

Study of motion sickness incidence in ship motion

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ABSTRACT

Motion sickness incidence index (MSI) is one of essential issues in ship motion research to access the comfort of passenger on board cruises and yachts. In the paper, wave energy spectrum and MSI will be

analyzed. Evaluation will not only provide an initial feedback of passenger's comfort in ship design stage but also estimate the suitable speed to steer the cruise comfortably.

Key words: *MSI, motion sickness incidence, passenger cruise, wave energy spectrum.*

1. INTRODUCTION

Nowadays, many prominent yacht builders research and apply the anti-rolling devices such as Beneteau, Azimut and Ferretti [1]. The cost of anti-rolling device installment contributes 10% of the cost of the luxury yacht like Azimut Flybridge 50 ft [2]. Recently, ship motion has been an essential topic in yacht design [3].

To comprehend the advantages of ship motion research, one of well-known luxury yachts, Azimut Flybridge 54 in figure 1, the roll motion is reduced up to 80% after installing anti-rolling device. Hence, the comfort of passengers and yacht owners plays the essential role in order to increase awareness of competition.



Figure 1. Anti-rolling device installed on Azimut Flybridge 53 reduces rolling motion up to 80% [4]

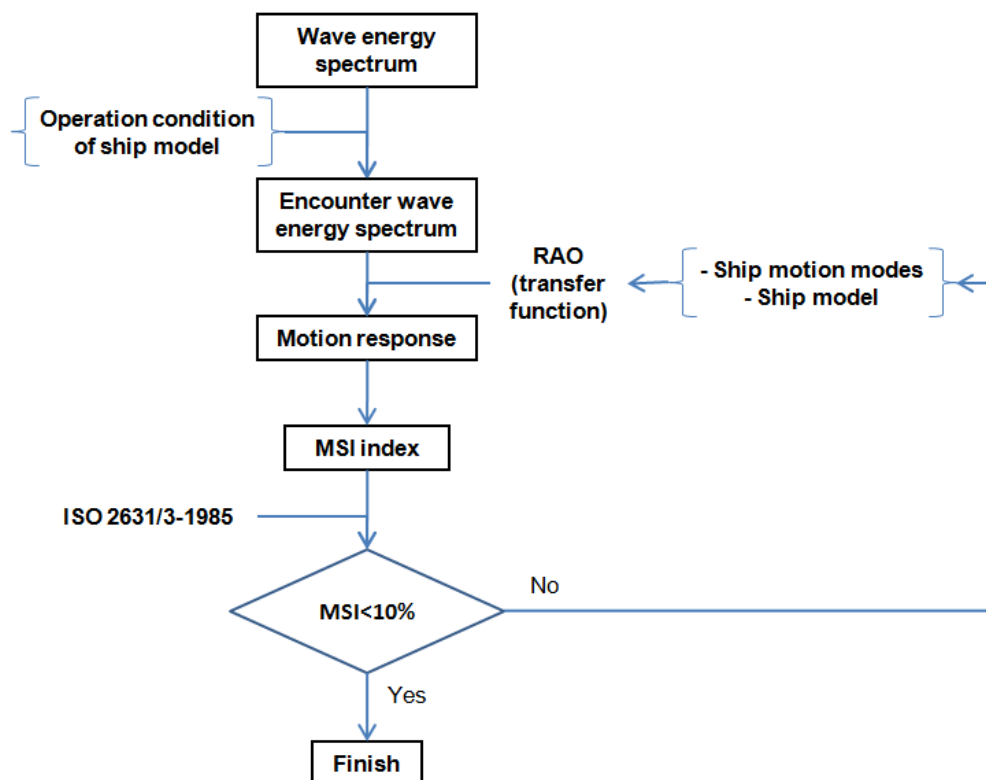


Figure 2. The proposed process of the comfort assessment

Our research focuses on a comfort of motion sickness incidence (MSI) of small passenger boats and yachts by following ISO 2631/3-1985. In addition, the well-known wave spectrum including Bretschneider spectrum and JONSWAP spectrum are applied to calculate the characteristics of the motion response spectrum. The analysis process of motion sickness incidence (MSI) calculation will be described briefly in the figure 2.

2. The process of the comfort assessment

First step, after collecting the characteristic of the wave including the observed circular frequency, the average period and the significant wave height, the wave energy spectrum is performed. Then, the characteristic of the ship operation condition including the ship course direction and velocity of ship are imported to calculate and to plot the encounter wave energy spectrum.

Next step, one computes response amplitude operators (RAO) by using the uncouple roll motion model and the characteristics of vessel, especially transverse metacentric height and roll gyradius. After that, the motion response spectrum will be estimated based on RAO.

Final step, motion sickness incidence index is computed according to ISO 2631/3-1985 to evaluate the comfort of passengers on board.

