# NOWADAYS PROBLEMS OF SEDIMENT TRANSPORT MODELING IN THE COASTAL ZONE

Ruben D. Kos'yan[1], Joacim Grune[2], Boris Divinskiy[1], Igor Podymov[1]

The ultimate purpose of sediment transport studies is the prediction of bottom relief in the zone of active wave effect accompanied by transport of significant sand volumes. The energetic longshore currents induced by the oblique wave approach, transport large amounts of sand lifted by waves from the sea bottom. This mass sediment transport and its variations finally determine the shore-line configuration and the location of accumulative and erosion areas on the underwater slope. Because of great practical significance, the problem of sediment transport has attracted much attention. When constructing theoretical models of suspended sediment mass transport by water flows, investigators have to face a number of difficulties. Modeling of the sediment transport is limited by the absence of clear physical mechanisms of sediment suspension. The main difficulties of the modeling are discussed in this report.

*Keywords: sediment transport, field experiments, suspended sediment concentration, bottom ripples*

A total ocean dynamics separately allocated coastal zone. Special hydro-, litho-, and morphodynamic conditions associated with intensive dissipation by the wave energy against high water exchange are formed within coastal areas. The character and intensity of bottom sediment dynamics are determined by the wave field transformation processes, advanced turbulence, and longshore currents system. Coastal sediment transport problems are of key importance in view of their great usefulness.

During storms the main part of sediments moves in suspensions. Quantitative forecasting of the suspended sand particles flux is the most important objective of the coastal zone dynamics. Such forecast is especially actual at the last time because of high coastal development including different types of hydrotechnical construction, protection of beaches against erosion, new artificial beaches, and the creation of underwater farms, providing ecological safety.

Prediction of sediment discharge, deformation of the bottom relief, and beach profile changes is vital for the security of various communications (cables, pipelines) and hydraulic works (scaffold bridges, oil-pumping works, etc.), for the support of beach recreational regimes, and for the creation of artificial beaches.

Due to the great difficulties in making direct measurements and estimates of near-bottom sediment discharge, rigorous prediction is evidently impossible. On the other hand, the immense practical significance of this problem has stimulated the development of some tens of equations for the evaluation of longshore sediment transport during the last 20 years.

Precise forecasting of offshore sediment discharge is basically impossible. At the same time, huge practical interest in the problem has led to the appearance of several dozen formulas for the estimation of sediment transport by water flows (Kos'yan et al., 2000). Semiempirical models compose the most numerous group, wherein the discharge value averaged over the inshore cross-section is accepted as proportional either to combinations of the wave parameters, bottom slope, and bottom sediment composition or proportional to the alongshore wave energy flow estimated by the break line waves' characteristics. Such models are reduced to the form:

$$\overline{Q_y} = A_y F_{\mathrm{yp}} \tag{1}$$

$$F_{\mathrm{yp}} = \left(Ec_g\right)_p cos\alpha_p sin\alpha_p \tag{2}$$

where $E$ is the wave energy, $c_g$ the group velocity, $\alpha_p$ the approach angle to the normal on the wave break line, and $Ay$ a coefficient.

The great number of models is a direct indication of the poor knowledge of the physical sense of these phenomena. Universal predictive models for the longshore sediment discharge are still lacking.

The absence of a universal method suitable for the practical calculation of the transportation of solid particles is obvious. Consequently all known solutions are acceptable in definite limits only.

The ultimate purpose of sediment transport studies is the prediction of bottom relief in the zone of active wave effect accompanied by transport of significant sand volumes. The energetic longshore currents induced by the oblique wave approach transport large amounts of sand lifted by waves from the sea bottom. This mass sediment transport and its longshore variations finally determine the

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[1] The Southern Branch of the P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences. Gelendzhik-7, 353467, Russia

[2] Coastal Research Centre FZK, Merkurstrasse 11, 30419, Hannover, Germany

shoreline configuration and the location of accumulative and erosion areas on the underwater slope. Because of its great practical significance, the problem of longshore sediment transport has attracted much attention.

