



GUIDANCE NOTES ON

SPRINGING ASSESSMENT FOR CONTAINER CARRIERS AND ORE CARRIERS

JUNE 2017

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Foreword

The 2017 edition of these Guidance Notes expands the scope from just container carriers to include ore carriers; which has necessitated the title change to the *ABS Guidance Notes on Springing Assessment for Container Carriers and Ore Carriers*.

These Guidance Notes provide detailed procedures for the assessment of springing loads and the subsequent structural fatigue damage for container and ore carriers. The technical background is based on direct analysis of hydrodynamic load and structure dynamic response.

Additionally, these Guidance Notes supplement the Rules and Guides that ABS has issued for the Classification for container carriers. The *ABS Guide for Application of Higher-Strength Hull Structural Thick Steel Plates in Container Carriers* requires the evaluation of the springing effect on fatigue damage of hull structures. These Guidance Notes address how to carry out such evaluations.

The 2014 edition included an updated wave scatter diagram table and editorial changes.

The 2017 edition includes new and updated standard speed profiles, a new time-domain approach for fatigue damage, updated S-N curves to include second segment, and editorial changes.

These Guidance Notes become effective on the first day of the month of publication.

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SECTION 1 Introduction

1 General (1 June 2017)

The design and construction of the hull, superstructure, and deckhouses of container carriers **and ore carriers** are to be based on the applicable requirements of the ABS Rules and Guides. As a supplement to the ABS Rules and Guides, these Guidance Notes provide detailed procedures for assessment of springing and the subsequent structural fatigue damage for container carriers **and ore carriers**. The procedure is easy to use and can be utilized to make quick estimates of the fatigue damage due to springing at the conceptual design phase and to perform a sensitivity study of its variation with main dimensions and operational profiles. The technical background is based on the direct analysis of hydrodynamic load and structure dynamic response.

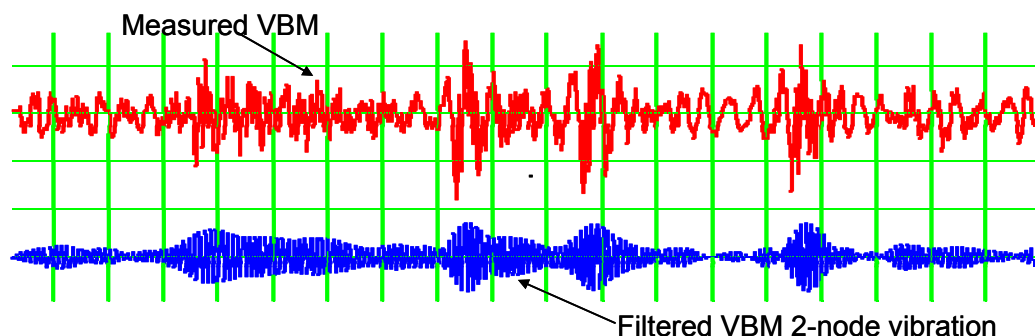
2 Springing Phenomenon (1 June 2017)

Springing is wave-induced hull girder vibration, and it is mainly excited by waves with an encounter frequency coinciding with the springing frequency. For a hull girder vibration, the most important springing frequency is its 2-node vertical natural vibration frequency. Springing can also be excited by waves with an encounter frequency of half of the springing frequency due to the second order contribution to the response. Springing could increase the fatigue load of the vessel, although its contribution to the extreme hull girder load may not be significant.

Springing is not a new topic. Early springing research has mainly focused on inland water ships. These ships, with large length/depth ratios, are flexible operating at low draft. Springing was not considered important for oceangoing ships due to the general observation that oceangoing vessels were relatively more rigid and their hull girder natural frequencies of vibration are farther away from the encountered wave frequencies.

However, wave-induced hull girder vibration has been observed from full-scale measurements in oceangoing ships (see Section 1, Figure 1). Also, with the rapid growth in ship size, especially container carriers, the new and next generations of post-Panamax container carriers are relatively flexible. These Guidance Notes provide procedures on the assessment of springing contribution to the structural fatigue damage and focus on the application to container carriers **and ore carriers**.

