2017

Guidance on Strength Assessment of Container ships Considering the Whipping Effect

KR

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GC-19-E

KR

APPLICATION OF "Guidance on Strength Assessment of Container ships Considering the Whipping Effect "

1. Unless expressly specified otherwise, the requirements in the Guidance apply to Container ships for which contracts for construction are signed on or after 1 July 2017.

TABLE OF CONTENTS

CHAPTER 1 GENERAL

Section 1 General

101. Application

1. Purpose of these guidances is to estimate the extreme load considering the whipping effect and to evaluate the structural integrity of the ship. It is applied to the ship which requires consideration of the whipping effect due to slamming load, in accordance with **Pt 7, Ch 4, 207.** of **Rules for the Classification of Steel Ships.** Other ships may be applied in consultation with the Society.

2. The whipping phenomenon is a dynamic response induced by an impact load such as slamming on the ship, which can be superimposed on the load response component caused by the motion of the ship to increase the overall response. Therefore, it is necessary to sufficiently study the whipping phenomenon in ships having characteristics such as high speed and bow shape that can cause large slamming load and low natural frequency of the hull girder.

3. In order to estimate the extreme load considering the whipping phenomenon, it is required to analyze hydro-elastic simulation and statistical analysis of the ship, and the program used for analysis should be approved by the Society.

4. When considering the whipping effect by methods other than those provided in these guidances, sufficient data on the applied theory, program and verification should be provided and approved by the Society.

102. Class Notations

Upon applicant's request, the Society may assign "**WHIP**" notations once review of compliance with these regulations is completed and satisfied to the Society.

Section 2 Analysis Procedure

201. General

The procedure for evaluating the strength of the hull considering the whipping effect is shown in **Fig 1.1**. This guidance sets out design wave method and design sea state method, and the applicant may choose one of the two methods.

202. Design Wave Method

1. The load response for the vertical bending moment is obtained by performing the linear load analysis, followed by determination of the heading angle and period of the design wave.

2. The amplitude of the design wave shall be calculated using the value of the vertical wave bending moment specified in **Pt 7, Ch 4, 202. 3** of the **Rules for the Classification of Steel Ships**.

3. The hydro-elastic simulation in the time domain is performed under the selected design wave condition.

4. Calculate the whipping contribution from the time series data of the design wave response that includes the high-frequency whipping effects.

5. The ultimate strength of hull girder is evaluated by taking into consideration the contribution of whipping to the vertical wave bending moment.

203. Design Sea State Method

1. Perform a linear load analysis to calculate the load response for all short-term sea states. The relevant load response should be vertical wave bending moment unless otherwise specified.

2. Select dominant short-term sea state with the greatest contribution to long-term load.

3. Perform the hydro-elastic simulation in the time domain in the selected short-term sea state.

4. Calculate the whipping contribution from the time series data of the load response involving the high-frequency whipping effect.

5. The ultimate strength of hull girder is evaluated by taking into consideration the contribution of whipping to the vertical wave bending moment. ⚓

