Generation of Double Peak Directional Wave by Dual Mode Snake–Type Wave Maker

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Abstract

The dual–mode snake–type directional random wave maker has been developed in order to reproduce double peak directional waves, long period waves and directional waves with oblique principal wave direction. Results from a series of wave generation tests demonstrate that the dual–mode generator system is suitable to reproduce the the target wave conditions with good accuracy.

Introduction

Various types of directional random wave generators have been developed to reproduce experimentally the wave condition similar to real sea waves. Especially, the recent development of active absorption theories of multi–directional waves (Ito,K.,et al.,1996) has made it possible to install a directional wave generator with three generator faces (multi–face directional wave generator)(Ito et al.,1996, Hiraishi et al.,1995). A wide area in the basin is possible to be employed as the effective test area(Funke et al.,1987) by the establishment of multi–face wave generators.

Meanwhile, recent systematic and large–scale field observation(Nagai et al.,1993) demonstrates that the directional spectrum observed offshore often has two peaks at different directions as shown in **Figure 1**. Each peak direction is usually apart more than 90° each other. Such double–peak directional waves are considered to be composed of 'wind wave' component with relatively short periods and 'swell' with long periods. Reproduction of double–peak directional waves is of great importance to carry out experimental study on the stability of offshore structures and navigating ships. A new type directional wave maker has been developed for the generation of double peak directional waves as well as the multi–face wave generation with active absorption (Hirakuchi et al.,1992).

Moreover, long period waves with period longer than swell become important for estimation of the stability and safety of floating structures and large cargo vessels moored to berths. Because long waves' periods are near to natural periods of the system composed of a ship and mooring ropes, their

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penetration into harbors may cause large surge motion and breakage of the ropes by resonance (Hiraishi,1997a). Periods of long waves range usually from 50 to 100 s in prototype (Hiraishi,1997b). The main energy of long period waves propagate as free waves from the offshore area. A standard spectrum of long period waves has been proposed to estimate influences of long period waves in harbor planning (Hiraishi,1998).

The proposed profile of a standard spectrum includes the short period components(wind wave and swell) and long period wave components. The spectral density of long period wave components is constant and its level is determined by results in field observation. In order to reproduce the long period components evaluated in the standard spectrum, relatively large stroke are necessary. The newly developed directional wave maker should be also applicable to the generation of combination of short and long period waves.

The following section describes the applicability of the newly developed wave generator with segmented piston- type paddles.

Frame of Dual- Mode Snake- type Wave Generator

Figure 2 shows a conceptional design of the directional wave generator with double faces and with double operation modes. The generator consists of 50 and 30 drive shafts respectively on each side. **Figure 3** shows cross section of the wave maker. The generator is named "Dual- mode snake- type wave generator" because of two generator faces. A paddle 130cm heigh is attached

