STUDIES ON THE SHIP'S OSCILLATIONS INDUCED BY OCEAN WAVES

Part I. On the Spectra of Ocean Waves and Ship's Oscillations

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Introduction

The ship's oscillations on the seaway are mainly induced by ocean waves and swell, the record of any properties of ship's oscillations looks very much like the record of wave surface.

In recent years, the prediction theory for ocean waves has been extended by means of the wave spectrum theory with statistical methods, especially a practical method of prediction for ocean waves having been devised by W. J. Pierson, G. Neumann and R. W. James.

Contemporaneously with the studies on the ocean waves, studies on the ship's oscillations induced by ocean waves have been advanced by the same way in wave analysis, that is, the theory of stationary time series is applied to the ship's oscillations in a seaway.

By means of statistical analysis and spectrum theory, the following relation is obtained:

$$[S(\lambda)]^2 = [R(\lambda)]^2 \cdot [A(\lambda)]^2 \qquad (1)$$

where

$[S(\lambda)]^2$: spectrum of ship's oscillation
$[A(\lambda)]^2$: spectrum of wave height
$[R(\lambda)]$: ship's response function

According to the above equation (1), to find the wave spectrum of a seaway, which it is expected can be got by means of wave prediction, the spectrum of a ship's oscillation in a seaway will be given as the product of the ship's response function and the wave spectrum. There are some statistical relations between the spectrum and the maximum amplitude of a ship's oscillations.

That is to say, if the ship's response function in a seaway is known, the properties of the ship's oscillation in a seaway or fishing ground can be predicted by the above noted relation and also by the use of the wave prediction theory.

In this paper, the authors discuss the ship's oscillation in a seaway on the basis of observations on board the "Hokusei Maru" a training ship of Hokkaido university G. T. 220 tons. The studies consisted of observations of wave heights using an 8 mm cine camera and Froud's wave pole and continuous records of the ship's oscillations when the ship was drifting near the wave pole.

Experimental

1. Apparatus

For the observations of the wave heights;

Use was made of an 8 mm cine camera and Froud's wave pole which is illustrated in Fig. 1. The relation between pole heights and weights is given in Fig. 2. The wave heights were observed by taking photographs of the wave pole from the ship's deck.

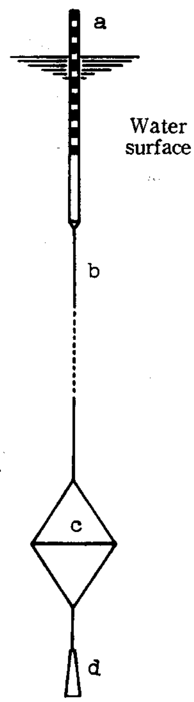

Fig. 1. Schematic diagram for Froud's wave pole

- a : Bamboo pole, painted every 20 cm alternately with white and red paint, length overall 6 meters
- b : 3/4″ dia. Manila rope, length overall 40 meters
- c : Canvas for damping the pole's heaving motions, which has a canvas covered 1 meter dia. steel ring
- d : Weights, cf. Fig. 2

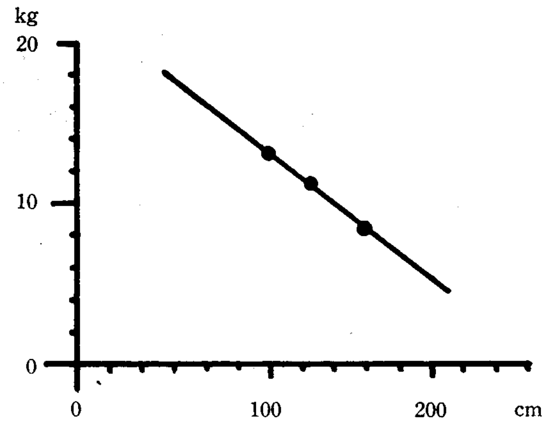

Fig. 2. The relation between weights and heights of the bamboo pole, from the water surface to pole head
Ordinate; Weights in Kg., Abscissa; Length from pole head to water surface

For the measurement of ship's oscillations;

Use was made of 2 pendulum types oscillation recording meters for measuring the ship's rolling and pitching angles. They were arranged so one of them was for measurement of rolling parallel to ship's fore and aft line and the other for measurement of pitching at right angles to it. (shown in Photo. 1)

2. Methods

On September 15th 1958, the ship was underway to Hakodate from the fisheries ground where she had been employed in Saury Stick-Held Dip Net fishing. The experiments were performed from 1400 to 1445.

