Analysis of Diffraction Waves Around a Ship Using
Projected Light Distribution Method

by Erwandi*, Member Toshio Suzuki**, Member

Summary

This paper is the second report that describes the capability of projected light distribution method to measure the diffraction waves generated by a ship operating in regular incident waves. In this method the waves are projected onto a screen as light distribution images and the images are recorded using a CCD Camera. In order to obtain diffraction waves, experiments were divided into two steps. Firstly, incident waves were measured. Secondly, the combination between incident waves with diffraction waves around a ship model was measured. The diffraction waves can then be obtained by subtracting incident wave images from combined one. The Kochin function was obtained using the same method as explained in the previous paper6). The results are evaluated by making some transverse cuts on the image data in the y-direction (transverse cut). The obtained Kochin functions are compared with the longitudinal cut results based on Ohkusu method, and also with theoretical results based on slender body theory. Using the results of Kochin Function, the wave pattern are recalculated and they are compared with the results of measurement using super sonic wave height meters.

1. Introduction

The problems of waves generated by a ship advancing with constant speed have attracted many researchers and subjected to many studies since the early days of ship hydrodynamics. Until the present day, numerous contributions were made to predict the added resistance in waves, theoretically and experimentally.

A technique of measuring and analyzing the unsteady waves around a ship model in waves was developed by Ohkusu1). This technique was adopted from Newman Sharma method to measure the steady wave making resistance. With this method the

distribution of the diffraction waves could be predicted along x direction (longitudinal cut). Naito et al2) developed a similar technique, namely transverse cut method as a pair of the longitudinal cut method. Both methods have merits and demerits, each method measures only along one line, whereas the value of Kochin functions sometimes differs, depending on the location of the cut line.

The study on unsteady waves usually needs much data. Advancement of the computer and digital video camera has enabled to measure the behavior of the unsteady waves two dimensionally. This possibility has many advantages, because the phenomena of diffraction waves can be observed in detail. M. Kanai4) reported the technique of measuring waves, namely Grid Projection Method. He used a camera to photograph the deformation of grid system projected on the water surface covered by aluminum powder. Miyata et.al.5) had applied this method to investigate the nonlinear phenomena of diffraction waves and the phenomena of free surface shock wave appeared in the wedge model. In this respect, the authors have

---

* Student at Graduate School of Engineering, Osaka University.
** Osaka University.

Received 10th Jan. 2001
Read at the Spring meeting 17. 18th May 2001
also reported in their first report the application of
projected light distribution method for two-
dimensional radiation waves measurement6). However, being a new method, the projected light
distribution method still needs verification with other
results based on linear theory. The merit of this
method is that the data obtained are abundant so
that it enables to investigate the phenomena of
unsteady waves in detail, including the nonlinear
phenomena of unsteady waves.

As a sequel to the first report, this paper also
describes the use of projected light distribution
method to analyze the diffraction wave problem of a
ship interacting with incident waves. This second
step of experiments with regard to diffraction waves
has been conducted based on procedures by which
experiments were conducted in the first report.

In order to obtain diffraction waves, the following
scheme is introduced here. The experiments were
carried out in two steps. Firstly, projected light
distribution images of incident waves, without ship
model, were recorded using a CCD camera. Next, the
CCD camera also recorded the images of a
combination of incident as well as diffraction waves
generated by the ship model. Finally, the differences
between those two images are calculated to obtain
the diffraction wave terms and steady wave terms.

The distribution of two-dimensional unsteady
waves was obtained by analyzing time history of
every pixel in every frame of diffraction wave data.
As in the first report, the equation of the transverse
cut method was applied to obtain the amplitude
function (Kochin function) of the diffraction waves.

The purpose of this paper is to study the
capability of the projected light distribution method
for measuring the distribution of diffraction waves.

The obtained Kochin Function was compared
with experimental results of Ohkusu method
(longitudinal cut method) and with theoretical
prediction based on slender body theory respectively.
Diffraction wave patterns are recalculated from the
Kochin functions and compared with measured one
and other recalculated patterns.

