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The prediction of the Motion Sickness Incidence index at the initial design stage

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Abstract

The article discusses the influence of those environmental conditions on the human being that may cause sea sickness. Different indexes describing motion sickness are presented. Besides, a mathematical inter-relation describing the effect of waves and design parameters on the motion sickness incidence index is described. The relation has been used for developing design guidelines designers may use at the initial design phase.

Motion sickness

The sea-going ship that operates in open waters rarely sails in calm weather. On the contrary, ship's behaviour at sea is often affected by waves and wind. The immediate effect of waves is ship's motions and accompanying phenomena, such as accelerations. Ship accelerations, in turn, particularly vertical ones, impact on the human body and may cause motion sickness.

The term "motion sickness", on ships known as sea sickness, is understood as a sickness due to ship motions that results in physical discomfort, with such symptoms as irregular breathing, nausea, vertigo, paleness and vomiting. In extreme cases a passenger or crew member has to be transferred to hospital. The actual reason for sea sickness is lack of conformity between different stimuli, eye signals and the labyrinth (inner ear), received by the human brain. People mainly suffer from sea sickness under deck, where the eye does not register any stimuli that the labyrinth would interpret as motion. For example, while in the cabin, visually no movement of the ship is observed while the brain sends stimuli when it detects variable burdens caused by ship motions. There is a conflict between the stimuli delivered by the sense of sight and the labyrinth responsible for body balance that causes this sickness.

Despite scientific observations and research, no exact relations have been determined between ship motions and motion sickness. McCauley and O'Hanlon estimated quantitatively the impact of ship motions on the percentage of people that would suffer from sea sickness. It turned out that vertical accelerations in particular were responsible for motion sickness, while rolling and pitching had slight influence. Additionally, it was found that at a frequency of 0.167 Hz the occurrence of motion sickness increased.

The MSI index (Motion Sickness Incidence) is commonly used for assessing possible occurrence of the illness [1]:

$$\mathrm{MSI} = 100\left[0.5 \pm \mathrm{erf}\left(\frac{\pm\log_{10}\frac{a_v}{g} \pm \mu_{\mathrm{MSI}}}{0.4}\right)\right] \tag{1}$$

where:

- MSI – motion sickness incidence index;
- erf – error function;
- a_v – mean value of vertical accelerations at a selected point;
- μ_{MSI} – parameter calculated from this equation:

$$\mu_{\mathrm{MSI}} = -0.819 + 2.32\left(\log_{10}\omega_E\right)^2 \tag{2}$$

The international standard ISO [2] defines methods for estimating the percentage of people who may have motion sickness symptoms. That standard defines the *motion sickness dose value*

(MSDV), that may be calculated by way of one of two methods (depending on the exposure period):

– if measurements are performed over a short exposure period:

$$\text{MSDV} = \bar{a}_v T_0^{1/2} \quad (3)$$

where:

$\bar{a}_v$ – mean value of vertical acceleration;

T_0 – time of exposure recording;

– if measurements are performed over the entire period of exposure:

$$\text{MSDV} = \sqrt{\int_0^T (a_v(t))^2 \,\mathrm{d}t} \quad (4)$$

where:

a_v – vertical acceleration referred to a given frequency, accounting for the weight [3];

T – exposure period.

Knowing the MSDV, it can calculate the number of people suffering from motion sickness PP:

$$\text{PP} = K_M \cdot \text{MSDV} \quad (5)$$

where:

PP – number of people that suffer from motion sickness;

K_M – a constant accounting for a population (females, males).

In the study [4] J.M. Riola and others propose to use superposition for the determination of the MSI index in irregular waves. To this end, on the basis of relation (1), a transfer function of the MSI index in regular waves $Y_{\text{MSI}}(\omega_E)$ was developed and by way of the spectrum function of wave energy $S_{\zeta\zeta}(\omega_E)$ the spectrum density function of the MSI index $S_{\text{MSI}}(\omega_E)$ was defined:

$$S_{\text{MSI}}(\omega_E) = | Y_{\text{MSI}}(\omega_E) | S_{\zeta\zeta}(\omega_E) \quad (6)$$

then the value of MSI index was calculated:

$$\text{MSI} = \int_0^\infty S_{\text{MSI}}(\omega_E)\,\mathrm{d}\omega_E \quad (7)$$

Prediction of motion sickness at the initial vessel design stage

From the ship design viewpoint, seakeeping performance depends on a number of factors, the most important of which are as follows:

1) impact of the marine environment (wind and waves);
2) vessel movement parameters (speed and relative bearing to waves);
3) vessel's design parameters.