FIGURE 1
Time History of Measured Vertical Bending Moment



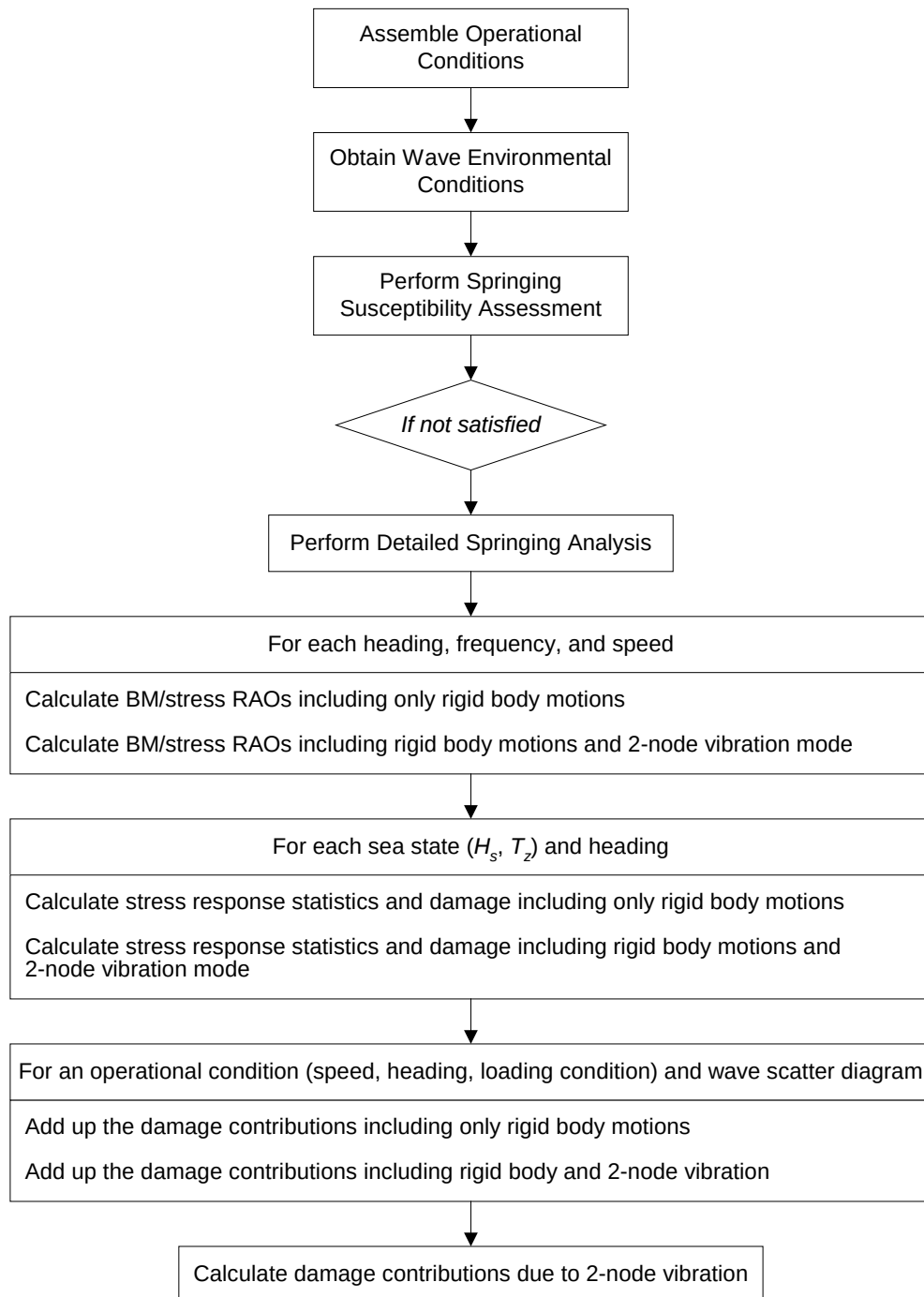
3 Springing Assessment Procedure

The recommended springing assessment procedure includes the following:

