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OPERABILITY GUIDELINES FOR PRODUCT TANKER IN HEAVY WEATHER IN THE ADRIATIC SEA

ABSTRACT

This paper presents operability guidelines for seafarers on a product tanker which navigates in the Adriatic Sea during heavy weather. Tanker route starts from the Otranto strait in the south to the island Krk in the north of Adriatic Sea. Heavy weather is caused by south wind called *jugo* (blowing from E-SE to SS-E, *sirocco* family). Operability guidelines are given based on an operability criteria platform for presenting ship seakeeping characteristics. Operability criteria considered in this paper are propeller emergence, deck wetness and bow acceleration of a product tanker. Limiting values of mentioned criteria determine sustainable speed. Heavy weather is described by extreme sea state of 7.5 m wave height. Wave spectrum used in this paper is Tabain spectrum which is developed specifically for Adriatic Sea. Seafarer's approach of decisions making in extreme weather is also shown and servers as a guideline for further research of the authors.

Keywords:
operational criteria, sustainable speed, Tabain wave spectrum, Integrated Navigation System.

INTRODUCTION

The Adriatic Sea is a three-sided enclosed basin located in the north central part of the Mediterranean Sea (fig. 1). Maritime transport has a great role in Adriatic Sea. Especially great density of traffic is in longitudinal direction of Adriatic Sea. Route considered in this paper is from Otranto strait to island Krk (fig. 2) where an oil terminal for product tankers is located. There is a great threat of an ecological disaster in case of a potential structural damage of a tanker vessel. To minimize the probability of such an event, ship maneuvering and operability have to be optimized.

Ship maneuvering is very important, especially on rough sea. Maneuvering on calm sea is, largely, a routine. Problems occur when environment conditions are extreme. Sustainable speed and route optimization are very important for safe navigation. The experience and knowledge of seafarers are priceless for navigation in extreme seas.

Sustainable speed can be determined by limiting values of operability criteria such as propeller emergence, deck wetness and absolute bow accelerations. Seafarers' understanding of the operability criteria is important for ship safety. Combination of mentioned knowledge and existing support on ships, such as Integrated Navigation System (INS), leads to safer navigation in heavy seas.

Fig. 1. Position of Adriatic Sea [source: Google Maps]

Fig. 2. Product tanker route from Otranto to island Krk (Omišalj oil terminal) [source: The potential, 2011]

HEAVY WEATHER IN ADRIATIC SEA

Adriatic Sea is connected to the Mediterranean through its south boundary, the Otranto strait, which is the only interface through which developed sea states enter. The wave climate of the Adriatic is therefore mostly governed by dominant winds and their inherent sea states. These winds are, in effect, affected by the surrounding mountain chains in terms of strength and direction. Additionally, local wind and sea stated are influenced by island topography along the east coast. In general the climate of the Adriatic sea is classified as Mediterranean, subtype Csa — Mediteranean climate with dry and hot summers [Favro S., Saganić I., 2007].

The basin is of rectangular shape, stretching from southeast to northwest, about 400 Nm in length and about 100 Nm wide.

The surrounding mountain chains, Dinaric on the east and Apennines on the west, channel and/or emphasize the dominant winds that cause characteristic extreme sea states. And while the strongest winds blow across the Adriatic, being accelerated coming down the mountains to the sea, they do not cause the highest sea states as they are limited in fetch. The highest sea states are caused by so called *jugo* wind (blowing from E-SE to SS-E, *sirocco* family). The nature of the wind is such that it usually develops during two-three days and reaches velocities of 30 m/s (over 100 km/h). Formed waves enter through the Otranto strait and they build up along the entire length of the basin forming large waves, especially in the north part. The highest waves are therefore recorded during *jugo* wind events. The highest wave ever officially recorder in the Adriatic sea was 10.8 meters high and measured from a platform in the north Adriatic [Parunov J. et al., 2011].

Table 1 gives sea states, i.e. wave height, period and length, in terms of occurrence for the Adriatic basin.

According to table 1 it is visible that 1% of highest sea states vary in wave height from 4.6 to 8.8 meters. The data given in table 1 correspond well to the research done by Leder et al. (1998), based on wave height date collected from gas platforms in the north Adriatic, which predicts theoretical most probable extreme significant wave heights for 20 and 100 year return periods of 7.20 and 8.57 meters respectively. The highest maximum significant wave height of 8.57 meters would relate to absolute maximum wave height of 13.54 meters which is again in valid reference to the maximum recorded wave.