Vessel design parameters are in fact defined at various design stages. Among the great number of vessel parameters, ship's behaviour in waves substantially depends on parameters specified at the initial stage of design, particularly at the parametric design phase. This complicates the process of design because:

– at subsequent design stages (or building of a ship) a change of parameters determined at the parametric stage (e.g. main dimensions of the ship) is difficult and practically uneconomic;
– improper choice of design parameters at the parametric design stage irrevocably deteriorates seakeeping properties of the ship.

Therefore, modeling of ship seakeeping characteristics, including motion sickness, is most beneficial at the parametric design stage.

In the study [5] a function approximating the MSI index depending on design and wave parameters is given:

$$\text{MSI}_{\max} = 97287997 \cdot \left(\frac{\exp(H_S)}{F_{\text{WL}}} \right)^3 \quad (8)$$

where:

$\text{MSI}_{\max}$ – maximum MSI index [%];

F_{WL} – waterplane surface area [m^2];

H_s – significant wave height [m].

The above relation was formulated from statistical analysis of the results of numerical calculations based on the hypothesis of planar flow of a wide range of ro-ro ferries. The above equation is characterized by a high value of the determination coefficient $R^2 = 0.93$ and low standard error RMS = 4.25% compared to reference values. Figure 1 compares values obtained from relation (8) to reference values. The comparison implies that relation (8) is sufficiently accurate and has the right trend.

The study [5] implies that relation (8) can be used for designing ro-ro ferries that would have the following parameters:

– length between perpendiculars to breadth ratio $L_{\text{pp}}/B = 5.8$–8.2;
– length between perpendiculars $L_{\text{pp}} = 124$–258 m;
– breadth $B = 19$–33 m;
– underwater hull block coefficient $C_B = 0.56$–0.64;
– midship block coefficient $C_M = 0.95$–0.98;
– vertical block coefficient $C_{B(V)} = 0.73$–0.79;
– distance between geometric centre of waterplane to after perpendicular XF = 53.2–110.6 m;
– surface area of waterplane $F_{\text{WL}} = 2136$–7237 m^2.