2. Theoretical Equation of Diffraction Waves

Suppose a ship model is advancing with constant
speed at regular heading waves of certain amplitude
and frequency. The reference frame O-xyz is assumed
to be moving steadily with the ship at speed V in Ox
direction. Let Oxy be the position of undisturbed free
surface, Oxz coincides with the centerplane, and Oyz
coincides with the midship section of the ship.

Let the incident waves be denoted as:

$$\eta(x, t) = \zeta_0(x) \cos(\omega t - k_0 + \varepsilon)$$  \hspace{1cm} (1)

Where $\zeta_0$ = amplitude of incident waves,
$\omega$ = frequency of encounter of incident waves.
$k_0$ = wave number = $2\pi/\lambda$
$\varepsilon$ = phase of incident waves.

Then the unsteady waves generated by the ship,
advancing with reference frame, at speed V in
regular waves relative to the ship's frame of reference
is expressed as

$$\zeta(x, y, t) = \zeta_0(x, y) + \zeta_1(x, y) \cos \omega t
+ \zeta_2(x, y) \sin \omega t + \eta(x, t)$$  \hspace{1cm} (2)

The first term on the right hand side of equation (2)
denotes the steady waves, the second and third terms
represent the unsteady waves, and the fourth denotes
the incident waves. The diffraction waves at the
location far away from the ship model are given in
the following equations:

$$\zeta_s = \zeta_0(x, y) - i\zeta_1(x, y)$$

$$= \frac{2\omega}{g} \left[ \int_{\zeta}^{\zeta} \int_{\zeta}^{\zeta} \left( 1 + \frac{k_1}{K\Omega} \cos \theta \right) \right.
\times \frac{H_1(\theta)k_1}{\sqrt{1 - 4\Omega \cos \theta}} \exp(-i(k_1x \cos \theta + k_1y \sin \theta)) d\theta
\left. + \frac{2\omega}{g} \left[ \int_{\zeta}^{\zeta} \int_{\zeta}^{\zeta} \left( 1 + \frac{k_2}{K\Omega} \cos \theta \right) \right.
\times \frac{H_2(\theta)k_2}{\sqrt{1 - 4\Omega \cos \theta}} \exp(-i(k_2x \cos \theta + k_2y \sin \theta)) d\theta \right] \hspace{1cm} (3)$$
Analysis of Diffraction Waves Around a Ship Using Projected Light Distribution Method

\[ k_i = \frac{g}{v^2} \left\{ \frac{1 - 2\Omega \cos \theta \pm \sqrt{1 - 4\Omega \cos \theta}}{2 \cos^2 \theta} \right\} \]

\[ K = \frac{\omega^2}{g} \]

\[ \Omega = \frac{V \omega}{g} \]

\[ \varphi = \tan^{-1}(y/x) \]

Where:

- \( H_i (i = 1, 2) \) is Kochin Function
- \( k_i (i = 1, 2) \) are wave numbers, positive \( i = 1 \), negative \( i = 2 \)
- \( g \) is acceleration due to gravity
- \( V \) is ship model speed

If the incident waves can be excluded from the right-hand side of equation (2), the unsteady wave terms (cosine term \( \zeta_c \) and sine term \( \zeta_s \)) can then be obtained. The Kochin function \( H_1 \) and \( H_2 \) in equation (3) can be computed accordingly.

The equation (3) shows that the unsteady wave pattern around ship model consists of elementary waves, which propagate into various directions \( \theta \) with \( x \)-axis. For each \( \theta \), two elementary waves propagate with different waves numbers \( k_i (i = 1, 2) \) and different complex amplitudes proportional to the Kochin function \( H_i (i = 1, 2) \).

From projected light distribution method the relation between waves and brightness of projected light on screen is given as:

\[ (\zeta_{\text{xx}}(x, y, t) + \zeta_{\text{yy}}(x, y, t)) \]

\[ = \frac{D + nH}{HD(n-1)} \frac{B_c(x, y, t) - B(x, y, t)}{B(x, y, t)} \]

(4)

Where

\( (\zeta_{\text{xx}}(x, y, t) + \zeta_{\text{yy}}(x, y, t)) \) is the second derivative of left hand side of equation (2). Subscript \( xx \) and \( yy \) denote the second derivative of wave elevation with respect to \( x \) and \( y \) directions.