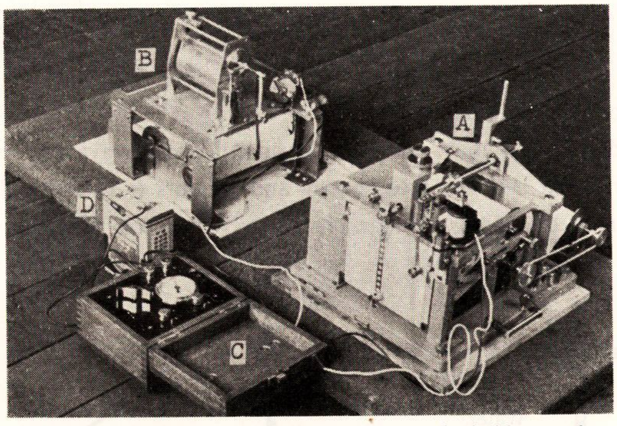

Photo. 1. Apparatus to measure rolling and pitching angles
A: For rolling angles, B: For pitching angles, C: Deck watch which contains the electrical contact switch, and D: Battery for time marker, 6 V

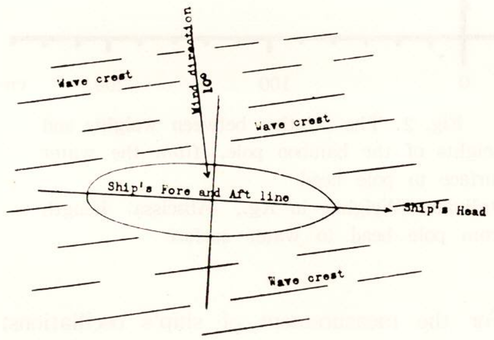

Fig. 3. The situation of ship, waves and wind during the experiments

The position was about 17 miles off Cape Erimo on true course 250 degrees (approx. position, 41°-49′N, 142°-53′E). Her draft was 1.34 meters in fore and 3.56 meters in aft. (cf. Table 1) Putting Froud's wave pole into the seawater, stopping the ship's engine and drifting near the pole, the wave height and ship's oscillation were recorded by the above noted pieces of apparatus at the same time.

Results

The wind direction and force at that time are shown in Table 2. The wave heights were read every 1 second on the 8 mm cine films on which the wave heights are recorded. The wave record was got as shown in Fig. 4 (a). (cf. Photo. 2)
The record of the ship's oscillation is shown in Fig. 4 (b).

Analysis

1. On the properties of wave observed near the experimental area

a) From Table 2, it can be deduced that the average wind force was 6.5 m/sec. According to G. Neumann's theory, it is calculated that the minimum fetch (F_m) was 23

Table 1. The ship's conditions

HOKUSEI MARU G.T. 220 tons, L=32.40 m, B=6.80 m, D=3.40 m

	Light cond.	Full cond. Leav. port	Full cond. Fish. ground	Full cond. Arriv. port
Drifting fishing				
Dead weights	255.146 tons	405.83 tons	368.461 tons	337.75 tons
Draft Fore	0.836	2.263	1.793	1.621
Aft	3.191	3.444	3.500	3.358
Mean	2.014	2.854	2.647	2.490
c_w	0.771	0.876	0.854	0.833
c_b	0.553	0.623	0.605	0.591
c_p	0.648	0.696	0.682	0.669
KB	1.204	1.741	1.570	1.479
KG	2.960	2.485	2.606	2.813
GM	0.492	0.795	0.686	0.502
KG/D	0.871	0.731	0.767	0.826
Line fishing				
Dead weights	253.850	404.404	352.603	314.743
Draft Fore	0.826	2.281	1.603	1.429
Aft	3.191	3.411	3.519	3.296
Mean	2.009	2.846	2.561	2.363
c_w	0.771	0.877	0.845	0.817
c_b	0.546	0.622	0.593	0.580
c_p	0.640	0.692	0.676	0.663
KB	1.204	1.673	1.524	1.405
KG	2.925	2.992	2.597	2.844
GM	0.527	0.788	0.703	0.496
KG/D	0.861	0.732	0.763	0.835

