RIO OIL & GAS
2008
EXPO AND CONFERENCE
15 - 18 de Setembro

IBP1795_08

NEW TECHNOLOGY IN LABORATORY WAVE TEST TANK

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Resumo

Este artigo apresenta uma nova tecnologia em tanque de ensaios com ondas, para fins de pesquisas em Engenharia Naval e Oceânica. Este tanque utiliza o conceito de geradores ativos de ondas em todo o perímetro (AMŒBA - Advanced Multiple Organized Experimental Basin – Naito et al., 1998) que produz um campo de ondas semelhante as condições de águas abertas. Medidas de ondas e forças em modelo mostram que o campo de ondas é homogêneo (±10%) dentro de 45% do diâmetro e pode manter as amplitude e fase de ondas irregulares por mais de 20 minutos, para freqüências de 1,6Hz até 3,0Hz. As forças medidas flutuaram ±2% comparando-se testes e repetições e ±7% comparando medidas atuais e outras realizadas 10 anos passados. As análises dos resultados do AMŒBA provam a aplicabilidade e confiabilidade deste novo conceito em tanque de ondas.

Abstract

This paper presents a new technology in testing tank for Naval and Ocean Engineering research. This tank is based on active wavemakers all around the perimeter concept (AMŒBA -Advanced Multiple Organized Experimental Basin – Naito et al., 1998) creating a wave field similar to open waters conditions. Measurements have shown that the wave field is homogeneous (R.A.O. ±10%) inside 45% diameter and can keep irregular wave amplitude and phase more than 20 minutes, for frequencies from 1.6Hz up to 3.0Hz. The experimental results for the diffraction force measured is within ±2% deviation band among tests and repetitions and within ±7% among present tests and those performed 10 years ago. These results of wave elevations and model force measurements have proved the AMŒBA new wave tank concept usefulness and reliability.

1. Introduction

The wave test tank can be ranked as one of the most important experimental facilities for Naval and Ocean Engineering purposes. This experimental installation is mainly used to research and developments, considering that the tank tests results can furnish very useful data to investigate and to solve a large range of uncertainty to the design, maintenance, operation and development of Naval and Ocean systems.

Usually they are very large installations being hundreds of meters long, tenths of meters wide and several meters deep with wavemaker at one end and an energy absorber at the other end. To Offshore research this is not a desirable shape taking into account that irregular and multidirectional wave field are strong requirements to this facility. Despite any tank geometry, among several interferences, the most influencing factor to the wave field is the wave reflections.

A new technology concerning laboratory wave test has been developed by Naito and co-workers (2006) since almost 15 year ago, in NAOE – Osaka University. The breakthrough idea is to arrange the active wavemakers in a closed configuration creating a tank with virtual walls (Naito and Minoura, 1994). The virtual wall is an active wavemakers boundary which besides to generate does not reflect any wave resulting in open waters like wave field. Following, the real application of this concept is presented after brief theoretical remarks as well as wave elevation and model force measurements with results discussion.

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2. Theoretical Approach

The main idea of plunger (often a wedge) type active wavemaker comes from wave energy absorber device combined to plunger wavemaker. The first one is a floating body which oscillates under the action of an incoming wave and the other is a floating body that creates an outgoing wave caused by a vertical oscillation. Equating the work done by the same device in these two situations it is possible to find out system physical parameters and conditions to satisfy the requirements.