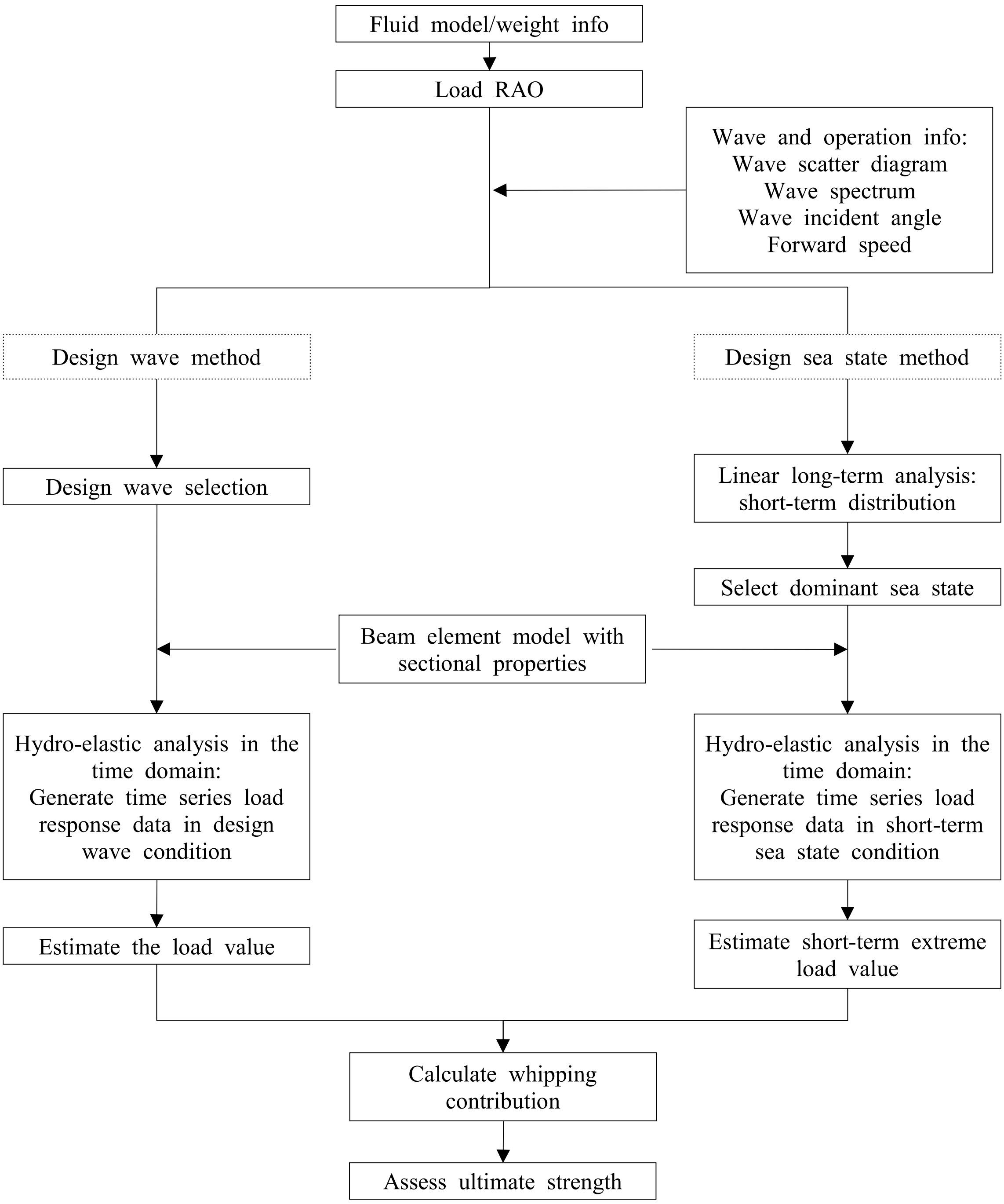

Fig 1.1 Whipping assessment procedure

CHAPTER 2 Selection of design wave and dominant sea state

Section 1 General

101. General

1. This chapter deals with the procedure for selecting the design wave and the dominant sea state which is the condition of the hydro-elastic simulation to evaluate the whipping effect on the vertical wave bending moment.
2. The terms not specifically described in this chapter are to comply with the requirements in **Pt 3**, **Annex 3-2**, **II. Direct Global Structural Analysis** of **Guidance relating to Rules for the Classification of Steel Ships.**

102. Loading condition

1. For container ships, the loading condition shall be selected where the hogging longitudinal bending moment is close to design bending moment in the full load condition.
2. For other ships, the loading conditions shall be selected whose longitudinal bending moments in the still water give the maximum sagging and maximum hogging bending moment considering the ballast and full load condition with high operation ratio.

103. Linear load analysis

1. Fluid model and weight models for hydrodynamic analysis shall follow **Pt 3**, **Annex 3-2 of Guidance relating to Rules for the Classification of Steel Ships.**
2. It is recommended to use 5 knots for forward speed.
3. Ship motion and wave load analysis are performed on the longitudinal bending moment amidships to obtain the load transfer function.
4. The program used for sea-keeping analysis should be approved by the Society.

Section 2 Design wave selection

201. Long-term analysis value of vertical wave bending moment

1. For container ships, use the linear wave bending moment as the long-term analysis value by excluding the non-linear correction factor f_{NL-Hog}, from the vertical wave bending moment for hogging M_{W-Hog}, in accordance with **Pt 7**, **Ch 4**, **202. 3** of **the Rules for the Classification of Steel Ships**.
2. Ships other than container ships are to be decided in consultation with the Society.

202. Design wave selection

1. The heading angle of the design wave is based on 180°, and the period is selected when the load transfer function with respect to the vertical bending moment is maximum at amidships.
2. The amplitude of the design wave is the value obtained by dividing the long-term analysis value of the vertical wave bending moment by the load transfer function(i.e. RAO).

Section 3 Dominant sea state selection

301. Short-term statistics

1. In each sea state of the wave scatter diagram, wave height is assumed to be stationary, narrow-band, and irregular sea state is represented by the wave spectrum. The wave spectrum follows the Modified Pierson-Moskowitz wave spectrum defined in **301. 2**, below.