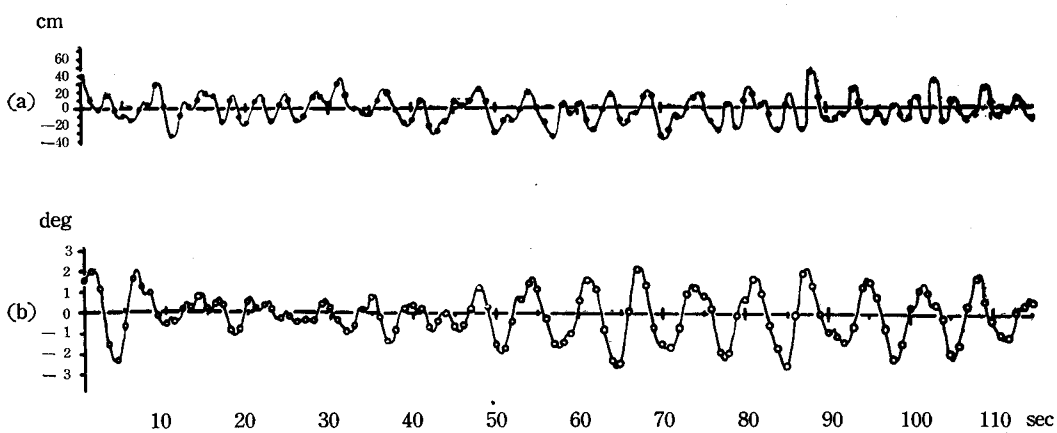

Fig. 4. (a) Record of wave heights, (b) Record of ship's rolling angles

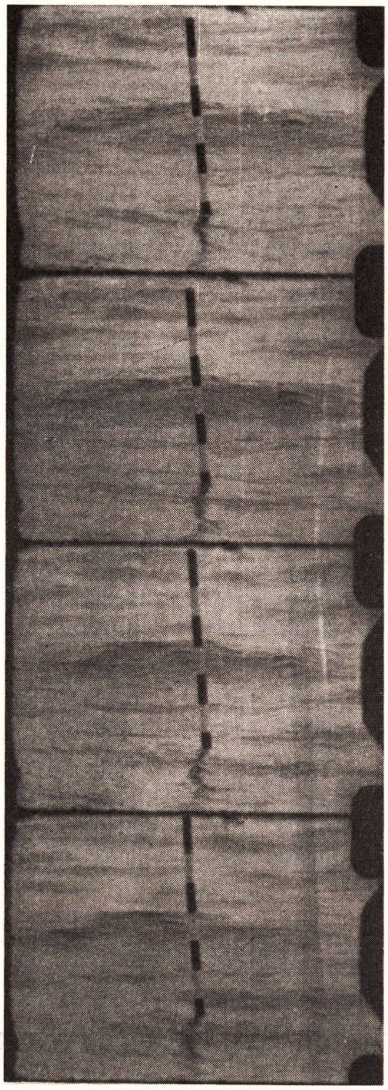

Photo. 2. Froud's wave pole which was taken with an 8 mm cine camera

Table 2. The wind observed during 1400–1445

Time	Wind direction	Wind force
1400	275°	6 m/sec
1415	260°	5.5m/sec
1430	260°	6 m/sec
1445	280°	7.5m/sec

miles, and the minimum duration of wind action (t_m) was 4.5 hrs.

