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METHODS OF DETERMINATION OF C COEFFICIENT FOR PERIOD OF ROLLING VESSEL IN CALM WATER FOR EXAMPLE OF PAX CARGO SHIP

Abstract

This article presents a different approach to calculate the C coefficient needed to determine the period of own rolling vessel in calm water $T_{\varphi} = \frac{C \cdot B}{\sqrt{GM}}$*. The C coefficient is usually adopted as the approximate value from the available literature, usually depending on the type of vessel, and less dependent on the loading condition. In experimental studies of marine properties (seakeeping) often have a problem with the selection of the correct value of the C coefficient, especially when we are dealing with an unusual type of ship, such as passenger and freight ship.*

In this article three approaches have been presented to determining the C coefficient. The difference in the obtained values of the C coefficient is about 10%, depending on the calculation method.

INTRODUCTION

With the period of own rolling we face during study of the seakeeping of vessel.

Seakeeping describe the behavior of marine vessel under the influence of wave and wind.

1. During examining the seakeeping of vessel, the most following assumptions are [3]:

a) wave is a stochastic process, uniform and stationary,
b) the vessel is moving on the wavy water at an average speed, permanent to the module and the direction $\overline{V} = const$,
c) rolling of vessel are small (linear and angular displacement and speed of these displacements).

The consequence of the impact of wind and waves is rolling of vessel. Rolling of vessel mostly depends on the type, intensity, and on the geometry and mass distribution, of the speed and angle of vessel relative to the direction of exchange rate of the wave. Rolling of the vessel are undesirable and cause intense rolling and dangerous side secondary effects. Rollings can cause [4]:

- Flooding the deck,
- Ascent to the propeller which gives rise to the variables of the propulsion system and a decrease in driving performance,
- Additional dynamic loads of hull (shock wave in the bottom, side or deck of the vessel),
- Vibration (general and local),
- Significant acceleration mechanisms that cause dynamic loads and equipment,
- An increase in resistance,

- Loss of efficiency drive,
- A decrease in safety and maneuverability.

Intensive side rolling hinders or prevent performance of operational functions while on the sea. They often lead to: decrease in the speed or change course, stop certain activities in the sea with a special function related to ship, increase loads of construction and cargo, reducing the use of certain equipment such as weapons and means of transport and reduce travel comfort for passenger ships. The solution to limiting the occurrence of adverse events are rocking side stabilizing device. The most commonly used are: keel, stabilizers tanks and so-called stabilizing fins.

1. PERIOD OF ROLLING VESSEL IN CALM WATER

The calculation of lateral rolling vessel is important to properly determine the *C* coefficient, which takes account the transverse moment of inertia of the vessel (this coefficient for many types of vessels weakly depends on the load).

Due to differences in determining of *C* coefficient is replaced at the same time the differences in the output values of the period of rolling side vessel. Three approaches can be used to determine the *C* coefficient, followed determine T_φ.

1. The first method by [5, 6]

$$T_\varphi = \frac{2 \cdot C \cdot B}{\sqrt{GM}} \tag{1}$$

$$C = 0.373 + 0.023 \cdot \frac{B}{d} - 0.043 \cdot \frac{L}{100} \tag{2}$$

where:
B - breadth of ship,
d - average draught,
L - length between perpendiculars,
GM - transverse metacentric height.

Dependence (2) is based on regression analysis to a limited group of vessels, and constitutes a type of averaging of value of the transverse axial inertia moment of ship.

2. The second method by Dyaer model [7] to calculate the *C* coefficient, the following calculation procedure:

1) The mass moment of inertia of vessel relative to the main longitudinal axis

$$I_x = \frac{D}{12g} \cdot (B^2 + 4z_G^2) \tag{3}$$

where:
D - displacement volume in tonnes,
z_G - distance of gravity of ship from base plane.

