CHAPTER 318

Sand Suspension Events and Intermittence of Turbulence in the Surf Zone.

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Abstract

The results of the joint field experiment Norderney-94 demonstrates the excellent coincide of fluctuations of suspended sand concentration and kinetic turbulent energy in the nearbottom region of the surf zone. Turbulent fluctuations were separated from the wave induced fluctuations as a part of the motions that are incoherent to the free surface elevation. The time and spatial scales of macroturbulent vortexes had been estimated and discussed.

Introduction

For the prediction of sediment transport in the breaking zone it is necessary to know the distribution of the suspended sediment concentration, of the water velocity and of the cross-correlation between them in the whole frequency spectrum of irregular waves. The analysis of modern approaches to the solutions of this problem published in literature and discussed at the international conferences during the last years (Coastal Dynamics 94, Barcelona/Spain, 1994; 24th Coastal Engineering Conference, Kobe/Japan, 1994; Coastal Dynamics 95, Gdynia/Poland, 1995; MAST 2 - Overall Meeting, Gdynia/Poland, 1995) shows that the most perspective ones are the models based on Boussinesq and Serra equations that afford to adapt these parameters to the time scales of approaching waves and k-e models. But the latter models today allow only to assess mean-time profiles of the suspended sediment concentration in the breaking zone. The possibility to use k-e model for the calculation of the suspended sand fluctuations in time is restricted by the absence of precise descriptions of the physical mechanisms of sediment

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suspension above the bottom, it's distribution in the water column within the breaking zone and by the absence of quantitative correlation between the suspended sediment concentration and parameters of the turbulence for field conditions.

From the physical point of view the presence of instantaneous water flows from the bottom with a velocity that exceeds the sand particle settling velocity is a necessary condition for the occurrence of sediment suspension. In the wave breaking zone such water motions are forced, most probably, by macroturbulent vortexes. Two basic mechanisms of such vortexes formation are possible:

1. Vortexes formation near the water surface under the crests of the breaking waves and its penetration to the bottom. Such a mechanism was observed in laboratory experiments with monochromatic waves above a hard and a movable bottom (Nadaoka, Kondoh, 1989; Zhang et al., 1994). By these experiments it was determined that vortexes were formed as well with horizontal axis as with inclined vertical axis depending on the wave parameters, on the type of their breaking and on the bottom slope. When reaching the bottom, such vortexes, like a tornado, can capture sand from the bottom and suspend it in the flow. The dominant action of this turbulence for sediment suspension is verified by Sato et al. (1990) in a wave flume.

2. Vortexes formation in the bottom boundary layer due to the shear instability of water flow above a plane rough bottom. In this case an explosive character of the generation of turbulent energy and formation of coherent vortexes takes place. Those vortexes are forced from the bottom to the water column. The possibility of realization of such a mechanism has been shown in laboratory experiments (Hino et al., 1983), and its responsibility for the sand suspension is indirectly confirmed in the papers of Foster et al. (1994) and of Pykhov et al. (1995).

The reality of the existence of the first mechanism under field conditions is confirmed by some (not numerous for the present) measurements of the macroturbulence in the surf zone (George et al., 1990; Rodriguez et al., 1995). The results of this research only give a possibility to assess a time-mean value of the turbulent energy, the integral length scale, the turbulent viscosity. But they do not afford to trace the temporal variability of these parameters, which is necessary for the analysis of time fluctuations of the suspended sediment concentration. In spite of the fact that the hypothesis about sediment suspension by such vortexes is shared by the majority of investigators, till now there is no confirmation by direct field measurements.

The aim of our paper based on the data of field measurements is to confirm the existence of turbulent mechanisms of sand suspending by the determination of the scales of fluctuations of turbulent kinetic energy and suspended sand concentration and by ascertaining dependencies between these fluctuations.

Experiment

Field experiment was carried out on a beach section of Norderney Island, North Sea in October 1994 (Fig. 1).

