15. Study for Application of the Statistical Method to the Prediction of Ship Vibration Characteristics

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Summary

Ship vibration characteristics is one of the important problem in the initial design stage. But it is very difficult to predict its characteristics value in high accuracy, because in the initial design stage, there are many unknown factors.

Therefore the vibration characteristics values are predicted usually by using the simply theoretical formula which are modified with consideration of the correlation between actually measured data and theoretical value, on every type of ship.

In general, the actually measured data has always some experimental error and the theoretical value includes some error caused by ideal or approximate treatment of phenomena and structural simplification. As these error terms can be treated as statistical value, statistical approach can be used for the derivation of empirical formula.

From the above mentioned reason, the authors developed the statistical method to predict the ship vibration characteristics.

Using this method, prediction can be easily carried out on the basis of the measured data of the similar ships with a few factors which are known in the initial design stage.

1. Introduction

To make ship vibration characteristics clear is one of the important work in the initial design stage. However, it is very difficult to predict its characteristics value in high accuracy, because there are many unknown factors affecting on it at the initial design stage.

Therefore, vibration characteristics values are predicted usually by using the simple empirical formula which are derived from theoretical formula corrected by actually measured data on every type of ship. In such a case, the accuracy of prediction is affected greatly by the nature of the data which are sampled as the data of similar ships from lots of measured data.

As, in general, the actually measured data always has some experimental error and the theoretical value includes some error caused by ideal or approximate treatment of phenomena and structural simplification. As these error terms can be treated as statistical value, statistical approach can be used to derive empirical formula.

From the above mentioned reason, the authors intended to develop the statistical method to predict the ship vibration characteristics by using the general particulars of object ship with the basis of actually measured data of similar ships.

Objects of prediction are following five items, of which many actually measured data have been collected already in specified format.

(1) Natural frequency of hull nodal vibration.

(2) Acceleration response at ship's aft end due to hull nodal vibration.

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(3) Mode curve of hull nodal vibration.
(4) Natural frequency of fore and aft vibration of deck house.
(5) Fore and aft acceleration at deck house top due to hull nodal vibration.

In order to obtain higher accurate prediction, multiple regression analysis, being introduced as the statistical method on this prediction, requires many measured data with ship's particular, which are retrieved as those of similar ships to the object ship from the data stored in computer data file.

In this paper, the way of data sampling for accurate prediction, the way to determine the regression model, method of analysis and a consideration on the result of prediction are presented.

2. Outline of Prediction System on Ship Vibration Characteristics

As one of the simple method for predicting the ship vibration characteristics, the empirical formula with experimental coefficients is usually used. And the experimental coefficients are derived from the result of comparison of predictor variables of object ship with those of existing ships.

In order to use the method above, factors of existing ships effecting on ship vibration characteristics are to be stored systematic as many as possible in computer data file.

In this system, measured data are stored together with necessary factors for prediction as one set in computer data file, and necessary data can be retrieved from the file by given conditions whenever requested to use the system.

Applying the multiple regression analysis to the retrieved data, the experimental coefficients having both point and interval estimators can be obtained statistically. General flow chart of prediction system including that for information retrieval is shown on Fig. 1.

3. Method of Prediction Based on Measured Data

As described in 2, multiple regression analysis method is introduced as a method to relate measured data with prediction. Some means as described hereafter are investigated in order to use this system effectively.

3.1 *Selection of Predictor Variables and Factors*

Generally, predictor variables for multiple regression analysis are to be composed of factors which have great effects on criterion variables of ship vibration characteristics, and these factors can be suitably selected from the factors already included in the existing formula by multivariate analysis method.

In addition to the above, to make the prediction at the initial design stage of ship easy,