2.1. Wave Generation by Floating Body

A floating body forced to oscillate vertically in a still water surface generates outgoing waves. Generically, this is called plunger wavemaker and one special kind of oscillating floating body has the cross sectional shape according to curves proposed by Lewis (1967). The full theory to express the plunger wavemaker performance is due to Wang (1974), and just to mention the basic equations, lets take ϕ as the velocity potential and φ the associated stream function, the appropriate boundary conditions, linearizing them, then it can be worked out the expressions:

$$\left[\frac{\partial\phi}{\partial z}+\frac{\omega^2}{g}\phi\right]_{z=0}=0\ ,\ \textit{(free surface)};\quad \frac{\partial\phi}{\partial n}=\frac{\partial\phi}{\partial z}\frac{\partial z}{\partial n}=U\left(\frac{\partial z}{\partial n}\right),\ \textit{(floating body surface velocity)} \tag{1a; 1b}$$

$$\eta(x,t)=\left[-\frac{1}{g}\frac{\partial\phi}{\partial t}\right]_{z=0}\quad \textit{(the surface wave elevation).} \tag{2}$$

$$\eta_a(x,t)=ka_0\pi z_0(\sqrt{A^2+B^2})^{-1}\sin(\omega t-kx+\varepsilon)\quad \textit{with}\ \ \varepsilon=arctan(B/A) \tag{3}$$

$$\eta_a(x,t)=A_h(\omega)z_0\sin(\omega t-kx+\varepsilon) \tag{3a}$$

where η_a is the wave elevation, a_0, A and B depend on surface curve and geometry as defined by Lewis, z_0 is the body vertical oscillation amplitude, k the wave number, ω the oscillating frequency, ε the phase angle and the non dimensional response $A_h(\omega)$ of the Lewis floating body.

2.2. Floating Body Heave Induced by Wave

Consider the real case that the floating body is attached to an external dynamic system, subjected to an incoming wave that causes a vertical movement. The balancing forces are known to be as follows:

$$f_m(t)=Mz'' \qquad \textit{(floating body inertia)} \tag{4}$$

$$f_r(t)=-m(\omega)z''(t)-n(\omega)z'(t)-cz(t) \qquad \textit{(floating body hydrodynamics)} \tag{5}$$

$$f_c(t)=-N_e(\omega)z'(t)-C_e(\omega)z(t) \qquad \textit{(external system force)} \tag{6}$$

$$f_w(t)=(\eta_a\rho g\,|A_h(\omega)|/k)exp\{\,i[\omega t+\varepsilon_h(\omega)]\} \qquad \textit{(wave force)} \tag{7}$$

where M is mass, $m(\omega)$ added mass, $n(\omega)$ damping coefficient and c restoration coefficient of the floating body; $C_e(\omega)$ spring coefficient and $N_e(\omega)$ damping coefficient of the external dynamic system; $\varepsilon_h(\omega)$ phase difference between incident wave and floating body vertical motion.

Balancing dynamically the floating body, meaning forces on body equals wave force, led to:

$$(M+m(\omega))z''(t)+(N_e(\omega)+n(\omega))z'(t)+(c+C_e(\omega))z(t)=(\eta_a\rho g|A_h(\omega)|/k)exp\{i\omega t+\varepsilon_h(\omega)]\} \tag{8}$$

The solution of equation 8 describes the vertical motion of floating body into fluid together the wave. This is done by taking $z(t)=z_0.exp(i\omega t)$, and after some manipulations it leads to the following equation:

$$\left|\frac{z_o}{\eta_a}\right|^2 = \frac{\dfrac{\rho^2 g^2 \left|A_h(\omega)\right|^2}{k^2}}{\{-[M+m(\omega)]\omega^2+[C_e(\omega)+c]\}^2+\omega^2[N_e(\omega)+n(\omega)]^2} \qquad 9$$

2.3. Wave Absorption by Floating Body

To evaluate the power in the system, force times velocity, let separate the force done by the fluid in the floating body, $[f_r(t)+f_w(t)]$, *k*nowing that these forces are given by equations 5 and 7, then:

$$W_1 = \frac{1}{T}\int_0^T [f_r(t)+f_w(t)]z'(t)dt = \frac{1}{T}\int_0^T N_e(\omega)\omega^2 z_0^2 \sin^2(\omega t)dt = N_e(\omega)\omega^2 z_0^2/2 \qquad 10$$