2) The moment of inertia mass water accompanying

Rotating ellipsoid

$$I_{xx} = \frac{\mu_1}{38.2} \cdot \frac{\gamma}{8} \cdot L \cdot B \cdot T(B^2 + 4T^2) \tag{4}$$

The cuboidal pontoon with dimension L, B, T

$$I_{xx} = \frac{\mu_2}{81.5} \cdot \frac{\gamma}{g} \cdot L \cdot B^4 \tag{5}$$

where:
$L = L_{WL}, B, T$ - main dimensions of ship,

μ_1 - coefficient of inertia moment of mass water accompanying to the Gx axis for ellipsoid rotary, μ_2 - coefficient of inertia moment of mass water accompanying for a cuboidal.

3) The additional moment of mass water accompanying to due to presence of the bilge keels

$$I_{xxBk} = \pi \cdot \rho \cdot b^2 \cdot l \cdot d^2 \tag{6}$$

where:

$\rho = \dfrac{\gamma}{g}$,

d - distance of gravity of keel from roll axis.

Period of rolling taking account of mass water accompanying and bilge keels

$$T_\varphi = 2\pi \sqrt{\frac{\Sigma J}{\nabla \cdot GM}} \tag{7}$$

$$T_\varphi = \frac{C \cdot B}{\sqrt{GM}} \tag{8}$$

where:

ΣJ - sum of moments (mass of vessel, mass of water accompanying, mass of water accompanying to due to presence of the bilge keels),

∇ - displacement volume in tonnes,

GM - metacentric height (transverse),

B - breadth of ship,

C - coefficient dependent on type of ship.

3. According to the third approach, to determine the C coefficient can use the following formula for the inertia moment of mass the vessel relative to the longitudinal axis:

$$I_x = 0.40B \cdot (\nabla + S \cdot 0.01) \cdot \rho \tag{9}$$

where:

∇ - displacement volume in [m^3],

ρ - mass density of sea water in [kg/m^3].

According to references [4] and [7] the C coefficient takes values:

Type of ship	Value of *C* coefficient
Warships	$0.71 \div 0.75$
Passenger ships	$0.80 \div 0.87$
Cargo ships with full loading	0.81
Trade ships	$0.78 \div 0.82$

2. TEST FOR DETERMINING OF C COEFFICIENT DEPENDING ON THE FORMULA USED ON INERTIA MOMENT I_x.

Example for Pax Cargo of ship.

Tab.1. Main data of ship

Symbol [unit]	**Loading conditions**	
	Design	**Ballast**
L_{PP} [m]	114	
L_{WL} [m]	117	122
B [m]	22	
T_F [m]	5.0	4.0
T_A [m]	5.0	5.2
∇[m^3]	9259	8523
S [m^2]	2991	2894

where:
L_{PP} - length between perpendiculars,
L_{WL} - length of waterline,
B - breadth,
T_F - draught- fore,
T_A - draught- aft,
∇ - displacement volume,
S - wetted surface.

<u>Period of rolling for design conditions in calm water</u> (according to Tab.1)

1. The moment of inertia the mass of vessel relative to the main longitudinal axis accordance with the formula (9)

$$\mathrm{I_x} = 0.40 \cdot 22(9259 + 2991 \cdot 0.01) \cdot 1.025 = 83.78 \cdot 10^3 \ \mathrm{t \cdot m \cdot s^2} \tag{10}$$

where:
$\rho = 1025.9\,\mathrm{kg/m^3},\ S = 2991\,\mathrm{m^2}.$

2. The moment of inertia the mass of vessel relative to the main longitudinal axis

By Dyaer pattern (3) we get:

$$\mathrm{I_x} = \frac{\mathrm{D}}{12\mathrm{g}} \cdot (\mathrm{B}^2 + 4 \cdot \mathrm{z_G^2}) \cong 63.53 \cdot 10^3 \ \mathrm{t \cdot m \cdot s^2} \tag{11}$$

where:
$D = 9520.8\ \mathrm{t},\ z_G = 8.682\ \mathrm{m}.$

2.1.The moment of inertia mass water accompanying
Rotating ellipsoid

$$\mathrm{I_{xx}} = \frac{0.56}{38.2} \cdot \frac{1.025}{8} \cdot 117 \cdot 22 \cdot 5(22^2 + 4 \cdot 5^2) \cong 14.12 \cdot 10^3 \ \mathrm{t \cdot m \cdot s^2} \tag{12}$$

gdzie:
$\frac{B}{T} = \frac{22}{5} = 4.4, \quad \mu_1 = 0.56.$

The cuboidal pontoon with dimension L, B, T

$$\mathrm{I_{xx}} = \frac{0.76}{81.5} \cdot \frac{1.025}{9.81} \cdot 117 \cdot 22^4 = 26.70 \cdot 10^3 \ \mathrm{t \cdot m \cdot s^2} \tag{13}$$

where:

$\frac{B}{T} = 4.4$, $\mu_2 = 0.76$.

assumed $I_{xx} = 20.41 \cdot 10^3 \mathrm{t \cdot m \cdot s^2} \approx 0.32 I_x$

2.2.The additional moment of mass water accompanying to due to presence of the bilge keels

$$\mathrm{I_{xxBK}} = \pi \cdot \rho \cdot \mathrm{b}^2 \cdot \mathrm{l} \cdot \mathrm{d}^2 \cong 3.4 \cdot 10^3 \ \mathrm{kg \cdot m^2} \tag{14}$$

where:

$b = 0.4\,\mathrm{m}$, $l = 37.93\,\mathrm{m}$, $d = 13\,\mathrm{m}$, $\rho = \gamma / g = 1.025 = 104.5\,\mathrm{kg \cdot s^2/m^4}$.

3. Period of rolling taking account of mass water accompanying and bilge keels

Taking into account $I_x = 83.78 \cdot 10^3$

$$\mathrm{T}_\varphi = 2\pi\sqrt{\frac{\Sigma \mathrm{J}}{\nabla \mathrm{GM}}} = 2\pi \cdot \sqrt{\frac{83.78 + 20.41 + 3.4}{9520.8 \cdot 2}} = 2\pi\sqrt{\frac{107590}{19041.6}} = 14.93\,\mathrm{s} \tag{15}$$

$$\mathrm{T}_\varphi = \frac{\mathrm{C} \cdot \mathrm{B}}{\sqrt{\mathrm{GM}}} \tag{16}$$

$$14.93 = \frac{\mathrm{C} \cdot 22}{\sqrt{2}} \Rightarrow \mathrm{C} = 0.960 \tag{17}$$

Taking into account $\mathrm{I_x} = 63.53 \cdot 10^3$

$$\mathrm{T}_\varphi = 2\pi\sqrt{\frac{\Sigma \mathrm{J}}{\nabla \mathrm{GM}}} = 2\pi \cdot \sqrt{\frac{63.53 + 20.41 + 3.4}{9520.8 \cdot 2}} = 2\pi\sqrt{\frac{87340}{19041.6}} = 13.45\,\mathrm{s} \tag{18}$$

Substituting into the formula (16) we get

$$13.45 = \frac{\mathrm{C} \cdot 22}{\sqrt{2}} \Rightarrow \mathrm{C} = 0.865 \tag{19}$$

4. Period of rolling according to (1), (2)

$$\mathrm{T}_\varphi = \frac{2 \cdot \mathrm{C} \cdot \mathrm{B}}{\sqrt{\mathrm{GM}}} = 13.07\,\mathrm{s} \tag{20}$$

$$\mathrm{C} = 0.373 + 0.023 \cdot \frac{\mathrm{B}}{\mathrm{d}} - 0.043 \cdot \frac{\mathrm{L}}{100} = 0.42 \tag{21}$$

or saved in form

$$\mathrm{T}_\varphi = \frac{\mathrm{C} \cdot \mathrm{B}}{\sqrt{\mathrm{GM}}} \tag{22}$$

$$\frac{\mathrm{C}}{2} = 0.42 \Rightarrow \mathrm{C} = 0.840 \tag{23}$$

Period of rolling for ballast conditions in calm water

1. The moment of inertia the mass of vessel relative to the main longitudinal axis accordance with the formula (9)

$$I_x = 0.40\cdot 22(8523 + 2894\cdot 0.01)\cdot 1.025 = 77.14\cdot 10^3\ \text{t}\cdot\text{m}\cdot\text{s}^2 \tag{24}$$

