## **CHAPTER 301**

#### Nearbed sediment concentration from tracer studies

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#### ABSTRACT

This paper reports on field investigations, in which the nearbed layer was one of major foci. The study was carried out at the IBW PAN Coastal Research Facility Lubiatowo. The radioactive sand tracer used in the study consisted of iridium glass beads with medium grain diameter D<sub>50</sub> from 0.2 to 0.25 mm and having physical properties close to their counterparts of natural sand on the Baltic coast of Lubiatowo. Some 150 core samples, each 30 cm long, were taken from the areas where the tracer was set in motion, i.e. bar crests, troughs between bars, and other regions subject to the action of waves and currents. Data analysis shows that sediment movement is characterized by high intermittence reflected in a stratified structure of bedlayer, whereby each sublayer is governed by different forcing factors. For identical external conditions the vertical tracer profiles are different at bar crests and troughs, showing clear diversification of sediment mechanics across the surf zone. Fairly thin sediment sheets, a few millimeters thick, travel at bar crests and troughs, due to high sand speed in onedirectional (longshore) movement. The aggregated vertical profile of tracer concentration stems from the superposition of a few quasi-parabolas (close to the injection point) or thin uniform laminas (futher away from the tracer source).

#### 1. INTRODUCTION

The surficial layer of seabed is affected by continuous dynamic motion of sea water due to waves and currents. As a result, sediment moves in an unstable and variable moveable layer. Adequate description of the active layer of sediment transport in the sea bed becomes now an urgent but yet controversial problem of coastal dynamics. The thickness of that layer has been assessed in a number of studies to range from a few grain diameters, see Kraus (1984) and Galvin (1987) to several grain diametes (Ingle 1966 and Horikawa et al. 1982) or as much as tens of centimetres (Drapeau et al. 1990). These estimates originate from analyses and investigations having different

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degree of accuracy, scales and site conditions. Among the conditions bringing about those different estimates of bed layer thickness one can enumerate:

- a) ambiguity of the distinction between bedload and suspended load;
- b) difficulties in determination of real sand grain speed profiles within the entire active layer of sea bed due to variable waves and currents, especially under random field conditions;
- c) problematic delineation of the vertical extension of the movement of single sand grains in sea bed during storms, and controversial singling out individual storm events from aggregated bed thickness due to storm spectrum;
- d) diversified conditions of investigations, analysis and their time and space scales (laboratory versus prototype etc.).

Because of the sophisticated patterns of the transmission of random energy of waves and currents to sea bed and its constituent grains, the problem is complex and highly dependent on scales of the phenomenon. Undistorted relationships between the forces controlling sediment transport stemming from the prototype seem to provide the most reliable and valuable information on the processes investigated here.

This study has aimed at analysing and estimating the bedload thickness in the sea, and its dynamic variability due to random waves and currents.

# 2. FIELD STUDIES

Our field studies were carried out by the use of radioactive tracers (Ir-192) in the form of iridium glass having geometric and physical properties identical with those of natural sand in the area of investigations (Pruszak & Zeidler 1994).

Some 150 core samples taken from various locations of the cross-shore profile (Fig. 1) were taken all over the area of characteristic coastal features such as sand bars at crests and troughs, under various circumstances created by random waves and currents.

Waves and two components of nearshore currents were measured continuously at two stations D1 and D3 on the cross-shore transect (Fig. 1) every three hours. In addition, wind and sea level oscillations were also recorded every three hours. The results described here stem basically from two measuring series of 23th September to 4th November 93 and 11th May to 30th June 94. Graphical distributions of some hydrodynamic parameters representative of the hydrological background of those situations are shown as examples in Figure 2. The times of core sampling over the area of tracer movement are also indicated on the drawing. Each of the core samples was about 30 cm thick and was subsequently subject to analysis in 2-cm layers with a sensitive apparatus for measurement of low radioactivity.

A special casting box  $0.5 \times 0.5 \times 0.25$  m filled up with the radioactive tracer was deployed at the point P1 (Fig. 1). Core samples were taken from that box at intervals of a few hours, in the course of wave and current action. This section of the study was intended as monitoring of the dynamic variability of sea bed in its linkage to changes in the thickness of the active sand layer as a function of time and external factors.