This is the power in the system induced by the wave but it is known that the energy content in the wave, taking $C_p = d\omega/dk$ as the wave phase velocity, can be expressed by:

$$W_w = \rho g \eta_a^2 C_p/2 \qquad 11$$

The case of perfect energy transfer from wave to floating body, by the energy conservation principle, implies that equation 10 must be equal to equation 11, and considering the absorption coefficient as the energy ratio $E=W_1/W_w$, the wave energy absorption in the deep water case will be:

$$E = \frac{N_e(\omega)\omega^2 z_0^2}{2}\Big/\frac{\rho g \eta_a^2 C_p}{2} = \frac{2N_e(\omega)\omega^3}{\rho g^2}\left|\frac{z_0}{\eta_a}\right|^2 \qquad 12$$

Substituting equation 9 into equation 12:

$$E = \frac{2N_e(\omega)\omega^3}{\rho g^2 k^2}\,\frac{\rho^2 g^2\left|A_h(\omega)\right|^2}{\{-[M+m(\omega)]\omega^2+[C_e(\omega)+c]\}^2+\omega^2[N_e(\omega)+n(\omega)]^2} \qquad 13$$

For maximum absorption, E must be unit and working out $A_h(\omega)$, the equation 13 can be satisfied when:

$$\begin{cases} C_e(\omega) = [M+m(\omega)]\omega^2 - c] & 14 \\ N_e(\omega) = n(\omega) & 15 \end{cases}$$

Analyzing and applying equations 14 and 15 is the key to design the external system to meet maximum wave absorption as required, but unfortunately there are some frequency dependent terms causing the more general theory to irregular wave absorption very difficult to obtain.

3. Experimental Developments

Taking the theoretical plunger type active wavemaker as a perfect boundary it was built a circular wave basin with wavemakers all around the perimeter by Naito and Minoura (1994), to test the hypothesis here presented. This was done first by Naito and Minoura (1999) and also by Martins (2006), at Ship Model Experimental Towing Tank and AMŒBA Laboratory, NAOE – Osaka University-Japan.

Following, it is presented the main results obtained from the experiments with active wave generation, wave field, and with four columns platform small scale model, diffraction forces. It was measured basically wave elevations and forces, under regular and irregular waves.

3.1 The AMŒBA basin

The circular wave basin with active wavemakers all around, called AMŒBA – Advanced Multiple Organized Experimental Basin, shown in Figure 1, was built measuring 1.6 m diameter and 0.30 m deep, with 50 active wavemaker units. Active wavemakers are computer controlled as well as the data acquisition, storage and processing units, presented in Figure 2.

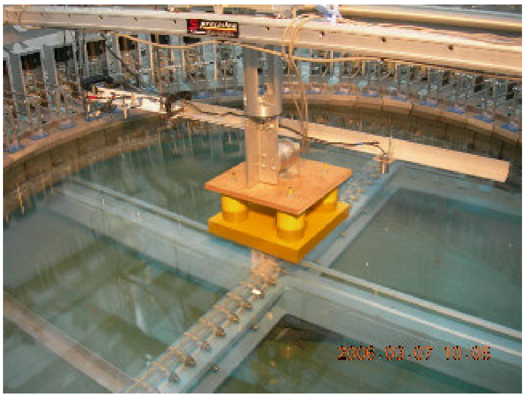

Figure 1 – AMŒBA basin view with wavemakers, platform model, bi-axial load cell and wave sensors.

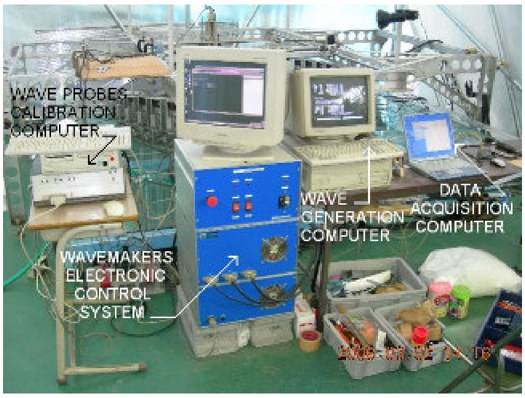

Figure 2 – Electronic systems to wave generation, active control, data acquisition and storage.

