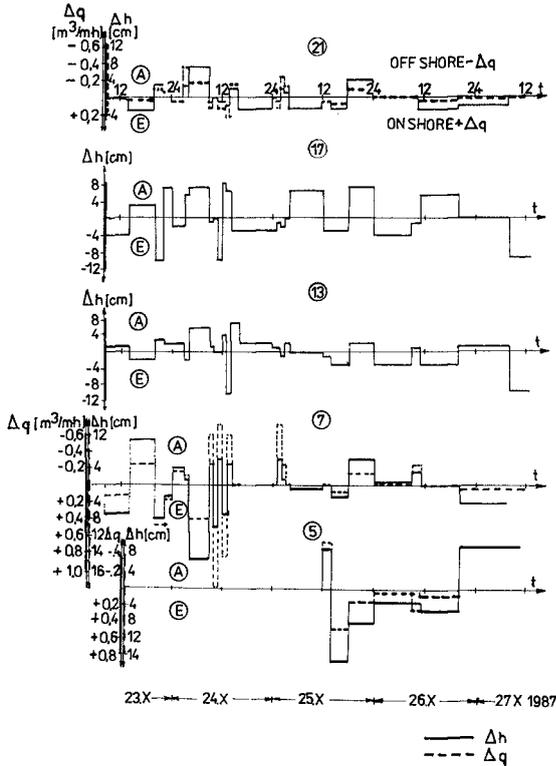ment with Komar and Miller's (1974) formula. The ratio of

Fig. 9 Depth Increments Measured vs Sediment Transport Rates Computed

average nearbed water velocity $\overline{V}$, to the effective speed
of tracer sand in the inshore zone $\overline{V}_s$, 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 $\overline{V}_s$ 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) for-
mula. 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, sub-
ject 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 oppo-
site 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 con-
firm 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 direc-
tion. 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 tran-
sport rate obtained from the field measurements of bed
changes agree with our wave flume experiments as to the oc-
currence 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 tran-
sport.

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