Figure 1. Study area



Figure 2. Distribution of wave height and currents at point D-3 during the second series of measurements (1994)

### 3. ANALYSIS

## 3.1 TIME AND SPACE CHARACTERISTICS OF THE BEDLOAD LAYER

Geometric characteristics of the variable active layer (primarily its thickness), in the time and space domain, have been analysed by reference to the core samples taken at different locations of the tracer plume. One of the situations tested in area B is illustrated in Figure 3, while the vertical distribution of the tracer concentration, providing insight into the thickness of the active layer with increasing distance from the point of injection, is depicted in Figure 4.



Figure 3. Location of tracer plume in area B during the first series of experiments



Figure 4. Vertical tracer concentration profiles at various location as a function of spacing L from injection point

Some other vertical profiles, illustrating the wide range of diversity at other locations of the cross-shore transect, are shown in Figure 5. All these results, on the background of the controlling factors have been employed in the determination of characteristic descriptors of the bedload layer.



Figure 5. Exemplary types of vertical tracer concentration profiles

As a result of our analysis of the core samples taken in both measuring series it has turned out that there is no prevailing type of vertical concentration within the bedload layer. Among a few possible general types of distribution one can suggest a quasiparabolic profile resulting from the superposition of two or even three "moving" parabolas and one or a few thin surface layers on top of those parabolas. The schematic representation of that profile is illustrated in Figure 6. The number of components, thus complexity of the profile, depends on the intensity of changes in wave and current climates at a given location. Since every sublayer of the core sample represents a certain instantaneous random hydrodynamic situation cut out of the complex series of events during the measurements, the storm history is obviously reflected in the configuration of the tracer within the core sample. The higher the diversity of the storm history the more complex the core sample.



Figure 6. Schematic decomposition of the vertical profile of tracer concentration

Clear-cut variability of the vertical tracer profiles in time and space (distance from the injection point) is visible. In the near field of the injection point, the vertical distribution of the tracer is close to the parabolic type, sometimes with an additional thin surficial sublayer. As one moves away from the injection point, the thickness of the tracer layer decreases and the higher activity "moves" from deeper depth to the sea bed surface.

The shape of the vertical bedload profile depends very much on the shape of sea bed itself and its macroforms such as sand bars. Under the same external conditions, at both crests and troughs the tracer travels in a thin surface layer (Fig. 7). The picture is different at bar slopes and in areas without large bed forms; the vertical profiles of tracer concentrations at those locations are less regular, more variable and close to the types depicted in Figures 4, 5 and 6.



Figure 7. Vertical profile of tracer concentration at bar crests and bar troughs

The core samples tested display a strong nonlinear variability of the bedload thickness as a function of waves and currents. The thickness of each sublayer in the vertical profile, created by various sequences of waves and currents, depends on the intensity and duration of wave motion. Very roughly, it can be described by the general function:

$$a = F(H,t) \approx f(H) \cdot g(b \cdot t/T_{st}) \tag{1}$$

in which  $T_{st}$  = time after which stabilisation of the controlling factors takes place and some equilibrium is attained for a given wave situation. This time is estimated as 10 to 100 wave periods T.

The function f(H) stands for the strength of forcing, thus the intensity of sediment transport, while the function  $g(b t/T_{st})$  represents the effect of the time necessary for generation of the bedload layer. After a sufficiently long time  $t = T_{st}$  one should get  $g(b t/T_{st}) = 1$  and accordingly  $a \approx f(H)$ , for a given combination of waves and currents. The vertical profiles of tracer concentration shown in Figures 4 and 5 (or schematically in Figure 6) are thus integrals of the quantity a due to individual segments of the wave and current history.

The thickness a can be estimated from the sediment transport rate  $q = (\rho_s - \rho) \cdot v_s \cdot a$  and independent assessments of the average grain speed  $v_{s_s}$  both resulting from our

analysis of the tracer movement and core samples. By such procedure one can claim that the thickness a is in the range of 2-4 centimetres during moderate storms.