3.2. Wave Elevations Measurements

Many wave propagation tests were performed into AMŒBA (Naito et al., 1998) and compared to theoretical calculations. First of all, wave elevation sensors were installed and calibrated by step motor and ball and screw device, controlled by computer. Computer based data acquisition system were wired to get and record wave elevation data.

Here is presented a summary of main tests results, in circular basin configuration. The figure 3 shows regular wave test results from wave probes along wave propagation direction and also along transverse direction, at the basin geometric center. Other results from similar tests performed by Martins (2006) are presented in figure 4.

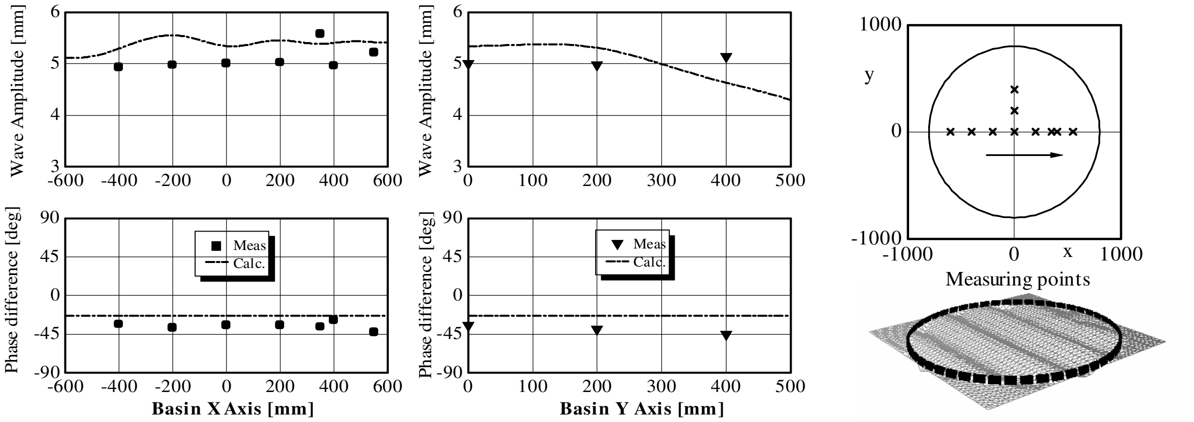

Figure 3 – Experimental and theoretical results comparisons, together wave probes location and wave field visualization sketches (adapted from Naito et al., 1998).

After regular wave experiments, it was performed directional irregular wave tests. The long crested irregular waves were generated and the external system had its parameters fixed at the proposed bandwidth center frequency of 2.2Hz (T=0.454 s) before testing. The angular frequency range of the target spectrum was $8.80 \leq \omega \leq 18.85$ rad/s, defined as follows:

$$S(\omega_n) = \begin{cases} (\omega - 8.80)^2 \,.\, (\omega - 18.85)^2 \;; \; for \;\; 8.80 \leq \omega \leq 18.85 \\ 0 \;; \; for \;\; \omega < 8.80 \;\; and \;\; \omega > 18.85 \end{cases} \tag{16}$$

