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PARAMETRIZATION OF WAVE TRANSFORMATION ABOVE SUBMERGED BAR BASED ON PHYSICAL AND NUMERICAL TESTS

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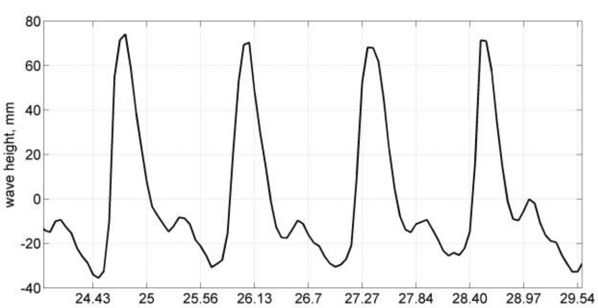
ABSTRACT

Using of artificial submerged structures with significant deepening for coastal protection has some advantages. For example, decreasing mean wave period due to nonlinear-dispersive features of waves and keeping of nature landscape and ecological environment in coastal zone due to deeper location of bars crest. The main aim of this work is parameterization of influence of underwater bar with significant deepening on changing of mean wave period based on comparison of physical and numerical modeling. Physical modelling in wave flume in scale 1:20 and numerical modelling in SWASH model in real scale were realized. According to results for both approaches, more effective decreasing of mean wave period occurs with length of construction from three to five times less than wavelength. Numerical modelling predicts longer relative wavelengths for effective decreasing of main wave period.

KEWORDS: underwater structures, nonlinear-dispersive decomposition of waves, secondary waves, mean wave period

1 INTRODUCTION

An artificial submerged structures can influence both on wave height and wave period depending on their deepening. Than less is the water depth above the top of submerged structure than more intensive will be wave breaking and reducing of wave energy. Result of significant deepening of structure is nonlinear wave decomposition and formation of secondary waves consisting from highest nonlinear wave harmonics. The basic nonlinear-dispersive mechanism of formation of secondary waves was described in details by many researchers (for example, Johnson et al.(1951), Beji and Battjes (1993), Masselink (1998), Van der Meer et al.(2000), Kuznetsov and Saprykina (2009, 2012)). Secondary waves arise as separate peaks on a surface of initial wave and consist from higher harmonics of main wave motion. Higher harmonics are formed due to nonlinearity during the wave propagation above top of submerged structures on shallow water. High dispersion in deep zone beyond structure leads to decomposition of wave profile due to decay into frequency components and formation of secondary waves (fig.1). In case of formation of secondary waves, wave impact on the shore decreases due to reducing of main wave period.



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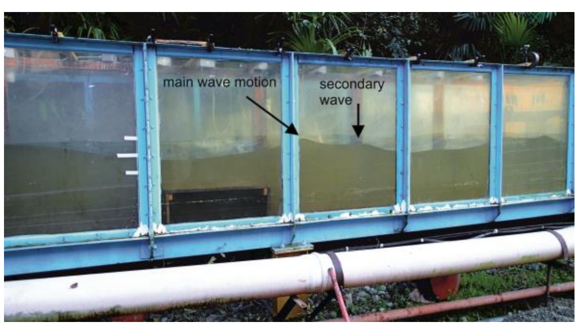


b

Figure 1. Example of secondary waves - separate peaks on surface of initial waves (a - fragment of wave record in laboratory experiment, b – formation of secondary waves in wave flume).

Another advantage of using submerged structures with significant deepening is a keeping nature landscape and ecological environment in coastal zone due to deeper location of bars crest. Parameterization of wave transformation above single underwater bar depending on initial waves makes using of this type of structure possible. The main aim of this work is parameterization of influence of underwater bar with significant deepening on decreasing wave period due to nonlinear wave transformation based on comparison of physical and numerical modeling.

2. METHODS AND EVALUATIVE CRITERIA

Investigation includes physical and numerical modeling of wave transformation above single solid bar. The laboratory experiment was performed in scale 1:20 in the wave flume of research center «Sea Coasts» in Sochi, Russia. The length of flume 22 m, the width – 0.6 m, the depth – 1 m. Numerical simulations were performed with help of model SWASH with parameters of construction in real scale. SWASH (Simulating WAves till SHore) is the phase-resolving nonlinear shallow-water wave model with added nonhydrostatic terms (Stelling and Zijlema, 2009, SWASH – User manual, 2015). For modeling bottom relief in SWASH was used grid with resolution 0.2 m.