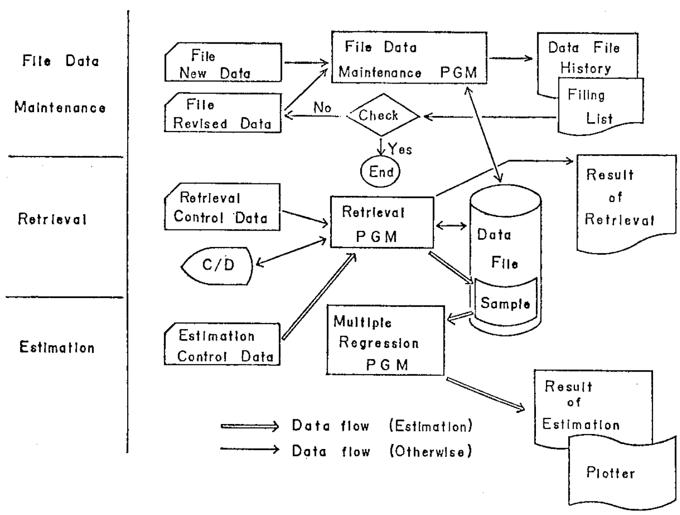

Fig. 1 Flow chart of system

the factors are expressed as simple form as possible. Now as example, taking natural frequency of 2-nodes hull vertical vibration, procedure to select the factors is explained as follows.

Now the followings are assumed to be dominant factors for natural frequency of 2-nodes hull vertical vibration.

1) I_v; moment of inertia of cross sectional area about horizontal neutral axis amidships.
2) R_{sv}; shear correction coefficient for I_v.
3) Δ; displacements of ship.
4) $1.2+B/3d$; virtual mass coefficient for Δ.
5) L; length between perpendiculars of ship.

From an existing theoretical formula, natural frequency of 2-nodes hull vertical vibration "N_2" is obtained by following formula.

$$N_2=C\sqrt{\frac{I_v}{(1+r_{sv})\Delta(1.2+B/3d)L^3}} \tag{1}$$

Eq. (1) can be re-written in a linear combination form for multivariate analysis as follow.

$$\log N_2=\alpha_0+\alpha_1\log I_v+\alpha_2\log(1+r_{sv})+\alpha_3\log\Delta+\alpha_4\log(1.2+B/3d)+\alpha_5\log L \tag{2}$$

Eq. (2) is a linear regression formula having five factors, and whole combination of these factors were analyzed by multivariate analysis method in order to clarify the effects on the accuracy of prediction due to the difference of combination of factors.

The results of multivariate analysis with the sample data of twelve cargo ships are shown in Table 1. These results are arranged sequentially from the case of combination of factors having higher multiple correlation to the lower one in this table.

"F_0" is the value of "F-distribution" at the significance level of 5%.

Multiple correlation value gives the correlation level between "$\log N_2$" and each combination of factors, and the correlation becomes higher as the multiple correlation value is nearer to 1.0.

"F" is the value which certifies, where $F>F_0$, that the combination of factors is able to represent the characteristic of criterion variables at the significance level of 5%.

Variance is the value showing the magnitude of error, and the accuracy becomes higher as the variance is smaller.

Multiple correlation values of case-a which includes all factors, case-b which excludes only the effect of "L" and case-c which has the same combination as Schlick's formula are high enough for representing characteristics of "N_2".

Comparing case-a and case-b, variance of case-a is greater than that of case-b, which is however mainly caused by the fact that the degree of freedom of case-a is less than that of case-b.

The fact mentioned above shows that it is

Table 1 Result of multivariate analysis of N_2

Case	Factor	Variance	Multiple correlation	F	F_0	Degree of freedom
a	1, 2, 3, 4, 5	0.992×10^{-3}	0.903	11.2	4.39	6
b	1, 2, 3, 4,	0.815×10^{-3}	0.903	16.3	4.12	7
c	1, 3, 4, 5	0.998×10^{-3}	0.886	13.6	4.12	7
d	1, 3, 4	2.370×10^{-3}	0.691	6.0	4.07	8
e	3, 4, 5	2.030×10^{-3}	0.735	7.4	4.07	8
f	3, 4	2.150×10^{-3}	0.685	9.8	4.26	9

Factor 1	2	3	4	5
$\log I_v$	$\log(1+r_{sv})$	$\log\Delta$	$\log\left(1.2+\frac{B}{3d}\right)$	$\log L$

better to use all the factors for the predictor variables than those of case-b, all factors of 1, 2, 3, 4 and 5 are included to compose the predictor variables of N_2 and therefore the regression formula is adopted as follows.

$$N_2=a_0+a_1X \tag{3}$$

where

$$X=\sqrt{\frac{I_v}{(1+r_{sv})\Delta(1.2+B/3d)L^3}}$$

This equation may be so called as modified Shlick's formula which includes the correction coefficient of "r_{sv}".