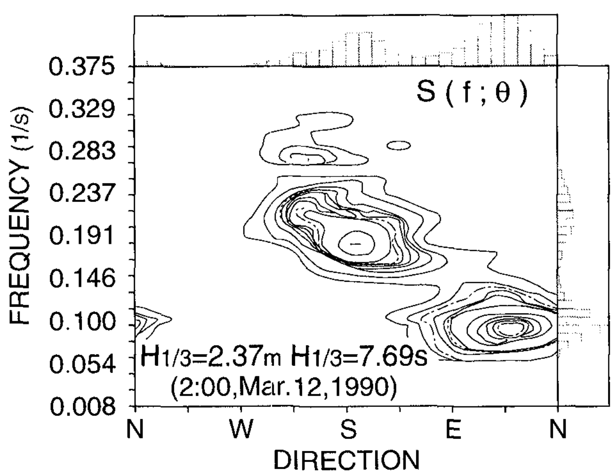

Figure 1 Observed directional spectrum with double peaks

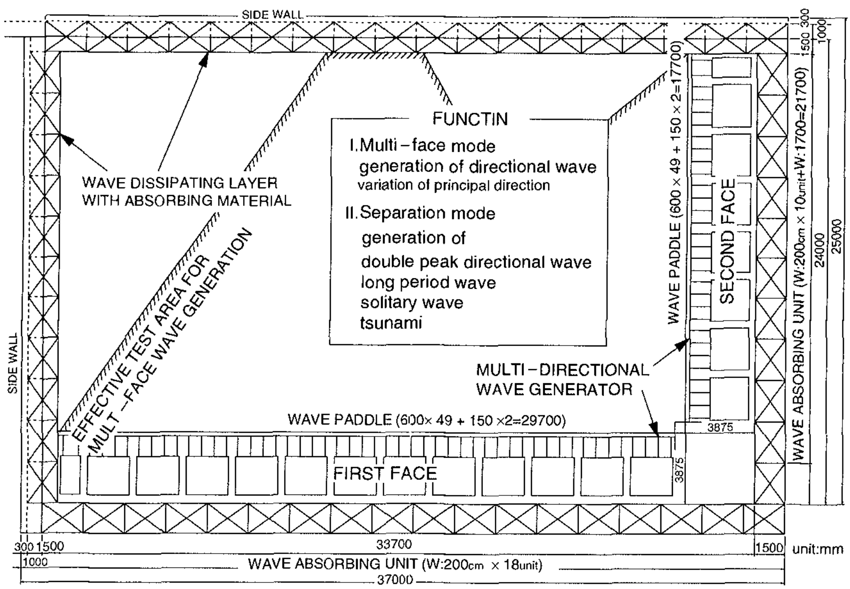

Figure 2 Arrangement of Dual-mode serpent type wave generator

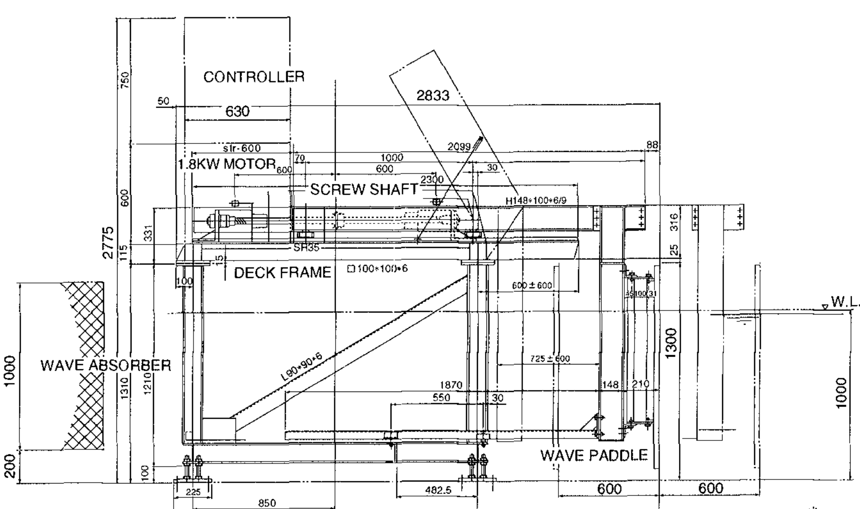

Figure 3 Cross section of wave generator unit

between adjoining two drive shafts. Wave paddles are displaced by the mechanical screw shaft system. The maximum water depth and wave height for generation is 100 and 30cm respectively. Each wave paddle is equipped with two wave sensors on its surface to measure the variation of water surface elevation at the front to carry out the active wave absorption for obliquely propagating waves (Ito et al.,1996). The side walls of the basin are covered with the wave dissipating layer composed of the wave energy absorbing material (Takayama et al.,1991). The wave energy absorbing layer is available to prevent waves reflected at the side walls without the generator faces and generated backward paddles. The generation face indicated below in Fig.3 is named "First face", and the right face "Second face" **Photograph 1** shows the overview of the dual– face serpent type wave generator.

The operation modes consist of the following two methods:

(a) Multi– face Mode :

The both of First and Second faces are operated as a single generator system to make single– peak multi– directional waves. The same target directional wave condition is given to the both faces with different phases. The paddle displacements in the both faces are synthesized according to the single summation model (Takayama and Hiraishi,1989) for directional wave generation. During operation, the re– reflected oblique wave components from wave paddle are prevented by the active wave absorption motion. The effective test area is much larger than a single face directional wave maker. The image of effective test area in the dual– mode generator is shown in Fig.3 as an area surrounded with broken lines.

A connecting removable pannel is attached at the corner between First and Second faces. The width of the pannel is variable corresponding to the positions of the adjoining paddles in the both faces. The position– shifted

Photograph 1 Overview of Dual– mode wave generator

pannel is proposed to prevent the wave height reduction on the straight line stretching obliquely from the corner(Hiraishi et al.,1995).

