Influence of JONSWAP Wave Spectra Form on Frequency Spectrum of Suspended Sediment Transport Values

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ABSTRACT

On the base of experimental data the comparison of the suspended sediment concentration fluctuations frequency spectrum with the wave energy spectrum, was fulfilled. It led to some interesting results.

Studies were carried out for different wave conditions, during which γ parameter varied from 1 to 10. Its changes affected the wave energy spectrum. Article examines influence of the wave energy spectrum on frequency spectra of suspended sediment transport.

The paper will provide detailed information about results of this investigation.

INTRODUCTION

In traditional models only the time averaged characteristics of water circulation, sediment and pollutant transport processes are considered. Sometimes the group structure of waves, their transformation within the coastal zone, the contribution of phase shift between sediments and the fluid at different frequencies of an irregular wave spectrum are taking into account. The influence of the form of surface wave spectra, however, has never been considered. First results of the possibility of such dependence were given by (Grüne et al., 2007), where it was shown that the form of wave spectrum could greatly influence on the suspended sediment concentration (SSC) values.

It was noted (first by Phillips in 1958) that at higher frequencies than the peak frequency, the energy in a given wave-field 'saturated'. This saturation produced relatively equivalent energies for a given frequency regardless of virtually all other parameters.

Hasselmann *et al.*, (1973), after analyzing data collected during the Joint North Sea Wave Observation Project (JONSWAP), found that the wave spectrum is never fully developed. It continues to develop through non-linear, wave-wave interactions even for very long times and distances. Considerable data taken off the western shore of Denmark was used to produce a model of the wave spectrum. The model is:

$$S(f) = E(f)\exp\left[-1.25\left(\frac{f_p}{f}\right)^4\right]\gamma^{\Gamma},$$

where

$\Gamma = \exp\left[-\frac{\left(f - f_p\right)^2}{2\beta^2 f_p^{\ 2}}\right]$; $E(f) = \frac{\alpha g^2}{(2\pi)^4 f^5}$; f - is the frequency; f_p – is the peak frequency (frequency at which $S(f)$ is a maximum); α - is the Phillips constant (sometimes called the equilibrium-range parameter); γ - is the peak-enhancement factor (usually taken to be 3.3); and β = 0.07 for $f < f_p$, or β = 0.09 for $f > f_p$.

Studies were carried out for different wave conditions, during which γ parameter varied from 1 to 10. Its changes affected the wave energy spectrum. Below are results of investigations of the wave energy spectra influence on frequency spectra of suspended sediment concentration. Results of the studies are important for modeling the processes of suspension and transport of insoluble particles in dynamic sea areas.

EXPERIMENTAL INVESTIGATION

Theoretical base. The JONSWAP spectrum is similar to the Pierson-Moskowitz spectrum except that waves continues to grow with distance (or time) as specified by the α term, and the peak in the spectrum is more pronounced, as specified by the γ term. The latter turns out to be particularly important because it leads to enhanced non-linear interactions and a spectrum that changes in time according to the theory of Hasselmann, (1966).

Wave spectra of a developing sea for different fetches measured at JONSWAP are shown in Figure 1 (Robert H. Stewart, 2006).

Using Hasselmann's wave model we have calculated dependences maximum of wave spectral density and frequency for maximum wave spectral density from the fetch, Figure 2a and Figure 2b. According to the Hasselmann's wave model wave spectral density, peak steep slope of the spectral density (the Peak-Enhancement Factor) and a frequency for the peak depend on fetch of a wave.

In turn value of a maximum of wave spectral density is functionally related to frequency. The dependence of a maximum of wave spectral density on frequency is shown in Figure 3. From drawing it is visible, that to great values of wave spectral density there correspond low values of frequency. That is natural in physical sense. This is one of main differences of Hasselmann's wave model from the model of Moskowitz (1964).