\( D \) is the distance between the water surface and the underwater light source (ref. Fig. 1).

\( H \) is the distance between the water surface and the screen.

\( n \) is the refractive index of water

\( B_c(x, y) \) is the brightness of the pixel for calm surface \( \zeta = 0 \)

\( B(x, y) \) is the brightness of the pixel for wavy surface.

Differentiating the equation (2) twice with respect to \( x \) and \( y \) yields

\[ (\zeta_{\text{xx}}(x, y, t) + \zeta_{\text{yy}}(x, y, t)) \]

\[ = (\zeta_{0\text{xx}}(x, y) + \zeta_{0\text{yy}}(x, y)) \]

\[ + (\zeta_{\text{Cxx}}(x, y) + \zeta_{\text{Cyy}}(x, y)) \cos \omega t \]

\[ + (\zeta_{\text{Sxx}}(x, y) + \zeta_{\text{Syy}}(x, y)) \sin \omega t \]

(5)

Equation (6) shows that there is relationship between the brightness of projected light on screen with second derivative of diffraction and incident waves generated by the ship. The brightness of projected light is proportional to the second derivative of combined diffraction waves and incident waves. The unsteady wave term is obtained by excluding steady component and the incident wave term from the pixel brightness of the left-hand side of equation (6).

Again, by differentiating the equation (3) twice with respect to \( x \) and \( y \) and following the procedure explained in the first report the Kochin function around the ship is obtained from equations (7), (8), and (9).
Longitudinal Cut

\[ H_i(\theta) = \frac{g}{4\pi\omega} \int_0^x \left( (\zeta_{\text{ext}}(x,y) + \zeta_{\text{oy}}(x,y)) - i(\zeta_{\text{ext}}(x,y) + \zeta_{\text{oy}}(x,y)) \exp[ik_x x \cos \theta] \right) dx \times \sin \theta \cdot \text{sgn}(\cos \theta) \exp[ik_y y \sin \theta \cdot \text{sgn}(\cos \theta)] (-k_1^2)(1 + k_1\Omega \cos \theta / K) \]

Equations (7), (8), and (9) are the first approximation of the Kochin function because they did not include the effects of integration regions. The integration regions of equation (3) are function of \( x \) and \( y \). Hence the term of differentiation of the integral regions with respect to \( x \) and \( y \) should appear. In order to include the term of differentiation of the integral regions, the iteration was employed to calculate the effect of integration. After 6 - 7 times iteration, the Kochin function usually converges. The differentiation of the integral regions did not show in the first report. The authors apologize that we did not discuss about this effect in the first report.

3. Measurement of Diffraction Waves

The experiments were conducted at the towing tank of Osaka University (\( L = 100 \text{ m}, B = 7.8 \text{ m}, D = 4.5 \text{ m} \)). We used the modified Wigley 1-m model, where the breadth of the model is constant, from the bottom up to the draft of the model, with small bilge circles. The mathematical water-plane form of Wigley Hull is expressed by following equation:

\[ y = \pm \frac{B}{2} \left( 1 - \left( \frac{2x}{L} \right)^2 \right) \]

\[ L : B = 1.0 : 0.2 \]

\[ T = 0.15 \text{ m} \]

The experiments were conducted at the towing tank of Osaka University (\( L = 100 \text{ m}, B = 7.8 \text{ m}, D = 4.5 \text{ m} \)). We used the modified Wigley 1-m model, where the breadth of the model is constant, from the bottom up to the draft of the model, with small bilge circles. The mathematical water-plane form of Wigley Hull is expressed by following equation:

\[ y = \pm \frac{B}{2} \left( 1 - \left( \frac{2x}{L} \right)^2 \right) \]

\[ L : B = 1.0 : 0.2 \]

\[ T = 0.15 \text{ m} \]