Table 1. Scale of sea state occurrences in the Adriatic [Maritime encyclopedia, 1976]

Jadran	WMO	H	T	λ	%
0	0	-	-	-	10
1	1	0,05	1,6	2	24,6
2	2	0,2	2,7	5	
3	3	0,5	3,7	9,5	43,0
4		0,8	4,6	14	
5	4	1,3	5,4	20	17,2
6		1,9	6,2	25	
7	5	2,6	6,9	32	4,2
8		3,5	7,6	39	
9	6	4,6	8,3	46,5	1,0
10		5,9	9,0	55	
11	7	7,3	9,7	66	0,01
12		8,8	10,4	79	

CRITERIA FOR SHIP OPERABILITY IN HEAVY SEA

Limiting values of operability criteria are used in seakeeping studies to validate ship response on different sea states. Exceeding limiting values leads to a reduction of ship operability. Operability limiting values distinct acceptable and unacceptable phenomena such as number of deck wetting in a minute, amount of vertical acceleration on the fore perpendicular or number of propeller emergences in one minute. However, exact limits are hard to define. Service data and experiences therefore have priceless value. Statistical analysis of service data in comparison with seakeeping calculations give the best validation of operation limiting values. Operability limiting values determine ship maneuvers that have to be done in heavy sea such as route change and voluntary speed reduction. Criteria taken under consideration in this paper are deck wetness, absolute vertical acceleration at forward perpendicular and propeller emergence.

Deck wetness

Appearance of deck wetness can happen at any place on the ship where freeboard is not high enough. It usually occurs in the fore part of the ship when relative motion of the bow exceeds height of the freeboard on bow. Deck wetness can cause equipment damage and loss of the cargo, especially on container ships.

This type of seakeeping criteria is the best recognized among seafarers because it is easily read and understood in its visual form. Probability of deck wetness is given as:

$$e^{-\frac{f_x^2}{2m_{0r}}}, \tag{1}$$

where:

f_x — freeboard on section x of the ship;
m_{0r} — zero spectral moment for relative motion.

Absolute vertical acceleration at forward perpendicular

Absolute vertical acceleration on the bow (forward perpendicular) can cause damage of structure or equipment. Furthermore, excessive accelerations could disturb seafarers in their normal activity on ship. Inexperienced or not adapted seafarers feel seasickness that leads to impossibility for normal work and a deficit of safety onboard. Vertical accelerations on the bridge are also important for seafarers but are not taken under considerations when calculating operability. Limiting value is given as the root mean square of mean value of acceleration:

$$RMS = a \cdot \mathrm{g}, \tag{2}$$

where:

a — number depending on ship type (for tanker is 0,19).

Propeller emergence

Emergence of the propeller out of the water causes damage on propeller, shaft and engine. It appears when relative motion of the aft part is larger than the height between propeller peak and water line. Probability of propeller emergence is given as:

$$P_{deck\,wetness} = e^{-\frac{h_x^2}{2m_{0r}}}, \tag{3}$$

where:

h_x — height between propeller peak and water line;
m_{0r} — zero spectral moment for relative motion.

APPLICATION OF OPERABILITY CRITERIA ON PRODUCT TANKER

Characteristics of analyzed product tanker:

Length between perpendiculars	169 m
Breadth	28 m
Draft	11 m
Maximum speed	14 kn
Deadweight	43500 t

Seafarer's safety is the most important issue. Second is the safety of cargo. To satisfy safety criteria seakeeping features of the ship have to be on satisfactory level. Seakeeping features can be described in many ways. The easiest way for seafarers and shipping companies is determine sustainable speeds in rough sea states. Sustainable speed is calculated for the mentioned tanker and the seafarers' approach is taken under consideration. Tanker is navigating full of cargo at the maximum draft. Route is from the Otranto strait to the island Krk (fig. 2). Heavy sea is described by Tabain spectrum [Tabain T., 1997]. Wind *jugo* is taken as cause of the heavy sea. Relative ship to wave heading is 0° which means following seas.

Methodology of calculation

The main goal is to derive sustainable speed which depends on the mentioned operability criteria limiting values. Tanker has to navigate with maximum speed when limiting values are not going to be over exceeded.