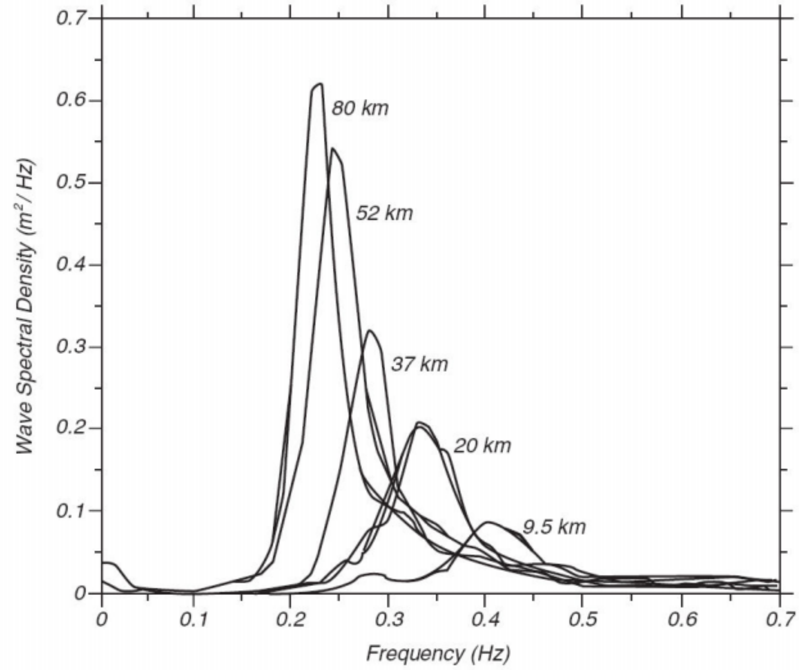


Figure 1. Wave spectra of a developing sea for different fetches measured at JONSWAP.

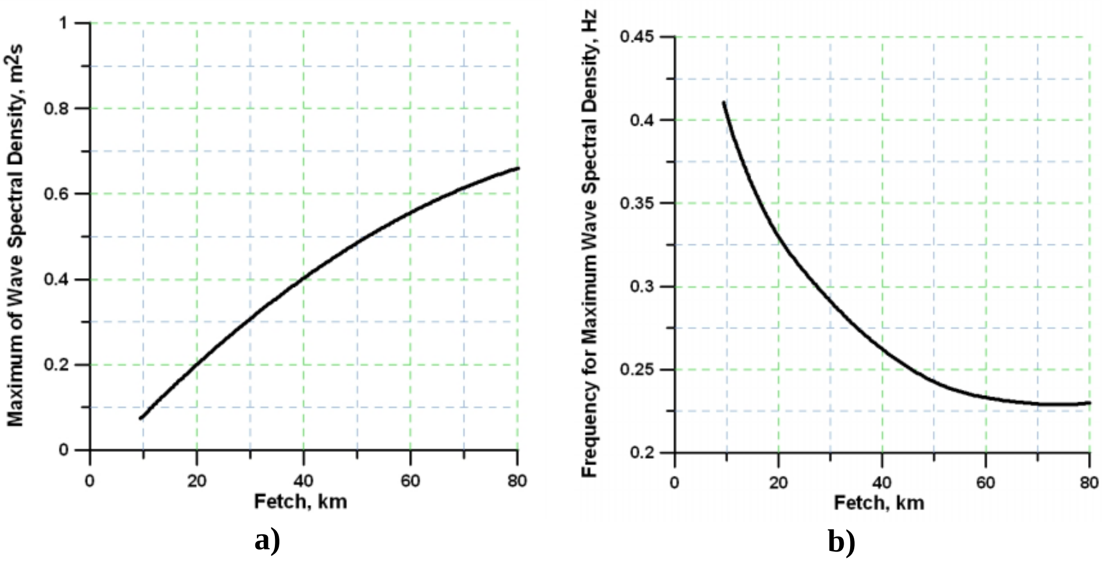


Figure 2. The dependence of wave spectral density maximum (a) and the frequency for wave spectral density maximum (b) from the fetch.

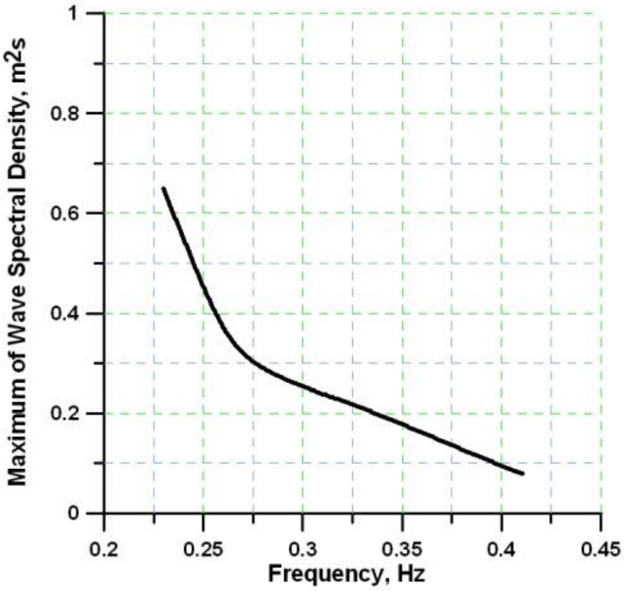


Figure 3. The dependence of wave spectral density maximum on frequency.