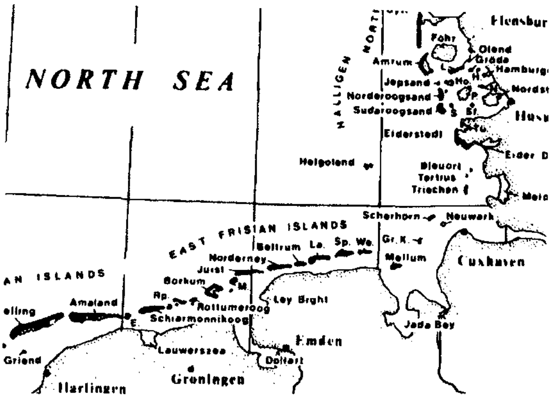

Figure 1. Site of the field experiment.

A joint German-Russian team of scientists carried out multipurpose survey at an especially equipped testing site, which is located on the north-western side of the island. In this paper the results of measurements in one point (10 centimeters and more above the bottom) are presented and discussed (Fig. 2). The suspended sand concentration, the free surface elevation and the two horizontal components of water velocity were measured synchronously by optical turbidimeter, pressure gauge and two-component electromagnetic current meter at sampling rate of 18.2 Hz over 20 minutes.

The turbidimeter measures the light beam attenuation at a distance of 6 centimeters that then is recalculated into the suspended sand concentration (Kos'yan et al., 1994). Two-component electromagnetic current meter and pressure sensors (Type NSW) had been used for measuring. Their linear calibration characteristics are in the band of frequency from 0 to 20 Hz. The diameter of the measuring head of the currentmeter is 6 centimeters.

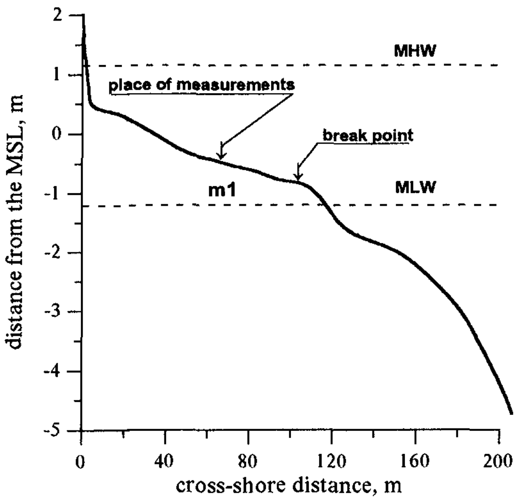

Figure 2. Bottom profile and point of measurements.

The bed consists of sand with a mean diameter of approximately 0.2 mm. The tidal range of about 2.4 m afforded to produce the measurements at a depth range from 0.5 to 2.5 m.. The measurements were carried out in the inner and middle parts of the surf zone under the wind wave and swell conditions. The 25 series of recording were obtained during the whole experiment.

Separation of turbulence

We consider the turbulence as a part of water particle fluctuations, which is incoherent to the elevations of the free surface. Spectral and mutual spectral analysis of fluid velocities and free surface elevations show the turbulent fluctuations of the cross- and the long-shore velocities at the frequencies $f > 0.8$ Hz. This is conformed by the absence of the coherence between cross-shore velocity ($u(t)$) and free surface elevations ($H(t)$) at the frequencies $f > 0.8$ Hz and by the change the velocity spectra ($S_u(f)$) gradient from $\sim f^{-4}$ to $\sim f^{-2}$ at $f = 0.8$ Hz (Fig. 3). Turbulent components of the cross-shore $u_t(t)$ and long-shore $v_t(t)$ velocities were obtained by digital filtering.

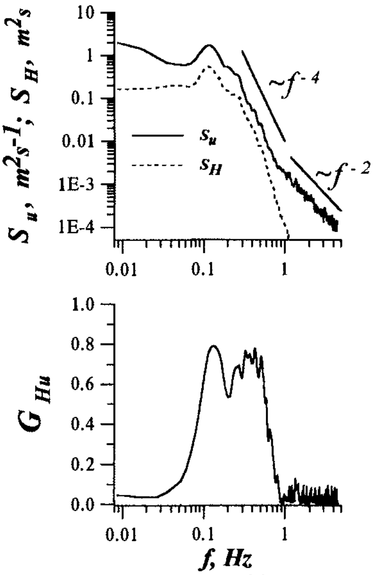

Figure 3. Determination of boundary frequency between waves and turbulence. f_b=0.8 Hz. Record 5a. H_S=1.03 m, T_P=8.7 s, $\bar{h}$=1.53 m, Sp.