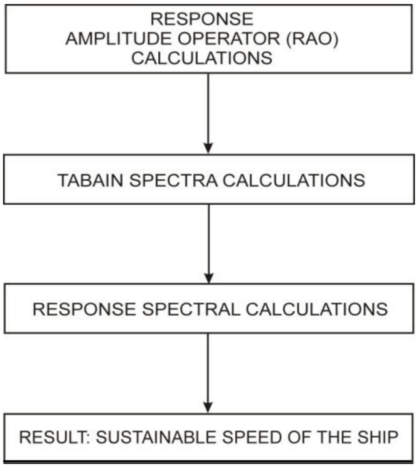

Fig. 3. Flow chart of the sustainable speed calculation

Response amplitude operators (RAOs) are calculated for product tanker using semi-analytical approach proposed and validated by Jensen et al. (2004). By this approach, which is particularly useful in conceptual studies, transfer function ϕ_M is given by the following closed-form expression:

$$\frac{\phi_M}{\rho g B L^2} = \kappa \frac{1-kT}{(kL)^2}\left[1-\cos\left(\frac{kL}{2}\right)-\frac{kL}{4}\sin\left(\frac{kL}{2}\right)\right]F_V(F_n)F_C(C_b), \tag{4}$$

where k is the wave number related to wave frequency ω through dispersion equation

$$\omega^2 = kg,$$

while L is the ship length, κ is the Smith correction factor given approximately as:

$$\kappa \cong e^{-kT}, \tag{5}$$

where T is the draught.

$F_V(F_n)$ is the speed correction factor that reads:

$$F_V(F_n) = 1 + 3F_n^2, \tag{6}$$

which is valid for Froude number $F_n < 0.3$. $F_C(C_b)$ in equation (3) is the correction factor for the block coefficient given as:

$$F_C(C_b) = \left[(1-\vartheta)^2 + 0.6\alpha(2-\vartheta)\right];\ \vartheta = 2.5(1-C_b);\ C_b = \max(0.6, C_b). \tag{7}$$

Response amplitude operators are calculated at the fore part of the ship for:

- relative vertical motion;
- absolute acceleration

and at aft part of the ship for:

- relative vertical motion.

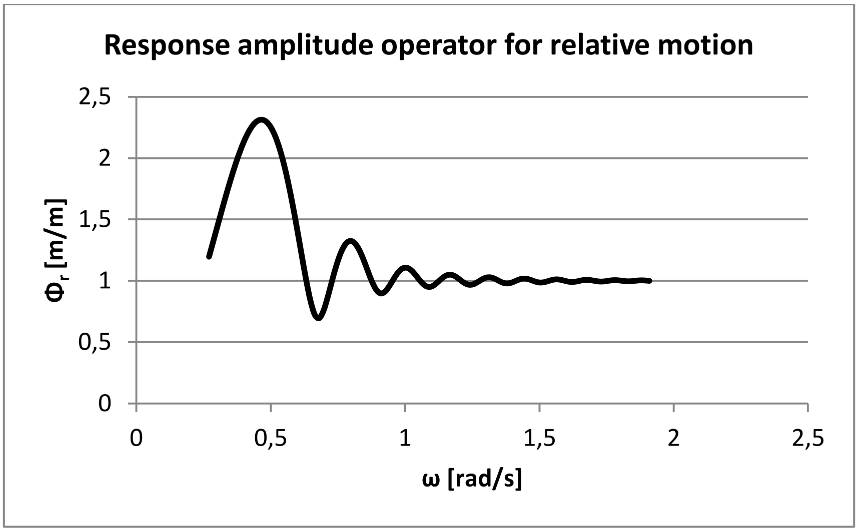

Fig. 4. Example of Response Amplitude Operator (RAO) graph for relative motion

Tabain wave spectrum (so called T-spectrum) for the Adriatic Sea is used:

$$S_\eta(\omega) = 0.862\,\frac{0.0135\,g^2}{\omega^5}\,e^{\left[-\frac{5.186}{\omega^4 H_{1/3}^2}\right]}1.63^p\,, \tag{8}$$

where:

$$p = e^{\left[-\frac{(\omega-\omega_m)^2}{2\sigma^2\omega_m^2}\right]}; \qquad \omega_m = 0.32 + \frac{1.8}{H_{1/3}+0.60}\,. \tag{9}$$

$$\sigma = 0.08\ za\ \omega \le \omega_m\,, \qquad \sigma = 0.1\ za\ \omega > \omega_m$$

T-spectrum represents slight modification of JONSWAP spectrum using shape parameter $\gamma = 1.63$ as well as parameters $\sigma = 0.08$ for the left side and $\sigma = 0.1$ for the right side of the spectrum.