Theoretical investigations of the bedload layer (Kaczmarek et al. 1995) suggest that the bedload layer thickness a should be smaller. A numerical simulation belonging to those studies is depicted in Figure 8 for the grain diameter  $D_{50}$  and wave period T typical of the area of investigation; the thickness a should obviously be a function of wave height and the depth of water.

Thickness of bedload layer, irregular waves



Figure 8. Theoretical bedload layer thickness for wave period  $T=4 \ s$  and variable wave height  $(H_{rms})$  and depth of water h (Kaczmarek et al. 1995)

Upon comparison of the simulated quantities and their prototype counterparts it can be inferred that the bedload layer is about a few millimetres thick, thus by one order of magnitude smaller theoretically than under prototype conditions. This disparity can partly be associated with the laboratory origin of the theoretical outcome. More important, the definitions of the bedload layer are different — Kaczmarek et al. (1995) adhere to the classical few grain diameters above and beneath bedline, while in this study the movable bed layer encompasses sheet flow as well.

The function f(H) can be approximated by  $f(H) \approx 0.027 H_{br}$ , as postulated by Kraus et al. (1982) and Pruszak & Zeidler (1994). On the other hand, the function  $g(b t/T_{st})$  can be estimated once  $T_{st}$  is given more accurately, which is however beyond the scope of this study.

# 3.2 LOCAL VARIABILITY OF ACTIVE SAND LAYER

In order to shed light on local variability of the active sand layer as a function of time and variable forcing by waves and currents, the second series of measurements included a special experiment under prototype conditions. The test box denoted by P1 was situated on a depth h=1.2 m, on the seaward slope of the sand bar, some 6 m from the bar crest (Fig. 1). The experiment was initiated at 12:00 on 26th May 1994 at calm weather. The tracer concentration on a depth about 25 cm below original sea bed was constant c=1500 pulse/s (Fig. 9). Moderate waves were noted between 12:00 and 14:00 (Table 1).

Time (t)	Wind		Wave (m)		Current (m/s) Average/ Max		Sea lcvel change (cm)	Depth of mixing (m)	Rate of depth changes	Remarks
	φ	v (m/s)	Н	H <sub>max</sub>	Long shore	Cross- shore				
26.05.94 13 <sup>00</sup> 12 <sup>00</sup> -14 <sup>00</sup>	272°	7.5	0.12	0.44	0.2/0.6	0.01/0.4	0.0	0.04	few D/ 2 h	One-point breaking
16°° 14°°-18°°	260°	2.2	0:11	0.45	0.2/0.6	0.01/0.4	-2.5	0.04	-1cm/4 h	
19 <sup>00</sup>	274°	6.8	0.16	0.48	0.2/0.6	0.01/0.4	+5.0			
22°°	328°	2.4	0.2	0.54	0.2/0.5	0.01/0.4	0.0			
27.05.94										
100	19°	4.9	0.25	0.96	0.3/1.1	0.01/0.8	+1.0			Multiple-
4°°	38°	7.5	0.35	1.0	0.4/1.2	0.02/0.9	+6.0	a few	mean value =	point wave
7 <sup>00</sup>	33°	6.5	0.40	1.17	0.4/1.4	0.02/1.1	+20	cın	10cm/10h	brcaking
1000	21°	3.0	0.35	1.0	0.4/1.4	0.02/1.0	+20			

Table 1. Parameters of water and sediment movement at box P1 (depth = 1.2 m, Fig.1)