On the other hand, as the vertical moment of inertia "I_v" can not be always calculated at initial design stage, the prediction formula by Todd's is also considered by using "BD^3" instead of "I_v". The corresponding regression formula is written as follows.

$$N_{2(T)}=a_{0(T)}+a_{1(T)}X_{(T)} \tag{4}$$

where

$$X_{(T)}=\sqrt{\frac{BD^3}{\Delta(1.2+B/3d)L^3}}$$

In order to compare the prediction accuracy of both formula, multivariate analysis of both Schlick's formula and Todd's formula were executed with the sample data of twelve cargo ships mentioned above, of which the results are shown in Table 2.

From Table 2, F being greater than F_0, both Schlick's formula and Todd's formula represent the characteristics of "N_2" at the significance level of 5%, but multiple correlation values show that Schlick's formula is better in such a prediction method than Todd's.

In general, predictor variables included in

Table 2 Comparison between Schlick's formula and Todd's formula

Formula	Variance	Multiple correlation	F	F_0	Degree of freedom
Schlick's	3.84×10^{-3}	0.767	32.8	4.96	11
Todd's	8.68×10^{-3}	0.472	9.0	4.96	11

regression formula must be so determined by the multivariate analysis as mentioned above. However, as the result seems to be same as the existing formula, it is simpler to determine the predictor variables corresponding to the existing formula than the determination by the multivariate analysis. Accordingly, the authors determined the regression formula for the other characteristics values in accordance with the existing formula as shown in Table 3.

3.2 *Derivation of Regression Coefficient by Multiple Regression Analysis*

(1) Data sampling

a) Basic conception for data sampling

Criterion variable y and predictor variable x with the linear relation between themselves are considered.

$$y=a_0+a_1x \tag{5}$$

a_0 and a_1 being unknown values, unbiased estimators $\hat{a}_0$ and $\hat{a}_1$ of them are obtained by the method of least square in accordance with the sample data of y_i and x_i $(i=1, 2, \ldots, k)$ as follows.

$$\hat{a}_0=\bar{y}-\hat{a}_1\bar{x} \tag{6}$$

$$\hat{a}_1=\frac{\sum(y_i-\bar{y})(x_i-\bar{x})}{\sum(x_i-\bar{x})^2} \tag{7}$$

As y_i includes error due to measurement, $\hat{a}_0$ and $\hat{a}_1$ inevitably include some error.

Unbiased estimator of population variance being $\sigma_E{}^2$, variance of a_1 is as follows,

$$\sigma^2(\hat{a}_1)=\frac{\sigma_E{}^2}{\sum(x_i-\bar{x})^2} \tag{8}$$

which becomes less as the sum of squares $\sum(x_i-\bar{x})^2$ increases. This means that x_i is to be taken from the wider range as far as the linearity between y and x is maintained.

Then, predicted value y_0 of y at a certain x_0 is as follows,

$$y_0=\bar{y}+\hat{a}_1(x_0-\bar{x}) \tag{9}$$

and the variance of y_0 is as follow.

$$\sigma^2(y_0)=\sigma_E{}^2\left\{\frac{1}{k}+\frac{(x_0-\bar{x})^2}{\sum(x_i-\bar{x})^2}\right\} \tag{10}$$

Variance of y_0 becomes less as $\bar{x}_0$ gets nearer to $\bar{x}$, that means accuracy of prediction becomes higher as prediction point of x_0 gets nearer to $\bar{x}$. That is to say that accuracy of prediction gets higher by using the sample of which mean value of x_i is near to x_0.

