ZESZYTY NAUKOWE AKADEMII MARYNARKI WOJENNEJ
SCIENTIFIC JOURNAL OF POLISH NAVAL ACADEMY

2017 (LVIII) 3 (210)

DOI: 10.5604/01.3001.0010.6583

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SIGNAL GENERATION AND VERIFICATION PROCESS FOR THE PHYSICAL MODELING OF OCEAN WAVES

ABSTRACT

This paper presents the implementation process of the design methodology for ocean waves in a laboratory tank using a wave generator, which is the basis for conducting hydrodynamic model scale research involving real sea conditions. The main focus is placed on generation of time sequences used as the control input for the wave generator and experimental verification methods for the generated waves and concluding with the results and validation of the developed process by achieving wave parameters sufficiently aligned with the theoretical model.

Key words:
ocean waves design, wave generation, laboratory flumes, experimental methods, signal processing.

INTRODUCTION

Optimal behavior parameters of sea operating structures, including ships, offshore platforms, wind farms and others standing as the foundation of the maritime industry, can be predicted by performing research using model structures in scaled real sea environments generated in laboratory conditions.

Authors of [1, 2, 7] describe the enormous complexity and applications of marine engineering and naval architecture as well as the role and challenges of model scale testing in this regard. In this paper the authors will focus on the aspect of model

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testing and specifically the process of generating optimal sea environments in laboratory basins. To implement and innovate this process a merge of expertise in different fields is required, including hydro-and aerodynamics and marine engineering as the foundation for the physical phenomena, but in a large part electronics, control theory, numerical analysis, measurement systems and signal processing, as this process can be generally viewed as optimizing specific signal parameters used to control wave generators using an offline feedback of parameters estimated from measurements of these generated phenomena.

The basis for this paper was in a large part the engineering thesis of the author of [5] which dealt with the entire process of designing, implementing and experimentally verifying new signal processing tools designed specifically for the process of generating both ocean wave and turbulent wind conditions in laboratory flumes. In this work the description of the developed methods is focused on the ocean wave aspect, although from the processing logic point of view the method is analogous for both phenomena. The context of the iterative wave design methodology in laboratory conditions, including the applied analytical model and innovated data processing algorithms have been thoroughly described in the authors previous work [6] and can serve as a more in-depth introduction into the work described in this article. This paper will present the proposed signal generation and value measurement methodology for the validation of the developed algorithms and tools, by means of achieving improved wave parameters in the final results.

WAVE SEQUENCE GENERATION

In order to assure the best parameters of the generated waves the input sequences for the wave generator were computed separately each time.

The sequence generation algorithm is relatively simple, as input it only requires an analytical spectral density distribution model for ocean surface elevation, which is provided by the JONSWAP formula as given in [3]:

$$S_J(\omega) = A_\gamma S_{PM}(\omega)\gamma^{\exp\left(-0.5\left(\frac{\omega-\omega_p}{\sigma\omega_p}\right)^2\right)}, \qquad (1)$$

where $$S_{PM}(\omega) = \frac{5}{16} H_s^{\,2} \omega_p^{\,4} \omega^{-5} \exp\left(-\frac{5}{4}\left(\frac{\omega}{\omega_p}\right)^{-4} \right),$$

and

ω_p — angular spectral peak frequency;
$A\gamma$ — 1– 0.287 in(γ) is a normalizing factor;
γ — non-dimensional peak shape parameter;
σ — spectral width parameter,

and the parameters describing the sea state of interest, usually significant wave height H_s and peak frequency ω_p, which depend on the physical geographical region where the vessel or structure is supposed to operate. Such parameters can be easily checked against the desired region in published tables like in [3], that are based on empirically obtained data by continuously performing tests in real sea conditions around the worlds seas, updating and sharing the existing databases.