Single solid bar in real scale have length 20 m and height 3.4 m. Water depth was 6.8 м. For the physical modelling this construction was built in scale 1:20 (length 1 m, height 0.17 m, water depth 0.34 m) and was placed on horizontal bottom. During physical experiment, 3 capacity wave gauges were used to measure the wave transformation processes (fig. 2). Duration of wave records was 1-2 min with sampling frequency 17 Hz. During numerical experiment were used 18 wave gauges. Gauges *s7*, *s11* and *s13* of numerical experiment correspond of gauges *f1*, *f2* and *f3* of physical experiment. In physical modeling wave energy was absorbed by berm of geksabits that was placed in the end of flume. In SWASH modeling dissipation of wave energy in the end of flume was defined by function «radiation». Therefore, impact of reflection on incoming waves was minimized.

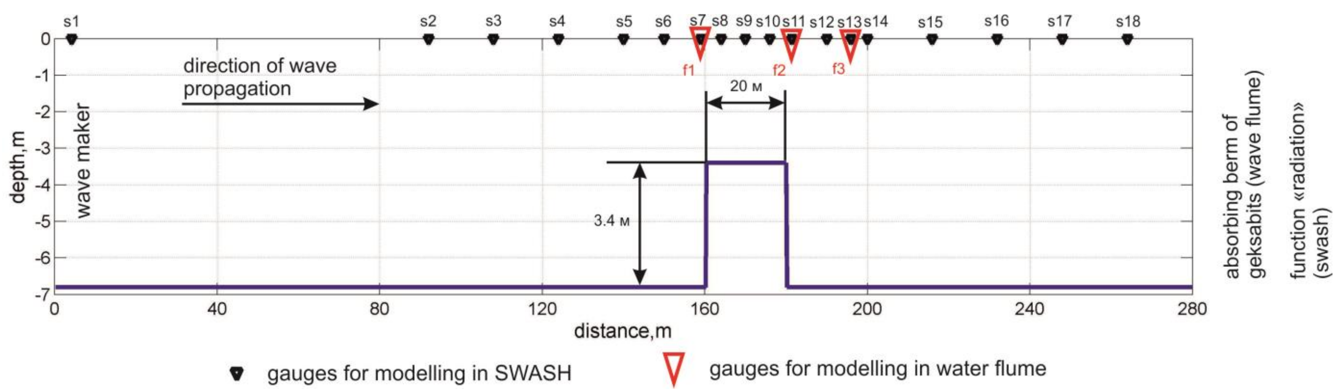


Figure 2. Scheme of experiments (real scale for modelling in SWASH).

Primarily, physical modeling with a number of wave regimes was realized. Was made attempt to model wide range of regular waves from long to steep waves with different combinations of wave parameters. Initial wave parameters, such us Hs – significant wave height (m) and Tm – mean wave period (s) were determined from chronograms of gauge *f1*. These parameters were used for determining initial wave parameters for numerical modeling ($\overline{H}$ - mean wave height (m) and Tm).

Significant wave height (Hs) was defined as:

$$\text{Hs} = 4\sqrt{m_0}\,, \qquad (1)$$

where $m_0 = \int Sdf$ (m_0 – dispersion), S – wave spectrum, f – frequency.

The mean wave period (Tm) was defined as:

$$Tm = \frac{\int Sdf}{\int Sfdf}, \qquad (2)$$

Mean wave height ($\overline{H}$) was defined as:

$$\overline{H} = 0.57Hs \text{ (Leontiev, 2001).} \qquad (3)$$

Wave length (L) was defined with help of relation for deep water:

$$\text{L} = \frac{\text{gTm}^2}{2\pi}, \qquad (4)$$

Wave parameter for numerical modeling was calculated for real scale based on geometrical similarity and equal Froude numbers:

$$\bar{H}r = \bar{H}b * \alpha , \quad (5)$$

where $\bar{H}r$ – mean wave height in real scale, $\bar{H}b$ - mean wave height in model scale, α – scale factor (in our case α=20);

$$\bar{X}r = \bar{X}b * \alpha , \quad (6)$$

where $\bar{X}r$ – linear size in real scale, $\bar{X}b$ - linear size in model scale;

$$Tmr = Tmb * \sqrt{\alpha}, \quad (7)$$

where Tmr – linear size in real scale, Tmb - linear size in model scale.