Consequently, in order to obtain the prediction in high accuracy, following cares have to be taken.

i) Predictor variables are to be of wide range as far as the linearity is maintained.

ii) Data are to be so sampled that mean of

Table 3 Regression model

Characteristics	Theoretical formula	Regression model	Annotation
Natural frequency of hull nodal vibration (fundamental mode)	$N=a\sqrt{\dfrac{q_1}{q_2q_3q_4q_5}}=aX$	$N=a_0+a_1X$	see sub-table below
Natural frequency of hull nodal vibration (higher mode)	vert. horzt. $N_n=N(n-1)^a$ tors. longl. $N_n=Nn^a$	$a=a_0$	n=number of nodes
Response (vertical and horizontal accel.) of aft end of hull	vert. $\alpha_n=aMK_m\dfrac{g}{\left(1.2+\dfrac{B}{3d}\right)\Delta L_{0A}}$ horzt. $\alpha_n=aMK_m\dfrac{g}{\left(1+1.1\dfrac{d}{B}\right)\Delta L_{0A}}$	$a=a_0+a_1\xi+a_2\xi^2$ $=a_0+a_1\xi_1+a_2\xi_2$	M=unbalanced moment of M/E K_m=dampingf actor$=\dfrac{3\times10^4}{N_n+100}$ ξ=(distance between M/E and aft end)$/L_{0A}$
Mode of hull nodal vibration		within $0.25L$ $y_{\text{mode}}=a_0+a_1\eta+a_2\eta^2+a_3\eta^3$ $=a_0+a_1\eta_1+a_2\eta_2+a_3\eta_3$	$\eta=\dfrac{\text{distance from aft end}}{L_{0A}}$ L_{0A}=length over all
Natural freq. of fore and aft vibration of deck house	$\dfrac{1}{N_{ss}^2}=\dfrac{C_r}{N_r^2}+\dfrac{C_s}{N_s^2}$	$\dfrac{1}{N_{ss}^2}=a_0+\dfrac{a_1}{N_r^2}+\dfrac{a_2}{N_s^2}$ $=a_0+a_1x_1+a_2x_2$	N_r=natural freq. of rotative vibration of deck house N_s=natural freq. of shear vibration of deck house
Response (fore and aft accel.) of deck house due to hull vertical vibration	$\beta_n=\theta\dfrac{H}{L_{0A}}\alpha_n$	$\theta=\dfrac{d}{d\eta}$ (mode curve) $=a_1+a_22\eta+a_33\eta^2$ $=a_1+a_22\eta_1+a_33\eta_2$	θ=slope of mode curve of hull H=height of deck house$+D/2$ α_n=vertical accel. of aft end of hull

Annotation (natural frequency, fundamental mode):

	Vert.	Horizt.	Tors.	Longl.
q_1	I_v	I_h	J_A	A_L
q_2	$1+r_{sv}$	$1+r_{sh}$	k^2	1
q_3	Δ	Δ	Δ	Δ
q_4	$1.2+\dfrac{B}{3d}$	$1+1.1\dfrac{d}{B}$	$1+J_w$	1
q_5	L^3	L^3	L	L

Table 4 Conditions of retrieval of similar ships

Nat. freq. of hull	Response of aft end	Mode of hull	Nat. freq. of deck house	Response of deck house	
Kind of ship	Kind of ship	Kind of ship	Profile of deck house	Kind of ship	High
Range of L_{pp}	Position of E/R	Range of L_{pp}	Front view of deck house	Position of E/R	
Range of D/W	Kind of M/E	Range of D/W	No. of tiers	Kind of M/E	
	Balancer and detuner	Ship type	With poop deck or not	Balancer and detuner	
	Stern form	Position of E/R	Range of N_s, N_r	Stern form	Priority
	Range of L_{pp}	Position and No. of deck house		Position of deck house	
	Range of D/W			Ship type	
				Range of L_{pp}	
				Range of D/W	Low

x_i can be near to prediction point of x_0

b) Procedure of sampling

For sampling the actual data, i) and ii) above are rewritten in other words as follows.

i) Data are to be sampled from those of similar ships.

ii) Data are to be sampled around the object ship.

Sampling condition of i) has great effects on ship vibration characteristics and is arranged sequentially with the priority of effectiveness on ship vibration characteristics as shown in Table 4.

By using these conditions, similar ship for each vibration characteristics can be defined. And in addition, continuous conditions such as L_{pp} and D/W etc. are used for data sampling around the object ship. Taking example L_{pp} and D/W, a plane formed by L_{pp} and D/W is considered, on which lots of existing ships are distributed. Object ship is shown by (L_{pp0}, D/W_0), and data are to be sampled around (L_{pp0}, D/W_0).