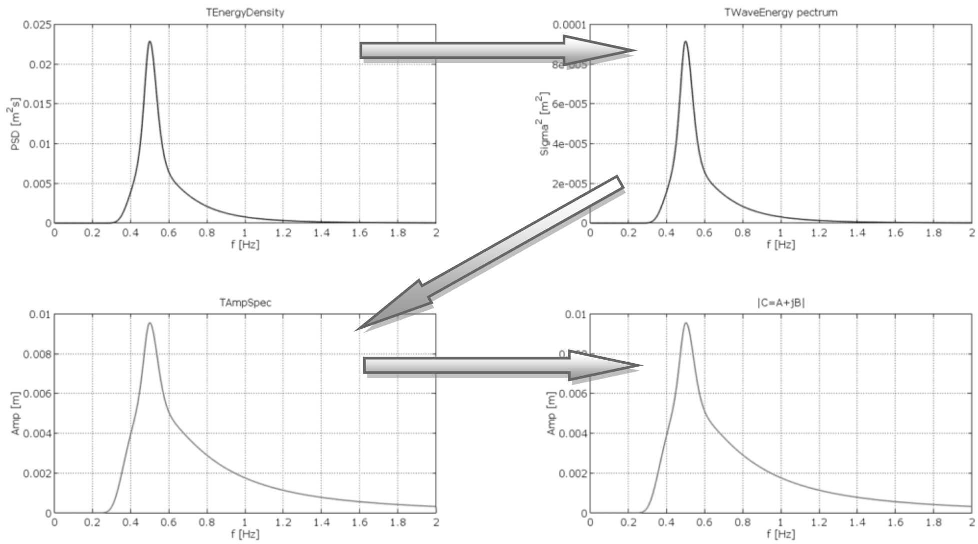

Fig. 1. The steps of generating the Hermitian Fourier Spectrum — energy density — energy — amplitude coefficients — creating complex coefficients with random phases and mirroring into Nyquist frequency (last graph shows the modulus of the created final spectrum) [own study]

There are a number of techniques of numerically generating time sequences with given spectral parameters, a good overview focused on practical wave generation is given in [4]. One the approaches described is the Random Phase Method, which has been adapted for this research, because of its deterministic nature which is often ideal for testing dependent on high levels of repeatability and stability. This means that the spectrum of the generated wave train will be identical to that of the target wave spectrum over the length of the time series, so two different realizations with different spectral properties can be directly compared. The reference shows the method applying the following general logic:

1. Define a target wave energy density spectrum, like JONSWAP (1).
2. Choose a sample frequency and a resolution of the spectrum and calculate the discrete wave energy spectrum.
3. Determine the discrete paddle-displacement energy spectrum, i.e. as proposed in the Biesel far field transfer function (due to the nature of the used wave generator this step was omitted).
4. Calculate the complex Fourier coefficients by picking a random phase between 0 and 2π for all frequencies smaller than the Nyquist frequency.
5. Mirror the complex Fourier components into the Nyquist frequency in order to obtain a Hermitian Fourier Transform.
6. Apply the inverse Fourier Transform and calculate the time series of the control signal for the wave paddle and use oversampling to get a better discretization of the control signal.