2. Find the response spectrum of the vertical bending moment at the hull transverse section to be considered by multiplying the load transfer function($H(\omega|\theta)$) obtained in **103.** and the wave spectrum($S_\eta(\omega|H_{si}, T_{zj})$) in the sea state(i, j) that corresponds to the significant wave height H_{si} and wave period T_{zj} of the wave scatter diagram.

$$S(\omega|H_{si}, T_{zj},\theta) = |H(\omega|\theta)|^2 S_\eta(\omega|H_{si}, T_{zj})$$

θ : Heading angle

$H(\omega|\theta)$: Load transfer function

$S_\eta(\omega|H_{si}, T_{zj})$: Modified Pierson-Moskowitz wave spectrum at short-term sea state

$$S_\eta(\omega|H_{si}, T_{zj}) = \frac{H_{si}^2}{4\pi}\left(\frac{2\pi}{T_{zj}}\right)^4 \omega^{-5}\exp\left[-\frac{1}{\pi}\left(\frac{2\pi}{T_{zj}}\right)^4 \omega^{-4}\right]$$

ω : Angular wave frequency (rad/s)

H_{si} : Significant wave height (m)

T_{zj} : Average Zero up-crossing wave period (s)

3. The area of the short-term response spectrum is given by the following formula.

$$m_0 = \int_\omega \sum_{\theta_0 - 90^\circ}^{\theta_0 + 90^\circ} f_s(\theta)\, S(\omega|H_s, T_z, \theta)$$

using a spreading function usually defined as $f_s(\theta) = k\cos^2(\theta)$

where k is selected such that:

$$\sum_{\theta_0 - 90^\circ}^{\theta_0 + 90^\circ} f_s(\theta) = 1$$

where,

θ_0 : Main wave heading

θ : Relative spreading around the main wave heading

4. Assuming that the probability density function of the short-term load follows the Rayleigh distribution, the probability of exceedance that the amplitude X of the load exceeds a certain value X_c is as follows:

$$G_{ij}(X > X_c) = \exp\left(-\frac{X_c^2}{2m_{0ij}}\right)$$

where, m_{0ij} is the area of the response spectrum in the short-term sea state (i, j) that follows article **3** above.

302. Long-term statistics

1. In the long-term statistical analysis, the load response probability($[G(X > X_c)]_L$) exceeding a certain limit value X_c is given by the following equation.

$$[G(X > X_c)]_L = \sum_{ij}\sum_{k}\sum_{l} p_{ij}\, p_k\, p_l \{G_{ij}(X > X_c)\}$$

p_{ij} : Probability of occurrence at of sea state (i, j) corresponding to H_{si} and T_{zj} of the wave scatter diagram

p_k, p_l : Probability of occurrence of each incident angle and loading condition

$G_{ij}(X > X_c)$: Probability of exceedance of response as described in article **301. 4.**

2. The wave data used for the long-term analysis shall be applied with **Table 3** of **Pt 3 Annex 3-2 of Guidance relating to Rules for the Classification of Steel Ships**.

303. Selection of dominant sea state

1. Find the extreme value, X_c, of 10-8 long-term probability level according to **302.** At this time, the incidence angles are set at equal intervals of 30 degrees or less, and the probability of occurrence of each incidence angle is the same. For a container ship, the probability of the loading condition, p_l, defined in 102. is 1.

2. Calculate the extreme value of the load response at each short-term sea state in accordance with **301. 4** and then calculate the contribution for each short-term sea state as follows. At this time, the contribution sum of the short term sea states under consideration should be 1.

$$contribution\ ratio = \frac{\sum_{k}\sum_{l} p_{ij}\, p_k\, p_l \{G_{ij}(X > X_c)\}}{[G(X > X_c)]_L}$$

3. The short-term sea state with the largest contribution is selected as the dominant sea state by comparing the calculated contribution of each short-term sea state as shown in **Fig 2.1**. ⚓