3. Measurement of Diffraction Waves

The experiments were conducted at the towing tank of Osaka University (\( L = 100 \text{ m}, B = 7.8 \text{ m}, D = 4.5 \text{ m} \)). We used the modified Wigley 1-m model, where the breadth of the model is constant, from the bottom up to the draft of the model, with small bilge circles. The mathematical water-plane form of Wigley Hull is expressed by following equation:

\[ y = \pm \frac{B}{2} \left( 1 - \left( \frac{2x}{L} \right)^2 \right) \]

\[ L : B = 1.0 : 0.2 \]

\[ T = 0.15 \text{ m} \]

### 3. Measurement of Diffraction Waves

The experiments were conducted at the towing tank of Osaka University (\( L = 100 \text{ m}, B = 7.8 \text{ m}, D = 4.5 \text{ m} \)). We used the modified Wigley 1-m model, where the breadth of the model is constant, from the bottom up to the draft of the model, with small bilge circles. The mathematical water-plane form of Wigley Hull is expressed by following equation:

\[ y = \pm \frac{B}{2} \left( 1 - \left( \frac{2x}{L} \right)^2 \right) \]

\[ L : B = 1.0 : 0.2 \]

\[ T = 0.15 \text{ m} \]
the screen in y direction.

Digital records captured by the CCD Camera were fed into computer and the images were analyzed frame by frame. The brightness, which is represented by pixel color, was converted into integer value between 0 - 255. The gamma correction $\gamma$ to correct the pixel brightness intensity displayed on the screen was applied. The bench test had determined that the value of $\gamma$ is 2.1.

The images usually have high frequency noise due to digital process phenomenon. The noise can be reduced by applying five period two-dimensional moving average methods for every image.

In order to obtain diffraction waves, the following procedure is conducted. In the previous section, the relationship between the brightness of projected light on screen with the unsteady waves is expressed by equation (6). In order to calculate the second derivative of unsteady wave components $\zeta_{C_{\infty}}(x, y) + \zeta_{C_{S_{\infty}}}(x, y)$ and $\zeta_{S_{\infty}}(x, y) + \zeta_{S_{S_{\infty}}}(x, y)$, the incident wave components $\eta_{C_{\infty}}(x, y) + \eta_{C_{S_{\infty}}}(x, y)$ have to be excluded from the equation (6).

The way of excluding the incident waves from the record is as follows

The brightness, which is projected onto screen, of regular incident waves were recorded without putting any ship model in towing tank, as shown in Fig. 2b. During the recording, a super sonic wave height meter, which was set 1.8 meters in front of the screen, measured the elevation of regular incident waves. Thus, there were two records. The brightness of incident waves projected onto the screen that were recorded by the CCD Camera, and the incident waves measured by super sonic wave height meter. Those data are identical, the difference is only in phase and the phase is always constant, if wave generator is controlled exactly.

Similar measurement procedure was also done when a ship model is put in the towing tank. The CCD Camera recorded the projection of the combination of diffraction waves and incident waves on screen, while the forward super sonic wave height meter measured only the incident waves. Fig. 2a illustrates the measurement.

To determine the starting point of the measurement, a marker was set at a fixed location in the towing tank. This marker will generate a pulse on the data of the super sonic wave height meter and it will switch on the LED lamp on screen.

The data from the super sonic wave height meter, during measurements without and with the ship, were evaluated. The aim of this evaluation is to synchronize the phase of the incident waves recorded by the CCD Camera with the unsteady waves, which was also recorded by CCD camera.

![Fig. 2a Measurement with ship](image)

![Fig. 2b Measurement without ship](image)

**Fig. 2** Measurement system of diffraction waves

Once the synchronous condition is determined, the diffraction waves can then be obtained by subtracting incident wave images from the combination of incident and diffraction wave images.

In order to confirm the accuracy of the incident waves, we measured the incident wave in the towing tank several times. The time averaged amplitudes and wavelengths are different by only a few percents. The diffraction waves may probably have an error due to these differences.

As comparative material, the diffraction waves were measured directly on the wave pattern field around a ship model. The method proposed by Ohkusu\(^{10}\), namely Point Measurement was adopted to get the wave component data. Ten sonic wave height meters were installed on the towing carriage. One sonic wave height meter was located at 1.8 meters in front of the ship model to measure the
incident wave elevation only. Moreover, the rests were positioned in the field of diffraction waves in the near field region. The space between sonic wave height meter is set to 10 cm.