where:
$\rho = 1025.9\,[\text{kg/m}^3],\ S = 2894\,[\text{m}^2].$

2. The moment of inertia the mass of vessel relative to the main longitudinal axis by Dyaer pattern (3) we get:

$$I_x = \frac{D}{12g}\cdot(B^2 + 4\cdot z_G^2) \cong 73.83\cdot 10^3\,\text{t}\cdot\text{m}\cdot\text{s}^2 \tag{25}$$

where:
$D = 9176.6\,\text{t},\ z_G = 10.76\,\text{m}.$

2.1.The moment of inertia mass water accompanying
Rotating ellipsoid

$$I_{xx} = \frac{0.66}{38.2}\cdot\frac{1.025}{8}\cdot 122\cdot 22\cdot 4.78(22^2 + 4\cdot 4.78^2) \cong 16.34\cdot 10^3\ \text{t}\cdot\text{m}\cdot\text{s}^2 \tag{26}$$

where:
$\frac{B}{T} = 4.60, \qquad \mu_1 = 0.66.$

The cuboidal pontoon with dimension L, B, T

$$I_{xx} = \frac{0.76}{81.5}\cdot\frac{1.025}{9.81}\cdot 122\cdot 22^4 = 27.85\cdot 10^3\,\text{t}\cdot\text{m}\cdot\text{s}^2 \tag{27}$$

where:
$\frac{B}{T} = 4.60, \qquad \mu_2 = 0.76.$

Taking into account $I_{xx} = 22\cdot 10^3\,\text{t}\cdot\text{m}\cdot\text{s}^2 \approx 0.20 I_x$

2.2.The additional moment of mass the water accompanying to due to presence of the bilge keels

$$I_{xxBK} = \pi\cdot\rho\cdot b^2\cdot l\cdot d^2 \cong 3.4\cdot 10^3\ \text{kg}\cdot\text{m}^2 \tag{28}$$

3. Period of rolling taking account of mass the water accompanying and bilge keels

Taking into account $I_x = 77.14\cdot 10^3$

$$T_\varphi = 2\pi\sqrt{\frac{\sum J}{\nabla GM}} = 2\pi\cdot\sqrt{\frac{(77.14 + 22 + 3.4)\cdot 10^3}{9176.6\cdot 2.75}} = 12.66\,\text{s} \tag{29}$$

Substituting into the formula (16) we get:

$$12.66 = \frac{C\cdot 22}{\sqrt{2.75}} \Rightarrow C = 0.954 \tag{30}$$

Taking into account $I_x = 73.83\cdot 10^3$

$$T_\varphi = 2\pi\sqrt{\frac{\sum J}{\nabla GM}} = 2\pi\cdot\sqrt{\frac{(73.83 + 22 + 3.4)\cdot 10^3}{9176.6\cdot 2.75}} = 12.45\,\text{s} \tag{31}$$

Substituting into the formula (16) we get:

$$12.45 = \frac{C \cdot 22}{\sqrt{2.75}} \Rightarrow C = 0.938 \quad (32)$$

4. Period of rolling according to (1), (2)

$$T_\varphi = \frac{2 \cdot C \cdot B}{\sqrt{GM}} = 11.40\ s \quad (33)$$

$$C = 0.373 + 0.023 \cdot \frac{B}{d} - 0.043 \cdot \frac{L}{100} = 0.43 \quad (34)$$

or in form

$$T_\varphi = \frac{C \cdot B}{\sqrt{GM}} \quad (35)$$

$$\frac{C}{2} = 0.43 \Rightarrow C = 0.860 \quad (36)$$

Tab. 2. The value of *C* coefficient and T_φ depending used method

Kind of calculation method	Design condition			Ballast condition		
	I_x	C	T_φ	I_x	C	T_φ
according to first method	---	0.840	13.07	---	0.860	11.40
according to second method	63.53	0.865	13.45	73.83	0.938	12.45
according to third method	83.78	0.960	14.93	77.14	0.954	12.66