(b) Separation Mode :

Each of First and Second face is operated in the different target wave condition in the separation mode. Therefore, First face wave maker is available to the generation of directional wind waves with short periods when Second face generates 'swell' with longer periods. For the generation, both faces are controlled with the active absorption function. The double peak directional waves are reproduced in the separation mode.

Long period waves with the periods longer than those in swell are generated in the separation mode. A rigid pier was installed at the corner connecting First and Second face. Therefore, no wave is induced due to motion of the corner part. The pier becomes a guide walls to the both faces. In the separation mode, both faces are applicable to reproduce the directional waves with long period wave components by employing the long driving shafts of 100cm.

Experimental Evaluation of Applicability of Wave Generator

(a) Absorption of Oblique Wave

One of the important functions of the generator is the active absorption function to oblique waves. Ito et.al.(1996) has already investigated the applicability of three-point measurement array system for active absorption. We investigated applicability of the active absorption system of the dual-mode serpent type wave generator operated in the separation mode. **Figure 4** shows location of wave gages to measure incident and reflected wave heights. In the test, the oblique regular waves were generated from Second face. The wave angle in the basin is defined as the normal propagation angle from First generator face becomes 0° . The wave angle normal to Second face is defined to be 90° .

In the oblique wave absorption test, the angle of waves generated from Second face became 135° . **Figure 5** shows the wave profiles measured in the wave gages W.1 and W.2 in case of the operation in the active absorption. The target wave height and period in the generation signal is 5.0cm and 2.0sec respectively. The water depth is 60cm. The generated wave train may be reflected on First surface if the active absorption function does not work. In Fig.5 for the active absorption methods, the wave heights measured at W.2 were small. Their heights were about 0.5cm in the maximum, which corresponds to 10% of the height of waves measured at W. 1. Therefore, the active absorption function for oblique waves is suitable in the basin.

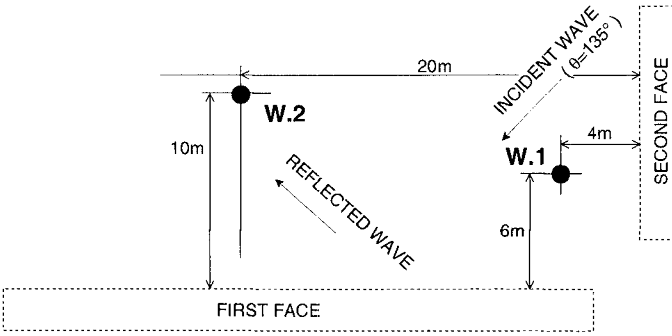

Figure 4 Measurement point of oblique wave profile

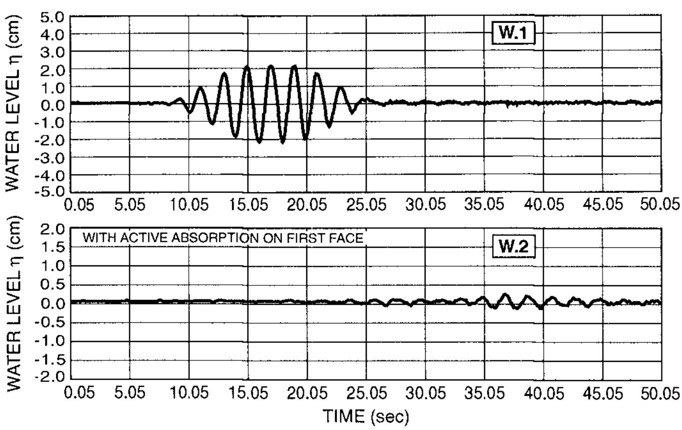

Figure 5 Wave profile measured at **W. 1** and **W. 2**

(b) Directional Waves Generated in the Multi−face Mode

Figure 6 shows the arrangement of wave gage array to analyze the directional spectrum. The extended maximum entropy principle (EMEP, Hashimoto et al., 1994) was mainly employed to obtain the directional spectrum from simultaneously measured wave profiles. The Bretschneider −Mitsuyasu type frequency spectrum and the Mitsuyasu−type directional function (Goda, 1985) is applied to form the directional spectrum. Directional spectrum is given generally by,

$$S(f;\theta) = S(f)\,G(\theta;f) \qquad (1)$$

The Bretschneider–Mitsuyasu spectrum $S(f)$ is expreesed as,

$$S(f) = 0.257H_{1/3}T_{1/3}(T_{1/3}f)^{-5}\exp[-1.03(T_{1/3}f)^{-4}] \tag{2}$$

where f, $T_{1/3}$ and $H_{1/3}$ represents the frequency, significant wave height and period. The Mitsuyasu directional function is expressed as,

$$G(\theta;f) = G_0\cos^{2s}(\theta/2) \tag{3}$$

where θ is the azimuth measured from counterclockwise from the principal wave direction. G_0 is a constant to normalize the directional function.