EXPERIMENT

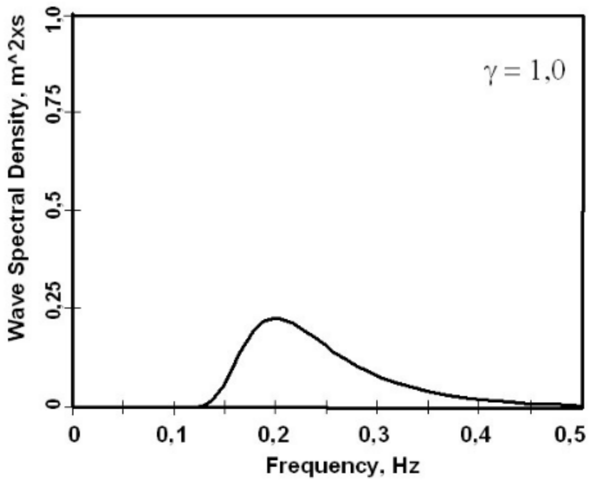
Experiment was performed in the large wave channel. For our investigations wave spectra were created by means of a wavemaker. Simultaneous measurements of suspended sediment concentration, free surface elevations and three-component velocities were carried out at several levels above the sea bed. γ - parameter changed in a scale 1-10. $\mathbf{H_{sign}}$ changed between 0.9 – 1.1m. Frequency for the maximum of wave spectral density had a stationary value. Spectra of suspended sediment concentration for different values of γ , for three values of significant waves height $\mathbf{H_{sign}}$ and for two levels are presented in Figure 4 – Figure 9.

In Figure 4 – Figure 9 the linear scales were employed for the clearness. Certainly, used in experiment parameter γ and parameter γ from Hasselmann's wave model are not identical completely. But they are very similar under the performances. Other analogue has not been found in the literature on oceanography. Results of a spectrum analysis are used for build-up of some statistical dependences. Figure 10 shows dependence of maximum of concentration spectral density on values of significant waves height, for six values of γ and for two horizons from the bottom. It is visible from Figure 10b that the greatest influence to fluctuations of suspended sediment concentration near the bottom is initiated by waves with parameter γ =1. Spectrum of such wave is the widest of the considered. It is interesting that increase of $\mathbf{H_{sign}}$ value leads to reduction of suspended sediment concentration near the bottom.

I.e., average value of suspended sediment concentration increases towards the surface. At the same time average value of suspended sediment concentration decreases near the bottom.

Figure 11 shows the dependence of maximum of concentration spectral density on γ values for three values of significant waves height and for two horizons from the bottom. The wave spectrum with parameters γ =6 and $\mathbf{H_{sign}}$=1.1m is the most interesting (see Figure 11b). It is possible to guess that increase of $\mathbf{H_{sign}}$ will lead to increase of a steepness of a curve for the maximum of concentration spectral density. The analysis of Hasselmann's wave model allows to calculate that parameters γ =6 and $\mathbf{H_{sign}}$=1.1m the wave reaches after distance 80km for fetch (see Figure 1).

In this paper preliminary results of spectral processing for various wave modes are only shown. It is planned that futher working with this subject will make more correct estimations of the presented materials.



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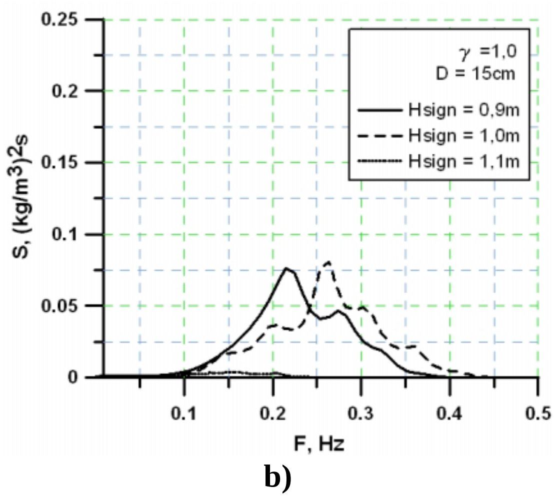

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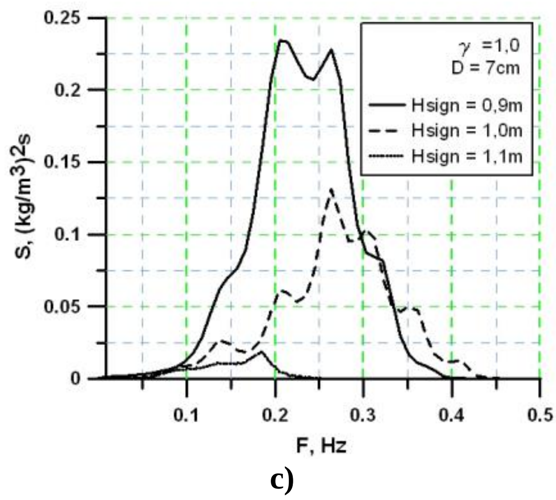