Significant wave height ($H_{1/3}$) used in spectra calculation is 7,5 m. Table 1 shows that mentioned wave height has appearance probability of only 0,01 but is interesting as extreme state.

For assessment of ship operability in heavy sea states, a ship response spectrum is calculated. Short term ship response is investigated based on an assumption that heavy sea states usually lasts a few hours [Prpić-Orši J., Čorić V., 2006]. One of the results of spectral analysis is the zero spectral moment m_0, from which significant response may be determined as:

$$R_S = 4 \cdot \sqrt{m_0}, \tag{10}$$

where:
R_S — significant response (double amplitude).

Result

Result of the calculation is the sustainable speed derived from combination of zero spectral moment m_0 and equations (1), (2), (3) and (10).

Table 2. Limiting values used in calculation of the sustainable speed

Limiting probability of propeller emergence [Aertssen et all, 1963, 1966, 1968, 1972]	0.25
Limiting probability of deck wetness [Moan et all, 2006]	0.05
Limiting RMS of vertical bow accelerations [Moan et all, 2006]	0.19g

Combination of equations and ship response analysis gives sustainable speed: $V_{sust.} = 5$ kn.

SEAFARERS APPROACH OF MANEUVERING ON HEAVY SEA

Operability criteria and limiting values are derived by engineers and naval architects. Seafarers, navigating on heavy sea, have meteorological, satellite and electronic support. Well-known is Integrated Navigation System (INS) which is positioned in wheelhouse and seafarers can monitor the situation. INS consists:

- anemometer;
- Position Observation System (POS) (collects meteorological reports and display them on ECDIS);
- MET manager (collects meteorological reports over CHART-CO);
- ECDIS (Electronic Chart Display and Information System);
- ROT (Rate of Turn).

ECDIS provides a prediction line part that predicts and optimizes route according to weather and geological parameters. ROT warns seafarers which is expected ship course according to weather parameters such as waves, wind and current. Visual observation and experience are very important to understand all prediction and warnings from various electronic systems.

DISCUSSIONS

Result of calculation provided in this paper is sustainable speed derived by engineering methods. Sustainable speed provides safer navigation on heavy sea. Selected route was in the Adriatic Sea with following waves. Significant wave height is very high and probability of appearance is very low. Calculation is made as an example and possible method for quick speed estimation. Adriatic Sea is three-sided enclosed basin and every collapse of ship structure could lead to an ecological disaster. Ship maneuvers should be done with great precision and navigation should be done on a high safety level. That includes careful maneuvers especially during heavy sea and rough weather.

Results, however, bare some uncertainties based on the adopted assumptions and methodology.

Calculation of sustainable speed has uncertainties because it depends on methods and theories that do not include all, real-life, conditions. Also it is calculated only for following seas. Other directions would be interesting for seafarers, e.g. including side heading waves and current. Comparison of calculated results and experience from real service would be valuable for this field.

Understanding of electronic instruments for route prediction and weather forecast make navigation safer.

Recommendation of authors is training of seafarers on navigational simulators. In that way they can train maneuvering in rough sea and practice will make their decisions safer and faster. Common contact between experienced seafarers and naval architects would, also, be very valuable.

The mentioned field is of interest for both naval architecture and maritime research disciplines which will lead to better incorporation of seafarers' maneuvering reactions in rough sea in ship structural design.

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STRESZCZENIE

W artykule przedstawiono propozycję wytycznych operacyjnych dla żeglugi tankowca na Morzu Adriatyckim podczas pogody sztormowej. Rozpatrywany szlak zaczyna się w cieśninie Otranto na południu i prowadzi do wyspy Krk na północy. Założono, że pogoda sztormowa jest spowodowana przez wiejący z kierunku SS-E wiatr południowy *Jugo* z grupy wiatrów lokalnych *Sirocco*. Zalecenia operacyjne zostały opracowane na podstawie kryteriów użytecznych dla osób odpowiadających za wachtę morską. Za takie uznano przede wszystkim: aspekt wynurzania się śruby napędowej, czynnik zalewania pokładu i przyspieszenia rejestrowane na dziobie statku. Wartości graniczne wspomnianych kryteriów określają dopuszczalną prędkość statku. Pogoda sztormowa została opisana przez dopuszczalny stan morza wyrażony wysokością fal (7.5 m). Dla opisu spektrum fal zastosowano kryterium Tabaina, najlepiej opisujące specyfikę Morza Adriatyckiego. Zaproponowane podejście zostanie również wykorzystane przez autora w dalszych badaniach.