Examples of relevant wave regimes represented in Table 1. Full data of investigated wave regimes with differentiation by wave steepness and marking wave breaking represented on figure 3. Values Hs and Tm for numerical modeling was determined from gauge s1. In SWASH model was investigate range of values Hs from 1 to 3.7 м and Tm from 3.5 to 9.7 s. In wave flume was investigate range of values Hs from 0.05 to 0.25 m (corresponding values in real scale from 1 to 5 m) and Tm from 0.8 to 2.3 s. (corresponding values in real scale from 3.5 to 10.2 s). Variance of wave breaking above bar can be explained by reflection of incoming waves from front wall of structure and changing of wave parameters before bar due to addition of incoming and reflected waves.

Table 1. Examples of relevant wave regimes for physical modeling (scale 1:20) and numerical modeling (real scale)

№	Physical modelling (scale 1:20)			Numerical modelling (real scale)	
	Hs, м	$\bar{H}$, м	Tm, s	$\bar{H}$, м	Tm, s
7	0.06	0.04	1.7	0.76	7.6
8	0.11	0.07	2.1	1.39	9.39
9	0.23	0.14	1.3	2.9	5.81

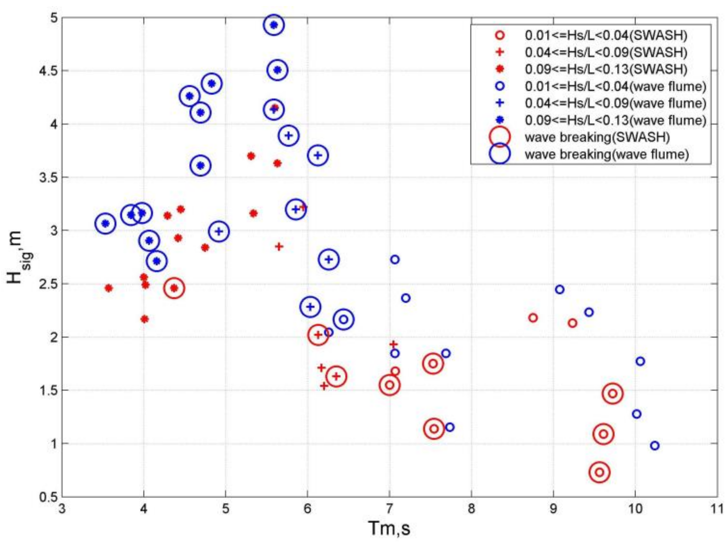


Figure 3. Wave regimes in real scale for physical and numerical modeling with differentiation by wave steepness and with marking wave breaking above and behind bar (for SWASH modeling wave parameters from gauge s1, for physical modeling wave parameters from gauge f1).

A transformation of initially pseudo monochromatic waves above solid bar was investigated. The transmission coefficient and changing of mean wave period were used for investigation wave transformation above structure and parameterization of length of bar on initial waves.

Changing of mean wave period was defined as T_{tr}/T_{in}, where indexes *tr* and *in* means transformed waves behind the bar and the initial waves before the bar respectively. As the T_{in} values was used T_1, that was calculated based on wave chronograms from gauge *f1* (*s7*). As the T_{tr} values was used T_2 and T_3, that were obtained from gauges *f2* and *f3* (*s11* and *s13* respectively).

The dependencies of mean wave period on the dimensionless parameters of bar and initial waves were studied:

- relative wave length - length of structure to length of waves on deep water: L_{bar}/L;