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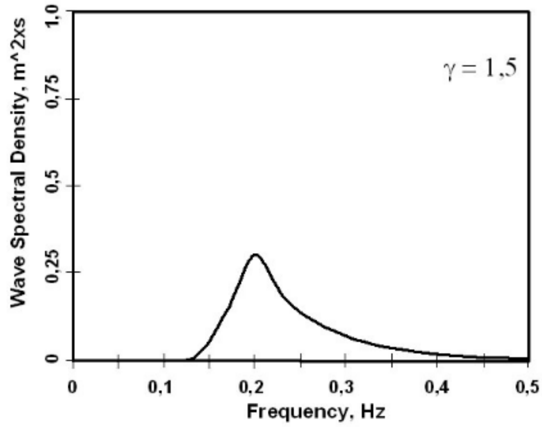
Figure 4. Wave spectral density for γ =1 (a); spectra of suspended sediment concentration (S) for γ =1, for three values of significant waves height H_{sign}, for the distance (D) from the bottom 15cm (b) and 7cm (c).



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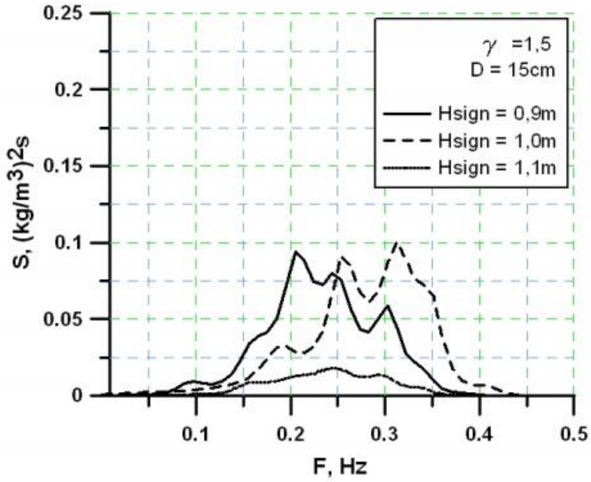

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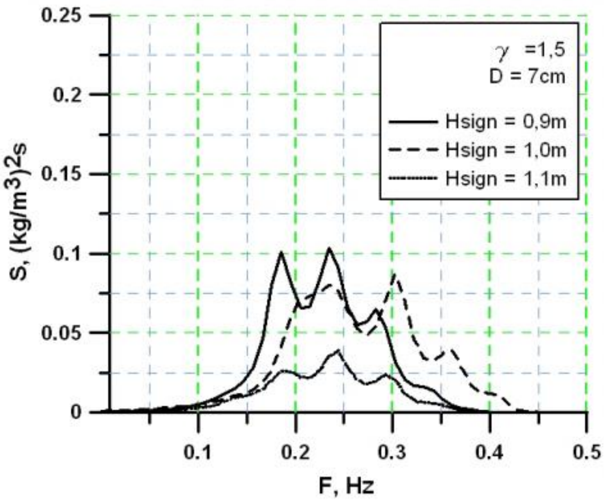

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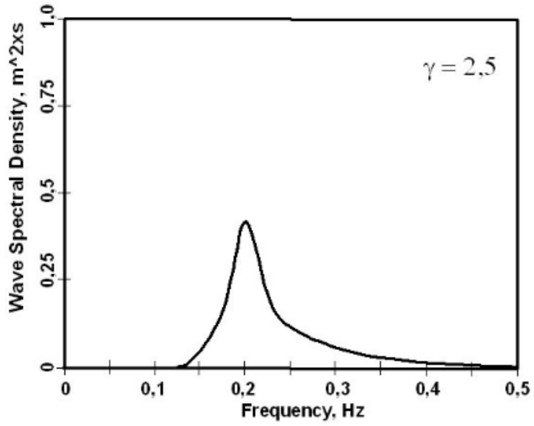
Figure 5. Wave spectral density for γ =1.5 (a); spectra of suspended sediment concentration (S) for γ =1.5, for three values of significant waves height H_{sign}, for the distance (D) from the bottom 15cm (b) and 7cm (c)



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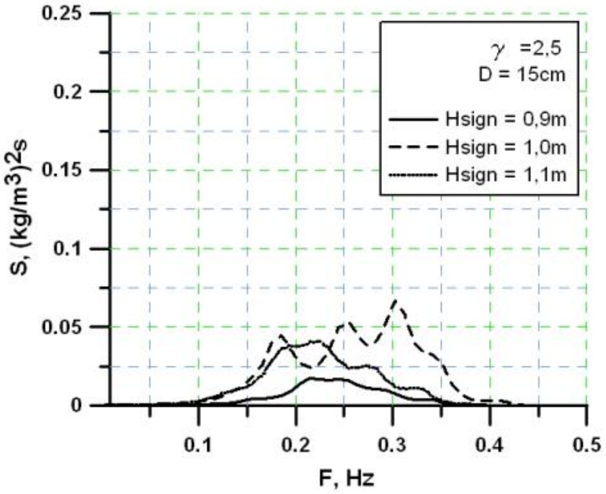