b) The average wave length ($\tilde{L}$), period ($\tilde{T}$) in a fully arisen sea and optimum band (F_{max}) where most of the spectral wave energy is concentrated are obtained as follows:

$$\tilde{T} = 0.555\ v,\ L = 2/3 \cdot g/2\pi \cdot T,$$

$$F_{max} = \sqrt{2g/3}\ /v$$

Then, the following results were got :

$$\tilde{T} = 3.6\ \text{sec},\ L = 13.5\ \text{m},\quad F_{max} = 0.190$$

To the record of waves as shown in Fig. 4 (a), the method of statistical analysis was applied; notations and definitions are given as follows:

T : Apparent period of wave (the time interval between successive wave crests)

H : Apparent wave heights (the average difference in elevation of the sea surface between two peaks and the intermediate trough computed as follows: $H = H_i + H_{i+1}/2$) (cf. Fig. 5)

Concerning the apparent wave heights and periods, the average wave heights, significant wave height, 1/10 highest wave height and average period were computed. These are shown in Table 3, and their energy spectrum is given in Fig. 6.

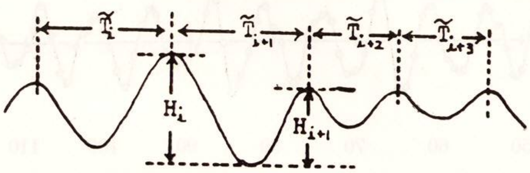

Fig. 5 Apparent periods and heights of wave in a wave record

2. On the ship's oscillation

a) On the record of the ship's rolling angles as shown in Fig. 4 (b),

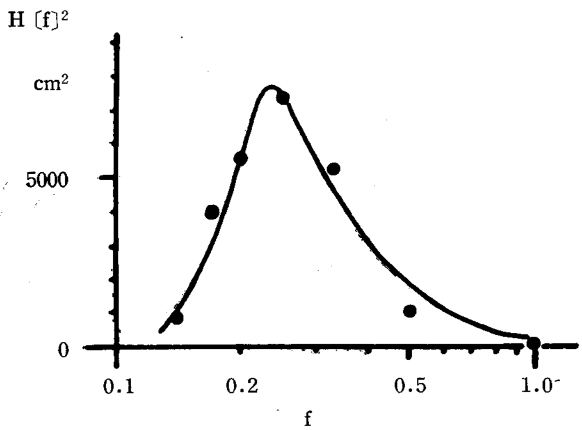

Fig. 6. Energy spectrum for wave heights

considering that this is the stationary time series, to compute the auto-correlation coefficient for it.

The following statistics were computed from N equally spaced observations for equally spaced time lags (τ).

Table 3. The wave properties in the experiments

The average wave height	30 cm
The significant wave heights	45 cm
1/10 average wave height	55 cm
The heighest wave height	60 cm
Mean period	3.8 sec

$$r = 1/N-\tau \cdot \sum_{t=1}^{N-\tau} (x_t - x_{1\tau})(x_{t+\tau} - x_{2\tau}) / s_{1\tau}s_{2\tau} = m_2(\tau) / s_{1\tau}s_{2\tau} \quad (2)$$

$$m_2(\tau) = 1/N-\tau \cdot \sum_{t=1}^{N-\tau} x_t x_{t+\tau} - \bar{x}_{1\tau}\bar{x}_{2\tau}$$

$$\bar{x}_{1\tau} = 1/N-\tau \cdot \sum_{t=1}^{N-\tau} x_t,\ \bar{x}_{2\tau} = 1/N-\tau \cdot \sum_{t=\tau+}^{N} x_{1t},\ s_{1\tau}^2 = 1/N-\tau \cdot \sum_{t=1}^{N-\tau} x_t^2 - \bar{x}_{1\tau}^2,\ s_{2\tau}^2 = 1/N-\tau \cdot \sum_{t=\tau+1}^{N} x_t^2 - \bar{x}_{2\tau}^2$$

b) The correlogrum is obtained by plotting the autc-correlation coefficient (r) as ordinate against abscissa (τ).

c) The correlogrum is transformed into a power spectrum by Fourier transform of the auto-correlation coefficient, the spectrum being given as follows:

$$F(\lambda) = 1/2\pi \cdot [1 + 2 \sum r(\tau) \cos\tau\lambda] \quad (3)$$

d) On the record of the waves in Fig. 4 (b), the correlogrum and spectrum are computed for N=266, τ=42, and shown in Figs. 8 and 10.