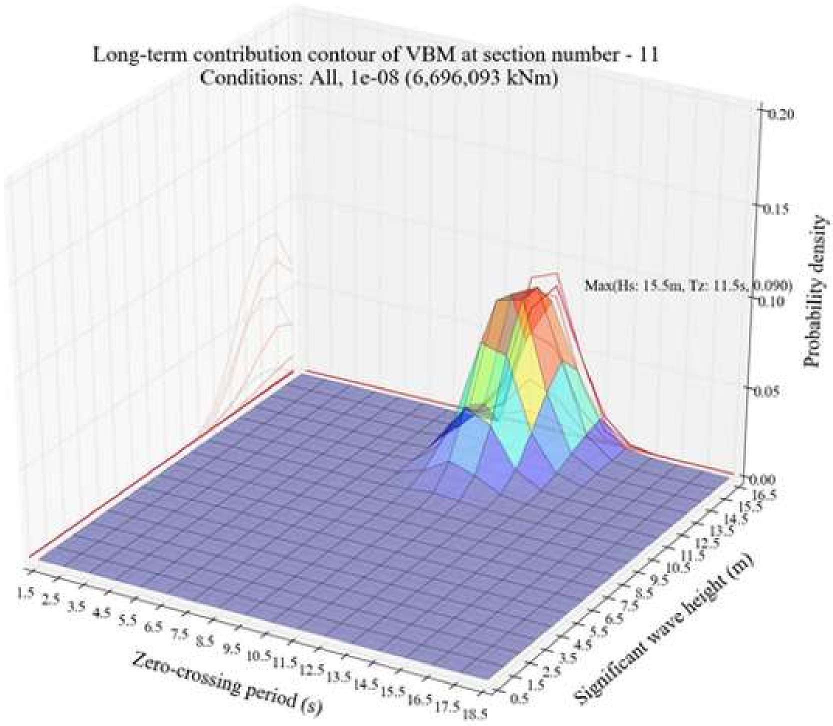

Fig 2.1 Long-term condtibution contribution contour of VBM

CHAPTER 3 Hydro-elastic simulation

Section 1 General

101. General

1. The problem of hydro-elasticity of hull is solved by performing fluid-structure interaction analysis.

2. The fluid domain assumes a three-dimensional potential flow and finds its solution by the boundary element method. Nonlinearity can be considered by using a weakly nonlinear approach that considers Froude-Krylov and hydrostatic forces (i.e. restoring forces) for the actual wetted area.

3. When obtaining the hull response for whipping, it is sufficient to make the hydro-elastic simulation by idealizing the beam element which shows the two-dimensional characteristics of the cross section of hull. However, if the cross-sectional characteristics are susceptible to torsion, it should be idealized to allow for such consideration.

4. The hydro-elastic simulation can be performed by direct integration method or mode superposition method.

Section 2 Hydro-elastic simulation in time domain

201. Simulation conditions

1. Wave incident angle

The contribution of whipping can be evaluated by performing an analysis based on an angle of 180° with respect to the wave. When directly calculating the long term analytical value considering the whipping, the calculation is performed at equidistant intervals of 30° or less considering all the encounter angles and long-term load analysis is performed. At this time, it is assumed that the probability of occurrence of each heading angle is the same. In order to reduce excessive nonlinear computation time, long-crested wave analysis may be performed without considering the short-crested wave effect.

2. Simulation time interval

The simulation time interval requires a sufficiently short time so that the impact pressure due to sla mming, etc. can be appropriately reflected. The time interval is set to 0.025 second or less.

3. Simulation time duration

When applying the design wave method, the simulation time should include at least 35 wave periods. When the design sea state method is applied, the simulation requires long enough time to ensure the stability of the statistical analysis. It is recommended that the simulation time for short-term sea state is 3 hours or more.

4. Regular waves constituting an irregular wave shall be at least four times longer than the length of the ship in case of long wavelength and in case of short wavelength, at least that frequency shall include the first vertical bending mode of the hull girder. There should be more than 150 regular waves between the minimum frequency and the maximum frequency.

5. Viscous roll damping

The viscous roll damping coefficient is recommended as a result of model testing or computational fluid dynamics, and a value of 5% can be used if there is no information.

202. Fluid model

1. The panels constituting the hull are to be of sufficient number of panels. In case of Rankine Source, more than 4,000 panels are recommended for semi-model as shown in **Fig. 3.1**, and the panel constituting the free surface of the fluid is appropriately created so that the radius of the free surface is more than three times the length of the ship.

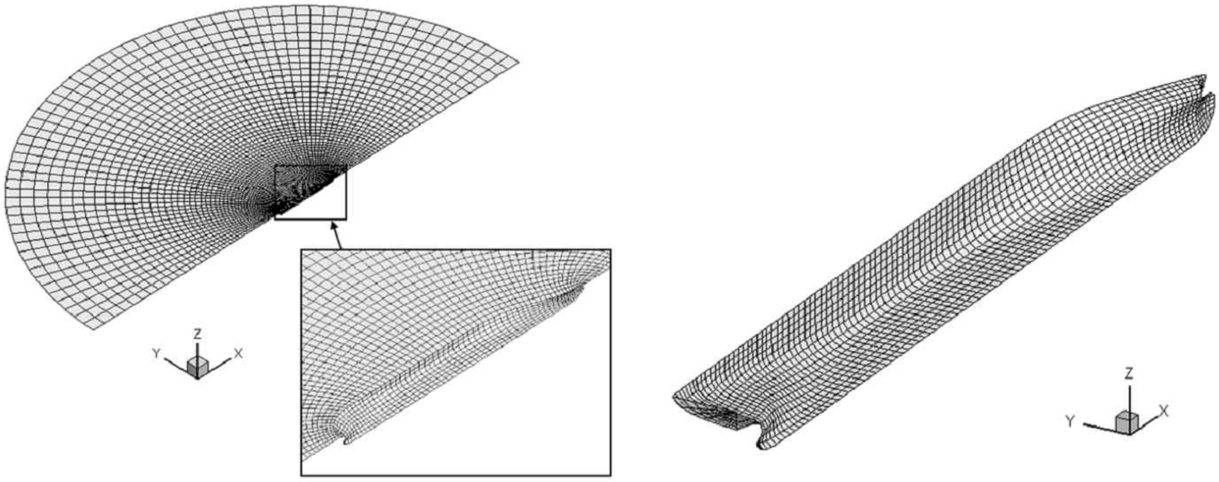

Fig 3.1 Rankine panel model for time domain analysis

2. The panel model for nonlinear analysis models up to the height of the strength deck of ship.

203. Structure model

1. The three dimensional structural model of the ship should be able to express the entire ship, and the size of the elements constituting the model should be less than the minimum girder or floor spacing. For 1-D elements of secondary support members, beam elements with bending stiffness are to be used.