Waves broke in a close vicinity of shoreline, far away from the area of investigations. Although quite small, the waves clearly affected the upper sand layer, reaching some 4 cm below original sea bed line. For similar waves and currents between 14:00 and 18:00 the activity of sand movement in the bedload layer was similar, but its intensity was growing, with the maximum at the surface and linear decrease to the depth  $h_d = 4$  cm below sea bed line. The latter value can be regarded as the depth of wave effect on sea bed grains; thus it somehow defines the thickness of the active sea bed layer at given external forcing. Substantially thinner bedload thickness, about a few grain diameters, is typical of that period for the grains belonging to the sea bed and being in motion at the same time. As a result of such wave and current forcing the bed was eroded by 1 - 2 centimetres over four hours, (Fig. 9). By the time of the next measurement at 9 o'clock on the next day, waves and currents grew considerably (Tab. 1). Multiple wave breaking was observed at the time

of the next measurements. About the area of the experiment, where one of the wave breaking lines was noted, the breaker height was about  $H_{br}$ =1.2 m and the maximum current velocity exceeded 1 m/s. Tracer concentration in the vertical profile decreased substantially and the concentration profile became irregular, close to the parabola shifted by a certain value below sea bed line. The maximum concentration of a tracer some 6-10 cm below sea bed line was much smaller than its initial counterpart (about five times). From thorough observations by scuba divers it can be reported that ripples were not present and strong sediment flux, somehow resembling a moveable sheet a few centimetres thick occurred. It should be stressed that the thickness of sediment movement layer estimated by scuba divers was about 2-4 cm (depending on the accuracy of estimation), but not a few millimetres. Further erosion by 9-10 cm was noted from 18:00 on 26th May to 9:00 on 27th May; the most intensive changes due to growing waves and currents took place most probably about midnight (Tab. 1).



Figure 9. Variability of vertical concentration profile as a function of hydrodynamic parameters

Subsequent measurements were impossible because of the growing storm. After several hours of that medium storm it was realised that the test box was washed away and no tracer was found in its area.

# 4. CLOSING REMARKS

From our analysis of the tracer distribution and its coupling with waves and currents one can draw some conclusions concerning the bedload layer. The following points should be made:

- sediment movement under dynamic surf zone conditions is characterized by high intermittence reflected in a stratified structure of bedlayer, whereby each sublayer is governed by different forcing factors. The entire vertical profile of tracer concentration represents then a sum of various sublayers, which are correlated with subsequent wave climate changes,
- vertical profile of tracer concentration displays a pronounced variability in time and space, with predominance of quasi parabolic profile close to the tracer injection point and a thin quasi uniform one away from the tracer source; being often the superposition of a few thin 'foils',
- for identical external conditions (wave and currents) the vertical tracer profiles are different at bar crests and troughs, showing clear diversification of sediment mechanics across the surf zone. Fairly thin sheets, below 2 cm in thickness, travel at bar crests and in troughs, due to high sand speeds in one directional (longshore) movement,
- the thickness of each sublayer of the nearbed load is a highly nonlinear function of wave and current velocity, depending on intensity (H) and duration (t) of subsequent wave action,  $a = f(H, t) \approx f(H) \cdot \log (b \cdot t/T_{st})$ .

## 5. REFERENCES

Drapeau G., Long B., Kamphuis J., W. (1990), Evolution of radioactive sand tracers to measure longshore sediment transport rates, Proc. 22nd ICCE, Delft, ASCE, p.2710-2723

Galvin C. (1987), Vertical profile of littoral sand tracers from a distribution of waiting times, Proc. Coastal Sediment's 87, ASCE, p. 436-451

Horikawa K. A., Watanabe A., Katori S. (1982), Sediment transport under sheet flow condition, Proc. 18th ICCE, Cape Town, ASCE, p. 1335-1352

Ingle J., C. (1966), The movement of beach sand: An analysis using fluorescent grains, Developments in Sedimentology, No. 5, Elsevier Pub. Company, Amsterdam

Kaczmarek L., Ostrowski R., Zeidler R. (1995), Boundary layer theory and field bedload, Proc. Coastal Dynamics'95, Gdańsk, ASCE, p. 664-675

Kraus N., C., Isobe M., Igarashi H., Sasaki T., Horikawa K. (1982), Field experiments on longshore sand transport in surf zone, Proc. 18th ICCE, Cape Town, ASCE, p.969-988

Pruszak Z., Zeidler R. (1994), Sediment transport in various time scales, Proc. 24th ICCE, Kobe, ASCE, p.2513-2526