Classification and parameterization of typical scenarios of nonlinear transformation of waves in coastal zone

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Waves in coastal zone are very important for all dynamics processes. Knowledge of wave transformation and changes of its parameters in coastal zone are necessary for solution of all practical and theoretical tasks and projects. Wave transformation in coastal zone is nonlinear-dispersive process due to near resonant nonlinear triad interactions of wave components. Main feature of this process is periodical exchange of energy between first and highest harmonics accompanying fluctuations of its amplitudes and highest wave statistical moments that influences on sediment transport in coastal zone. Meanwhile in many engineering calculations and models of vulnerability of coastal zones the formulas of the linear theory of the wave transformation, not considering nonlinear properties of waves, or the theory of waves on shallow water, assuming non dispersive evolution of waves in coastal zone, are widely used.

The purpose of this work - classification of coastal zones on a scenario of nonlinear waves transformation, depending on parameters of input waves and mean bottom slope of coastal zone.

For the analysis the data of field experiment «Shkorpilovtsy 2007» carried out on Black sea (Bulgarian part) had used. During experiment for registration of free surface elevation 15 wire type gauges were installed. The mean bottom slope was equal 0.022. Measurements in all 15 points were made synchronously with sampling frequencies 5 - 20 Hz and duration from 20 min up to 1 hour and 65 wave records have been registered.

For definition of characteristic scenarios of nonlinear wave transformation an evolution of spectra of waves in time and in space was considered. Spectra of waves have been constructed on Welch method. Special attention was given to periodical changes of amplitudes of first and second wave harmonics across the coastal zone. The details of nonlinear wave transformation were confirmed by bi-spectral analysis. As nonlinear parameters of waves a steepness of waves H/L to characterize the nonlinearity of input waves and relative height of waves H/h to characterize the nonlinearity of waves on shallow water were used. Iribarren and Ursell numbers connect nonlinear parameters of waves with depth of water and bottom slope:

$$Ir = \tan\alpha \,/\sqrt{H_0/L_0}\,,$$

where α - bottom slope, H_0 – characteristic wave height, L_0 – characteristic wave length;

$$Ur = \frac{1}{2}\frac{H}{h}\frac{L^2}{h^2},$$

where h - depth of water, L - length of a wave, H - height of waves.

For the classification of coastal zones the dependences of these numbers on nonlinear parameters of waves have been constructed. For an estimation of influence of characteristic scenarios of nonlinear wave transformation on sediment transport the Bailard's formula was used (Bailard, 1981). For modeling of irregular wave transformation above different bottom slope the Boussinesq type model with extended dispersion characteristics was applied.

Results and discussion

23 wave records of «Shkorpilovtsy 2007» experiment have been selected, in which the spectrum was narrow enough to separate the frequency bands of the first and second harmonics. Change of amplitudes of the first and second harmonic was estimated as change of wave energy of a corresponding frequency band. Four characteristic scenarios of evolution of the second harmonics have been allocated: 1) on an input in experimental area of coastal zone (250 m from shore) the second harmonics are small, and their amplitude grows only more close to coast; 2) there is a periodic exchange of energy between the first and second harmonics, and inside of a coastal zone the amplitude of the second harmonic reaches a maximum; 3) the amplitude of the second harmonic is small in all coastal zone and there is no its strongly pronounced maximum; 4) on an input in experimental area of coastal zone the second harmonic has enough large amplitude which decreases to the coast. It was shown, that coastal zones in depending on Iribarren and Ursell numbers can be classified into this 4 typical scenarios of wave transformation.

In the result of analysis of field data and numerical simulations it was revealed, that the relative large amplitude of second harmonics and periodical exchange of energy between the second and first harmonics are typical for coasts with gentle slope, less than 0.03.

Ursell number equal 10 on an input in a coastal zone is criterion for distinguish of scenarios of transformation of waves. If $Ur > 10$, the amplitude of the second harmonics is greater already on an input in a coastal zone or reaches a maximum due to a periodic exchange of energy inside of it. In this case, the full period of an exchange by energy or its half is observed. For these waves – $Ir > 7*H_0/L_0$, where H_0/L_0 - a steepness of waves on an input in a coastal zone. If $Ur < 10$, and $Ir < 7*H_0/L_0$ it can be observed two and more periods of an exchange of energy between harmonics, and amplitudes of the second harmonics increase only near at coast or remain small. Iribarren number on an input in a coastal zone can be used as criterion for expected relative value of amplitudes of the second harmonics

inside of a coastal zone: if Ir < 0.27 the relative value of amplitude of the second harmonic will be large. Such coastal zones can be pointed to coastal zones, for which nonlinear behavior of waves are most expected. The influence of all scenarios of nonlinear wave transformation on sediment transport in coastal zone was discussed.

Thus, Iribarren and Ursell numbers together with parameters of nonlinearity of waves on an input in a coastal zone can be used for an estimation of possible scenarios of transformation of waves and classification of coastal zones on its expected nonlinear properties and spatial variability of sediment transport. The obtained results can be a basis for development of criteria of vulnerability of the coastal zone, considering its nonlinear dynamics.