An Approach to Assess the Excessive Acceleration Based on Defining Roll Amplitude by Weather Criterion Formula with Modified Applicability Range

Prof. Rudolf Borisov, State Marine Technical University of St. Petersburg, rvborisov@mail.ru

Ph. D. Alexander Luzyanin State Marine Technical University of St. Petersburg,

aaluzyanin@rambler.ru

Dr. Michael Kuteynikov, Russian Maritime Register of Shipping, kuteynikov.ma@rs-class.org

Vladimir Samoylov, Russian Maritime Register of Shipping, samoylov.vr@rs-class.org

ABSTRACT

Development of the second-generation intact stability criteria is focused on five dynamical stability failure modes and three-level approach which indicates susceptibility and degree of susceptibility of a ship to a specific failure mode. The criteria of levels 1 and 2 are based on significant simplifications and have been developed considering substantial safety margins. Until now, the work has been concentrated on the development of levels 1 and 2 criteria and standards. The agreed proposal for excessive acceleration vulnerability criteria was generally made, but some undecided items regarding formulae of roll amplitude and period, formulae for effective wave slope and their applicability still exist. Besides, nonlinear components were not taken into account in the proposed level 1 vulnerability criteria for excessive accelerations, which could decrease the safety margin.

The purpose of the paper is to provide some additional information that can be used during finalization of the development of vulnerability criteria for excessive acceleration.

The possibility of application of a current IMO Weather Criterion to ships with ratio B/d > 3.5 and having restricted navigation area is considered. Some drawbacks of formulae for calculation of coefficient c that is necessary for calculation of roll period in the current IMO Weather Criterion are pointed out and the proposal for its correction is made. Criterion for excessive linear acceleration based on the assumptions of IMO Weather Criterion with modified applicability for several types of ships is presented and justification of the value 0.3g as a standard is made. The paper also includes information about the influence of nonlinear components on the value of acceleration and contribution of roll to the balance of horizontal accelerations.

Keywords: *acceleration, weather, stability*

1. INTRODUCTION

This paper contains some information about acceleration criterion, based on the assumptions of IMO Weather Criterion with modified applicability for ships with different navigation restrictions and ratios B/d > 3,5. Presumably it can be used during finalization of the development of vulnerability criterion for excessive acceleration in scope of the development of second generation intact stability criteria. The proposed criterion is mostly suitable for the 1 level of the vulnerability criteria for excessive acceleration.

2. JUSTIFICATION OF ACCEPTABLE VERTICAL ACCELERATION VALUE 0,3g

There are several types of vessels which have acceleration limitations during roll on heavy sea. This limitations are connected with cargo type, vessel's purpose, or necessity of meeting certain conditions of operation safety.

Vertical accelerations due to roll are usually considered, but sometimes total vertical accelerations are normalized in different combinations of ship motions: roll + heave (on the upper decks and the bridge), pitch + heave (at fore perpendicular) [5]. Here are the main factors, which make normalizing of accelerations necessary.

Biological factors. Roll causes seasickness among crew and passengers. The main reason of seasickness is physiological influence of angular and linear roll accelerations on human body.

Operational factors. These include shifting of containers, bulk and timber cargo, swing of cargo suspended on crane hook, deterioration, and sometimes inoperability of main and auxiliary machinery.

Strength factors. Overall hull strength and strength of particular structures (stern and stem, constructions of cranes and cargo booms and etc.).

Operational and strength factors for transport vessels are basically considered in the appropriate sections of national and international rules [10], [4] for ensuring safe transport technology and marine operations. Stability standards envisage the assessment of bulk cargo safety conditions and indirectly take inertial forces during roll into account.

Developers of limitations for sea-river vessels [17] considered "… bulk cargo shift, loose cargo shift, especially deck cargo, deterioration of machinery operation conditions, seasickness of the crew, … dangerous stresses in ship's hull connections", i. e. it seems they created universal mean, that took into account all three groups of factors mentioned above.

Standards which take into account operational and strength factors is often less severe than standards which take into account biological factors. Therefore acceptable accelerations are usually chosen on the basis of biological factors.

Let's look at the factors in more detail. The threshold of human sensitivity to angular accelerations is within 2 – 3 deg./s^2, and to vertical accelerations – within 0,4 – 0,12 m/s^2. Seasickness is significantly increased when the vertical accelerations reach nearly $0{,}1g \approx 1$ m/s^2. Vertical accelerations in the specific point of vessel arises not only from linear but from angular ship motions. Therefore the greatest vertical accelerations occur near vessel's ends.

The majority of the medical scientists tend to think that seasickness is a result of vestibular apparatus malfunction caused by vertical accelerations [11].

The degree of ship motions influence on human body can be seen from the graph, shown in Fig. 1.