- i) Determine the critical loading conditions, forward speed, and operational headings.
- ii) Select wave environmental data, such as wave scatter diagram and wave spectrum.
- iii) Perform springing susceptibility assessment.
- iv) Perform detailed springing assessment:
 - Calculate vertical bending moment/stress RAOs including only rigid body motions.
 - Calculate vertical bending moment/stress RAOs including rigid body motions and 2-node vibration.
 - Calculate stress response statistics and fatigue damage including only rigid body motions.
 - Calculate stress response statistics and fatigue damage including rigid body motions and 2-node vibration.
 - Calculate total fatigue damage including only rigid body motions.
 - Calculate total fatigue damage including rigid body motions and 2-node vibration.
 - Calculate springing contribution to fatigue damage.

The analysis flowchart is given in Section 1, Figure 2. Detailed descriptions for the analysis procedures are given in Sections 2 through 7.

FIGURE 2
Springing Assessment Procedure





SECTION 2 Loading Conditions, Speeds, and Headings

1 General

For a given vessel, springing is influenced by, among other factors, loading conditions, encountered waves, and vessel speed. These conditions need to be considered in the springing assessment.

2 Loading Conditions (1 June 2017)

For the fatigue assessment of a vessel, a minimum of two loading conditions is recommended:

- Homogeneous loading condition at design draft
- Homogeneous loading condition at lowest draft

3 Standard Speed Profile (1 June 2017)

In high seas, the ship speed may be reduced voluntarily or involuntarily. If a specific operational profile for the vessel is not available, a standard speed profile is to be applied based on the significant wave height as shown in Section 2, Table 1 for container carriers and Section 2, Table 2 for ore carriers, where V_d is the design speed.

4 Wave Heading

It is assumed that springing mainly occurs in bow sea conditions. It is recommended that wave headings of head sea (180-degree), 165-degree, and 150-degree bow seas are to be included in the springing analysis.

TABLE 1
Standard Speed Profile for Container Carriers (1 June 2017)

Significant Wave Height, H_s	Speed
$0 < H_s \leq 6.0 \text{ m (19.7 ft)}$	100% V_d
$6.0 \text{ m (19.7 ft)} < H_s \leq 9.0 \text{ m (29.5 ft)}$	75% V_d
$9.0 \text{ m (29.5 ft)} < H_s \leq 12.0 \text{ m (39.4 ft)}$	50% V_d
$12.0 \text{ m (39.4 ft)} < H_s$	25% V_d

TABLE 2
Standard Speed Profile for Ore Carriers (1 June 2017)

Significant Wave Height, H_s	Speed
$0 < H_s \leq 4.0 \text{ m (13.1 ft)}$	100% V_d
$4.0 \text{ m (13.1 ft)} < H_s \leq 6.0 \text{ m (19.7 ft)}$	75% V_d
$6.0 \text{ m (19.7 ft)} < H_s \leq 9.0 \text{ m (29.5 ft)}$	50% V_d
$9.0 \text{ m (29.5 ft)} < H_s$	25% V_d



SECTION 3 Wave Environments

1 Wave Scatter Diagram (1 February 2014)

As seagoing vessels are typically designed for unrestricted service in the North Atlantic, the wave scatter diagram given in Section 3, Table 1. The numbers in the diagram represent the probability of sea states described as occurrences per 100,000 observations.

TABLE 1
ABS Wave Scatter Diagram for Unrestricted Service Classification (1 February 2014)