The following continuity equation is a physical basis which connects changes of the bottom level and sediment flux (Kachel and Smith, 1989):

$$\frac{\partial H}{\partial t}+\frac{1}{1-n}\left(\frac{\partial Q_x}{\partial x}+\frac{\partial Q_y}{\partial y}\right)=0$$

$$Q_x(x,y,t)=\int_{-H}^{h}\frac{1}{T_M}\int_{0}^{T_M}C(x,y,z,t)\bullet U(x,y,z,t)dtdz$$
$$Q_y(x,y,t)=\int_{-H}^{h}\frac{1}{T_M}\int_{0}^{T_M}C(x,y,z,t)\bullet V(x,y,z,t)dtdz \qquad (3)$$

where the x-axis is directed along the cross-shore, the y-axis is directed to the longshore, and the z-axis is directed from the bottom to the sea surface; n is the concentration of sediments at the bottom level; Qx and Qy are depth integral sediment fluxes in the cross-shore and longshore directions; T is the time period of averaging (in field conditions, usually 10–60 minutes); a horizontal line marks the time averaging.

Instantaneous values of concentration and velocity components for irregular waves can be presented as the sum of the main time scales:

$C(x,y,z)= C + C_w + C_l + C',$ (4)

$U(x,y,z)= U + U_w + U_l + U',$ (5)

$V(x,y,z)= V + V_w + V_l + V',$ (6)

where U and V are the mean values of sediment concentration and water velocity components in the cross-shore and longshore directions for time period T; $C_w$, $U_w$, and $V_w$ are fluctuations of those characteristics in the gravity band of the spectrum of irregular waves; $C_l$, $U_l$, and $V_l$ are fluctuations of sediment concentration and water velocity components in the infragravity band; C', U', and V' are turbulent components of these characteristics. The boundary frequencies between infragravity and gravity bands of the spectrum of irregular waves are 0.05 and 1 Hz between the gravity and turbulence bands. The frequency of 0.05 Hz is a relative one, and from a physical point of view it is not a constant one. Its value can be determined by a certain power spectrum of wind waves and swell waves in the course of field measurements. Substituting (4)–(6) and taking into account that the values of fluctuation components of concentration and water velocity are averaged over time and that their products for different frequencies are equal to zero, we get the following expressions for local sediment fluxes:

$q_x = CU + C_wU_w+ C_lU_l+ C'U'$ (7)

$q_y = CV + C_wV_w+ C_lV_l+ C'V'$ (8)

It is seen from (7) and (8) that for the strict and grounded from a physical aspect assessment of local sediment fluxes in the cross-shore and longshore directions, it is necessary to know the dependencies of the mean and concentration fluctuation components on the parameters of irregular waves and their cross-correlations with water velocity components at the different distances from the bottom. The possibility of obtaining such dependencies occurred in the last years due to the creation of optical and acoustic devices for field measurement of instantaneous values of suspended sediment concentration with the discreteness in a tenth of a second. That allows us to analyse fluctuations of concentration in a full band of the spectrum of irregular waves.

Similar field observations were carried out in the Black Sea, North Sea, Mediterranean Sea, and South China Sea. Optical turbidimeters, Drucksonde NSW-48 electromagnetic two-component velocity sensors, string wave meters, a “Vector” three-component acoustical current meter, bottom- form transducers, and sediment traps were used in the studies. Devices for the synchronous measurements were placed on mobile sledges (Kos’yan et al., 2003; Nguen Manh Hung et al, 2011).

Several complex laboratory experiments based on the Large Wave Channel of the Coastal Research Centre (FZK) in Hannover (Germany) were actualized (Kos’yan et al., 2010). Synchronous measurements were carried out by means of optical turbidimeters, Stromungssensor Type “S” electromagnetic two-component velocity sensors, string wave recorders, a “Vector” three-component acoustical current meter, acoustical sensors of suspended sediment concentration (ABS), pumps for suspended sediment sampling on the five horizons online (TSS), sediment traps, and a parallel type 80-

channel ACP, allowing the incoming data to be collected in terms of 15-bit words at the velocity of 40 Hz; computer system, serving a measuring instrument complex and management of wave generator work mode according to the experiment's inherent program; software complex; photo-video equipment were carried out in the experiments. Measuring instruments were mounted on optional constructions situated in a certain scheme along a box. Specially designed weights and bracings were used as turbidimeter bearers.