2. Container loads should be applied considering the center of gravity of the stack as shown in **Fig 3.2** and it is recommended to use elements that do not affect the stiffness of the structural model, e.g. Nastran RBE3 element. In case of 20ft container, it is possible to be applied by substituting with weight of 40ft container.

3. Other loads should be applied properly considering the center of gravity.

4. In the hydro-elastic analysis, the 3D structural model can be idealized as a one-dimensional beam theory model in order to save computation time when the structural response is calculated by direct integration method. In this case, a beam theory model which can consider torsional deformation should be used.

5. The beam theory model should allow at least one beam element to be constructed for each bay of the container ship, and the beam element should take into consideration the central transverse section characteristics of each bay.

6. In the case of container ships, it is difficult to idealize the beam element to reflect the torsional stiffness of the bulkhead. In this case, the torsional stiffness of the bulkhead can be considered by comparing the mode analysis results of the three-dimensional structure model and the mode analysis results of the beam element model as shown in **Fig 3.2** and then modifying the stiffness of the beam element model appropriately.

7. The mode response frequency of the substituted one-dimensional beam theory model should be less than 5% for the first torsion and vertical bending modes compared to the results of the three-dimensional structure model.

8. If there is no other data for structural damping, a 2% value of the critical damping can be used.

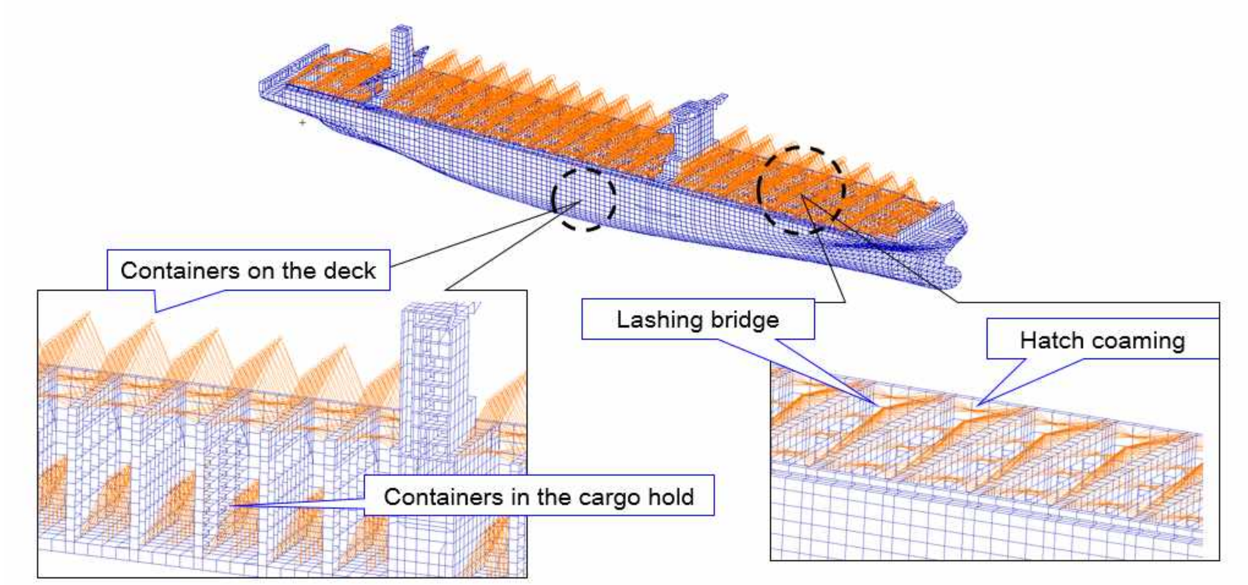

Fig 3.2 Three-dimensional structural model of container ship

204. Calculation of slamming load

1. The slamming load can be calculated using the Generalized Wagner Model (GWM) or the two-dimensional wedge method. If other methods are used, sufficient data should be submitted to the Society for approval.

2. The fore and aft sections where slamming loads may occur should be modeled with a sufficient number of sections to reflect the transition in slamming load over time. ⚓

CHAPTER 4 Evaluation of hull girder strength considering the whipping effect

Section 1 General

101. General

1. This chapter deals with the evaluation of the ultimate strength of the hull considering the whipping effect on the vertical wave bending moment obtained by the design wave method and the design sea state method.