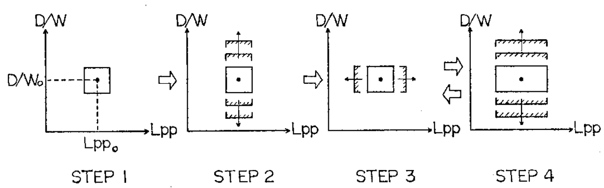

Fig. 2 Method of retrieval of similar ships

In this case, priority is to be taken into consideration. That is, priority of L_{pp} being higher than that of D/W, range of L_{pp} is to be as narrow as possible. Considering the above mentioned, procedure of sampling was established as shown on Fig. 2.

At STEP 1, data are searched in range of $L_{pp0} \pm \delta L_{pp}$ and $D/W_0 \pm \delta D/W$. If the expected size of data cannot be obtained in STEP 1, at STEP 2, the range of D/W is only expanded step by step up to the given range for searching the data. If the expected size of data cannot be obtained in STEP 2, at STEP 3, once the range of D/W is narrowed to that of STEP 1, and the range of L_{pp} is expanded for a step for searching the data. If the expected size of data cannot be obtained in STEP 3, at STEP 4, the range of D/W is only expanded step by step up to the given range for searching the data. And STEP 3 and 4 are repeated until the samples of expected size are obtained.

(2) Derivation of experimental coefficients

Carrying out the multiple regression analysis of regression model shown in Table 3 with the sample data obtained through the procedure mentioned above, unbiased estimator of experimental coefficient is obtained, and with which value, point estimator and interval estimators of vibration characteristics of object ship are obtained.

Now, generalizing the case described in 3.2 (1) a), we consider the case that number of predictor variables are "n".

$$y=a_0+a_1x_1+a_2x_2+\cdots+a_nx_n \tag{11}$$

Number of data sampled being k, sample size is k and the sample is written as follow.

$$\begin{pmatrix} y_1 & x_{11} & x_{12} & \cdots & x_{1n} \\ y_2 & x_{21} & x_{22} & & \vdots \\ y_3 & & \ddots & & \vdots \\ \vdots & & & \ddots & \vdots \\ y_k & \cdots & \cdots & \cdots & x_{kn} \end{pmatrix} \tag{12}$$

Using multiple regression analysis, unbiased estimator $\hat{a}_0, \hat{a}_1, \ldots, \hat{a}_n$ of experimental coefficients $a_0, a_1, \ldots, a_n$ are obtained as follows.

$$(\hat{a}_1, \hat{a}_2, \ldots, \hat{a}_n)=\{S(y, x_1), S(y, x_2), \ldots, S(y, x_n)\}S^{-1}$$

$$\hat{a}_0=\bar{y}-\sum_{i=1}^{k}\hat{a}_i\bar{x}_i \tag{13}$$

where

$$S(x_i, x_j)=\sum_{p=1}^{k}(x_{pi}-\bar{x}_i)(x_{pj}-\bar{x}_j)$$

$$S=\begin{pmatrix} S(x_1, x_1) & S(x_1, x_2) & \cdots & S(x_1, x_n) \\ S(x_2, x_1) & S(x_2, x_2) & & \vdots \\ \vdots & & \ddots & \vdots \\ S(x_n, x_1) & \cdots & \cdots & S(x_n, x_n) \end{pmatrix}$$

Assuming $(x_{10}, x_{20}, \ldots, x_{n0})$ as the coordinate of the ship in question, point estimator y_0 and variance $\sigma^2(y)$ of object ship are obtained as follows.

$$y_0=\hat{a}_0+\sum_{i=1}^{k}\hat{a}_i x_{i0} \tag{14}$$

$$\sigma^2(y)=\sigma_E^{\,2}\left(1+\frac{1}{k}+\underset{\sim}{\boldsymbol{x}_0}^t S^{-1}\underset{\sim}{\boldsymbol{x}_0}\right) \tag{15}$$

where

$$\underset{\sim}{\boldsymbol{x}_0}=\begin{pmatrix} x_{10}-\bar{x}_1 \\ x_{20}-\bar{x}_2 \\ \vdots \\ x_{n0}-\bar{x}_n \end{pmatrix}$$

$$\sigma_E^{\,2}=\frac{1}{k-n-1}\sum_{p=1}^{k}\{y_p-(\hat{a}_0+\sum_{i=1}^{n}\hat{a}_i x_{pi})\}^2$$

Using α for significance coefficient, interval estimators are obtained as follows.

$$\left.\begin{matrix} y_{0U} \\ y_{0L} \end{matrix}\right\}=y_0\pm t(k-n-1;\,\alpha)\sigma(y) \tag{16}$$

where

$t(\phi;\,\alpha)$=values of Student's t−distribution
ϕ; degree of freedom
α; significance coefficient

Then, these equations in each case of vibration characteristics are defined as shown in Table 5.