$$G_0=\left(\int_{\theta min}^{\theta max}\cos^{2s}\left(\frac{\theta}{2}\right)d\theta\right)^{-1} \tag{4}$$

The parameter S_{max} represents the angular spreading parameter (Goda and Suzuki,1975) which may give the energy concentration to the principal wave direction. The smaller S_{max} corresponds to the wider spreading of wave energy. Goda and Suzuki(1975) has suggested the parameter S_{max} becomes about 10 for the normal wind waves. The location of wave gage array is included in the effective test area for First face generator.

Figure 7 shows comparison of the target and experimentally obtained contour map of directional spectrum at the center of basin for waves generated in condition of $S_{max}=5$. In the figures, the vertical and horizontal axis represents the frequency and wave direction respectively. During generation, Second face is working as the wave dissipating layer with active absorption. If the obliquely propagating components may be reflected at Second face, the obtained directional function may be distorted by the effect of obliquely reflected waves in energy contour map for wave with oblique principal direction because of the wide spreading of wave energy with $S_{max}=5$. The obtained directional spectrum contour in Fig.7 becomes symmetric, which means the effects by reflection waves are negligible. The obtained wave spectral contour in the left figure becomes similar to the target ones in the right. Therefore, the dual mode snake–type wave generator is applicable to reproduce directional waves with wider spreading of wave energy.

One of the large advantages to employ the dual–mode snake type wave generator is the possibility to make directional waves with oblique principal wave direction θ_p. We tested the applicability of generation of directional waves with the principal direction of $\theta_p = 45°$. In order to generate the directional waves of $\theta_p=45°$, the appropriate motion of connecting board is inevitable.

Figure 8 shows comparison of the target and obtained directional spectrum in contour expression. The right and left figure represents the target and obtained wave energy contour map respectively. The obtained contor becomes similar to the target one. The peak of spectrum density appears at $\theta = 45°$ at the both cases of target and obtained contours. We compared the directional function at the peak frequency to have a detail check of the principal wave direction. The input parameter S_{max} for synthesizing wave signals is 25.

Figure 9 shows the directional function at the peak frequency f_p of the target and obtained directional waves. In the figure, the profiles analyzed in

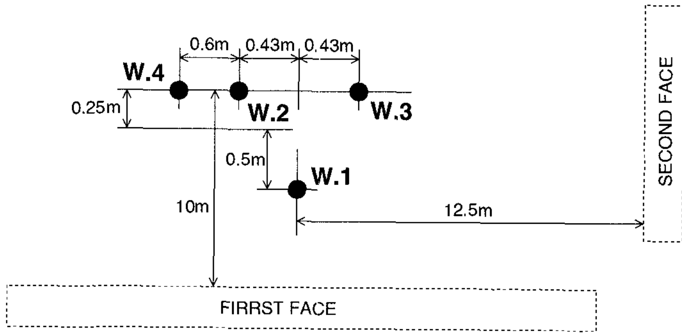

Figure 6 Measurement point of directional wave spectrum generated in multi-face mode

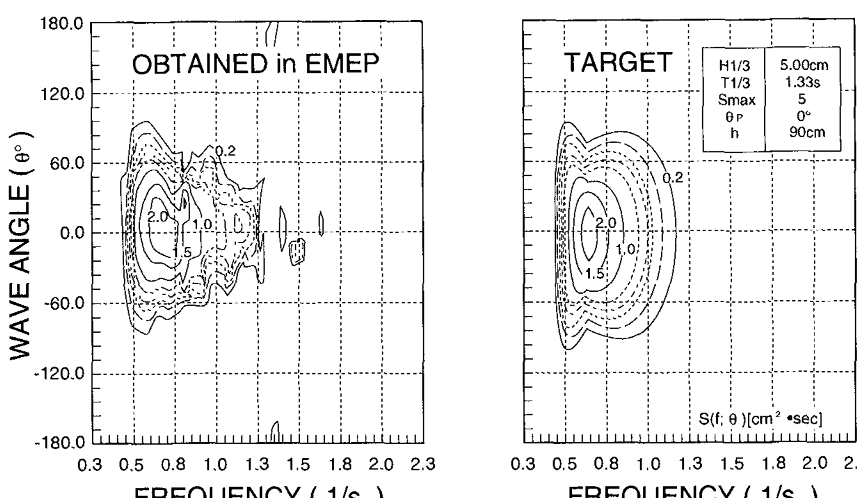

Figure 7 Comparison of measured and target directional spectrum in energy contour map