2. In cases where methods other than those given in this chapter are to be applied, sufficient data on theory and program verification shall be submitted to the Society for approval.

3. The design wave method has the advantages of short computation time and simple procedure but the results could be rather conservative as the slamming load could be overestimated since the actual irregular sea state is calculated as a substitute of a single regular wave.

4. The design sea state method simulates the actual sea state and the irregular wave so that the slamming load can be approximated, therefore, the reliability of the result is high. However, compared with the design wave method, relatively longer analysis time is required, and it is difficult to ensure the reproducibility of the time series load response data. Therefore, statistical analysis based on multiple analysis data is required.

Section 2 Estimation of whipping contribution by design wave method

201. Application

The design wave method is used to calculate the contribution of whipping based on regular time series load response data.

202. Peak value extraction and extreme load calculation during load cycle

1. In order to remove the response due to the initial transient response in the time series analysis, the initial five wave periods are ignored. Then, the peak values of the vertical bending moment including the hull response due to whipping and the peak values of the vertical bending moment not including the said hull response, i.e. assumed as a rigid body, are extracted for at least thirty wave periods.

2. Check whether the extracted peak values show a certain level and check whether high frequency response by whipping is observed under hogging and sagging condition.

3. The whipping contribution is calculated as the average value by calculating the ratio of the peak value of the response considering whipping and the peak value of the response when the ship is assumed as rigid body in each cycle.

Section 3 Estimation of whipping contribution by design sea state method

301. Application

The design sea state method is used to calculate the whipping contribution based on time series load response data in the short-term sea state.

302. Extraction of peak value during load cycle

1. Obtains time-series response data of more than 3 hours including whipping response in short-term sea state.

2. Time series load response data that does not include the whipping response is obtained under the same irregular wave condition expressing the short-term sea state. In this case, the time series load response data that does not include the whipping response can be replaced with the load response data with the high frequency hull girder vibration components removed, which is acquired from the time series load response data including the whipping response through the low-pass filter. The cut-off frequency of the low-pass filter is about 90% of the frequency of hull vibration mode in the mode analysis result of the wetted condition. It is to be confirmed that the dynamic response components, as shown in **Fig 4.1**, are properly removed, after comparing the determined cutoff frequency with the Fast Fourier Transform(FFT) results of the time series data that includes the whipping response.

3. The zero up-crossing period is considered as the loading period, as shown in **Fig 4.2,** using the time series data that does not include the whipping response and the maximum and minimum values in each period are set as the peak value.

4. The peak values of the time series load response data including the whipping response are obtained in the same periods.

303. Estimation of parameters of the probability distribution

1. Based on the peak values obtained in **302.**, cumulative relative frequencies can be calculated and the parameters of the Weibull distribution can be estimated using the least squares method or the maximum likelihood estimation based on the linearized data by logarithmic scale.

2. Apply the shape parameter and the scale parameter of the Weibull distribution obtained from the above **1.** to the following equation to obtain the exceedance probability of the load response in given irregular wave as shown in **Fig 4.3**.