In addition to the above, following predictor variables which are not directly measured are stored in computer data file after processing as follows.

The exponent of higher mode natural frequency of hull nodal vibration.

vert. horzt. $\quad a_i=\dfrac{\log(N_{ni}/N_i)}{\log(n-1)}$

tors. longl. $\quad a_i=\dfrac{\log(N_{ni}/N_i)}{\log n}$

Coefficient of aft end acceleration of hull vibration.

vert. $\quad a_i=\alpha_{ni}\Big/\left\{MK_m\dfrac{g}{\Delta(1.2+B/3d)L_{0A}}\right\}$

horzt. $\quad a_i=\alpha_{ni}\Big/\left\{MK_m\dfrac{g}{\Delta(1+1.1(d/B))L_{0A}}\right\}$

Table 5 Empirical formula and variance

Characteristics	Empirical formula	Variance	Degree of freedom	Annotation
Natural frequency of hull nodal vib. (fundamental mode)	$N_0=\hat{a}_0+\hat{a}_1X_0$	$\sigma^2(N)=\sigma_E^2\left(1+\frac{1}{k_N}+\underset{\sim}{x_0}^tS^{-1}\underset{\sim}{x_0}\right)$	$\phi_N=k_N-2$	k_N=sample size
Natural frequency of hull nodal vibration (higher mode)	vert. horzt. $N_{n0}=N_0(n-1)^{\hat{a}_0}$ tors. longl. $N_{n0}=N_0n^{\hat{a}_0}$	$\sigma^2(N_n)=N_{n0}^2\left[\frac{\sigma^2(N)}{N_0^2}+\{\log(n-1)\}^2\sigma^2(a)\right]$ $\sigma^2(N_n)=N_{n0}^2\left[\frac{\sigma^2(N)}{N_0^2}+(\log n)^2\sigma^2(a)\right]$	$\phi_{Nn}=\dfrac{\left[\frac{\sigma^2(N)}{N_0^2}+\{\log(n-1)\}^2\sigma^2(a)\right]^2}{\frac{\sigma^4(N)/N_0^4}{k_N-2}+\frac{\{\log(n-1)\}^4\sigma^4(a)}{k_a-1}}$ $\phi_{Nn}=\dfrac{\left[\frac{\sigma^2(N)}{N_0^2}+(\log n)^2\sigma^2(a)\right]^2}{\frac{\sigma^4(N)/N_0^4}{k_N-2}+\frac{(\log n)^4\sigma^4(a)}{k_a-1}}$	k_a=sample size
Response of aft end of hull	$\alpha_{n0}=a_0MK_m\frac{g}{\Delta_1L_{0A}}$	$\sigma^2(\alpha_n)=\alpha_{n0}^2\sigma_a^2$	$\phi_{an}=k_{an}-3$	k_{an}=sample size vert. $\Delta_1=\Delta(1.2+B/3d)$ horzt. $\Delta_1=\Delta(1+1.1d/B)$
Mode of hull nodal vibration	$y_{\text{mode}}=\hat{a}_0+\hat{a}_1\eta_{10}$ $+\hat{a}_2\eta_{20}$ $+\hat{a}_3\eta_{30}$	$\sigma^2(y_{\text{mode}})=\sigma_E^2\left(1+\frac{1}{k_{\text{mode}}}+\underset{\sim}{\eta_0}^tS^{-1}\underset{\sim}{\eta_0}\right)$	$\phi_{\text{mode}}=k_{\text{mode}}-4$	k_{mode}=sample size
Natural frequency of deck house	$\frac{1}{N_{ss0}^2}=\hat{a}_0+\frac{\hat{a}_1}{N_{r0}^2}$ $+\frac{\hat{a}_2}{N_{s0}^2}$	$\sigma^2\left(\frac{1}{N_{ss}^2}\right)=\sigma_E^2\left(1+\frac{1}{k_{N_{ss}}}+\underset{\sim}{x_0}^tS^{-1}\underset{\sim}{x_0}\right)$	$\phi_{N_{ss}}=k_{N_{ss}}-3$	$k_{N_{ss}}$=sample size
Response of deck house	$\beta_{n0}=\theta_0\frac{H}{L_{0A}}\alpha_{n0}$	$\sigma^2(\beta_n)=\beta_{n0}^2\left(\frac{\sigma^2(\alpha_n)}{\alpha_{n0}^2}+\frac{\sigma^2(\theta)}{\theta_0^2}\right)$	$\phi_{\beta n}=\dfrac{\left[\frac{\sigma^2(\alpha_n)}{\alpha_{n0}^4}+\frac{\sigma^2(\theta)}{\theta_0^2}\right]^2}{\frac{\sigma^4(\alpha_n)/\alpha_{n0}^4}{\phi_{\alpha n}}+\frac{\sigma^2(\theta)/\theta_0^4}{\phi_{\text{mode}}}}$	$\sigma^2(\theta)$ $=\sigma_E^2\{1+\eta'^tS^{-1}\eta'\}$ $\sigma_E^2=\sigma_E^2$ of mode $S=S$ of mode $\eta'=\begin{pmatrix}1\\2\eta_1\\3\eta_2\end{pmatrix}$