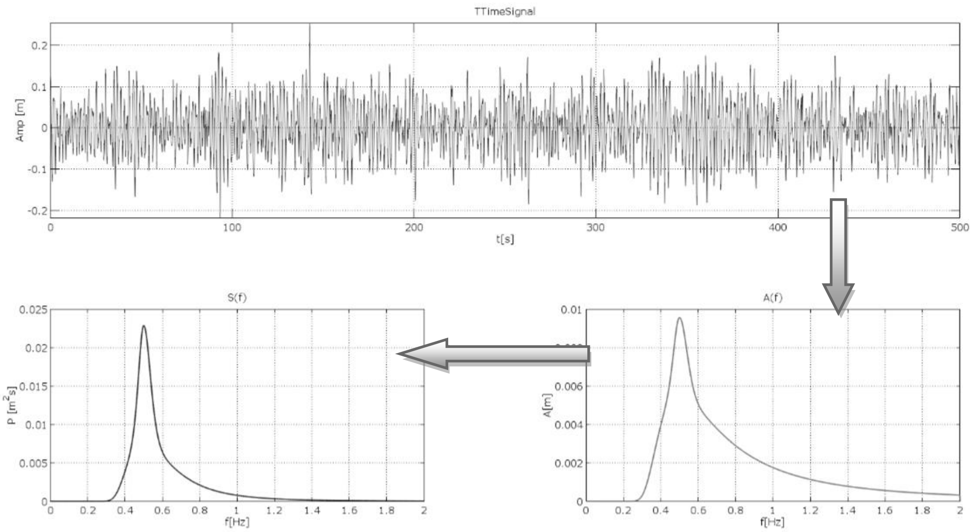

Fig. 2. Generated time sequence and computed amplitude and energy density spectrum for final verification [own study]

An example application of this logic has been represented with figures 1 and 2.

EXPERIMENTAL VERIFICATION

Following the wave design methodology for different wave distributions, waves sequences were generated as described, implemented as control sequences in the wave generator, then run and measured. Afterwards the developed signal processing algorithms were applied to verify the effectiveness and accuracy of the developed tools.

Fig. 3. CTO S.A. Offshore Laboratory Wave Flume (left) and Wave Generator (right) [authors' photos]

The tests were conducted in the model basin of the Ship Design and Research Centre CTO S.A. Offshore Laboratory and by means of the installed programmable wave generator there (fig. 3). The model basin is 49.67 m long, 6.97 m wide and 3.14 m deep. The tests were performed by measuring the surface wave elevation of the generated waves with sensors placed at half the length of the basin. The measurement sensors were classic resistance probes operating linearly in a +/–20 cm wave elevation range.

In order to verify the effectiveness of the proposed process and developed tools for a wide range of possible distribution applications, tests were performed for generated waves according to the JONSWAP spectrum (1) for a significant wave height H_s = 25 cm, spectral peak frequency of f_p = 0.5 Hz and cycling over three different coefficients of distribution kurtosis γ. After measuring the initially generated waves the developed signal processing protocols were applied and best possible generator gain correction functions have been estimated. These gain correction functions were then applied to modify the original sequences and implemented again as control sequences for the wave generator. The waves were then run and measured again, so in total 6 cases have been examined:

1) H_s = 25 cm f_p = 0.5 Hz γ = 1;
2) H_s = 25 cm f_p = 0.5 Hz γ = 3;

3) H_s = 25 cm f_p = 0.5 Hz γ = 5;
4) H_s = 25 cm f_p = 0.5 Hz γ = 1 + gain correction;
5) H_s = 25 cm f_p = 0.5 Hz γ = 3 + gain correction;
6) H_s = 25 cm f_p = 0.5 Hz γ = 5 + gain correction.

RESULTS

In this chapter the final results of the applied process using the developed tools are shown. The spectra computed from measured data have been graphed before and after applying the estimated gain correction function and against the theoretical spectral density distribution. Additionally the agreement of characteristic wave parameters H_s (significant wave height) and T_z (wave elevation zero crossing period) was verified against the assumed analytical model before and after applying a gain correction function. In every tested case all the computations of spectra, wave parameters, uncertainty and gain correction functions were performed by analysis of the measured data using the methodology and tools for data processing described in the authors previous work [6] and the obtained final results are presented in table 1 and figures 4–6.

Tab. 1. Comparison of computed characteristic wave parameters for the measured wave before and after application of one generator gain correction [own study]

	H_s = 0.25 m f_p = 0.5 Hz γ = 1		H_s = 0.25 m f_p = 0.5 Hz γ = 3		H_s = 0.25 m f_p = 0.5 Hz γ = 5	
	H_s [cm]	T_z [s]	H_s [cm]	T_z [s]	H_s [cm]	T_z [s]
Theoretical	24.99	1.42	24.99	1.54	24.99	1.61
Measured before	21.73	1.55	22.59	1.60	23.36	1.64
Measured after	25.26	1.53	24.86	1.59	24.96	1.62
Error before	13.0 %	8.9 %	9.5 %	3.9 %	6.6 %	1.9 %
Error after	1.0 %	7.7 %	0.4 %	3.4 %	0.1 %	1.2 %