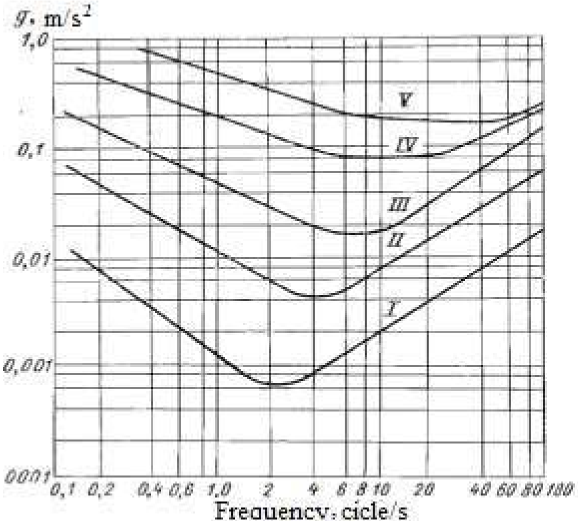

Fig. 1

Curve I marks the boundary of inceptive influence, curve II – boundary of sensible influence, curve III – strong influence, i. e. the beginning of seasickness and discomfort, curve IV – sensible discomfort and curve V – unbearable vibration. The diagram was obtained by Nieuwenhuysen [8]. The graph in Fig. 2 shows that the percentage of diseased passengers increases from 20% to 85% while accelerations increase from 0,1g to 0,4g.

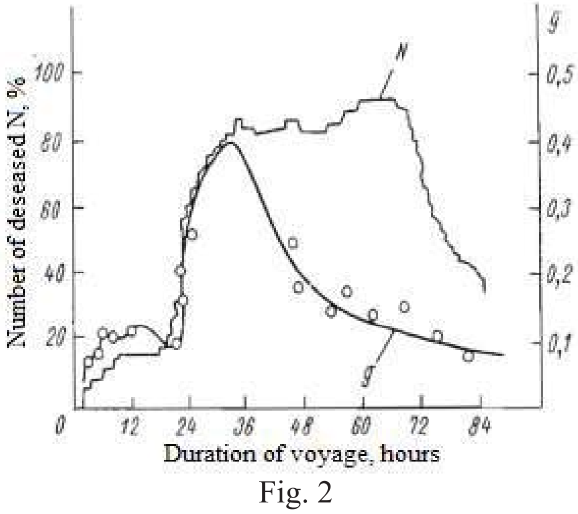

Fig. 2

Professional sailors adapt to seasickness, but this adaptation is not significant, as shown in Fig. 3. Therefore reduction of ship motions is necessary not only for passenger ships.

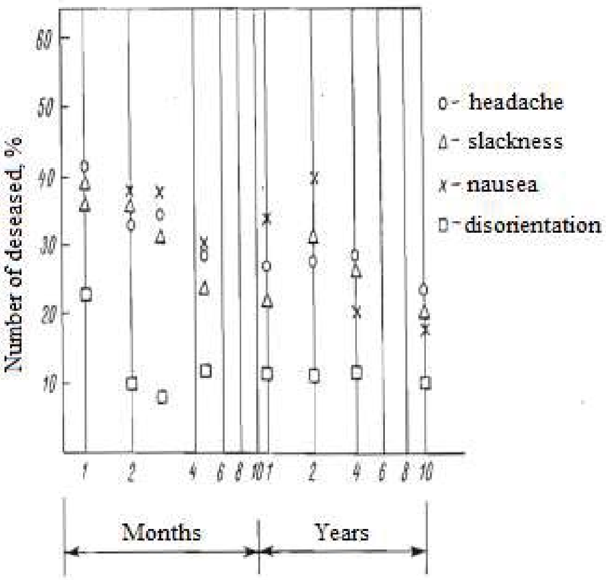

Fig. 3

Proceeding from the graph in Fig. 1 and collected data about the number of diseased people, shown in Figs. 2 and 3, the standard for vertical acceleration 0,3g was selected.

2. PROPOSAL FOR ACCELERATION CRITERION

Acceleration criterion is proposed taking into account the acceptable value of vertical accelerations mentioned above. It allows to input the operational limitations for acceptable wave height for ships with parameters $\frac{\sqrt{h_0}}{B} \geq$ 0,08 and $B/d \geq 2{,}5$ (where h_0 is initial transverse metacentric height without free surface correction; B is breadth of the vessel; d is draught).

Main proposals in the form of acceleration criterion were included in Rules for Classification and Construction of Sea-Going Ships of Russian Register in 1974 year. These ideas survived to the present day with slight changes in calculation procedure. Their point is as follows.