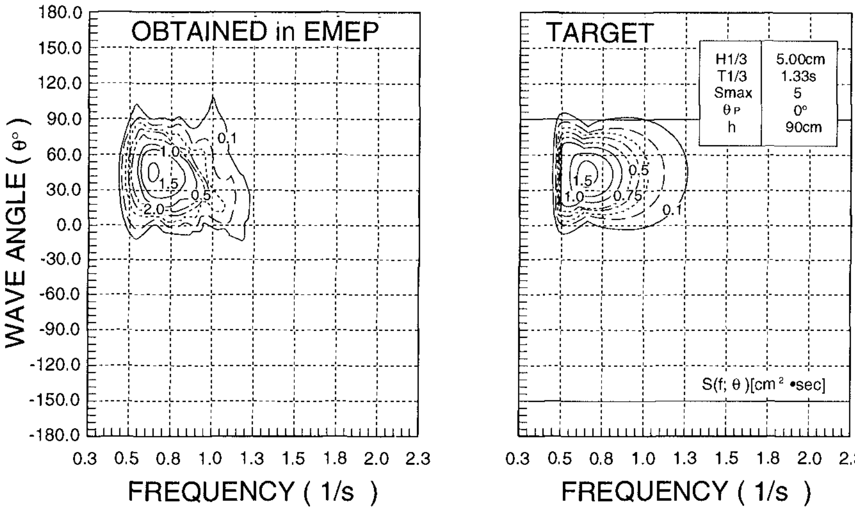

Figure 8 Measured and target directional spectrum for case of oblique principal wave direction

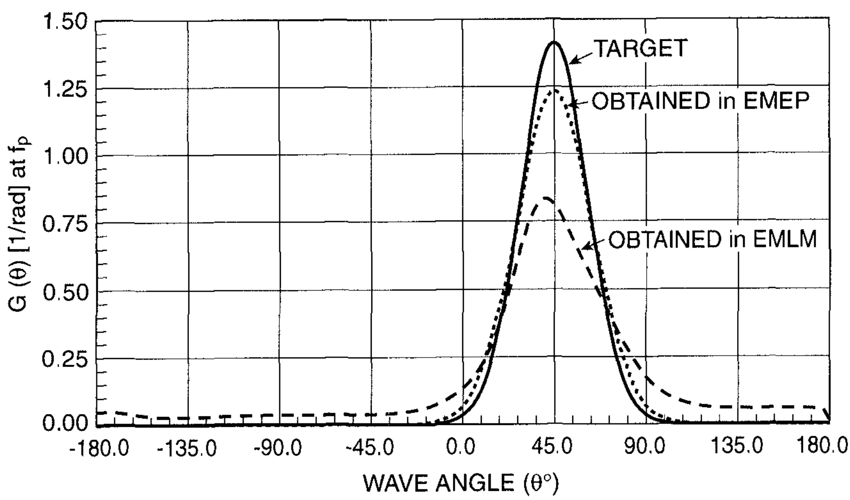

Figure 9 Comparison of directional function at peak frequency f_p of measured and target waves with oblique principal direction

EMEP and in the Extended Maximum Likelyfood Method (EMLM) (Isobe, 1988) are indicated in the dot and broken line respectively. The directional function profile analyzed in EMEP agrees with the target one indicated in the solid line. Meanwhile, the profile analyzed in EMLM shows the peak lower than the target. The mehod of EMEP is more appropriate to obtain the directional spectrum from the wave data simultaneously measured in a wave gage array than the method of EMLM. The peak angle of obtained directional function agrees well to the target of 45°. The multi-face mode operation of the serpent type wave generator is applicable to generate the directional waves with the oblique principal wave direction expressed as $\theta_p = 30°, 45°$ and so on.