$$G(X > X_c) = \exp\left(-\frac{X_c}{\eta}\right)^{\xi}$$

ξ : Shape parameter

η : Scale parameter

X_c : Vertical bending moment

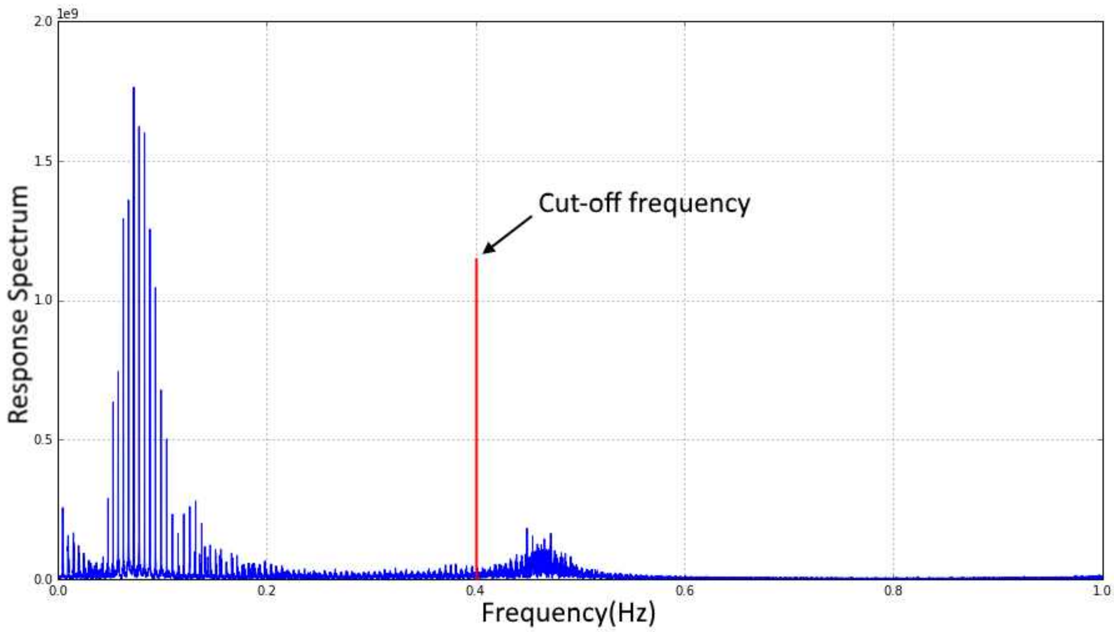

Fig 4.1 Example of applying cutoff frequency in FFT result of time series data including whipping response