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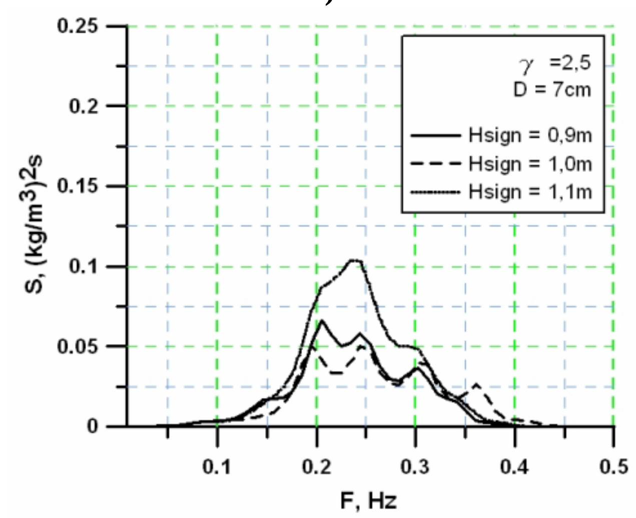
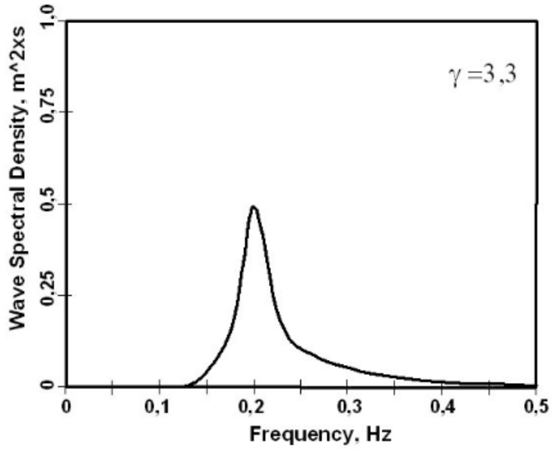


c)

Figure 6. Wave spectral density for γ =2.5 (a); spectra of suspended sediment concentration (S) for γ =2.5, for three values of significant waves height H_{sign}, for the distance (D) from the bottom 15cm (b) and 7cm (c).



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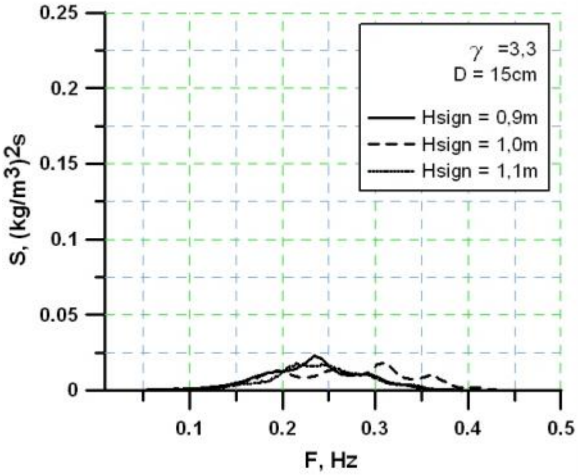

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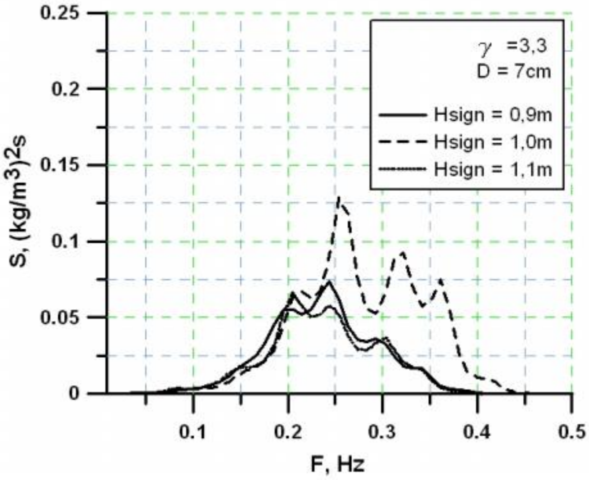

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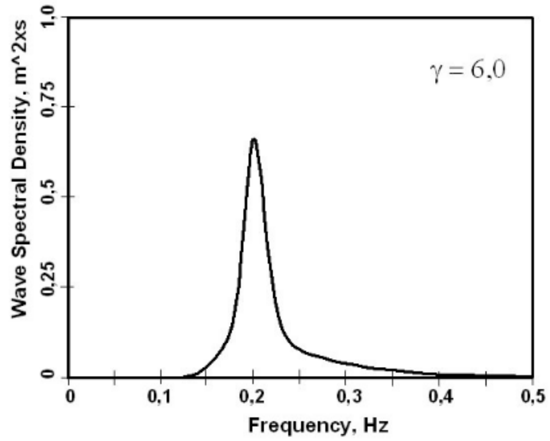
Figure 7. Wave spectral density for γ =3.3 (a); spectra of suspended sediment concentration (S) for γ =3.3, for three values of significant waves height H_{sign}, for the distance (D) from the bottom 15cm (b) and 7cm (c).