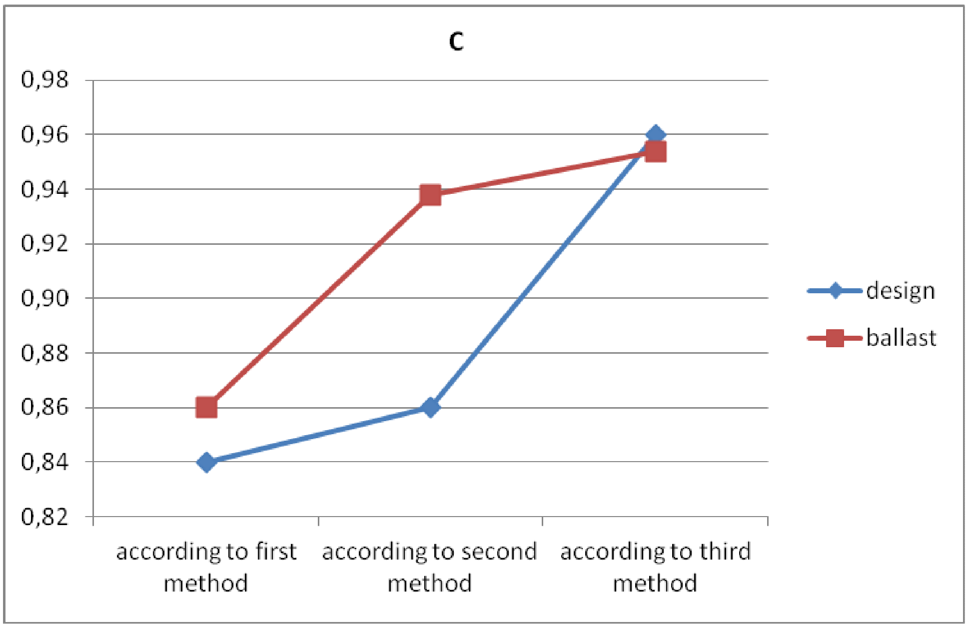

Fig. 1. The C coefficient according to kind of method

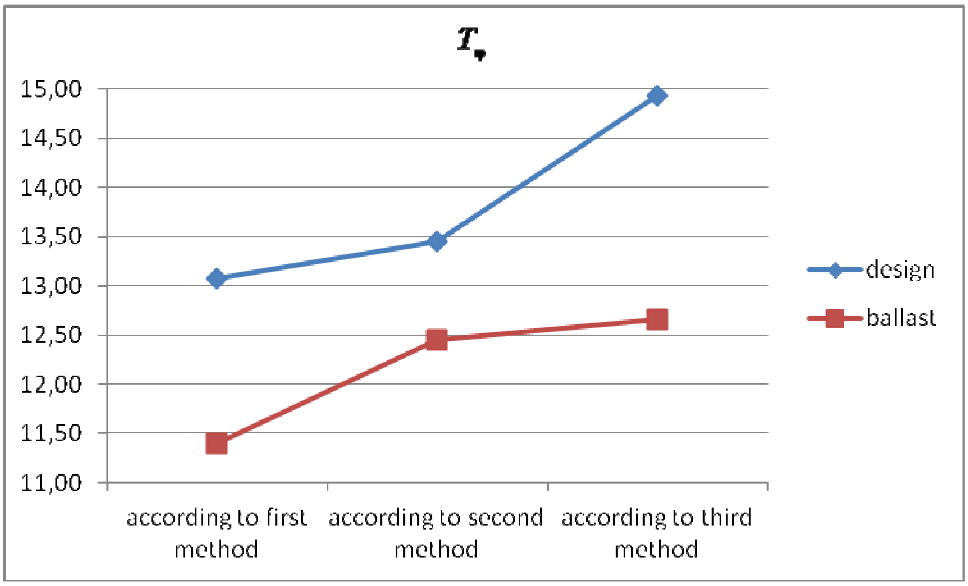

Fig. 2. Period of rolling according to kind of method

The nature of transverse-rolling of the vessel usually improves with an increase in the period of rolling T_φ, and thus the period of rolling should be as large as possible. To increase the period of lateral rolling we should:

a) increase the moment of inertia of the vessel mass and the moment of inertia accompanying water mass ($I_x + I_{xx}$),

b) reduce the transverse metacentric height GM (be careful with this, so as not to impair the stability of the vessel, and doesn't degrade the characteristics of rolling).