* Wave heights taken as significant values, H_s

** Wave periods taken as zero crossing values, T_z

		Wave Period (sec)**											Sum Over All Periods
		3.50	4.50	5.50	6.50	7.50	8.50	9.50	10.50	11.50	12.50	13.50	
Wave Height (m)*	0.5	8	260	1344	2149	1349	413	76	10	1			5610
	1.5		55	1223	5349	7569	4788	1698	397	69	9	1	21158
	2.5		9	406	3245	7844	7977	4305	1458	351	65	10	25670
	3.5		2	113	1332	4599	6488	4716	2092	642	149	28	20161
	4.5			30	469	2101	3779	3439	1876	696	192	43	12625
	5.5			8	156	858	1867	2030	1307	564	180	46	7016
	6.5			2	52	336	856	1077	795	390	140	40	3688
	7.5			1	18	132	383	545	452	247	98	30	1906
	8.5				6	53	172	272	250	150	65	22	990
	9.5				2	22	78	136	137	90	42	15	522
	10.5				1	9	37	70	76	53	26	10	282
	11.5					4	18	36	42	32	17	7	156
	12.5					2	9	19	24	19	11	4	88
	13.5					1	4	10	14	12	7	3	51
	>14.5					1	5	13	19	19	13	7	77
Sum over All Heights		8	326	3127	12779	24880	26874	18442	8949	3335	1014	266	100000

2 Wave Spectrum

Sea wave conditions are to be modeled by the two-parameter Bretschneider spectrum, which is determined by the significant wave height and the zero-crossing wave period of a sea state. The wave spectrum is given by:

$$S_{\zeta}(\omega) = \frac{5\omega_p^4 H_s^2}{16\omega^5} \exp\left[-1.25(\omega_p / \omega)^4\right]$$

where

$$\begin{aligned}
 S_{\zeta} &= \text{wave energy density, m}^2\text{-sec (ft}^2\text{-sec)} \\
 H_s &= \text{significant wave height, m (ft)} \\
 \omega &= \text{angular frequency of wave component, rad/sec} \\
 \omega_p &= \text{peak frequency, rad/sec} \\
 &= 2\pi/T_p \\
 T_p &= \text{peak period, sec} \\
 &= 1.408 T_z
 \end{aligned}$$

To consider short-crested waves, “cosine squared” spreading is to be utilized, which is defined as:

$$f(\beta) = k \cos^2(\beta - \beta_0)$$

where

$$\begin{aligned}
 \beta &= \text{wave heading, following sea is 0 degrees, and head sea is 180 degrees, in the range of} \\
 &\quad \beta_0 - \frac{\pi}{2} \leq \beta \leq \beta_0 + \frac{\pi}{2} \\
 \beta_0 &= \text{main wave heading of a short-crested wave} \\
 k &= \text{factor determined such that the summation of } f(\beta) \text{ is equal to 1.0, i.e.:} \\
 &= \sum_{\beta_0 - \pi/2}^{\beta_0 + \pi/2} f(\beta) = 1
 \end{aligned}$$



SECTION 4 Springing Susceptibility Assessment

1 General

Springing is wave-induced vibration. Its effect on the operation and the structure of vessels can become important when the natural frequency of the vessel is close to the encountered wave frequency. If the natural frequency of the vessel is far from that of encountered waves, springing effect may be considered as insignificant. The first step in the springing assessment is to evaluate the springing susceptibility of the vessel. This Section describes the recommended springing susceptibility criteria.

2 Hull Girder Natural Frequency (1 February 2014)

The hull girder natural frequency can be obtained through finite element method, beam method, or full-scale measurement. If they are not available, the following formula can be used to estimate hull girder natural frequency:

$$\omega_n = \mu [I_v / (\Delta_i L_{BP}^3)]^{1/2}, \text{ rad/sec}$$

where:

μ	=	321500 (176118)
I_v	=	moment of inertia, m ⁴ (ft ⁴)
Δ_i	=	virtual displacement, including added mass of water, t (Lt)
	=	$[1.2 + B/(3d_m)] \Delta$
B	=	breadth of vessel, m (ft)
d_m	=	mean draft of vessel, m (ft)
Δ	=	vessel displacement, t (Lt)
L_{BP}	=	vessel's length between perpendiculars, m (ft)

3 Wave Characteristics (1 June 2017)

Waves are normally generated by winds and they are random in nature. Waves can be characterized by zero up-crossing periods, peak periods, wave energy spectrum, and other parameters. For a sea state (or storm), the peak period is defined as the wave period at which the wave energy spectrum reaches its peak. It means that the greatest wave energy of the storm is associated with that wave period.