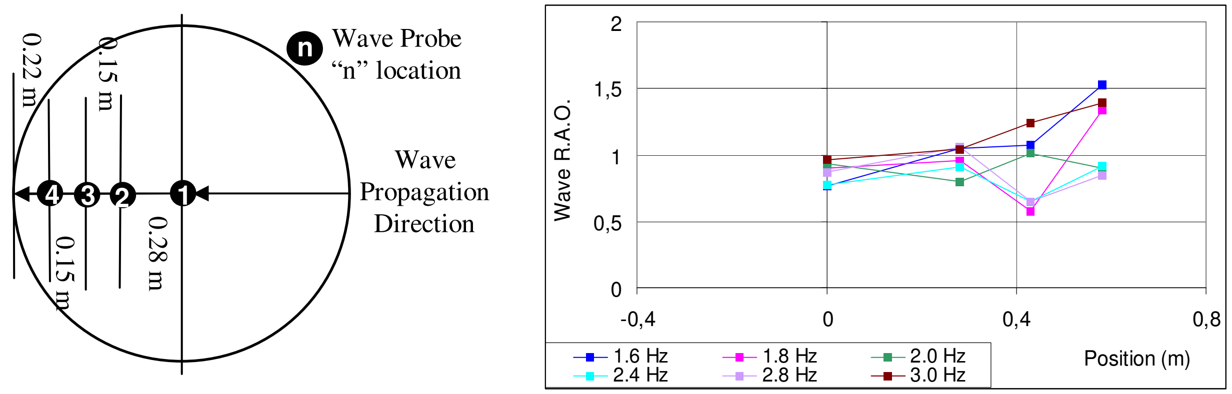

Figure 4 – Wave probes locations sketch and regular wave propagation test results for test basin entire frequency range (Martins, 2006).

Wave probes locations for measuring irregular waves are shown in figure 5 together the results for required and measured spectra for point #1. These values show good agreement as well as those presented in figure 6. The envelope for generated, wave1 and wave4 spectra are close to the required one, except for wave1 at 2.3Hz peak. In figure 7 it is shown a sample of incoming wave and surge and heave forces measured during irregular wave tests.

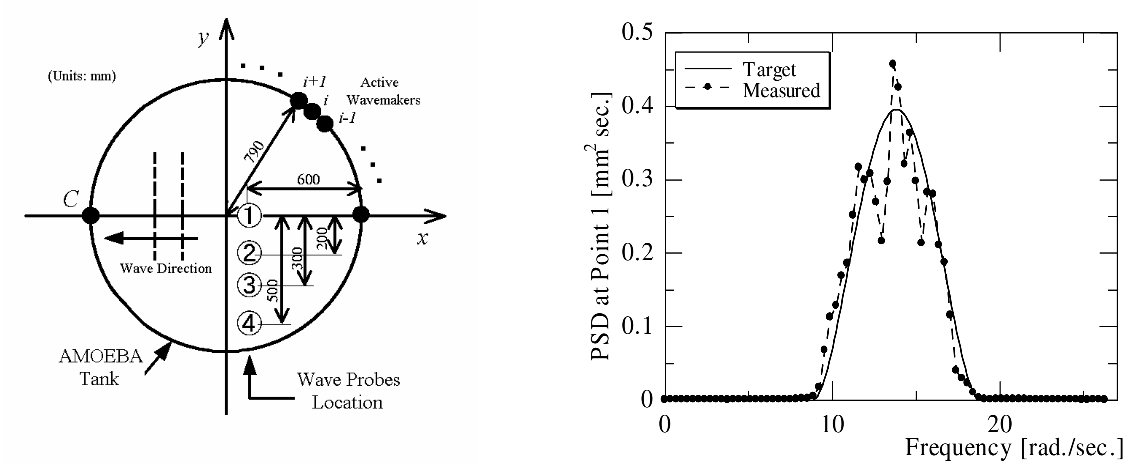

Figure 5 – Wave probes locations and results for irregular wave propagation test (Naito et al., 1998).

These results analyses show the good agreement between theoretical and experimental wave elevations and also the data consistency when comparing experimental results themselves. This means that the wave field into AMŒBA is homogeneous at certain extension and precision, reliable and reproducible.

3.3. Platform Model Forces Measurements

The platform model test setup, shown in figure 1, highlights the model and instrumentation arrangement. The bi dimensional unidirectional waves were generated from the right side to the left side of the picture, and the wave propagation direction coincides with X axis in the drawings.