4. Experiment on Longitudinal Cut

The Longitudinal Cut measurement based on Ohkusu method was conducted as a comparative material to confirm the accuracy of the present method.

Nine super sonic waves height meters were placed at a distance 0.25-m from centerline of ship model at the middle of towing tank. Another measurement in the different y position was not done. According Ohkusum, for the slender model, like Wigley model, there is almost no difference result of Kochin function between two difference location in y direction.

The spacing distance between every super sonic waves height meters is 10 cm. If there is a short elementary wave with wavelength less than 10 cm, then that elementary wave cannot be measured.

The diffraction waves were measured in the similar condition with the projected light distribution method, i.e.: Fn = 0.15 and Fn = 0.20, with the values of \( \lambda/L \) are equal to 0.75, 1.00, and 1.25. The amplitude \( (\zeta_r) \) of the incident waves was 0.01 m.

5. Theoretical Prediction of Unsteady Waves

The theoretical prediction of Kochin function was also evaluated to compare the accuracy of the present method. Following the slender body theory, the diffraction waves generated by ship moving forward at regular waves with frequency of encounter \( \omega_r \) are given in the far field by the pulsating sources distributed on the x-axis of the reference frame. The source strength \( \sigma(x) \exp(i\omega t) \) is given as

\[
\sigma(x) = \frac{g \omega \zeta_a}{4 \pi \omega^2} A(x)e^{i\epsilon(x)} \tag{11}
\]

where \( A(x) \) and \( \epsilon(x) \) are the amplitude and the phase of the out going waves determined by solving the 2-dimensional problem of forced unit amplitude heaving motion of each transverse section at x-axis. \( \zeta_r \) denotes the amplitude of incident waves. The Kochin functions of the diffraction waves induced by the regular incident waves is expressed using the source strength determined by the equation (11) in the form

\[
H_i(\theta) = \int_{-l/2}^{l/2} \sigma(x)\exp[ik_x \cos \theta]dx
\]

\[
= \frac{g \omega \zeta_a}{4 \pi \omega^2} \int_{-l/2}^{l/2} A(x)\exp(i\epsilon(x))\exp[ik_x \cos \theta]dx
\]

6. Results and Discussion

The diffraction wave images extracted from the procedure explained on section 3 are still in the time-domain. In order to obtain the steady term, cosine term, and sine term, they must be transformed into frequency-domain. The FFT is then applied to transform the time history of every pixel on the image. Fig. 3,4,5,6, and 7 show the specimen results of transformation. They are proportional to the second derivative of unsteady wave distribution at \( Fn = 0.20 \) and \( \lambda/L=1.00 \) in two-dimensions. Fig. 3 corresponds to the steady term of equation (6), Fig. 4 and 5 present illustratively the cosine term and sine term of equation (6) respectively. Fig. 6 and 7 show the cosine term and sine term at \( Fn = 0.15 \) and \( \lambda/L=1.00 \). The reader should note that Fig. 3, 4, 5, 6, and 7 are not real wave-height records.

From every image of unsteady wave terms in Fig. 4,5,6 and 7, three transverse cut lines were made. The position of cut lines were \( x = -0.931 \) m, \(-0.773 \) m, and \(-0.604 \) m aft of midship. The profiles of transverse cuts of the unsteady term are illustrated in Fig.8 at \( Fn = 0.20 \), \( \lambda/L=1.00 \) and Fig.9 at \( Fn = 0.15 \), \( \lambda/L=1.00 \).

The Kochin functions \( H_i(\theta) \) and \( H_2(\theta) \) can be calculated by substituting the data of the transverse cut line into equation (9). It should be noted,
However, that $H_1(\theta)$ is very small compared with $H_2(\theta)$, so that $H_1(\theta)$ is not discussed here\(^\text{12}\).