The main processes controlling the time-scales, amplitude, and phase correlations between concentration fluctuations and suspended sediment discharge in the coastal area were reviewed based on field studies (Kos'yan et al., 1999). Seaward of the breaking zone in the lightly deformed wave and ripple bed field, vortexes are the basic mechanism of suspension of sand from the bottom, formed beyond the ripple backs. In the case of two-dimensional ripples, the sediments are suspended only under waves passing through with amplitude of velocity exceeding it root-mean-square value. Consecutive sand suspension under the influence of every wave in those groups resulted in the formation of broad-concentration peaks. The peak-duration depended on the quantity of waves in the group; it was in the order of several tens of seconds. The fluctuations of the sand-concentrations, with the same period as the waves, occurred within these peaks. The concentration peaks are confined to flow reversal moments during the deceleration phase and flow acceleration phase. The highest values of concentration are observed during the flow deceleration phase (Fig.1).

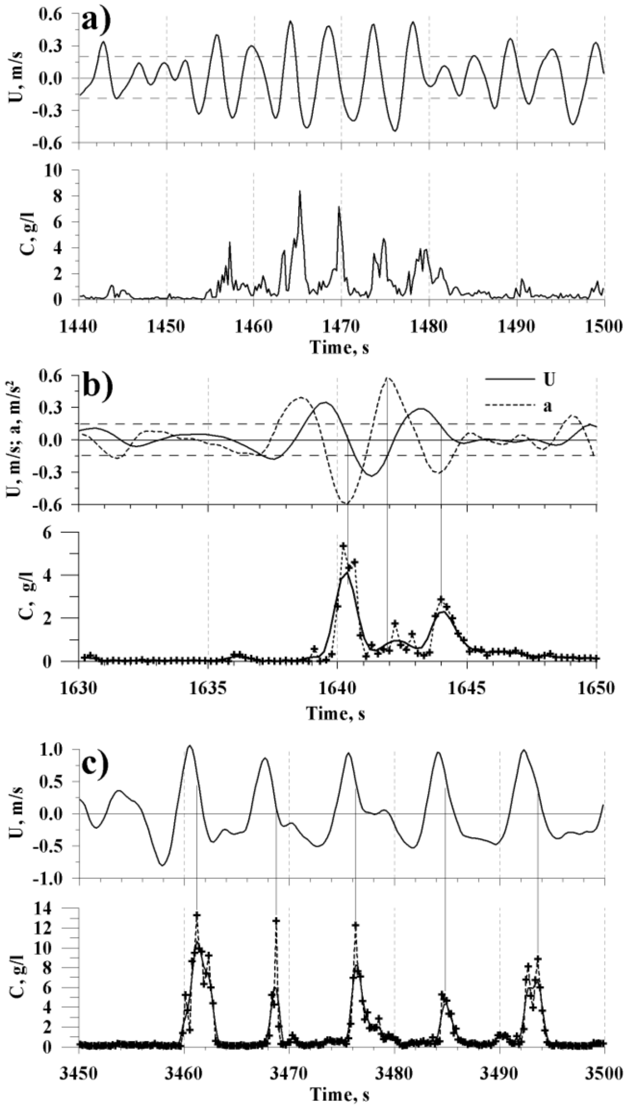

**Figure 1. a),b) – rippled bed, c) – flat bed.**

Statistically significant coherence values between concentration fluctuations and the normal-to-the-shore sea-bottom velocity component occur at the wave spectrum maximum frequency and those between the concentration and enveloping velocity occur at frequencies of < 0.08 Hz (Kos'yan et al., 1999).

The concentration fluctuations lag in phase by π/2 relative to the normal-to-the-shore water velocity component at the frequency of the wave spectrum maximum and relative to its envelope from π/4 to 0 in the frequency range < 0.08 Hz. The two-dimensional ripples at the surface of the sea-bottom transform to three-dimensional ripples with the increase of wave deformation and sea-bottom water velocities. In this case, sediment suspension happens only after the wave ridge passes into the flow deceleration phase under the flow reversal moments. In comparison with the case of two-dimensional ripples, the decrease in coherence and phase lag between concentration fluctuations and water velocity at the frequency of the wave spectrum maximum and between the concentration and envelope of the cross-shore velocity at low frequencies is observed. Sand suspension by the vortexes formed because of the sea-bottom boundary layer shearing instabilities is the most probable mechanism of sand suspension in the greatly deformed wave zone before their breaking, where ripple disappear and the sea-bottom is nearly plain (Fig.2).