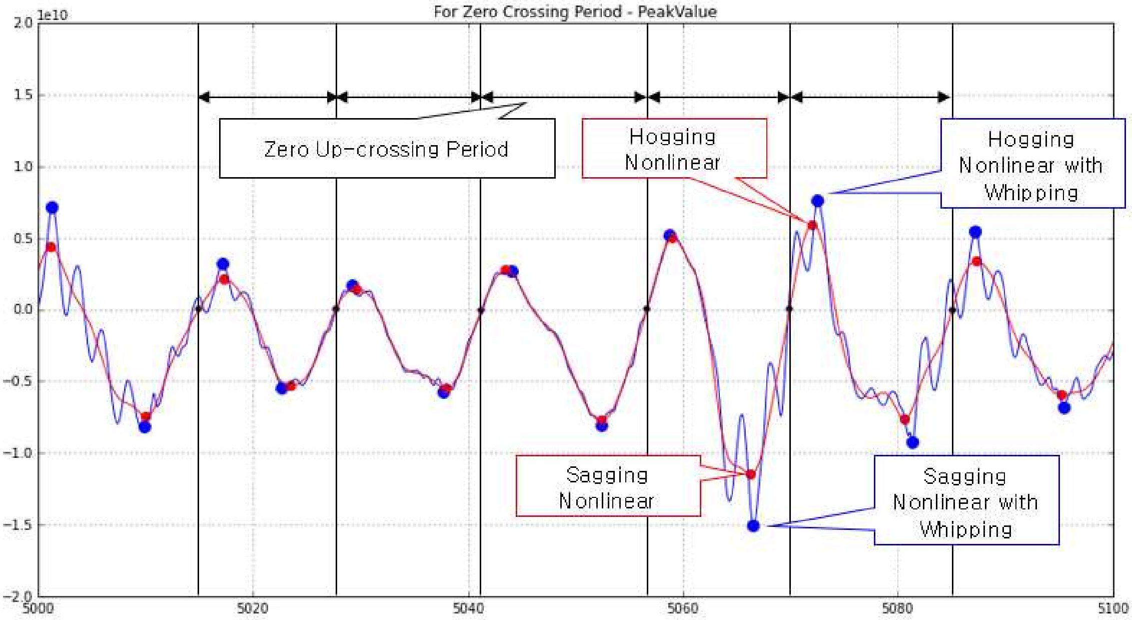

Fig 4.2 Extraction of peak values during load cycle

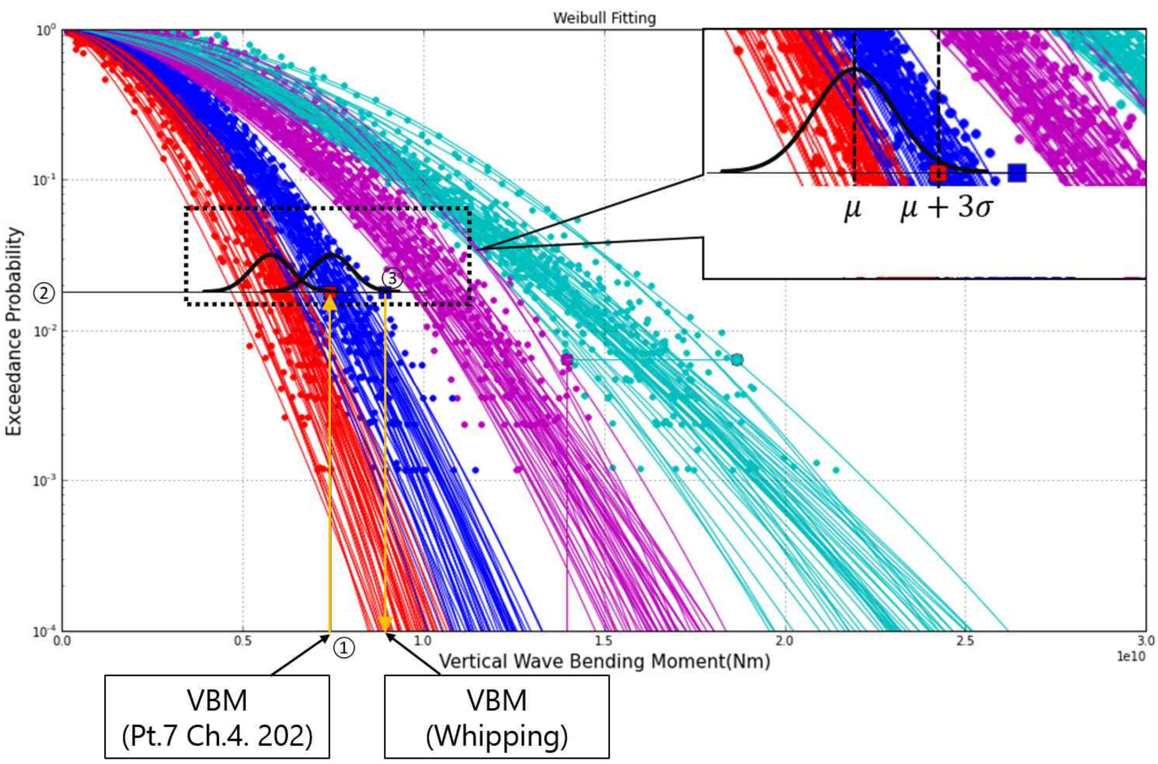

Fig 4.3 Weibull fitting of cumulative probability distribution

3. When calculating the cumulative relative frequency using the histogram, it is recommended that the interval of the histogram be determined by the optimization method. If other methods are used, sufficient data on the theory and method should be submitted to the Society for approval.

4. When estimating the parameter of Weibull distribution function, the tail weighting method can be applied to improve the accuracy of the fitting. For this, the cumulative relative frequency of at least 20% to 25% can be ignored.

304. Estimation of probability level and calculation of extreme load

1. Because the irregular waves used in the design sea state method are composed by the sum of overlapping regular waves based on the wave spectrum defined by significant wave height and wave period, many irregular waves can be generated depending on the various phase of the regular wave constituting the irregular wave.

2. It is difficult to confirm the reproducibility of the load response when considering the nonlinearity of the ship motion in waves in a number of irregular wave conditions representing the same sea state. To account for this, a representative value in the short-term sea state can be estimated through statistical analysis, assuming that the load response at the same exceedance probability follows normal distribution as shown in **Fig 4.3**.

3. The exceedance probability level for estimating the extreme load is the level when the representative value of the load response without whipping reaches the value of the vertical bending moment in accordance with **Pt 7, Ch 4, 202. 3** of the **Rules for the Classification of Steel Ships.** The representative value for each exceedance probability is the value of three times the standard deviation added to the mean value of normal distribution.

4. In order to obtain the reliability of the representative value of the normal distribution, a sufficient population is required. For this, 30 ~ 50 analyses may be required to achieve convergence in various irregular wave conditions expressing the same sea state.

5. In the exceedance probability level obtained in the above **3.**, a representative value of the load response considering whipping is calculated, and this is regarded as an extreme load considering whipping. The contribution by whipping is calculated as the ratio of the representative values at this time.

Section 4 Estimation of whipping contribution of vertical bending moment and ultimate hull girder strength

401. Calculation of whipping contribution of vertical bending moment

The whipping contributions defined in **Sec 2** and **3** can be rewritten as:

$$\gamma_{whip} = \frac{M_{whip}}{M_{rigid}}$$

γ_{whip} : Whipping contribution to vertical wave bending moment

M_{whip} : Vertical wave bending moment with whipping effect

M_{rigid} : Vertical wave bending moment without whipping effect

402. Hull girder ultimate strength assessment considering the whipping effect

In case of container ship, the hull girder ultimate strength of hogging condition considering whipping for amidship should satisfy the following criteria. Ships other than container ships are to be decided in consultation with the Society.

$$\gamma_S M_S + \gamma_W \gamma_{whip} M_W \leq \frac{M_U}{\gamma_M \gamma_{DB}}$$

M_S : Permissible still water vertical bending moment at hogging condition(kNm).

M_W : Vertical wave bending moment in accordance with **Pt 7**, **Ch 4**, **202. 3** of the **Rules for the Classification of Steel Ships**(kNm).

M_U : Vertical hull girder ultimate bending capacity in accordance with **Pt 7**, **Ch 4**, **206. 3** of the **Rules for the Classification of Steel Ships**(kNm).

γ_S : Partial safety factor for the still water bending moment, to be taken as 1.0.

γ_W : Partial safety factor for the vertical wave bending moment, to be taken as 1.2.

γ_{whip} : Whipping contribution to vertical wave bending moment, defined in **401**.

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