3. On the response function

a) According to equation (1), to find the ship's response function, the correlogrum and spectrum for wave heights are calculated by equations (2) and (3) for N=138, τ=36 on the record of Fig. 4 (a) and are shown in Figs. 7 and 9.

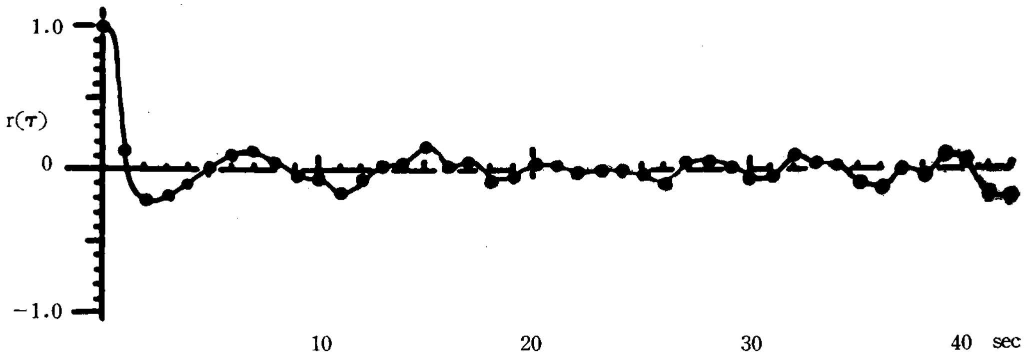

Fig. 7. Correlogrum for wave heights

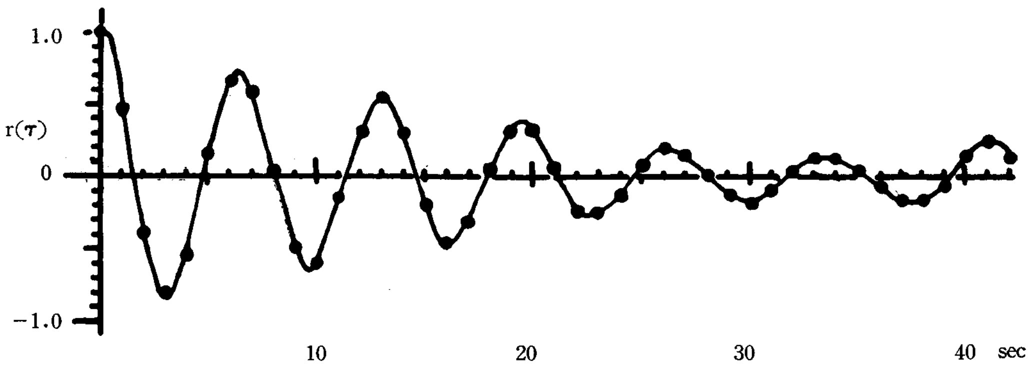

Fig. 8. Correlogrum for the ship's oscillation (rolling motion)