Fig. 10 and 11 illustrate the Kochin Function $H_2(\theta)$ for three transverse cut lines which is given in Fig. 8 and Fig. 9 respectively. They show that the results of the projected light distribution method (present method) fluctuate around the result of longitudinal cut method for angles up to 90° for elementary waves. The present method gives disagreement with the longitudinal cut when $\theta$ is larger than 100°. The present method overestimates in this region. Similar disagreement is found between the theoretical result and longitudinal cut result. These disagreements are quite strange, and are probably caused by long elementary waves as suspected and found by Ohkusu\(^\text{1}\). The present method generally fails to predict the $H_2(\theta)$ around $\theta = 160° \sim 180°$. This failure does not seem to be strange because the transverse cut method cannot measure the elementary waves, which propagate almost parallel to the x-axis.

The Kochin functions are not only investigated along transverse cut lines behind the stern of the ship model, but also investigated along the lines in front of separation of viscous wake near the stern of the ship model. Transverse cut lines were made at $x = -0.198$ m, $-0.041$ m, and $0.128$ m from midship. Although these transverse cuts lines probably violate the far field theory of unsteady waves, it is still interesting to investigate the Kochin function in near field region. Because the viscous wake causes the velocity and pressure to be different from their inviscid values. Consequently the integral of equation (9) is not evaluated from $y = 0$. However, it is evaluated from the position of the hull of the ship model. The integral from $y = 0$ to the half-breadth of the hull where the transverse cut line start, is neglected.

Fig. 12 and 13 show the results of the Kochin Functions for $\lambda/L=1.00$ at $F_n=0.20$ and $F_n=0.15$ respectively. This condition is similar with the one, which is shown in Fig. 10 and Fig. 11. The difference is only in the location of the cut lines.

The results, as given in Fig. 13, show a good agreement with the result of longitudinal cut method up to $\theta = 100°$, especially for the lower forward speed $F_n = 0.15$ and at $x = -0.198$ m from midship. The disagreement with longitudinal cut method occurs when the forward speed is faster. Fig. 13 also shows that the present method has the same tendency with longitudinal cut method up to $\theta = 140°$, for $x = -0.041$ m and $x = 0.128$ m. At $F_n = 0.20$ generally the results of present method fluctuate around $\theta = 90° \sim 140°$ as shown in Fig. 12.

Fig. 14 and 15 show the Kochin Functions $H_2(\theta)$ for $F_n = 0.15, \lambda/L=0.75$ and $\lambda/L=1.25$ respectively, at $x = -0.198$ m. Disagreement between present method, longitudinal cut, and theoretical result occurs when $\lambda/L$ is 0.75 as given in Fig. 14. The results of present method are completely different when comparing with longitudinal cut method for $\lambda/L=1.25, F_n = 0.15$. However they show the same tendency with theoretical results up to around $\theta = 110°$ for $\lambda/L=1.25$, as shown in Fig. 15.

The projected light distribution method only presents the second derivative of unsteady wave components as shown in Fig. 3 - Fig. 9. Using the results of Kochin function at Fig. 9 - Fig. 15, however, the distribution of unsteady wave components can be predicted with equation (3). The results can then be compared with the data obtained from wave measurement, using sonic wave height meters.

The results of Kochin Function in Fig. 13 are chosen and averaged as a study case to predict the contour of unsteady wave components. As shown in Fig. 16, the averaged Kochin function has quite large values and fluctuation where $\theta$ larger than 130°. We predict a wave pattern using the average value, however it shows large transverse wave component. It seems not reliable, so we cut down the value over 130° and predict the wave contour. The unsteady wave components finally can be obtained by substituting the value of the Kochin function in equation (3).

Fig. 17 are the computed wave contour plots of the study case in Fig. 16 (Mean & Zero). The contour plot shows the cosine and sine parts. The wave contour obtained from longitudinal cut measurement is shown in Fig. 18. The results from direct measurement of unsteady waves using super sonic wave height meter are given in Fig. 19. Comparing the Fig. 17 and 18, it is shown that the qualitative
agreement of wave pattern is obtained. In the result of direct measurement, Fig. 19 there is a deformation of wave pattern near the bow. It must be the non-linear effect as Miyata et.al. pointed out before. Positive wave region near the bow is pushed out to y direction about a half breadth of ship or more. Second positive amplitude regions around \( y/L = 0.5, y/L = 0 \) are well recalculated in both Fig. 17 and 18. The readers should note that these results are only one special case and not the general conclusion, however it shows the possibilities to improve the present method.