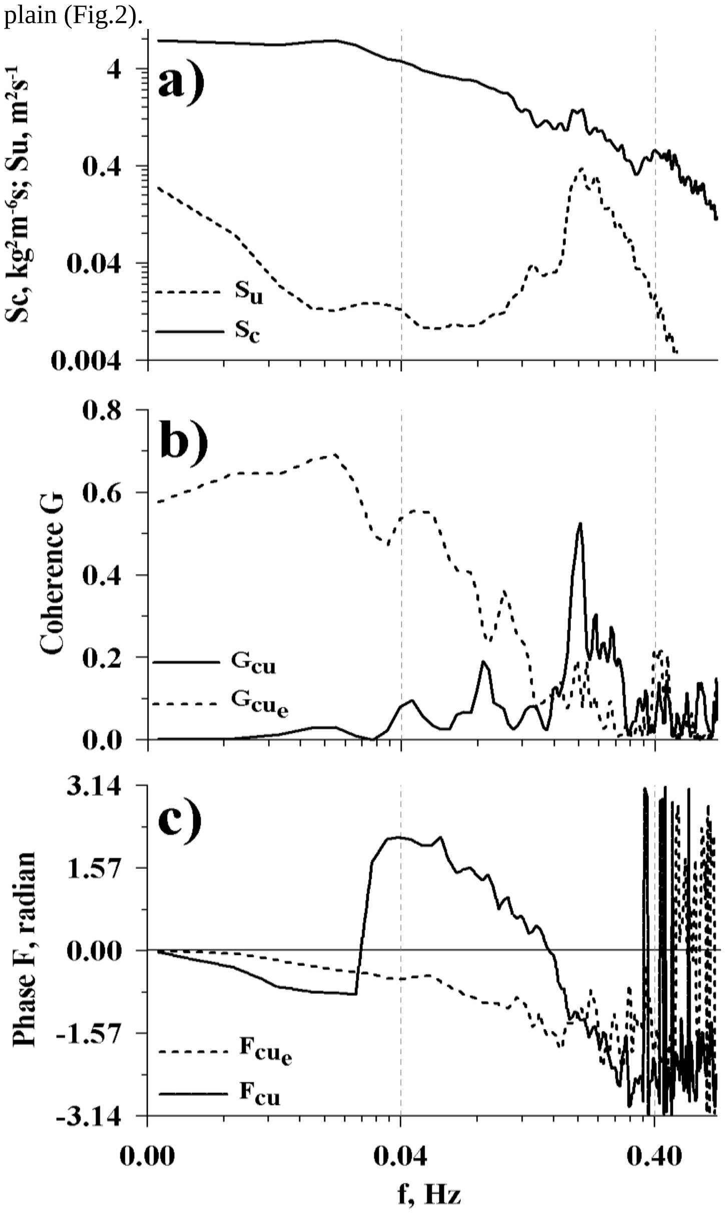

**Figure 2. The spectra of the suspended sediment concentration ($S_c$) and cross-shore velocity ($S_u$) - a); the coherence function and the phase shift between the sediment concentration and the cross-shore velocity ($G_{cu}$, $F_{cu}$) and between the sediment concentration and the cross-shore velocity envelope ($G_{cue}$, $F_{cue}$) - b), c), respectively.**

The macroturbulent vortexes that are generated under plunging and spilling breakers are the driving forces for the mechanism of sand suspension in the surf zone. The most intensive suspension events are formed under plunging breaking waves. These events correspond in time to the forward front of cross-shore velocity. Because the wave induced vertical velocity at the moment of the steep forward front of the wave crest passing directed upward from the bottom, the suspended sediment flux is also directed away from the bottom. Because the turbulence determinates the sediment suspending process and there is no direct dependency between the magnitudes of turbulent kinetic energy and the cross-shore velocity, it is no surprisingly that the correlation between the concentration and the velocity is very low, as demonstrated with the field data of the measurements.