4. Result of Prediction and its Consideration

(1) An example of prediction

On natural frequency of 2-nodes hull vertical vibration of bulk carrier, the prediction executions were carried out.

The principal dimensions of the predicted bulk carrier are as follows.

L_{pp} : 211.0 m
B : 31.8 m
D : 17.5 m
d : 11.5 m
D/W : 54400 t

As the conditions of data sampling, followings were considered,

kind of ship = bulk carrier
$105 \leqq L_{pp} \leqq 316$ m
$27000 \leqq D/W \leqq 81000$ t

and the size of sample obtained was 18, which excludes of course the measured data of the object ship.

Results of prediction together with the predicted values obtained from the other existing formula are shown in Table 6.

P in Table 6 shows the deviation, which is normalized by $\sigma(N_2)$, from the point estimator of 0.842. P becomes less as the error decreases. From Table 6, point estimator obtained by this statistical method, which has the deviation of $0.559\sigma(N_2)$ from measured data, is much accurate as compared with the others.

Table 6 Natural frequency of 2-nodes hull vertical vibration

Method of prediction	Frequency (Hz)			P
Measured data	0.867			0.559
Statistical method ($\alpha=30\%$)	Lower limit	Point estimator	Upper limit	±1.071
	0.794	0.842	0.882	
Formula by MHI	0.900			1.297
Formula by The Kansai Society of Naval Architects, Japan[4] (using I_v)	1.053			4.718
Do. (using BD^3)	1.158			7.066
				($\Delta=29360t$)

In addition, results of prediction shall be always shown on figures for visual recognition as shown in Fig. 3, which shows the relation between natural frequency of hull nodal vibration and displacements of ship.

(2) Consideration

(a) Applicability

To clarify the vibration characteristics is very important for ship initial design, however data are not always sufficient for executing the prediction calculation at that design stage. In such a case, it is much effective for this method to use the measured data of similar ships designed by the same designing philosophy as the ship in question. And applying this method to existing data, designer can pull out the true means from the data which have many useful informations.

(b) Problems

1. To execute the multiple regression analysis accurately, the regression model is to be determined to realize the independence, unbiasedness, equality and normality of residual error. While, as the technique of ship designing progresses, ship vibration characteristics varies little by little, and accordingly, the best regression model changes its form. Therefore, to make the highly accurate prediction by this method, the regression model is to be