For a fully developed sea, the relationship of peak period and zero up-crossing period can be written as:

$$T_p = 1.408 T_z \text{ sec}$$

where T_p is peak period and T_z is zero up-crossing period in second.

The peak frequency is the inverse of the peak period. The vessel encountered wave frequency can be written as:

$$\omega_e = \omega - \omega^2 V / g \cos(\beta) \text{ rad/sec}$$

where

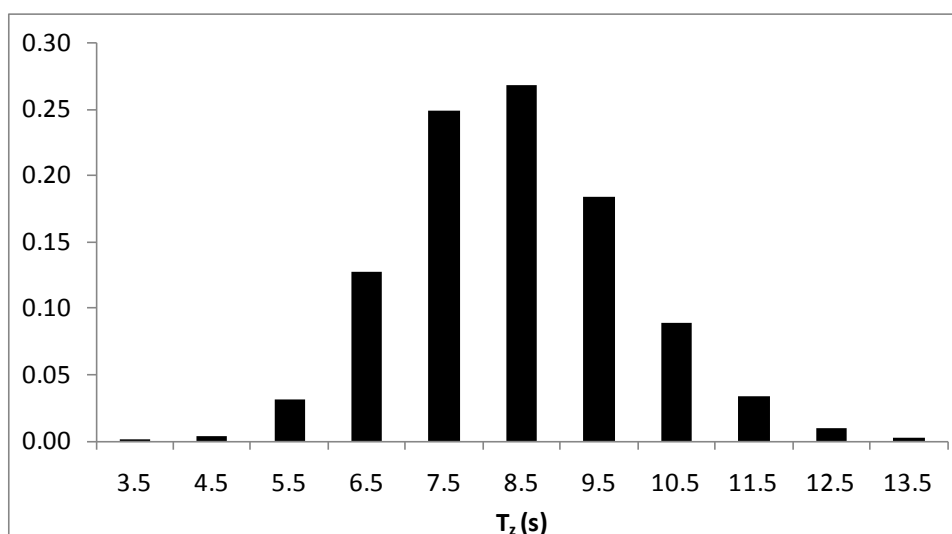
- ω = wave frequency, rad/sec
 V = vessel forward speed, m/sec (ft/sec)
 g = acceleration of gravity, m/sec² (ft/sec²)
 β = wave heading

For head sea conditions, the **encountered** frequency can be written as:

$$\omega_e = \frac{2\pi}{T_p} + \left(\frac{2\pi}{T_p} \right)^2 V/g \text{ rad/sec}$$

For North Atlantic waves, Section 4, Figure 1 depicts the probability distribution of zero crossing wave periods according to Section 3, Table 1.

FIGURE 1
Probability Distribution of T_z (1 February 2014)



4 Springing Susceptibility (1 June 2017)

Springing is a dynamic response of the hull girder to the wave load. As for any dynamic problem, the dynamic response amplification factor can range from near zero to a very high value at the resonance frequency. Section 4, Figure 2 depicts the dynamic amplification factor for a typical one-degree-of-freedom vibration problem. The x-axis in the plot is the ratio of load frequency to the natural frequency of the system.

To avoid a large dynamic response, the system should be designed so that the natural frequency of the system is far from the load frequency.

For a **vessel**, the springing susceptibility indicator can be formulated based on the natural frequency of the 2-node hull girder vibration and the **encountered** wave frequency. If the natural frequency of the 2-node vibration mode is greater than approximately three times that of the **encountered** wave frequency, springing is considered to be insignificant. According to Subsections 4/2 and 4/3, the springing susceptibility indicator, η , can be written as:

$$\eta = 3 \frac{\omega_e}{\omega_n}$$

If the indicator is larger than one, a further detailed springing analysis is recommended. Section 4, Figure 3 shows an example plot for η as a function of ship speed and wave period. Typically, the **short** waves that are usually associated with the **shorter** wave periods are **more** important for springing.