The most intensive suspension events are created by the largest turbulent vortexes. The presented examples for different recording runs demonstrate that at the moments of the most intensive suspension events the turbulent velocity in some times exceeds its r.m.s. value. This conclusion is in qualitatively agreement with the turbulence data under breaking waves, presented in the publications of (Cox D.T., Kobayashi 1999; Kos'yan et al., 1999; Ting, Kirby, 1995; Ting, Kirby, 1996).

In the breaking zone, where the group structure of waves degenerates because of energy dissipation, the concentration fluctuations mainly take place in the infragravity wave band. Then, in some cases, significant values of the coherence between concentration and the cross-shore velocity of infragravity waves can be obtained.

Significant coherence values are observed only between concentration fluctuations and turbulent kinetic energy in the inner part of breaking zone, where wave crest dispersal processes predominate (Fig.3). When turbulence determines the suspension and there is no dependence between turbulent energy values and water velocity in the breaking zone, it is no surprise that the coherence between concentration fluctuations and water velocity is very low. The highest value of suspended sediment concentration occurs when the large vortex passes through measurement point, while the velocity pulsation intensity exceeds their root-mean-square by several times.

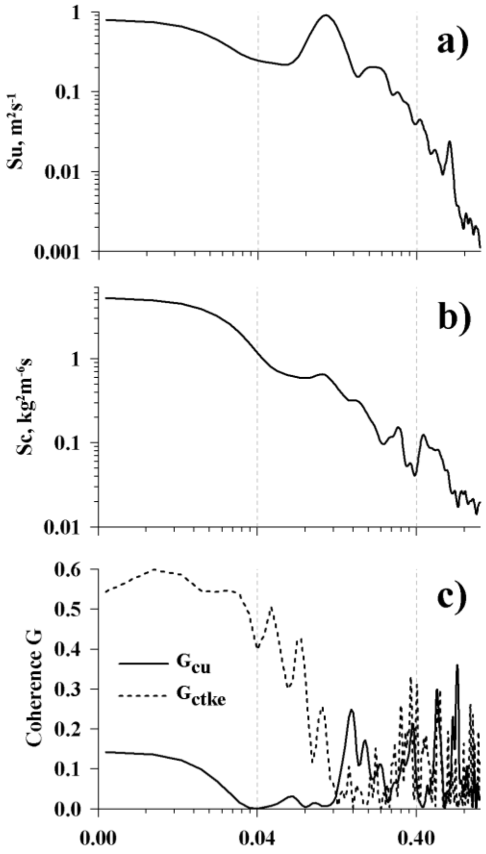

**Figure 3. Time series of 400 seconds: a) spectra $S_u$ of the cross-shore velocity (u); b) spectra $S_c$ of the suspended sediment concentration (C); c) spectra of the coherence between $S_c$ and $S_u$ ($G_{cu}$) and between the spectra of the sediment concentration and of the turbulent kinetic energy ($G_{ctke}$).**

One of the difficulties of suspension modelling is the problem of identifying the dependence between values of suspended sediment concentration and the form of the wave spectrum.

Up to the present moment, the question of the influence of wave energy frequency distribution in a surface wave spectrum on the sea-bottom sediment transport was a problem which was not studied practically. Some points about the possibility of such influence was postulated in the papers (Divinsky et al., 2011; Grune et al., 2007). The preliminary investigation were developed in the research presented in (Kos'yan et al., 2010).

The difference found in the bottom erosion response to external disturbance represented by irregular surface waves with constant integral characteristics (significant wave height and spectrum peak period) and changeable frequency distribution of the wave energy was the main object. Complex experimental data obtained in 2008 by the co-operative efforts of Russian and German scientists in the Large Wave Channel of the Coastal Research Centre in Hannover were used for this research.

As an initial irregular wave field was set by a sequence of the free surface elevation, having JONSWAP-spectra with specified characteristics (random phases).