2.1. The encounter wave energy spectrum

Two models of wave energy spectrum such as Bretschneider spectrum and JONWAPS (Joint North Sea Wave Project) spectrum are used.

Bretschneider spectrum use two parameters that are the characteristic wave height \bar{H} [m] and the average period \bar{T} [s]. Bretschneider wave spectrum is suitable for open sea areas with long crest [1]. Bretschneider wave spectrum $S_{\zeta}(\omega)$ [$\text{m}^2 \cdot \text{s}$] is described as follows:

$$S_{\zeta}(\omega) = 172.75 \frac{\bar{H}^2}{\bar{T}^4} \omega^{-5} \exp\left(-\frac{691}{\bar{T}^4} \omega^{-4}\right) \quad (1)$$

The JONSWAP spectrum with the peakedness factor $\gamma = 3.3$ in the paper will be described as follows [2] [1]:

$$S_{JONSWAP}(\omega) = 0.658 \cdot 172.75 \frac{\bar{H}^2}{\bar{T}^4} \omega^{-5} \exp\left(-\frac{691}{\bar{T}^4} \omega^{-4}\right) \cdot C(\omega) \quad (2)$$

where

$$C(\omega) = \gamma^{\exp\left(-\frac{1}{2\sigma^2}\left(\frac{\omega}{\omega_0}-1\right)^2\right)}$$

ω : the circular wave frequency $\left[\frac{rad}{s}\right]$
 σ : the step function

$$\sigma = 0.07 \text{ for } \omega < \omega_0$$

$$\sigma = 0.09 \text{ for } \omega > \omega_0$$

Circular frequency at spectral peak

$$\omega_0 = \frac{4.849}{\bar{T}}$$

JONSWAP spectrum comprises Bretschneider spectrum. Figure 3 shows the difference between JONSWAP and Bretschneider spectrum, the statistic data in Aegean Sea are calculated as a case study [3].

The encounter wave energy spectrum

When yacht moves on wave, the angle between yacht direction and wave travel is named encountering angle μ (Figure 4).

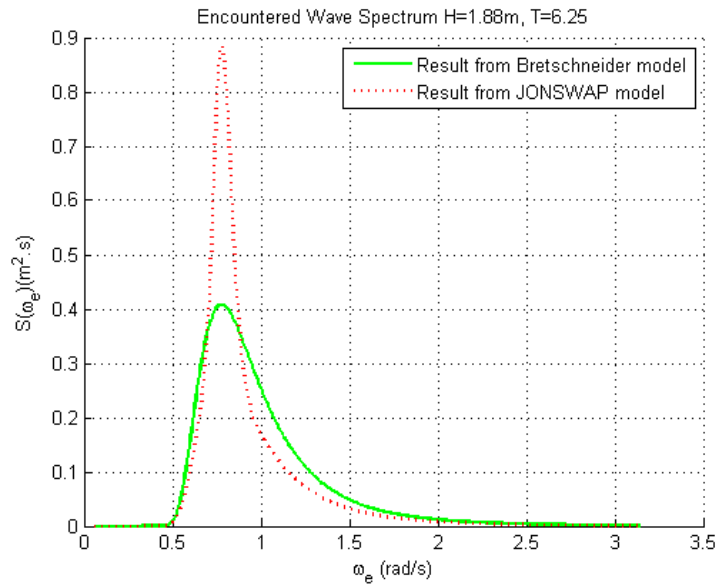


Figure 3. The encounter wave energy spectrum were plotted based on Bretschneider and JONSWAP model

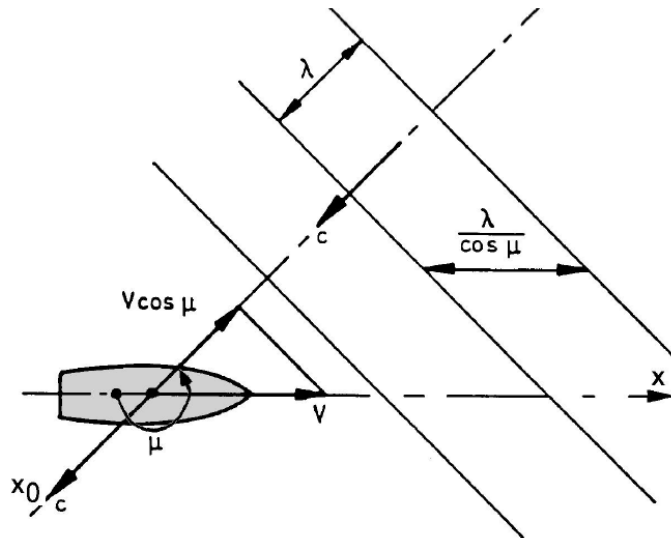


Figure 4. The encountering angle μ [1]

The encounter frequency describes as follows [4]:

$$\omega_e = \omega \left(1 - \frac{\omega V}{g} \cos \mu \right) \quad (3)$$

where:

V: ship speed, [m/s];

g: gravity acceleration, [m/s²];

ω : Wave frequency, [rad/s];

μ : The encountering angle [deg], beam wave condition at $\mu=90$ deg, a heading wave condition at $\mu=180$ deg.