FIGURE 2
Typical Dynamic Amplification Factor

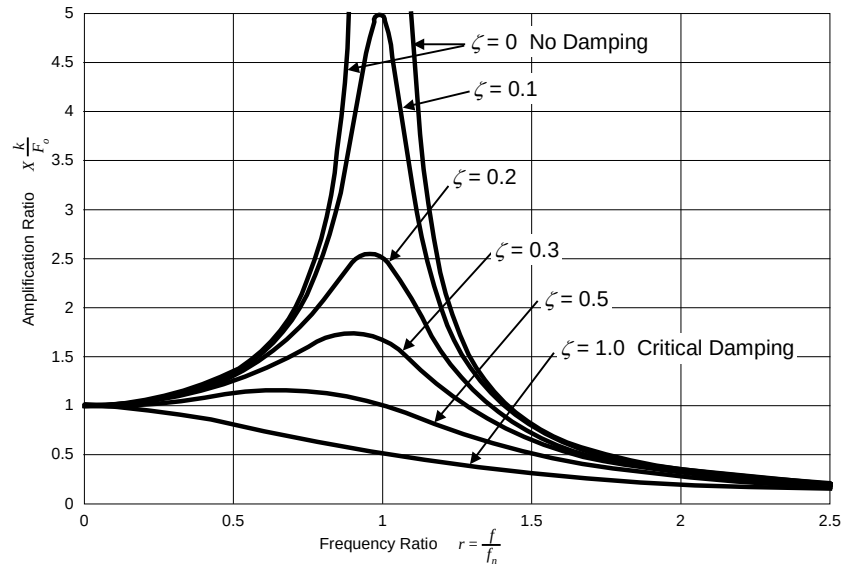
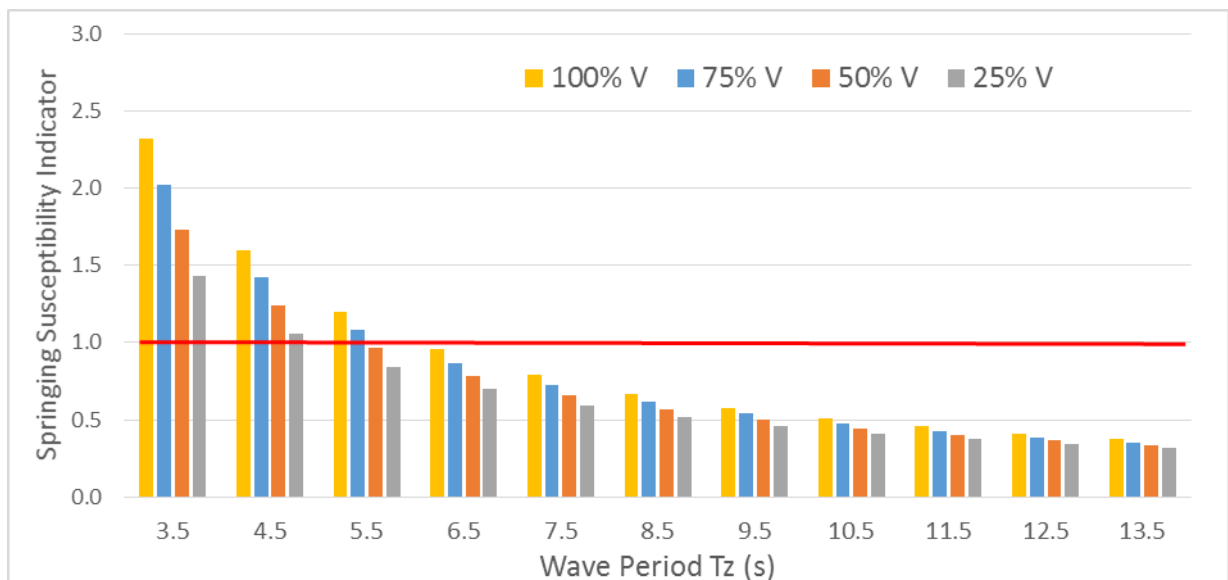


FIGURE 3
Springing Susceptibility Indicator (1 June 2017)



SECTION 5 Calculation of Response Amplitude Operator

1 General

Springing mainly increases hull girder fatigue load. The detailed springing analysis includes the calculation of response amplitude operator (RAO) of vertical bending moment, the response statistics and the fatigue damage calculation. The objective of the detailed springing analysis is to obtain the springing contribution to the fatigue damage of the vessel structure. The contribution can be defined as the ratio of the fatigue damage due to springing to that when vessel is considered as rigid body.