The effects of the differentiation of the integral regions were evaluated using iteration method. It was found that the terms do not affect the results very much for \( \theta \) less than 100°, and the difference is 10% or less in the range \( \theta \) greater than 100°.

So far, the transverse cut method adopted as analysis tool to predict the Kochin function doesn't give satisfactory result compared with longitudinal cut method. However, there is another possibility to make other cutting type instead of transverse cut or longitudinal cut. Because the projected light distribution method provides much data, it enables to make a circular cut or combination between circular cut and transverse cut.

6. Conclusion

The following conclusion can be drawn from the results:

1. It is easy to visualize the 2 dimensional curvature distribution of diffraction wave pattern using the projected light distribution method.

2. The measurement data of projected light distribution method can be used to predict the amplitude function (Kochin function) of diffraction waves, although the comparison with longitudinal cut method gives not so good agreement, especially in the range of larger angle of elementary waves.

3. The diffraction wave components can be presented not only in 1 dimensional wave field but also into 2 dimensional wave field using projected light distribution method.

4. The projected light distribution method provides a lot of data and possibilities, which is useful to study the behavior of diffraction waves.

Acknowledgement

The authors acknowledge their appreciation to Professor Shigeru Naito, Osaka University for their encouragement and support in the course of this study. Their thanks also go to Associate Professor Yasuyuki Toda who help us during the experiment. Special thanks go to every student who always help us to conduct the experiment in the towing tank.

References

7. Suzuki, T., Sumino, K., "A Technique to Measure Wave Height using Projected Light Distribution on the Screen near the surface -1-"


Fig. 7 Sine Term, $F_n=0.15$, $\lambda/L=1.00$, $\zeta=10$ mm

Fig. 8 Unsteady Brightness Pattern. Top, transverse cut at $x=-0.931$ m, middle $x=-0.773$ m, bottom $x=-0.604$ m. ($F_n=0.20$, $\zeta=10$ mm, $\lambda/L=1.00$)

Fig. 9 Unsteady Brightness Pattern. Top, transverse cut at $x=-0.931$ m, middle $x=-0.773$ m, bottom $x=-0.604$ m. ($F_n=0.15$, $\zeta=10$ mm, $\lambda/L=1.00$)

Fig. 10 Kochin Function of Diffraction Waves ($F_n=0.20$, $\lambda/L=1.00$)

Fig. 11 Kochin Function of Diffraction Waves ($F_n=0.15$, $\lambda/L=1.00$)
Analysis of Diffraction Waves Around a Ship Using Projected Light Distribution Method

Fig. 12 Kochin Function of Diffraction Waves at different position of transverse cut with Fig. 10
(Fn=0.20, λ/L = 1.00)

Fig. 13 Kochin Function of Diffraction Waves at different position of transverse cut with Fig. 11
(Fn=0.15, λ/L = 1.00)

Fig. 14 Kochin Function of Diffraction Waves at position x = -0.198 m (Fn=0.15, λ/L = 0.75)

Fig. 15 Kochin Function of Diffraction Waves at position x = -0.198 m (Fn=0.15, λ/L = 1.25)
Fig. 16 Comparison between average value of Kochin Function of Fig. 13 with theoretical result and Longitudinal Cut ($F_n=0.15, \lambda/L = 1.00$). The average value is taken up to 132°, 133° to 180° is set zero.

Fig. 17 Wave contour plot of the Kochin Function Fig. 16 (Mean & Zero). Upper part is cosine term and lower is imaginary term.

Fig. 18 Wave contour plot of the Kochin Function of Longitudinal cut method ($F_n=0.15, \lambda/L=1.00, y=0.25$ m). Upper part is cosine term and lower is imaginary term.

Fig. 19 Wave contour plot from direct measurement using supersonic wave height meter. ($F_n=0.15, \lambda/L=1.00$). Upper part is cosine term and lower is imaginary term.