Using the wave energy spectrum $S(\omega)$ and the encounter frequency to calculate the encounter wave energy spectrum $S(\omega_e)$ [4]:

$$S(\omega_e) = \frac{S(\omega)}{\left| 1 - \frac{2\omega V}{g} \cos \mu \right|} \quad (4)$$

2.2. Uncoupled roll motion model

The standard model of uncoupled roll motion in regular wave is the second order differential equation: [2]

$$\begin{aligned} (I_4 + A_{44})\ddot{\eta} + B_{44}\dot{\eta} + C_{44}\eta \\ = F_4 (\cos \omega_e t \\ + i \sin \omega_e t) \end{aligned} \quad (5)$$

where:

I_4 : Mass inertia of roll motion, $I_4 = k_{xx}^2 \nabla \rho$, [kg.m²];

k_{xx} : Gyradius of yacht about the x-axis through the center of gravity CG, [m];

∇ : Displacement volume of yacht, [m³];

ρ : Density of sea water, 1025 kg/m³;

A_{44} : Added inertia coefficient of roll motion, $A_{44} = 0.3I_4$, [5];

C_{44} : Hydrostatic restoring coefficient of roll motion, $C_{44} = GM_t \cdot \nabla \cdot \rho \cdot g$;

GM_t : Transverse metacenter height, [m].

Response amplitude operator (RAO) in the roll motion describes as the below equation:

$$RAO_{roll} = \frac{1}{\sqrt{(1 - \lambda^2)^2 + 4\beta_{44}^2 \lambda^2}} \quad (6)$$

where:

Tuning factor:

$$\lambda = \frac{\omega_e}{\omega_0}$$

Natural frequency of uncoupled roll motion ω_0 [rad/s]:

$$\omega_0 = \sqrt{\frac{C_{44}}{I_4 + A_{44}}}$$

2.3. Ship motion response and the criteria of the comfort of passengers

Ship motion is strongly effected by the encounter wave energy from wave travel and excitation forces through RAO [4]. The below equation describes the ship motion response of roll motion [2]:

$$S_{zRoll}(\omega_e) = RAO_{roll}^2 S_{\zeta}(\omega_e) \quad (7)$$

The root mean square (RMS) of the 2nd order spectral moment of roll motion response spectrum m_2 is the root mean square acceleration v_{zRMS} [m/s^{0.5}], [2]:

$$v_{zRMS} = \sqrt{m_2} = \sqrt{\int_{\min(\omega_e)}^{\max(\omega_e)} \omega_e^2 \cdot S_{zRoll}(\omega_e) \cdot d\omega_e} \quad (8)$$

The root mean square (RMS) of the 4th order spectral moment of roll motion response spectrum m_4 is the root mean square acceleration a_{zRMS} [m/s^{1.5}]: [2]

$$a_{zRMS} = \sqrt{m_4} = \sqrt{\int_{\min(\omega_e)}^{\max(\omega_e)} \omega_e^4 \cdot S_{zRoll}(\omega_e) \cdot d\omega_e} \quad (9)$$

In 1974, O’Hanlon and McCauley represented firstly the concept “Motion sickness incidence” [6]. Obeying ISO 2631/3-1985, MSI value has to be smaller than 10% in 2 hours exposure time [7]. According to Lloyd (1998)

MSI after 2 hours exposure described as below expression [5]:

$$MSI [\%] = 100 \cdot \Phi \left\{ \frac{\log_{10} \left(\frac{|\dot{s}_3|}{g} \right) - \mu_{MSI}}{0.4} \right\} < 10\% \quad (10)$$

where:

\dot{s}_3 : the heave acceleration, $\dot{s}_3 = 0.798\sqrt{m_4}$ [m/s²];

$\Phi(x)$: the standard normal cumulative distribution function with zero mean and unity standard deviation.