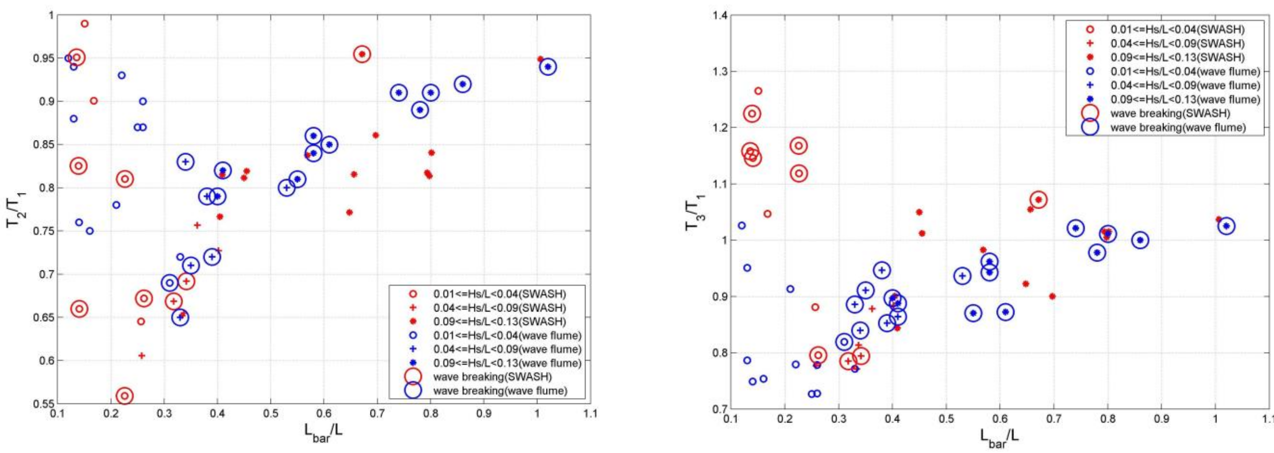
- steepness of waves before bar: $H_{s\ in}/L$.

3.DISCUSSION OF RESULTS

Changing of mean wave period in SWASH modeling has approximately the same values as in the physical modeling for relative short waves (fig. 4). For long waves difference between changing of mean wave period for physical and numerical modeling increases. It should be noted that for long waves SWASH data shows less values T_2/T_1 than data of physical modeling immediately after construction (fig. 4a). Further, during propagation waves after construction mean wave period increases and values T_3/T_1 significantly higher than the corresponding values for physical modeling (fig. 4b). Values that characterize more effective changing wave period for both types of modeling are shown in table 2.

Comparison of free-surface evolutions in wave flume and in SWASH (fig. 5a) showed that numerical modeling predicts more significant increasing of wave height before bar due to addition of incoming and reflected waves. Furthermore, behind bar was fixed more pronounced secondary waves in difference of physical modeling (fig 5b). These differences between physical and numerical modelling of free surface evolution lead to more effective decreasing of wave period that predicts by SWASH model.

For more detail comparison was conducted analysis of wave spectrum for three types of regimes (fig.6) – steep waves (Hs/L = 0.13), waves with mean steepness (Hs/L=0.05) and long waves (Hs/L=0.04). Spectrum of steeper waves (type 1) shown that energy of main harmonic decreases due to energy dissipation and increasing of spectral density of higher harmonics is minor (fig. 6a). Wave period for these waves changes only above structure and after structure period close to initial value (T_1). Waves with mean steepness (type 2) transform above bar with more effective decreasing of wave period, but after construction values of mean wave period not stable. It can be explained by energy exchange between nonlinear harmonics during propagation of waves as can be seen on the spectrum (fig. 6b). Numerical modelling for long waves has shown that wave period above structure decreases not significant. After construction decreasing of wave period continues due to increasing of amplitudes of higher harmonics (fig. 6c).



a b

Figure 4. Dependence of change of mean wave period on the relative wavelength and wave steepness according to the results of physical and numerical modelling (a – change of mean wave period on gauge f2(s11), b – change of mean wave period on gauge f3(s13)).

Table 2. Minimal values of T_{tr}/T_{in}.and corresponding relations of length of bar to wavelength

		Physical modelling	Numerical modelling
T_2/T_1	Minimal value for T_2/T_1	0.65	0.55
	More effective relative wave length $\frac{L_{bar}}{L}$	0.32	0.22
T_3/T_1	Minimal value for T_3/T_1	0.73	0.78
	More effective relative wave length $\frac{L_{bar}}{L}$	0.25	0.32