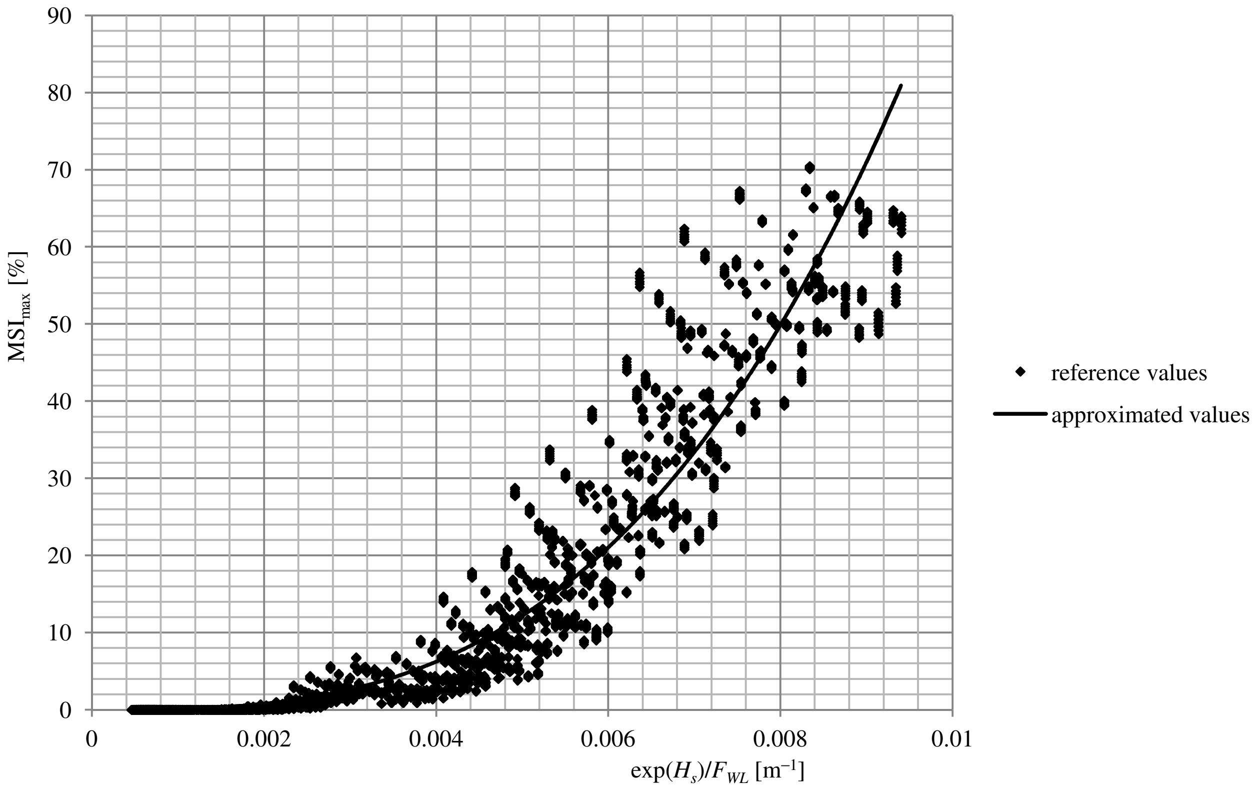

Fig. 1. Comparison of maximum approximations of the MSI index with reference values [5]

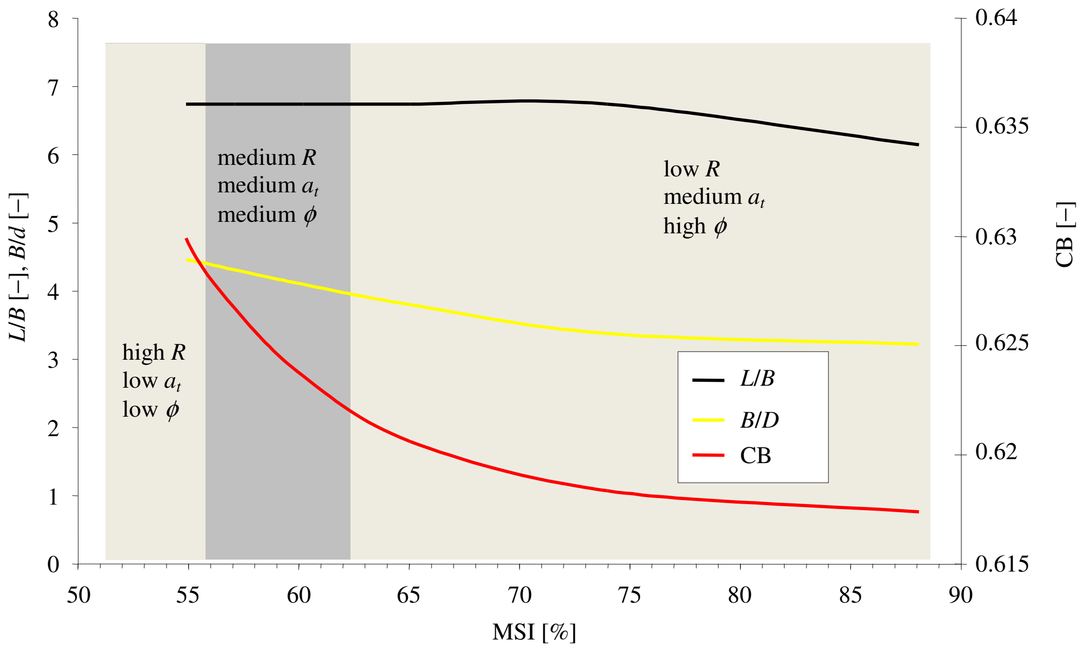

Fig. 2. Values of design parameters depending on MSI index, where: R – additional resistance from waves, a_t – transverse accelerations, ϕ – rolling, L – length between perpendiculars, B – moulded breadth, d – moulded depth, CB – waterplane block coefficient [1]

Publications on the subject do not contain approximations that would allow to predict MSI index based on main design parameters and irregular wave parameters. Some methods [1, 2, 4] permit to calculate the index based on vertical accelerations, while relation (8) considerably extends that range.

Conclusions

The discussed relation (8) can be used in analyses done at initial stages of vessel design. In the study [1] an example of such analysis is given and, based on calculations, the final guidelines were developed in an example design task as shown in figure 2.

Recommended parameters presented in figure 2 allow to easily estimate how design parameters affect various seakeeping properties of the ship and to determine the values of parameters meeting design assumptions. The designer may have a choice of three ranges of design parameters values for which the following occur/s:

– high wave resistance, but MSI index has low values, minor rolling and transverse accelerations;
– low MSI index, medium values of additional wave resistance, rolling and transverse accelerations;
– high values of MSI index, transverse accelerations and rolling, but low additional wave resistance.

This approach allows naval architects to take into account the influence of environmental conditions on the comfort of passengers and crew.

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