The range of regular waves was from 0.33 s to 0.62 s, with constant wave amplitude. The load cell was calibrated fixing it in the bench and applying a known load in the appropriated direction. This was done for both heave and surge directions. Data acquisition and recording were the same as already stated in wave tests.

The heave and surge forces were measured by a two forces component load cell rigidly attached to the model and to the rod connected to the carriage. During tests runs there were no perceptible movements in any direction, in the model or in the supporting frame and structure.

The surge and heave forces collected were analyzed and processed giving the results illustrated in figure 8. The results displayed are theoretical calculation compared to early tests results by Naito and co workers together present tests. It can be noticed that all experimental points are within ±2 % deviation band showing a very good match between tests and repetitions.

Also there is a good agreement when comparing theoretical calculations, past results and the results here presented, with ±7% maximum deviation for all data, even considering the electrical noise in the load cell due to the very low unfiltered signal level.

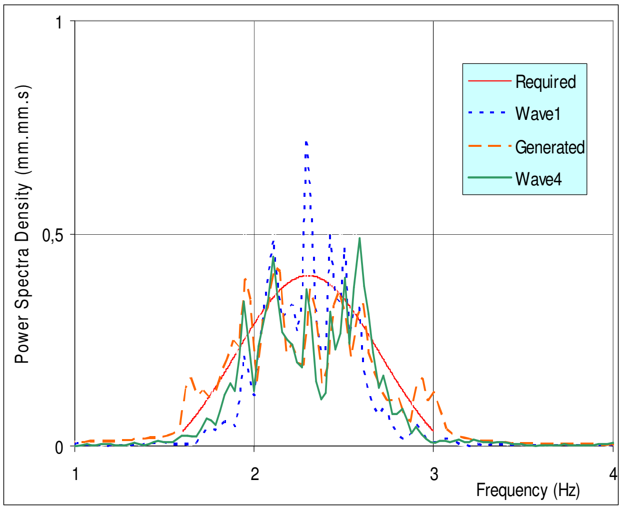

Figure 6 – Irregular wave spectra measured against required and generated ones (Martins, 2006).

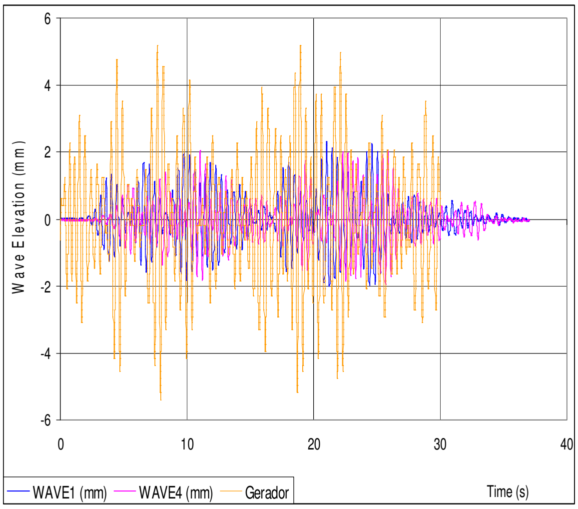

Figure 7 – Time series of wave elevations and generation for irregular waves tests (Martins, 2006).