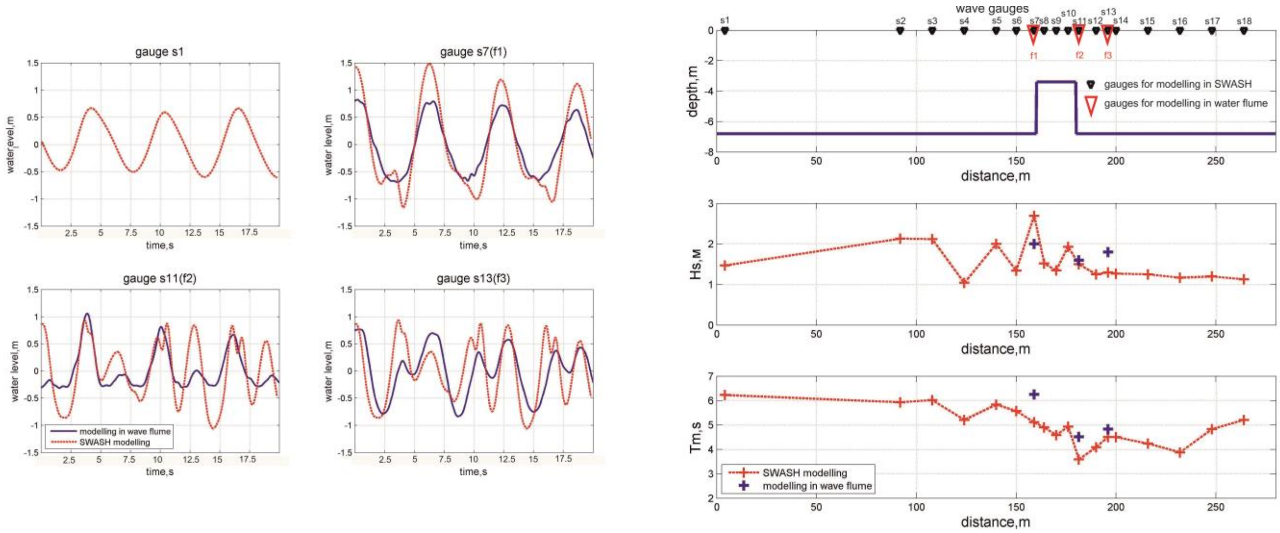


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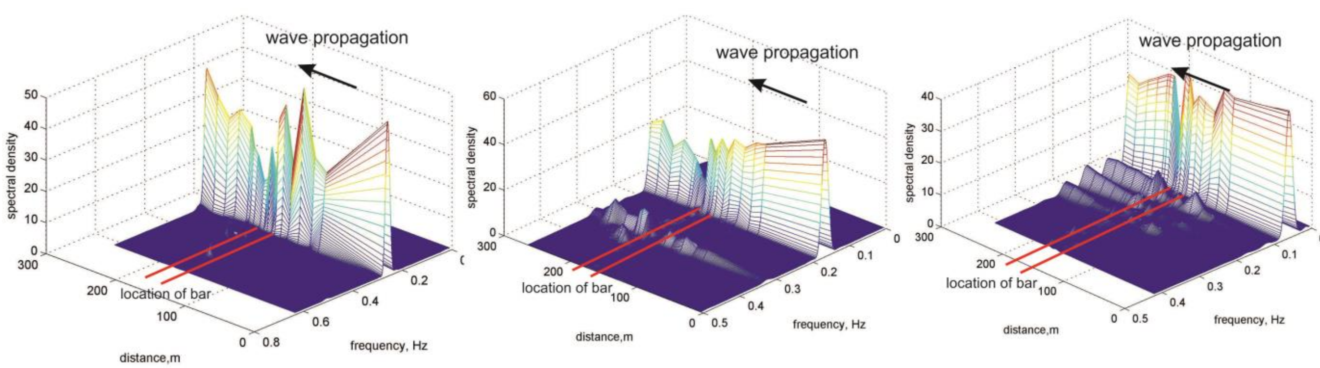
Figure 5. Evolution of free-surface (a) and changes of wave parameters (b) during wave propagation above a bar.



a b c

Figure 6. Spectrums of wave regimes with different steepness (a – steep waves, Hs/L=0.13; b – waves with mean steepness, Hs/L=0.13, c - long waves, Hs/L=0.04 m)

4. CONCLUSIONS

Comparison of numerical and physical modeling permits define more optimal parameters of submerged bar for decreasing mean wave period. According to results for both approaches, more effective decreasing of mean wave period occurs with length of construction from three to five times less than wavelength. For both types of modelling effective changing of mean wave period occurs in range $0.22 \le L_{bar}/L \le 0.32$ for wave steepness $0.04 \le H_s/T_m \le 0.09$. Wave propagation after structure with effective decreasing of wave period depends on energy change between main and higher harmonics that connected with steepness of waves. In contrast to physical modeling, SWASH model predicts longer relative wavelengths for effective decreasing of main wave period, more significant increasing of wave height before bar due to wave reflection from front wall of structure and more pronounced secondary waves behind bar.

ACKNOWLEDGEMENT

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