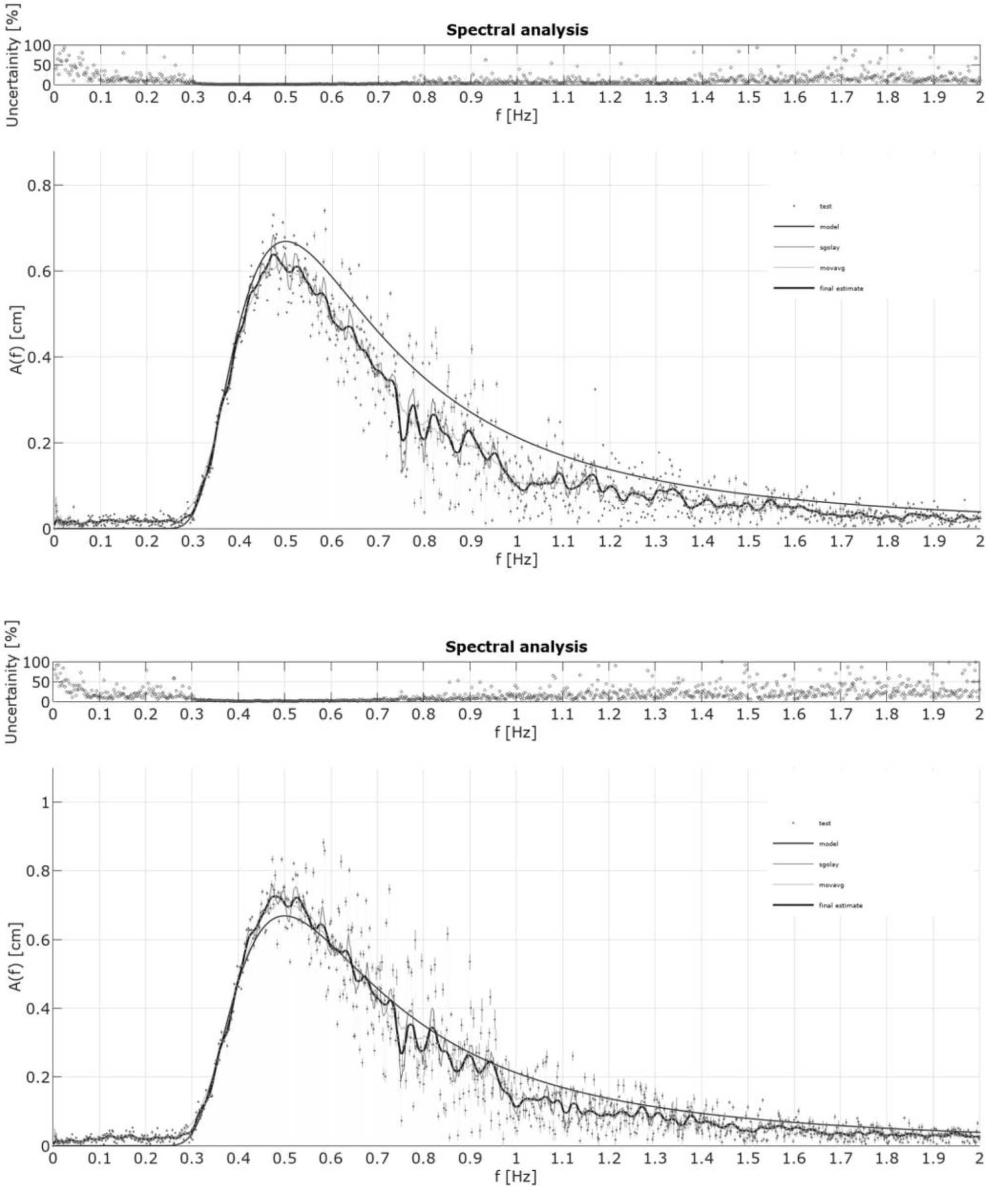

Fig. 4. Spectral analysis for JONSWAP distribution H_s = 0.25 m f_p = 0.5 Hz γ = 1 before and after application of one estimated gain correction function [own study]