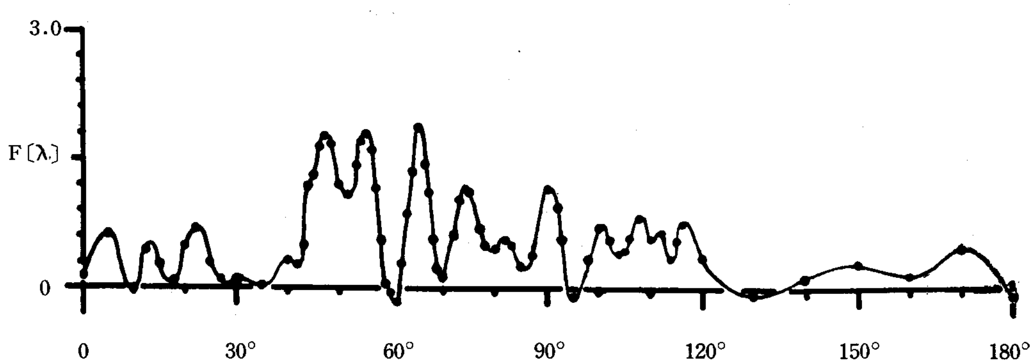

Fig. 9. Spectrum for wave heights

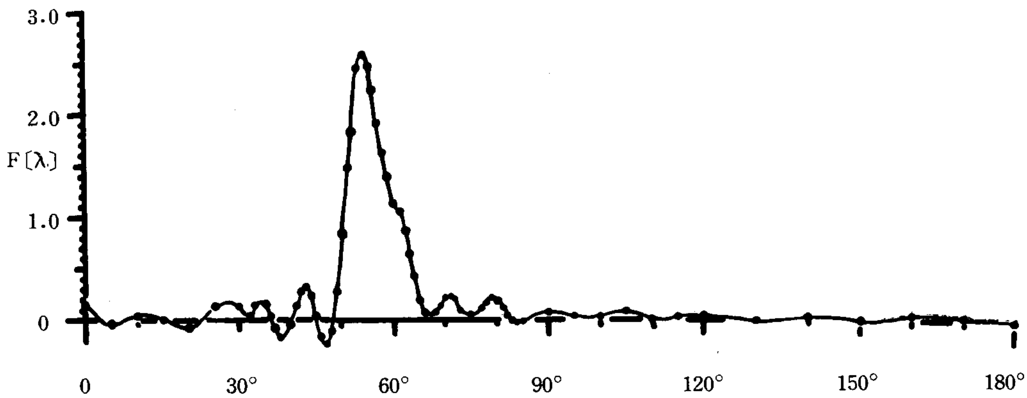

Fig. 10. Spectrum for the ship's oscillation

b) In Fig. 8, the abscissa is the apparent angular velocity, as the ship was drifted by the wind force which was exerted on 10 degrees before the left beam. (cf. Fig. 3) When the wind force is 6.5 m/sec, her drifting speed is approximately 0.5 m/sec.

c) To make comparison the two spectra in Figs. 9 and 10, it is necessary to use the apparent angular velocity in Fig. 10; the relation between these angular velocities in Figs. 9 and 10 are given in Table 4.

Table 4. The spectrum and angular velocity

λ	40°	50°	54°	60°	70°	80°	90°	100°
λe	54°	72°	81°	92°	113°	137°	162°	189°
S[λ]	0.57	0.20	0.18	0.36	0.12	0.03	0.80	—
R[λ]	0.05	0.84	2.56	1.12	0.22	—	0.06	0.04

Discussion

1) Concerning the wave heights in that area where the experiments were held, the statistical properties of waves are shown in Table 3. Considering those properties and properties calculated by G.Neumann's methods, it was not a fully arisen sea.

2) As to the ship's oscillations, the pitching angles are very small, therefore discussion is given for the rolling angles. Generally speaking, as to the rolling motion in the irregular sea, the most of the ship's oscillation consisted of natural oscillations. In this paper, from Fig. 10, it will be noted that natural rolling motion is predominant, the natural period being about 6.7 seconds.

3) According to equation (1), calculating the relation between the spectra of waves and ship's oscillations, one gets the ship's response properties as shown in Fig. 11.

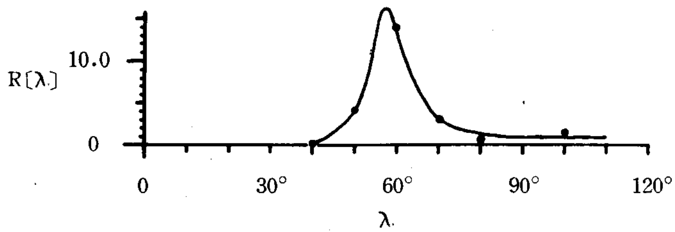

Fig. 11. The ship's response properties in respect to rolling motion

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