O’Hanlon and McCauley (1974) suggested the factor μ_{MSI} based on the encounter frequency f_e as the below expression [8]:

$$\mu_{MSI} = 0.654 + 3.697 \log_{10} f_e + 2.32(\log_{10} f_e)^2 \quad (11)$$

3. Case study

The specification of the model of vessel and ship operation conditions in case study describes as follows (Figure 6):

- Waterline length LWL = 6.9 m;
- Maximum beam B = 2.1 m;
- Draft T = 0.4 m;
- Displacement volume $\nabla = 2.545 \text{ m}^3$;
- Transverse metacenter height GMt = 1.453 m;
- Gyradius of roll motion $k_{xx} = 0.923 \text{ m}$;
- Damping factor of 0.05 is suggested by Lewis (1989) [9]
- Beam wave condition, $\mu = 90 \text{ deg}$
- Operation speed V = 10 knot



Figure 6. Small passenger ship

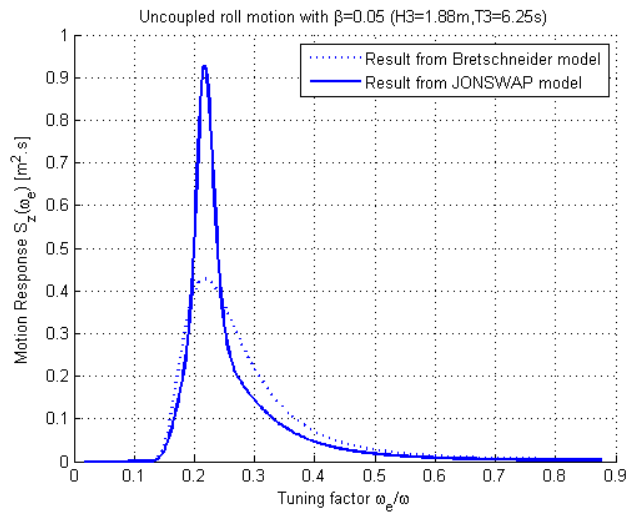


Figure 7. Ship motion response is calculated at Sea State 4 in Aegean Sea (the characteristics wave height 1.88 m and the average period 6.25 s) [3]

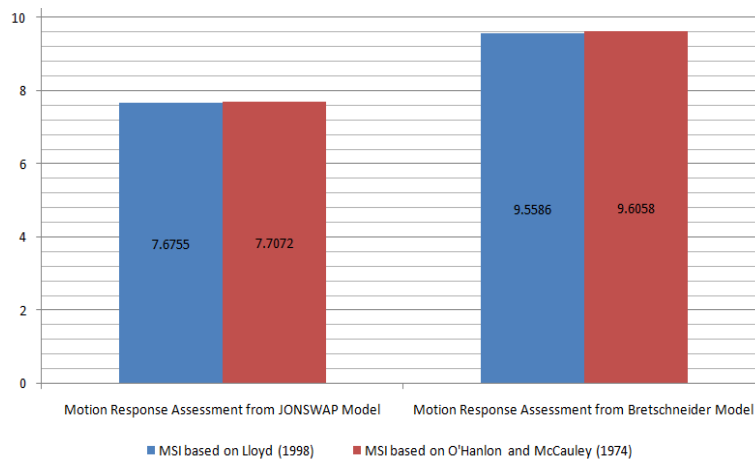


Figure 8. Result of MSI [%] in case study

Figure 7 indicates that ship motion response based on JONSWAP model is narrower and higher than Bretschneider model. Moreover, roll motion response of JONSWAP model decreases faster than roll motion response of Bretschneider model.

In 2014, the research of EU-7FP project FAROS conducted by Finland and UK suggests using the criteria of ISO 2631/3-1985 of 10% to assess the comfort of passengers in exposure time up to 2 hours [7]. In case, MSI exceeds 10%, ship owner should recognize the solution of anti-rolling device installment.

After calculating MSI of case study, results in figure 8 represents the comfort of passenger do not exceed the criteria of ISO 2631/3-1985 of 10% in two cases using Lloyd's expression (1998) or using O'Hanlon. In addition, it is said that under 10% of passengers on board does not suffer any vomit and seasickness.

6. CONCLUSIONS

In the paper, we offer the progress of assessment of the comfort based on JONSWAP and Bretschneider models. After calculating MSI, ship designer or yacht owner can decide to alter the weight distribution including ballast tank, sewage tank and fuel tank in initial stage or consider anti-rolling device installment. Besides that, captain can consider the suitable velocity to make passengers on board feel comfortable.

On the other hand, the research also supports undergraduate students to comprehend difficult subjects including wave energy spectrum, response amplitude operation, and MSI in ship motion.

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Nghiên cứu chỉ số gây say sóng MSI trong chuyển động tàu

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TÓM TẮT

Chỉ số gây say sóng MSI là một trong những vấn đề quan trọng được nghiên cứu trong chuyển động tàu để đánh giá sự thoải mái của hành khách trên tàu và trên du thuyền. Trong bài báo này, chương trình tính toán MSI sẽ được xây dựng dựa trên các phổ

năng lượng sóng đã được công nhận. Nghiên cứu không chỉ giúp nhà thiết kế tàu đánh giá ban đầu về sự thoải mái của hành khách trong giai đoạn thiết kế, mà còn giúp ước lượng tốc độ phù hợp để điều khiển tàu hạn chế say sóng cho hành khách.

Từ khóa: MSI, say sóng, tàu khách, phổ năng lượng sóng

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