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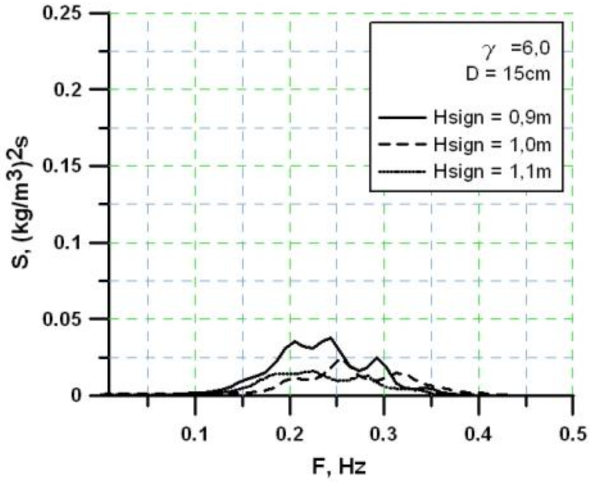

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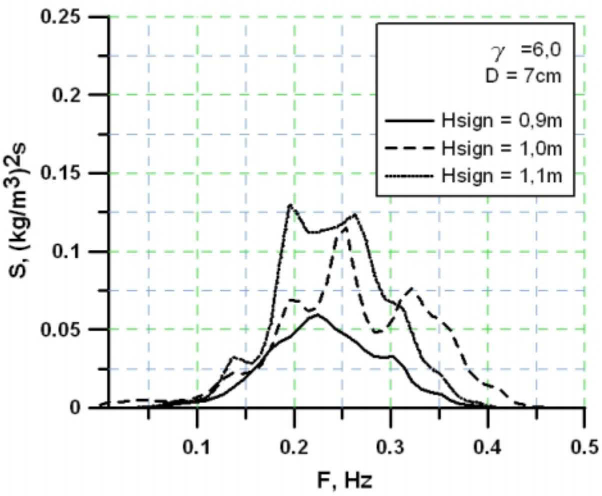

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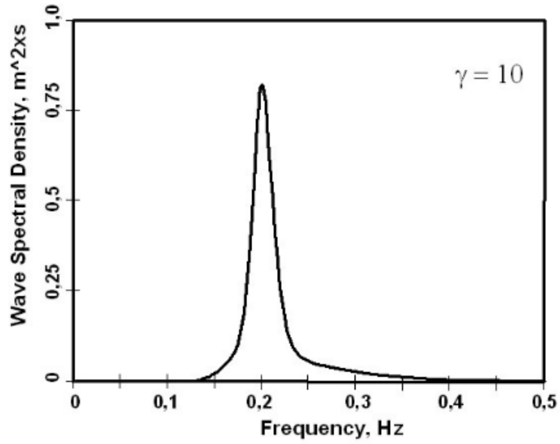
Figure 8. Wave spectral density for γ =6 (a); spectra of suspended sediment concentration (S) for γ =6, for three values of significant waves height H_{sign}, for the distance (D) from the bottom 15cm (b) and 7cm (c).



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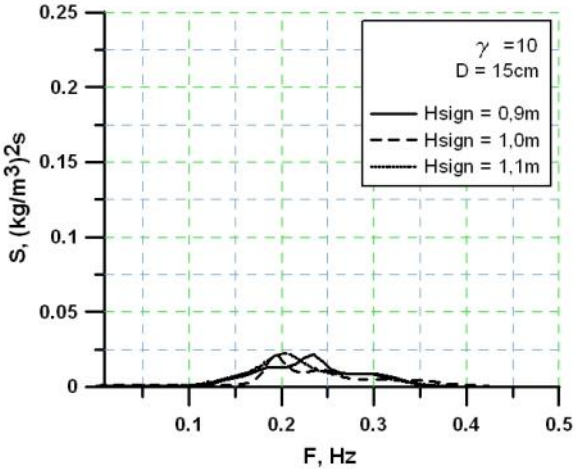