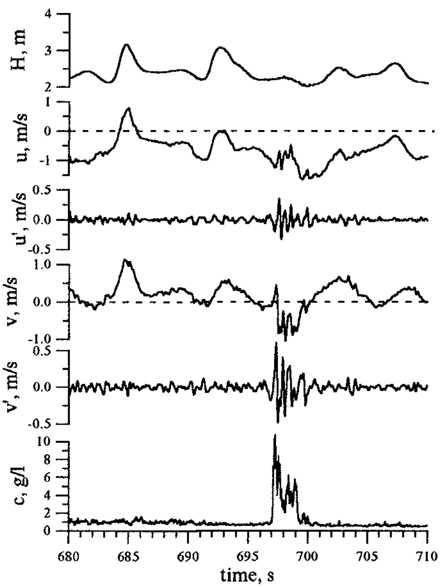

Figure 4. Example of single suspending event. Record 6a. H_S=1.07 m, T_P=8.7 s, $\bar{h}$=1.53 m, Sp.

Examples of events

Analyses of the records show a rapid appearance and disappearance of suspended sand events, which are well coincided with the appearance and disappearance of turbulent fluctuations of the cross- and long-shore velocities.

A typical example for a single suspending event is given by Figure 4. Recorded are wind waves with a significant height H_s=1.07 m, mean period T_P=8.7 s, breaking by spilling at the depth $\bar{h}$=2.36 m. $H(t)$ is the free surface elevation, $u(t)$ and $u'(t)$ are the cross-shore velocity and its turbulent component, $v(t)$ and $v'(t)$

are the long-shore velocity and its turbulent component, $C(t)$ is the suspended sand concentration. The splash of turbulent velocity fluctuations and the splash of concentration between 697 to 700 s may be explained by horizontal advection of turbulent vortexes with trapped sand at the sensor array.

Figure 5 shows the two consecutive events of sand suspending for a more intensive wave regime (H_s=0.90 m, T_P=8.7 s, $\overline{h}$=1.62 m, breaking type is between spilling and plunging). The change of the amplitude of the turbulent fluctuation coincides well in time with the splash of concentration.

Figure 6 demonstrates the intermittence of turbulence and the corresponded events of sand suspending events during the 500 s for the same record as shown on Figure 5. The fluctuation of turbulent kinetic energy ($E(t)$) coincides well with the fluctuation of suspended sand concentration. Turbulent kinetic energy was calculated as the sum of the squared turbulent velocity components: $E(t) = u'^2(t) + v'^2(t)$

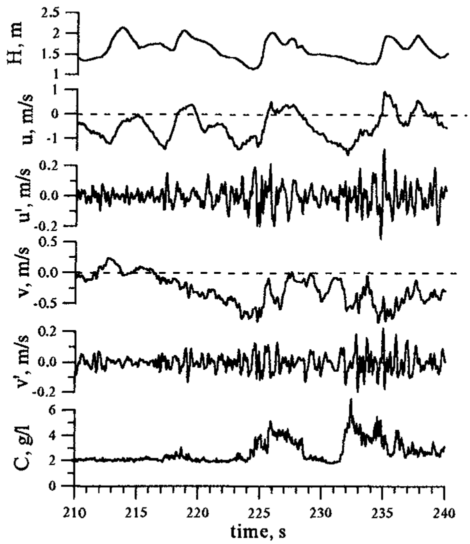

Figure 5. Example of two consecutive events of sand suspending. Record 7f. H_S=0.90 m, T_P=8.7 s, $\overline{h}$=1.62 m. Sp-Pl.

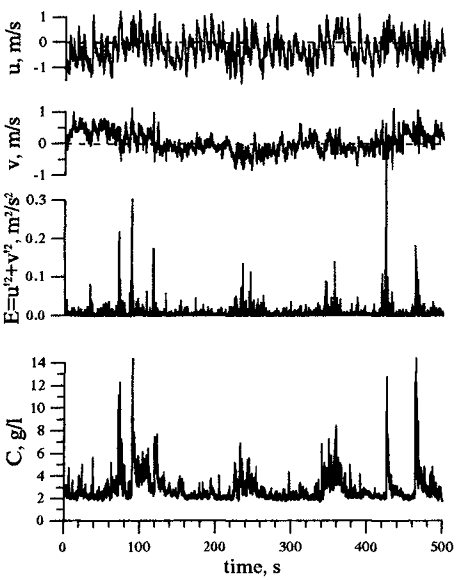

Figure 6. 8-minutes fragment of suspending events. Record 7f. H_S=0.90 m, T_P=8.7 s, $\overline{h}$=1.62 m. Sp-Pl.