CONCLUSIONS

In the first method, the calculation of lateral rolling of period doesn't include the value of the transverse moment of inertia vessel in a given loading condition. In the other two methods, the differences in the moment of inertia a mass of vessel I_x are oscillates at the level around 24%.

Upon receipt of the final result for C coefficient, these differences are reduced to about 10%. If we have the larger the moment of inertia a mass of vessel, then we get the greater the period of rolling, and thus a greater the C coefficient.

For the tests carried out for passenger and freight vessel, the C coefficient ranged of $C \in (0.840 \div 0.960)$ for the design conditions and $C \in (0.860 \div 0.954)$ for the ballast conditions. The value of C coefficient exceeded the value reported in literature [7], where for passenger vessels the coefficient C have the range of $C \in (0.80 \div 0.87)$ and for freight vessels of amounts $C = 0.81$.

The described cases show, that don't have one universal of method, that would provide the greatest accuracy in determining the C coefficient.

Can be use the available in literature the approximate values of C coefficient, but as the examples show they do not apply for unusual vessel, the mixed, type passenger and freight, where we obtain the results different from adopted in literature. The different types of vessels and type of cargo dictates selection of the appropriate method of calculating the C coefficient, and at the same time get the most accurate results in determining the rolling period.

REFERENCES

1. Bass D.W., Haddara M.R., *Roll and Sway-Roll Damping for Three Fishing Vessels*, International Shipbuilding Progress, Vol.38, No.413, pp.51-71, 1991.
2. Brown D.T., *Estimation of vessel stability at sea using roll motion records*, Trans. Royal Institution of Naval Architects, Vol.132, pp.99-115, 1997.
3. Druet Cz., *Dynamika morza*, Wyd. Uniwersytetu Gdańskiego, Gdańsk 2000.
4. Dudziak J., *Teoria okrętu*, Fundacja Promocji Przemysłu Okrętowego i Gospodarki Morskiej, Gdańsk 2008.
5. IMO, *Intact Stability Code*, Londyn 2002.
6. Krata P., *Ewaluacja próby kołysań bocznych jako metody wyznaczania wysokości metacentrycznej statku*, czasopismo Logistyka, Nr 4, 2010.
7. Poradnik Okrętowca t.II, *Teoria okrętu*, Gdynia, Wydawnictwo Morskie, 1960.
8. Procedury ITTC, *Sea Keeping Experiments*, Procedure no. 7.5-02-07-02.1, 2011.
9. Spouge J.R., *A technique for estimating the accuracy of experimental roll damping measurements*, International Shipbuilding Progress, Vol.39, No. 419, pp.247-265, September 1992.
10. Wełnicki W., *Mechanika ruchu okrętu*, Wyd. Politechniki Gdańskiej, Gdańsk 1989.

METODY WYZNACZANIA WSPÓŁCZYNNIKA C DLA OKRESU KOŁYSAŃ BOCZNYCH WŁASNYCH STATKU NA WODZIE SPOKOJNEJ NA PRZYKŁADZIE STATKU PASAŻERSKO-TOWAROWEGO

Streszczenie

W artykule zaprezentowano różne podejście do wyliczenia współczynnika C potrzebnego do wyznaczenia okresu kołysań własnych statku na wodzie spokojnej $T_\varphi = \frac{C \cdot B}{\sqrt{GM}}$.

Współczynnik C zostaje najczęściej przyjęty jako przybliżona wartość z dostępnej literatury, najczęściej w zależności od typu statku, a słabiej zależy od stanu załadowania. Przy badaniach eksperymentalnych właściwości morskich bardzo często występuje problem z doborem prawidłowej wartości współczynnika C, zwłaszcza gdy mamy do czynienia z nietypowym rodzajem statku jak np. statek pasażersko-towarowy.

W niniejszej pracy zaprezentowane zostały trzy podejścia do wyznaczania współczynnika C. Różnice w uzyskanych wartościach współczynnika C wynoszą około 10% w zależności od zastosowanej metody obliczeniowej.

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