In generalized form the JONSWAP spectrum can be written as:

$$S(f) = \frac{\alpha g^2}{(2\pi)^4} f^{-5} exp\left(-\frac{5}{4}\left(\frac{f}{f_m}\right)^{-4}\right)\gamma^{exp\left(-\frac{1}{2\sigma^2}\left(\frac{f}{f_m}-1\right)^2\right)}$$

or in the parameterized form:

$$S(f) = \alpha H_{m0}^2 f_m^4 f^{-5} exp\left(-\frac{5}{4}\left(\frac{f}{f_m}\right)^{-4}\right)\gamma^{exp\left(-\frac{1}{2\sigma^2}\left(\frac{f}{f_m}-1\right)^2\right)}$$

Here:

$$\alpha \approx \frac{0.0624}{0.230+0.0336\gamma-\left(\frac{0.185}{1.9+\gamma}\right)}$$

$$\sigma \approx 0.07 \quad f \le f_m$$

$$\sigma \approx 0.09 \quad f > f_m$$

$\gamma$ – peak enhancement coefficient.

The JONSWAP spectrum is determined by three parameters: significant wave height $h_s$, spectrum peak period $f_m$, and parameter $\gamma$ which characterizes the wave energy frequency distribution within one peak spectrum.

In this case, a series of experiments corresponded to the sorting out of the spectral parameters of the primary wave field:

- Significant wave height $h_s$=0.8, 1.0, 1.2 m.
- Spectrum peak period $f_m$=0.2 Hz.
- Peak enhancement coefficient $\gamma$=1.0, 1.5, 2.0, 2.5, 3.0, 3.3, 4.0, 6.0, 8.0, 9.9.

Differences in the sea-bottom abrasion responses to the external disturbance represented by the irregular surface wave with constant integral characteristics (significant wave height and spectrum peak period) and changeable frequency wave energy distribution were established during the investigation:

- In the experiment the influence of hydrodynamic conditions on the sea-bottom is expressed in the predominant formation of sea-bottom ripples, which determine the suspension picture. The wave energy concentration near the main spectrum maximum, indicated by the increase in the spectrum peak enhancement coefficient $\gamma_{JONSWAP}$, contributes to a rise in the linear dimension of the sea-bottom microform.
- The rise in value of the parameter $\gamma_{JONSWAP}$ from 1.0 to 10 leads to an increase of 10–15% of the ripple's length. The increase in the geometric ripples' dimension contributes to more intensive injection of bottom sediments to the upper layers, accompanied by a rise in the suspended sediment concentration.
- Under low values $\gamma_{JONSWAP}$ with the removal from the bottom, a decrease in the particle mean diameter values is observed. The granulometric suspended sediment composition under the removal from the sea-bottom almost does not change with the rise in the peak enhancement coefficient.

Thus, it can be concluded, that the wave energy frequency distribution peculiarities determine the specification of the wave's effect on the bottom sediments under the same integral characteristics of the irregular surface wave ($h_s$, $f_m$=const). The wave energy concentration near the spectrum maximum frequency contributes to the transit from irregular to regular waves and in general to the dynamic influence to the bottom. Physically it leads to the realization of more stable conditions for the development of the bottom microform relief.

## Conclusion

The complex picture of hydro- and lithodynamic processes interaction arising in the coastal zone requires an integrated research approach, including:

1. Improvements to methods of sea and laboratory measurement of the suspended sediment concentration and composition for different temporal averaging scales (wave period, wave group, certain storm, synoptic variability) and under different physical conditions (wind wave, main current presence).
2. The analysis of the composition and initial wave field spectral structure. Mathematical modeling method has to be engaged for getting statistically positive estimations.
3. The verification of existent suspended sediment concentration estimations and suspension fluxes based on data of field experiments and the development of a base for new model elaboration.
4. The elaboration of new sediment dynamics models in different hydrodynamic conditions.

Let us note in summary that processes of sediment fluxes formation in the coastal zone are extremely complex and multifaceted and with current knowledge it is impossible to propose the universal calculation method, kinematic structure and sediment fluxes composition. The investigation of sediment movement processes is viable on different temporary averaging levels. Characteristic time-averaging selection limits the scope of work, argument list, and prognostic possibilities. It is necessary to be aware of what transport mechanisms being modeled and of the mistakes to which the disregard of other mechanisms can lead.

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