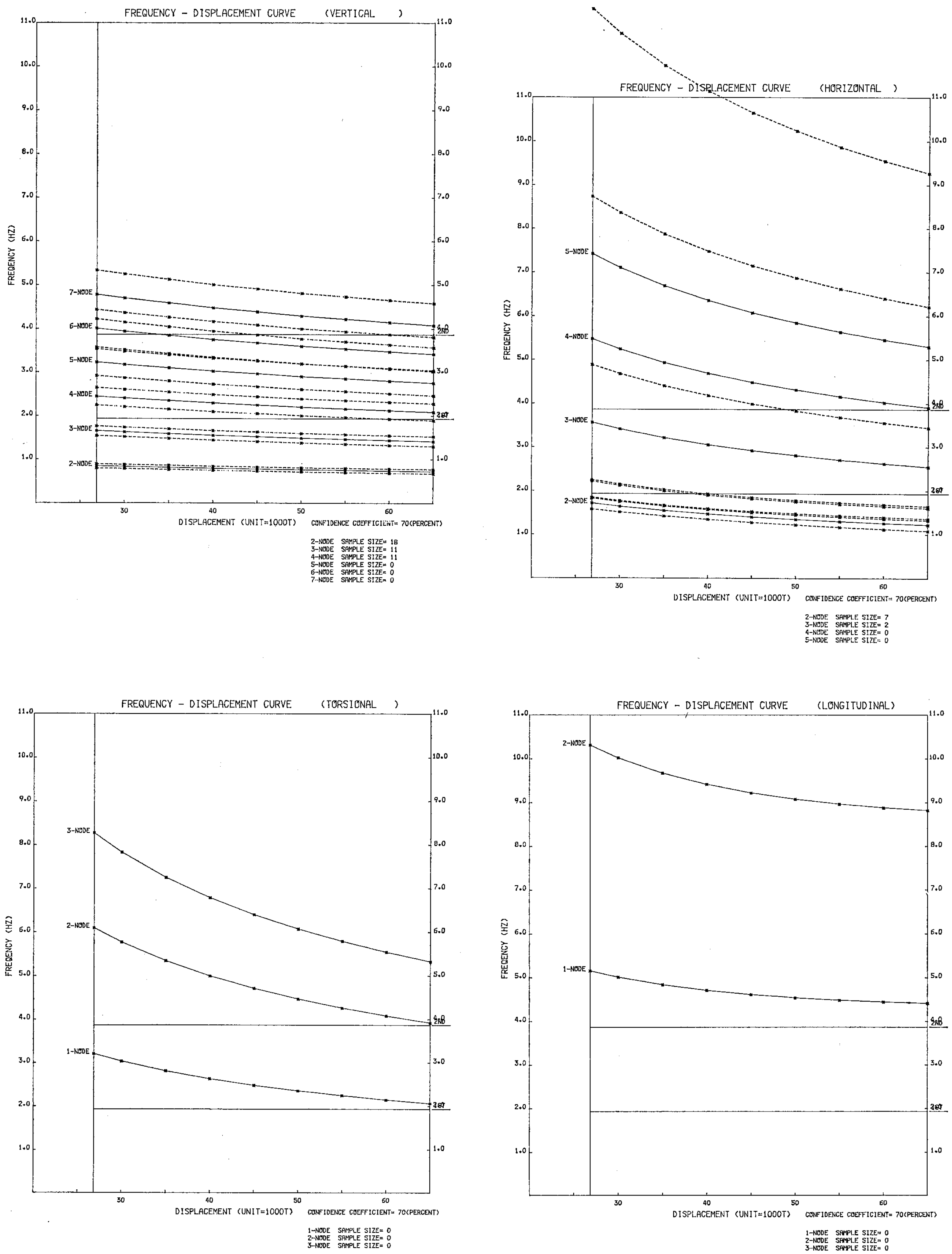

Fig. 3 Out-put example of estimation

verified constantly about the four conditions above on the basis of the measured data obtained by that time, and is to be changed if necessary.

2. To sample the data around the object ship, more sampling conditions are processed to be quantitative. As for kind of ship, ships are to be re-classified in relation to ship vibration characteristics by such a method as multivariate analysis.

3. Multiple regression analysis requires generally the degree of freedom of variance twenty on more. For the sake of the above, collection of more data and system maintenance are very important.

5. Conclusion

In this report, authors investigated the possibility for applying the statistical method to the prediction of ship hull vibration and to clarify the confidence of prediction on hull vibration characteristics which was left as unknown.

Although it shall be required for well applying this method to collect many more data prepared by specified format, this statistical treatment for analyzing the existing data was found to be effective for the prediction on frequencies of hull nodal vibration from author's trial execution with a few data.

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