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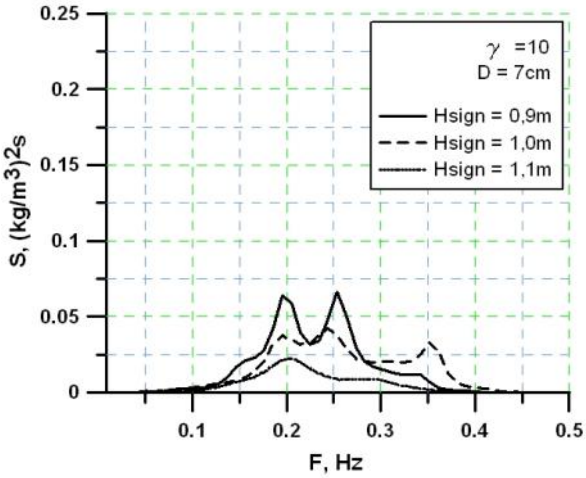

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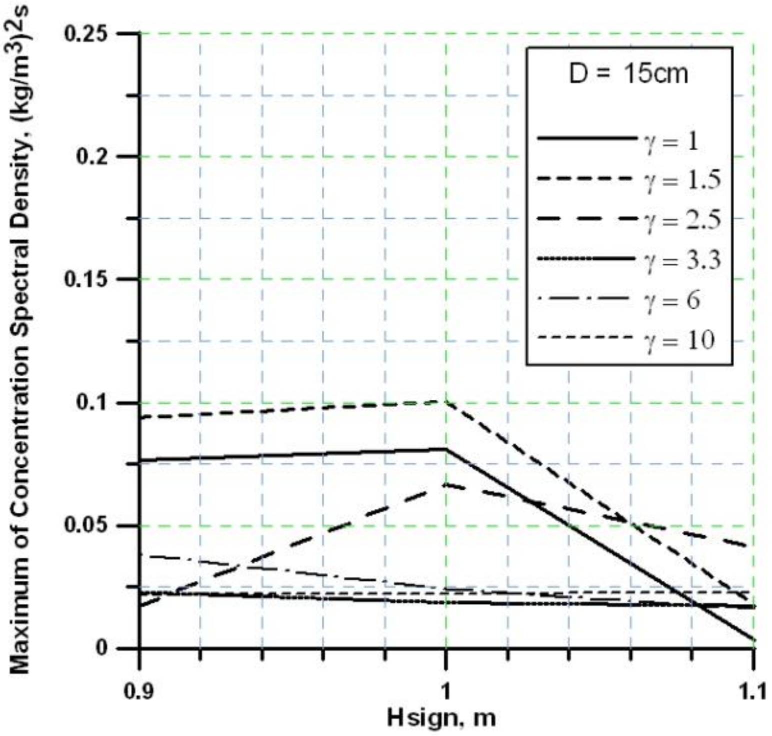
Figure 9. Wave spectral density for γ =10 (a); spectra of suspended sediment concentration (S) for γ =10, for three values of significant waves height H_{sign}, for the distance (D) from the bottom 15cm (b) and 7cm (c).



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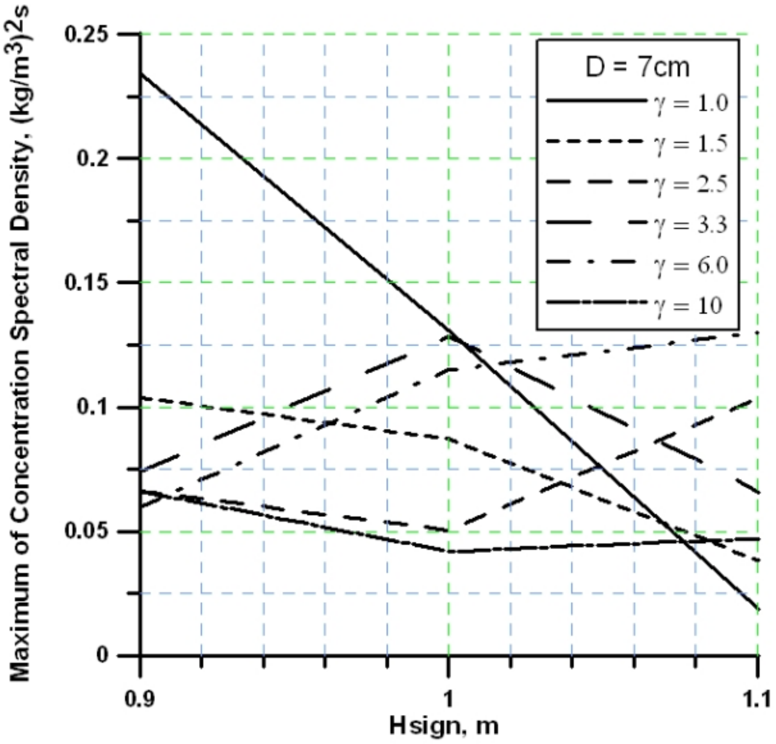