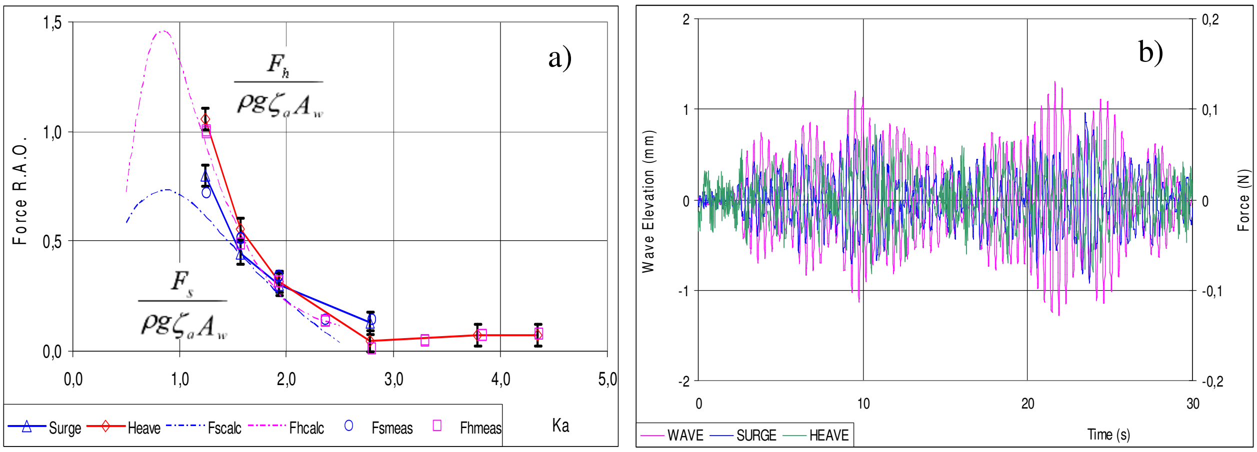

Figure 8 – a) Results comparison among calculated, early data (Naito et al., 1998) and present measurement (Martins, 2006) of surge and heave forces in platform model tests, and b) sample of irregular wave and force data.

4. Conclusions

After all these past and present wave and model force tests results analyses it is possible to affirm that the small circular basin equipped with active generator all around the perimeter is a very powerful tool for experimental Naval and Ocean Engineering research and education. The experimental results obtained agree well to calculations, theoretical and numerical, and also matching amongst different sets of experiments, by different authors and time.

It was proven the methodology correctness and the equipment reliability and tests repeatability. The AMŒBA performance main conclusions from the experiments and calculations can be shortened as the following:

- it is possible to generated a wave field, regular and irregular, in the range of 1.6 Hz to 3.0 Hz, with confidence within ±10 % deviation in wave elevation measured along wave propagation direction, up to 45% radius off center position. Only remarks are for 1.8 Hz frequency and for the region outside about half diameter circle centered at the origin;
- the experimental results for the diffraction force measured into AMŒBA have been found within ±2% deviation band among tests and repetitions and within ±7% among present tests results and those performed 10 years ago;
- when the wavemaker external dynamic system is optimized for the absorption of the narrow band spectrum central frequency wave of the long crested irregular waves, almost all central frequency waves and the waves close to the central frequency are absorbed. Thus, these wave fields can be generated for a long time;

However, there are experimental difficulties in the AMŒBA because of the very small scale factor. For instance, it is difficult to measure the second order force such as the drift force because its small amplitude and sensitivity. Also it is recommended to investigate the circular tank resonance frequencies and oscillating modes, and how they affect the wave field, to better choose the frequency range and the model locations into the tank.

These subjects indicates future field of investigations for the multi directional wave generation in the AMŒBA, as well complete irregular wave absorption for wide band spectrum. At the present, a theoretical solution for wide band spectrum for irregular waves was worked out, but not yet experimentally implemented. It will take some time and efforts to materialize the solution, to test and develop the system to absorb wide band spectrum for irregular waves.

The effectiveness and reliability of small tank test for Naval and Ocean Engineering purpose has been demonstrated by theoretical, numerical and experimental ways. The space utilization, economic and engineering aspects are quite obvious from construction and operation point of view, as well as material and human resources needed to implant and to keep the facility running.

The concepts here explained is a technological breakthrough in Naval and Ocean Engineering Laboratory testing and should be widely discussed and perfected to widespread this important experimental field of scientific and technical investigations.

7. Acknowledgements

The author expresses his gratitude to NAOE-Osaka University Staff, especially to Professor Shigeru Naito, for the receptiveness and project advising, also to Mr. Yasuhiro Shimizu for equipment preparation.

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