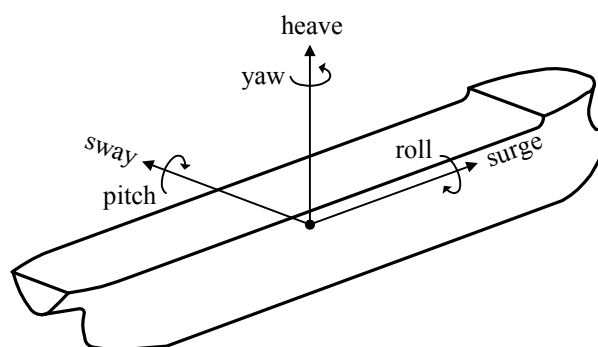
Springing can be excited when the encountered wave frequency is close to the natural frequency of the hull girder 2-node vibration mode. It can also be excited when the encountered wave frequency is about the half of the 2-node vibration frequency due to second order wave effects. Therefore, the second order seakeeping analysis approach may be used for the calculation of vertical bending moment.

This Section provides procedures for the calculation of bending moment RAOs of vessels with springing (flexible vessels) and without springing (rigid vessels).

2 Vertical Bending Moment RAOs of Rigid Body

The Response Amplitude Operators (RAOs) are the vessel's responses to unit amplitude, regular, sinusoidal waves. The vertical bending moment RAOs of a rigid body can be obtained through a conventional seakeeping analysis in which six degrees of rigid body motions are included in the analysis. The six degrees of motion are surge, sway, heave, roll, pitch, and yaw. Section 5, Figure 1 illustrates the definition of six degrees of motion.

FIGURE 1
Definition of Ship Motion



A frequency domain analysis program, in general, can be used for the calculation of the RAOs. Two-dimensional strip theory and three-dimension panel method are also applicable for the calculation of RAOs.

A sufficient range of wave headings and frequencies should be considered for the calculation of RAOs. The Response Amplitude Operators are to be calculated for wave headings from head seas (180 degrees) to following seas (0 degrees) in increments of 15 degrees. It is recommended that the range of wave frequencies include 0.2 rad/s to 2.0 rad/s in increments of 0.05 rad/s.

2.1 General Modeling Consideration

For each loading condition, the draft at F.P. and A.P., the location of center of gravity, radii of gyration, and sectional mass distribution along the ship length are to be prepared from the Trim and Stability booklet. The free surface GM correction is to be considered for partially filled tanks. For a tank with filling level above 98% or below 2% of the tank height, the free surface GM correction may be ignored.

The evaluation of the seakeeping analysis model should include the following:

2.2 Hydrostatic Balance

For each cargo loading condition, the hydrostatics of the vessel calculated based on the panel model are to be verified. At a statically balanced loading condition, the displacement, trim and draft, Longitudinal Center of Buoyancy (LCB), transverse metacentric height (GMT), and longitudinal metacentric height (GML) should be checked against the values provided in the trim and stability booklet. The differences should be within the following tolerances:

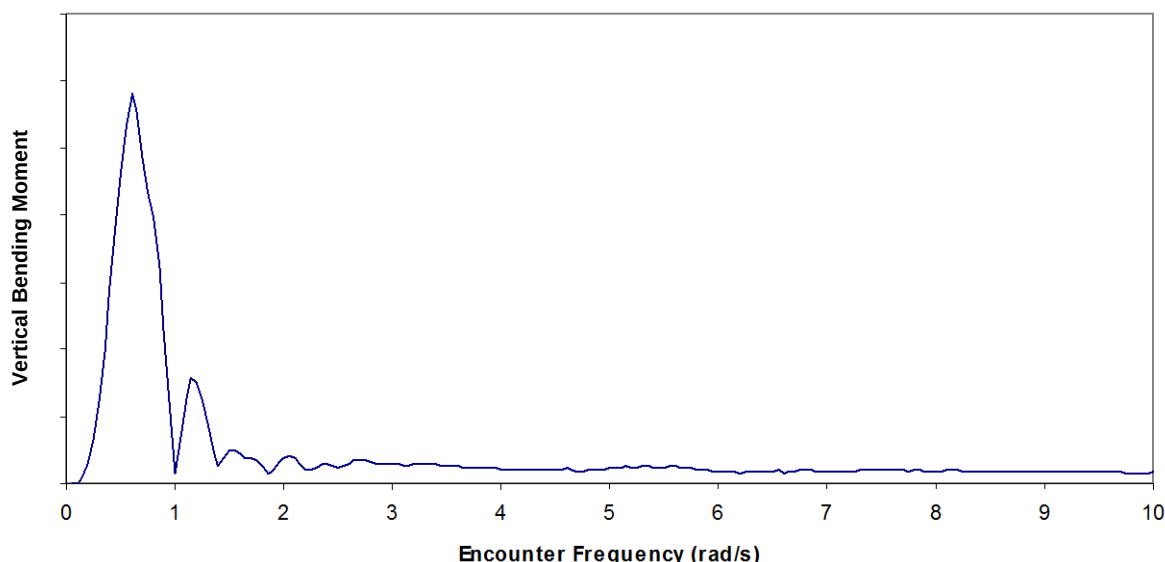
Displacement:	$\pm 1\%$
Trim:	± 0.1 degrees
Draft:	
Forward	± 1 cm (0.4 in.)
Aft	± 1 cm (0.4 in.)
LCB:	$\pm 0.1\%$ of length
GMT:	$\pm 2\%$
GML:	$\pm 2\%$
SWBM:	$\pm 5\%$

2.3 Roll Damping

The roll motion of a vessel at beam or oblique seas is greatly affected by viscous roll damping, especially with wave frequencies near the roll resonance frequency. For seakeeping analysis based on potential flow theory, a proper viscous roll damping model is required. Experimental data or empirical methods can be used for the determination of the viscous roll damping. In addition to the hull viscous damping, the roll damping due to rudders and bilge keels is to be considered. If this information is not available, 10% of critical damping may be used for overall viscous roll damping.

Section 5, Figure 2 is a typical vertical bending moment RAO plot including second order wave effect.

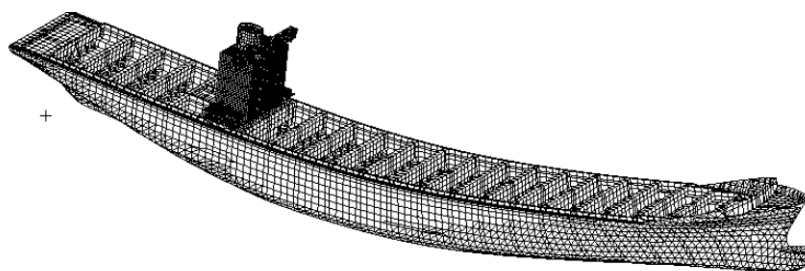
FIGURE 2
Vertical Bending Moment RAO (rigid body)



3 Vertical Bending Moment RAO of Flexible Body

The calculation of the vertical bending moment RAO of a flexible body is similar to that for a rigid body but with the extension to the flexible mode of motion (i.e., 2-node hull girder vibration mode). Section 5, Figure 3 is a plot of the 2-node vertical vibration mode of a container carrier.

FIGURE 3
2-Node Vertical Vibration Mode



For the vertical bending moment calculation of a flexible body, the following additional calculations are to be included in the analysis.

3.1 Calculation of 2-Node Vibration Mode

The 2-node vibration mode can be calculated using a finite element 3-D model or using a simplified one-dimensional non-uniform beam model. For the beam model, the vessel can be divided into a number of sections (21 or above). For each section, the following structural properties are to be provided:

- Mass per unit length
- Shear stiffness
- Bending stiffness
- Mass moment of inertia