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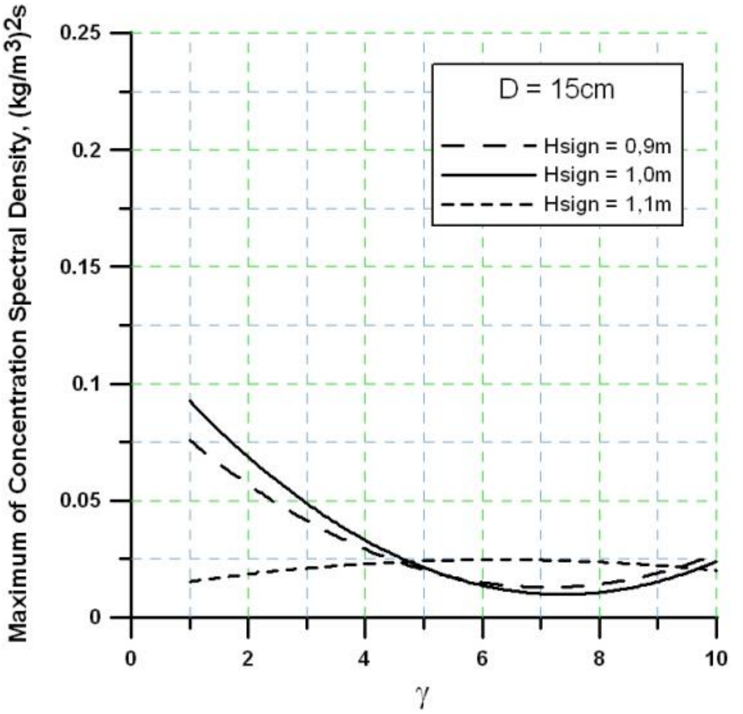
Figure 10. Dependence of maximum of concentration spectral density on values of significant waves height H_{sign}, for six values of γ and for two horizons from the bottom: (a) D=15cm, (b) D=7cm.



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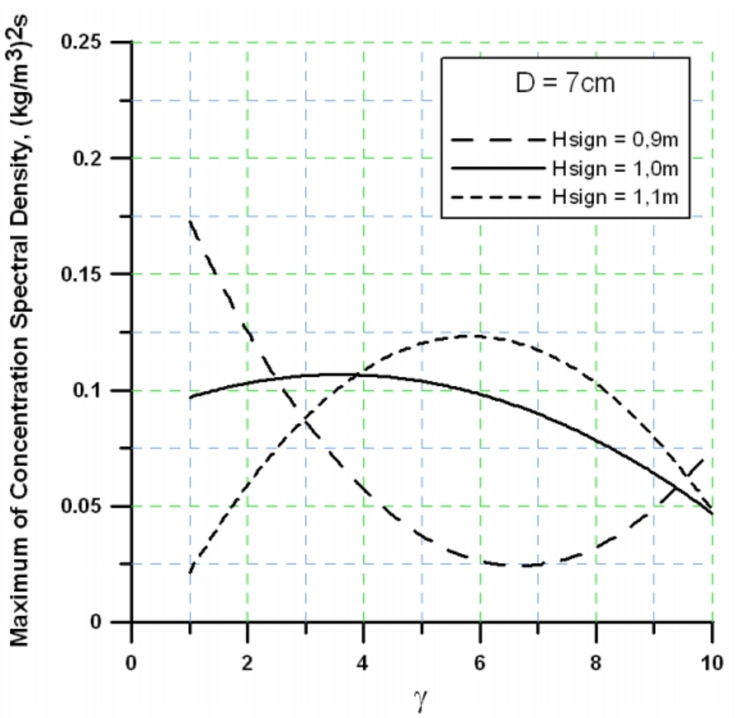

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Figure 11. Dependence of maximum of concentration spectral density on γ values for three values of significant waves height H_{sign} and for two horizons from the bottom: (a) D=15cm, (b) D=7cm.

CONCLUSION

From the Figure 4 – Figure 9 it is seen that wave spectra forms and wave parameters greatly influence on the suspended sediment concentration values. However functional dependence between these parametres is very complicated.

Waves with the expressed power spectra on peak frequencies possess the most part of kinetic energy. They participate in processes of suspension and carrying over of solid particles more actively. It is possible to presume that for such processes it is possible to describe mechanisms of transport of the suspended sediments by the simplified numerical model (in particular, by one-dimensional diffusion equation for suspended sediment concentration) with enough accuracy.

The preliminary analysis shows that for waves with a wide power spectrum it will not be possible to describe mechanisms of suspended sediment transport by the simplified numerical model. It will be necessary to investigate and describe the reasons forsuspension at each frequency of a spectrum, using methods of the mutual spectral analysis.

Later on, it is planned to investigate the conditions, when the spectral energy is redistributed between peak frequency and the higher frequencies, as well as choose other conditions when degree of influence of wave energy on solid particles is maximum all over the frequencies spectrum.

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