(c) Long Period Wave

In order to investigate the efficiency and stability of floating structures in oceans, the reproduction of long period waves is important. **Figure 10** shows comparison of the obtained and target frequency spectrum of uni-directional random waves including the long period wave components. The uni-directional waves were generated from Second face and First surface was employed as a fixed guide wall. In the figure, the solid line represents the target frequency spectrum. The target spectrum has a constant level in the long period wave range. The broken line represents the experimentally obtained spectrum. The

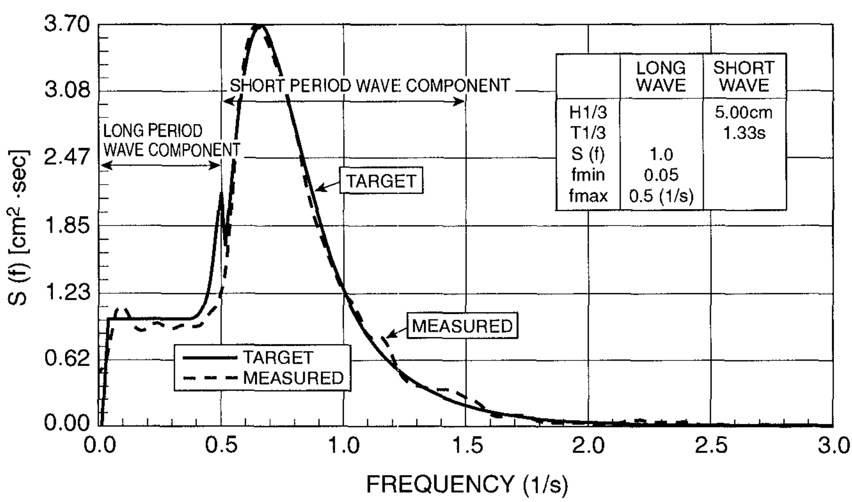

Figure 10 Measured and target wave frequency spectrum including short and long period wave component

obtained spectrum agrees well with the target even in the range of long period waves. Therefore, the generator with long stroke is expected to be applied to generate the uni-directional wave condition with free long period wave components in the experimental basin.

(d) Double-peak Directional Wave

In the evaluation tests, wind waves are generated by First-face and swell by Second face. The propagating angle of wind waves and swell is 0° and 90° respectively. The target period of generated wind waves and swells is 1.33 and 2.0sec respectively. **Figure 11** shows the measured directional spectrum at the basin center. The target conditions of wind wave and swell component is indicated as 'WAVE-1' and 'WAVE-2' respectively in the upper-left side table. In the figure, the two-dimensional directional spectrum is represented. The two dimensional directional spectrum is given by,

$$G_2(\theta)=\int_0^\infty S(\theta;f)df \quad (5)$$

The profile analyzed in EMEP has peaks at the same to the target angles. The energy level of swell component at θ =90° is slightly smaller than the target. In the wind wave components generated by First surface, the obtained peak angle and energy level agrees well with those of target spectrum. Therefore, the double-peak directional waves can be reproduced with good accuracy in dual-face directional wave generator.

Figure 12 shows comparison of the directional function at the peak frequency of swell components. The directional function's peak angle and energy level agree with those of target respectively. For the wind wave components, the peak angle slightly differs from the target, however, the differences are less than 20° . Considering the directional function at peak frequency, the dual-mode snake type wave generator is expected to be applicable to genarate double-peak directional random waves.

Figure 13 shows the frequency spectrum measured at the gage W.1. In the case for Fig.13, the target significant wave period for wind waves and swell is 1.0 and 2.2sec respectively. In the figure, the target frequency spectrum is represented in the solid line and the obtained by the broken line. The frequency spectrum of generated waves agrees well with the target spectrum and they have spectral profiles with two peaks typically observed in the double-peak directional wave condition in the field (Nagai et al.,1993). The good agreements in the directional function and frequency spectrum profile between the measured and target double-peak directional waves demonstrate the possibility of the generator to reproduce the complicated sea conditions composed of wind waves, swell and long period waves.