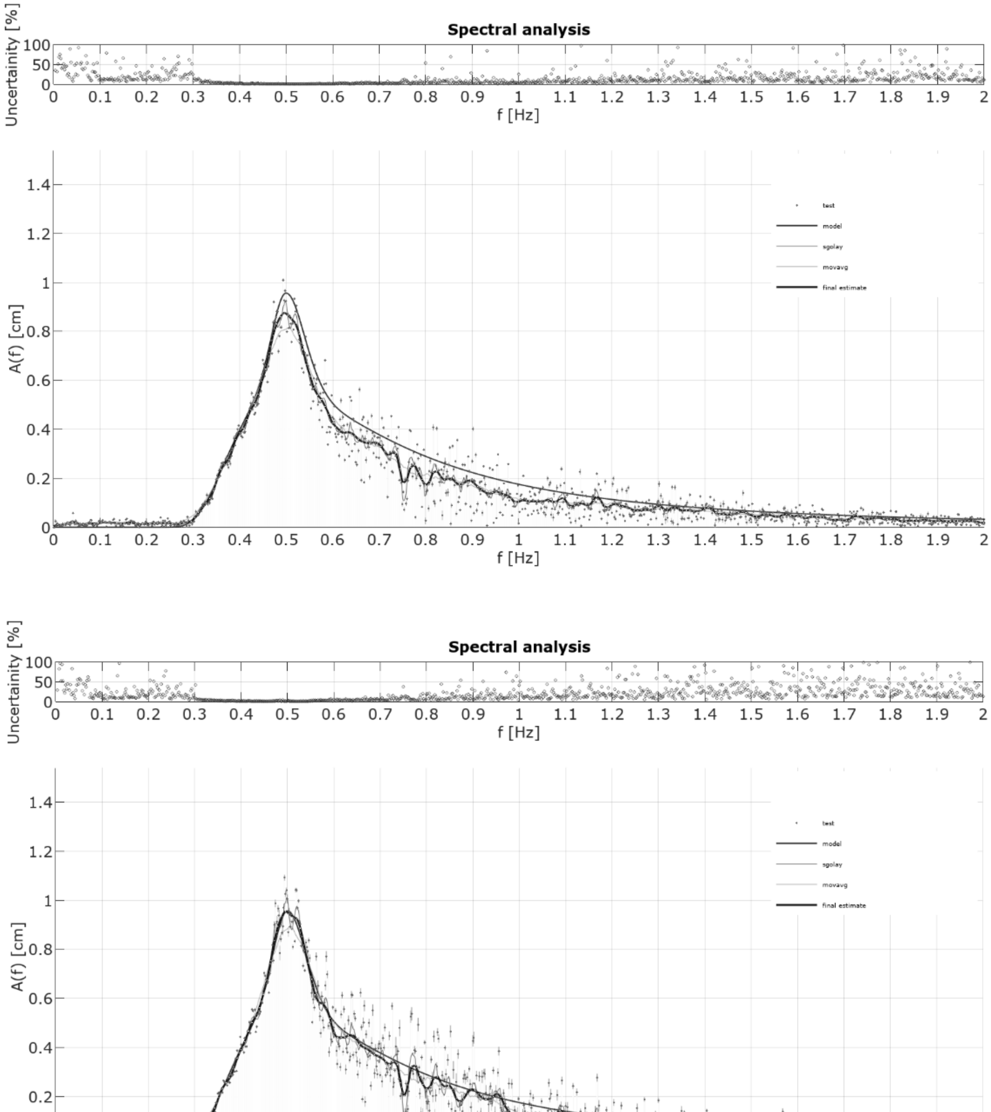

Fig. 5. Spectral analysis for JONSWAP distribution H_s = 0.25 m f_p = 0.5 Hz γ = 3 before and after application of one estimated gain correction function [own study]