Time scales of the turbulence

The upper parts of Figure 7 show the typical spectra describing the concentration fluctuations $S_C(f)$ and the kinetic turbulent energy variations $S_E(f)$ as function of frequency. Both spectra coincide with increasing frequency. The concentration spectrum has a feebly marked peak at the main wave frequency. Turbulent energy spectrum is decreasing monotonously with inereasing frequency except the peak at the frequency of 1.6 Hz, which is called forth by the method of the turbulence selection, i.e. by the filtering with a boundary frequency of 0.8 Hz, and therefore it has no physical sense (when squaring ($E(t) = u'^2(t) + v'^2(t)$) the frequencies are doubled).

The lower left part of Figure 7 displays the squared coherence function $G_{CE}(f)$. Significant values of the coherence G_{CE} at the frequencies $f < 0.05$ Hz afford to say, that the low frequency suspended sand fluctuations are determined by the bursts of the turbulent velocity fluctuations.

The lower right part of Figure 7 shows for low-frequencies ($f < 0.05$ Hz) the relation between the related components of concentration (C_{low}) and of kinetic turbulent energy (E_{low}). It demonstrates that the deviations from the linear connection are not caused by the nonlinearity, but by random reasons.

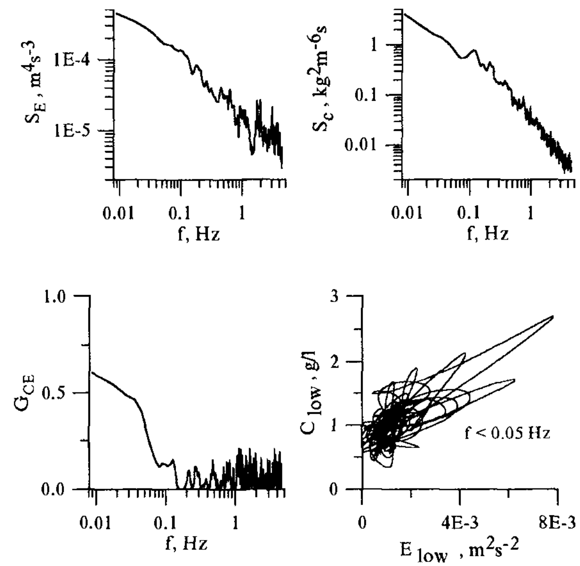

Figure 7. Connection between suspended sand concentration and turbulent energy. Record 5a. H_S=1.07 m, T_P=8.7 s, $\bar{h}$=2.33 m. Sp.

Let us consider the regularities of turbulent fluctuations within one suspension event.

Figure 8 presents the chronograms of turbulent components of velocities and their hodograf for a single suspending event, which was demonstrated at Fig. 4. The hodograf shows, how that the end of the vector of turbulent velocity component runs two full circles during one second. This may correspond to the passing of a series of four vortexes, as principally shown in the lower right part of Figure 8. Neighboring vortexes must rotate in opposite directions.

An assumption about the passing of a series of several consecutive vortexes is confirmed by results of laboratory investigations presented at the conference Coastal Dynamics'94 by Zang et al. who presented the nomogram of the type and number of turbulent vortexes that are formed in the moments of wave breaking depending on Reynolds number and breaker-type index given by Galvin. The nomogram shows that all our recorded wave regimes occurred in the region of formation of triple oblique vortexes.