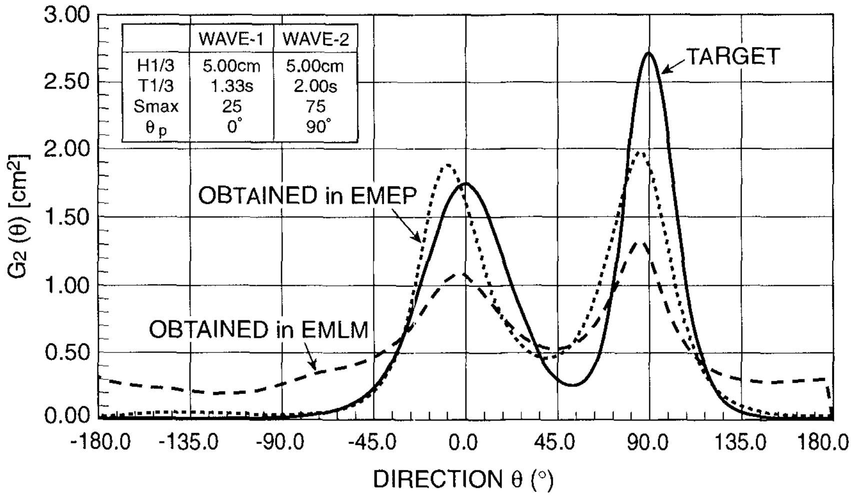

Figure 11 Comparison of two dimensional directional spectrum of measured and target double-peak directional wave

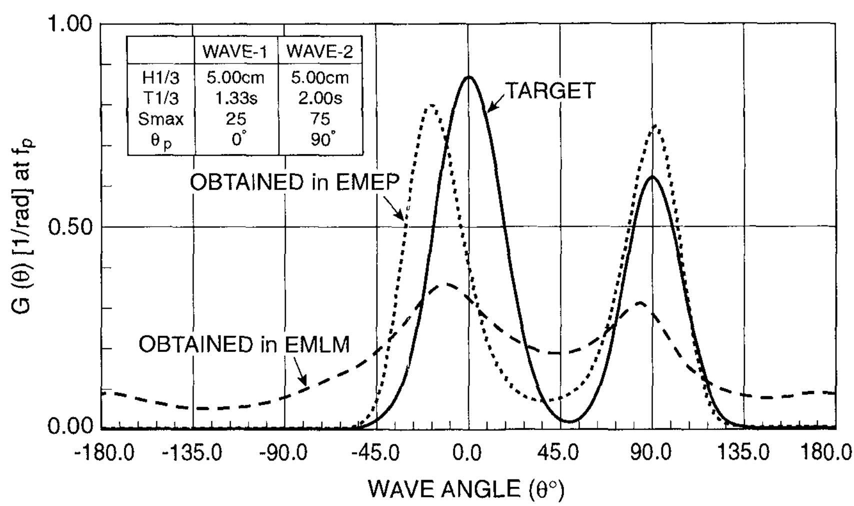

Figure 12 Comparison of directional function at f_p of measured and target double-peak directional wave

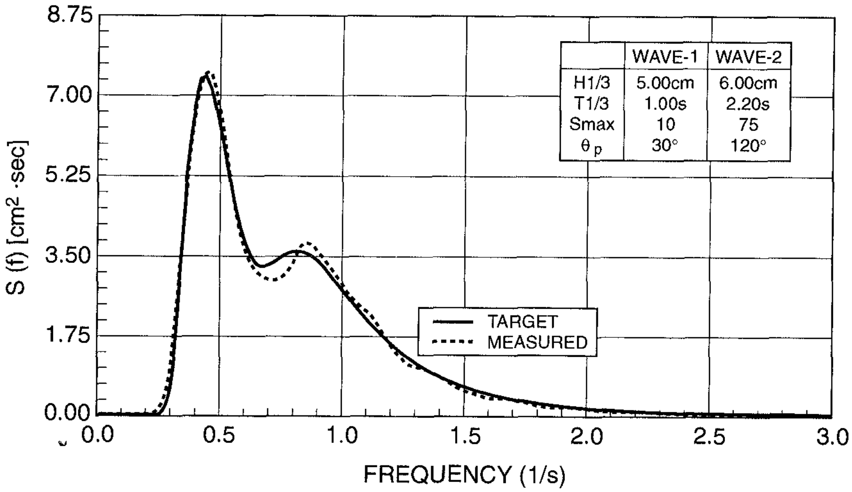

Figure 13 Comparison of frequency spectrum of measured and target double-peak directional wave

CONCLUSIONS

A Dual-mode snake type wave generator has been newly developed. The generator is composed of First and Second faces and is operated in the multi-face and the separation mode. The generator is available to reproduce;

i) directional waves with oblique principal direction,
ii) long period waves,
iii) double-peak directional waves,

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