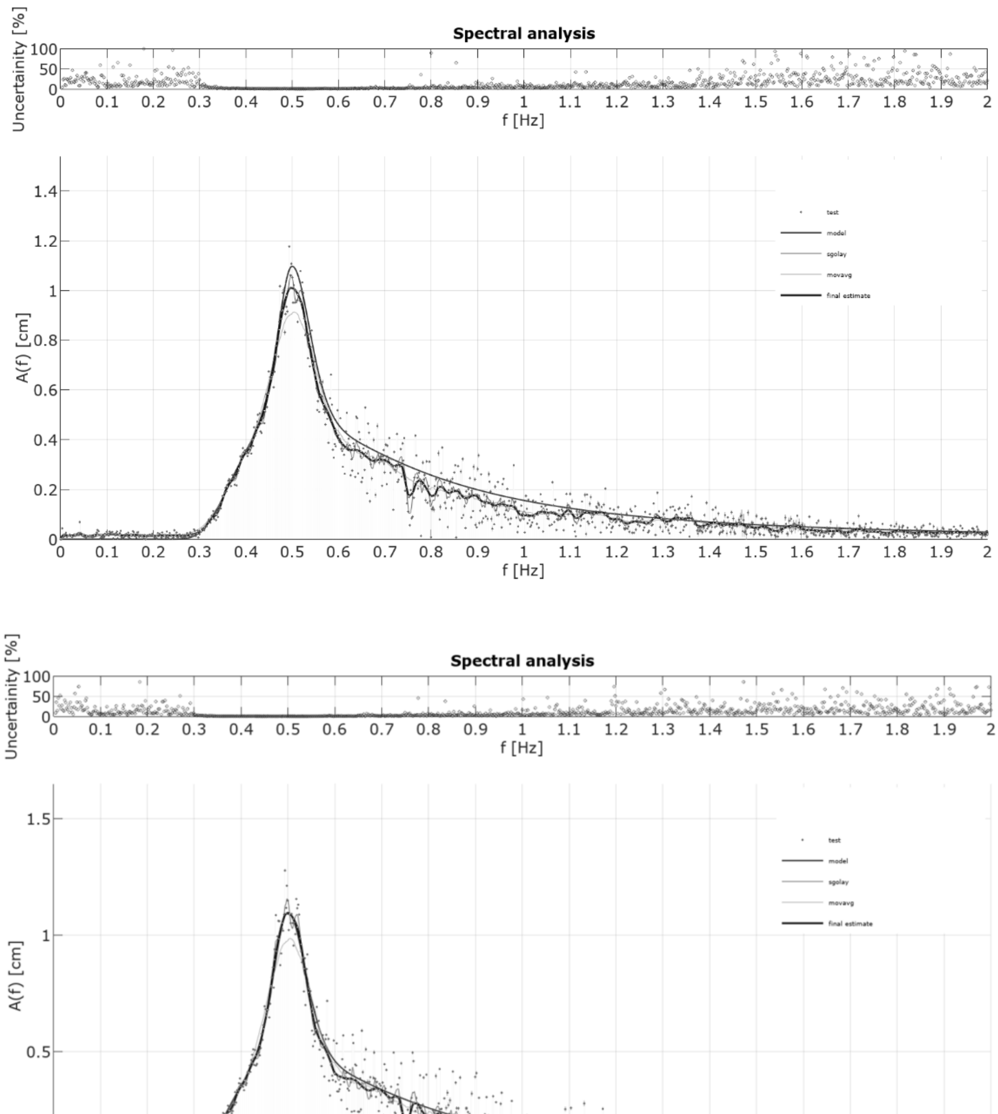

Fig. 6. Spectral analysis for JONSWAP distribution H_s = 0.25 m f_p = 0.5 Hz γ = 5 before and after application of one estimated gain correction function [own study]

A clear improvement in match and error reduction of the main characteristic wave parameters for the waves generated after just one correction function, especially with regards to H_s can be observed. Additionally by closely examining the fit around the peak of the spectral distribution almost ideal fit can be seen, which is the most significant aspect to achieve through the wave iteration process. The measured waves generated for γ = 3 and γ = 5 show very good alignment with the theoretical parameters and thus can be used for further structure hydrodynamics research after just one iteration. In this case the wave generated for γ = 1 after applying the gain correction can be seen as overshooting the theoretical distribution and hence would require an additional iteration to achieve a better fit around the spectral peak.