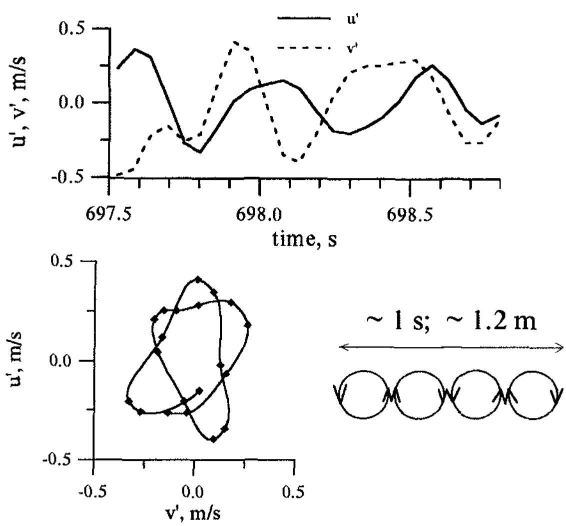

Figure 8. Time scales of turbulent vortexes.

Spatial scales of turbulence

To assess spatial scales of turbulence the chronograms of the turbulent velocity fluctuations were recalculated into series of fluctuations along trajectories of the vortex movement according to Tailor's hypothesis "about frozen turbulence". Wave components (f < 0.8 Hz) were used as carrier velocities. The obtained series of spatial distribution of turbulent velocity fluctuations are presented as stick diagrams, an example is presented on Figure 9. The zero point of the spatial coordinate has been fixed arbitrarily.

The obtained stick diagrams show that turbulent vortexes are grouped in large structures. The passing of these vortex-structures across the point of

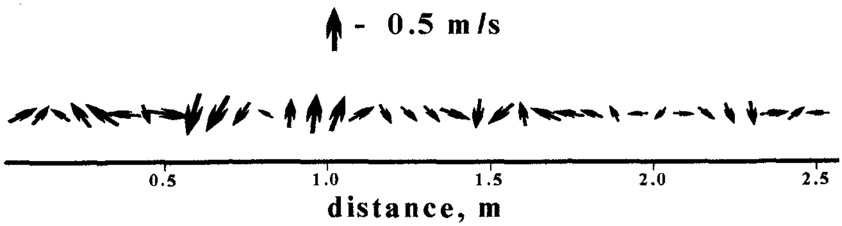

Figure 9. Example of stick-diagram. Record 5a.

measurements coincides with the sand suspending events. The spatial boundaries of such structures were determined visually by using the velocity value of 0.1 m/s as a boundary between the vortex structure and the background turbulence. The length of such structures was varied from 1 to 10 m. Linear scales of vortexes in the recorded structures varied from 0.3 to 1.5 m and there were the vortexes of different size in one structure. There were also the structures of different size in one series of measurements. Since we had only one velocity gauge in operation, we could not determine whether the central or the outline part of turbulent vortex had been recorded. It was a reason of definite incoherence between wave flow dimensions and vortex size. But if we will consider only the largest vortexes in the structures, such correlation becomes obvious.

The dependency between the largest vortex size in a series and a water depth is presented in Figure 10. It demonstrates how the diameter of vortex increases with depth. This dependency confirms the classic idea about a proportionality between sizes of vortexes and flow.

To improve the accuracy of the assessment for the turbulent vortex size the next series of experiments will operate several gauges simultaneously, which were be placed at a distance about one meter.

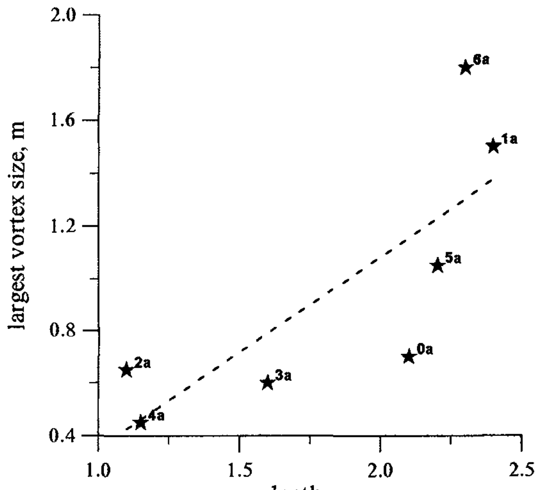

Figure 10. Spatial scales of vortexes.

Conclusions

Our results demonstrate that suspension events in the middle and inner parts of a surf zone are determined by macro-turbulent vortexes and that the intermittence of turbulence determines the low-frequency fluctuations of suspended sand concentration. In our future investigations we will investigate the connections between intermittence of turbulence and wave parameters and the correlation between parameters of turbulence and the suspended sand concentration.

Acknowledgment

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