CONCLUSIONS

The main aim of this work was to generate and analyze physical phenomena for modeling environmental sea conditions needed for conducting laboratory hydrodynamic research. A wave signal generation and value measurement methodology was proposed and validation of the developed algorithms and tools was presented by means of achieving improved wave parameters in the final results. The wave generation is a complex and significant process, which requires methods and tools for specific model based sequence generation, significant measurement environment, system and resource requirements as well as the development of advanced signal processing algorithms and tools to get the most information out of measured data.

As part of this work wave time series were generated according to the Random Phase Method and implemented in the wave generator as control sequences. A series of tests using this process was performed for different input wave spectral distributions. Measurements were acquired and run through the developed processing tools in order to generate very accurate and stable output information either back to the wave generator or verify the alignment with the assumed input parameters at the same time verifying the developed methods and tools.

In all test cases after applying just one correction iteration to the generated waves a significant improvement in parameters and better spectral distribution fit to the model can be observed. It can be then shown that the proposed process is very reliable even after only one iteration, which can lead to significant time and resource savings in preparing waves of desired parameters for further hydrodynamics and marine engineering research. This process and developed tools and methods have been implemented and validated many times since their inception and have shown great practical improvements in the process of generation of environmental conditions for laboratory research. In order to achieve even better results the process can be repeated although it is worth noting that in the authors experience this is hardly ever needed and the most iterations ever encountered to be necessary in applying this process were three.

REFERENCES

[1] Bertram V., *Practical Ship Hydrodynamics*, Butterworth-Heinemann, Oxford 2000.

[2] Dudziak J., *Ship theory* [in Polish], Publ. Fundacja Promocji Przemysłu i Gospodarki Morskiej, Gdańsk 2008.

[3] *Environmental Conditions and Environmental Loads*, Det Norske Veritas, Recommended practice DNV-RP-C205, 2010, [online], http://www.dnv.com [access 16.06.2017].

[4] Frigaard P., Amdersen T., *Technical Background Material for Wave Generation Software*, Aalborg University Departament of Civil Engineering, Aalborg 2010.

[5] Gatz M., *Program Development for the experimental verification of time-frequency wind and wave models*, B. Sc. Thesis, Gdynia Maritime University, Gdynia 2016.

[6] Gatz M., Studański R., Łuksza A., *Data processing methodology for experimental modeling of ocean waves*, „Scientific Journal of Polish Naval Academy", 2016, No. 4, pp. 17–31.

[7] Jarosz A., Ship model basins [in Polish], Publ. Wydawnictwo Morskie, Gdańsk 1977.

PROCES GENEROWANIA I WERYFIKACJI SYGNAŁÓW NA POTRZEBY FIZYCZNEGO MODELOWANIA FAL OCEANICZNYCH

STRESZCZENIE

W artykule przedstawiono proces implementacji metodologii projektowania fal oceanicznych w basenie modelowym przy wykorzystaniu generatora fal, który stanowi podstawę do hydrodynamicznych badań modelowych uwzględniających rzeczywiste warunki oceaniczne. Główny nacisk położono na generowanie przebiegów czasowych i ich wykorzystanie jako wejściowych sygnałów sterujących dla generatora fal oraz metody eksperymentalnej weryfikacji wygenerowanych w ten sposób fal. Przedstawiono także wyniki końcowe i walidację opracowanego procesu, uzyskując parametry fali odpowiednio dopasowane do modelu teoretycznego.

Słowa kluczowe:

projektowanie fal oceanicznych, generowanie fal, korytarze laboratoryjne, metody eksperymentalne, przetwarzanie sygnałów.