The stability is judged as satisfactory according to the acceleration criterion if acceleration (in fractions of g) is not more than the permissible value, i. e. the following condition is fulfilled

$$K^* = 0{,}3/a_{cal} \geq 1, \qquad (1)$$

Where K^* – is the acceleration criterion;
a_{cal} – is the calculated acceleration (in fractions of g) determined by the formula

$$a_{cal} = 0{,}0105 \frac{h_0}{c^2 B} k_\theta \theta_r \qquad (2)$$

Here, θ_r is the calculated amplitude of roll determined in accordance with [4]
$\theta_r = 109 X_1 X_2 \sqrt{rS}$ as well as in case of weather criterion;
c – is the inertia coefficient determined during calculation of the weather criterion according to the formula
$c = 0{,}373+0{,}023B/d-0{,}043L_{wl}/100;$ (3)
k_θ – coefficient that takes into account the peculiarities of roll for ships of river-sea navigation determined from Table 1.

Table 1

B/d	≤ 2,5	3	3,5	4	4,5	5	5,5	6	6,5
k_θ	1	1,08	1,11	1,11	1,2	1,3	1,45	1,56	1,61

In certain cases, it may be allowed the operation of the ship with the criterion K* < 1. In this case, an additional wave height restriction shall be introduced. The permissible wave height with 3 per cent probability of exceeding level is estimated proceeding from the value of the criterion K* as given in Table 2. The specific loading conditions with K* < 1 shall be stated in the Stability Booklet.

Table 2

K^*	1,0 and higher	1,0 – 0,75	0,75 and less
Permissible wave height with 3 per cent probability of exceeding level, m	6,0	5,0	4,0

The vessel is assumed to be in beam sea and undergoes rolling and heaving. Vertical accelerations are assessed on amidships at side and actual waterline intersection point.

The acceleration criteria mentioned above can be utilized as the basis for the revision of excessive acceleration vulnerability criterion of 1 level that is being created while developing the second generation intact stability criteria. The formula for calculation of roll amplitude can be used for the vessels with ratio *B/d* > 3,5, as shown below.

3. POSSIBILITY OF APPLICATION OF WEATHER CRITERION TO SHIPS WITH RATIO B/d > 3,5

It is well known, the formula for roll amplitude θ_r represents the formula of nonlinear roll theory that is reduced to handy calculation form and was used by authors of Japanese “Stability standards for passenger ships” and then corrected by SLF Subcommittee specialists in order to take into account the influence of B/d, C_B and bilge keels on roll damping in more detail. At the same time multipliers r and s in formula for θ_r are taken right from Japanese “Standards” and multipliers $X_1(B/d)$, $X_2(C_B)$ and k – from “Stability standards” of Russian Maritime Register of Shipping (in the editions published between 1970 and 1995) as noted in MSC.1/Circ. 1281 dated 9 December 2008.

The consideration of the value of r showed it to be a reduction coefficient, averaged on the basis of the results of many calculations to the main part (Krilov's part) of disturbing moment. It is well known from the roll theory, this coefficient can't be more than one. This is how effective coefficient of wave slope changes (according to the terminology of Japanese "Standards"). It is calculated in compliance with Watanabe method for 60 passenger vessels of Japan and underlies linear statistical dependence of IMO IS Code: $r = 0{,}73 \pm 0{,}6 OG / d$, where OG is the distance between center of gravity and waterline (+ if center of gravity is higher than the waterline).

Calculations for other types of ships with high center of gravity mainly cargo ships and industrial ships (for the purpose of this paper it means crane ships, drilling ships and dredgers) shows that in a number of cases the value of r becomes more than one, which is not in compliance with its physical meaning and leads to unreasonable overstating of roll amplitude θ_r. So, r = 1,06 for cargo ship (L = 65,0 m, B = 10,0 m, C_B = 0,66) with loading case "without cargo 10% consumables" (d = 2,42 m, OG = 1,34 m, GM = 0,88 m), and r = 1,29 for crane ship (L = 80,4 m, B = 25,4 m, C_B = 0,60) during voyage (d = 3,91 m, OG = 3,65 m, GM = 10,7 m) that leads to amplitude $\theta_r = 29^{\circ}$ which was not observed during operation of this ship in practice. Therefore it is proposed to take r = 1 during calculation of θ_r where r turns out to be more than one.

Analysis of dependence $X_1(B/d)$ showed that using scheme of roll calculation θ_r this dependence considers only increasing damping coefficient of rolling with growth of B/d. It is confirmed by results of numerous model tests carried out in different countries. Meanwhile the value of factor X_1 in Table 3 at any $B/d \geq 3{,}5$ is limited by its marginal value X_1 = 0,8. Such limitation is not appropriate to calculation scheme for roll amplitude θ_r of IMO IS Code. Using of experimental data on damping coefficients of rolling gained in model basin of Saint-Petersburg State Marine Technical University (SPbSMTU) for different types of ships with wide range of B/d provided the justified prolongation of the dependence $X_1(B/d)$ in region of $B/d > 3{,}5$ till $B/d = 7{,}0$. It practically exhausts the real values of dependence B/d for wide range of classes of ships including cargo and industrial ships. Such dependence is presented in Table 3. It is gained by averaging of calculation results of factor X_1 for 15 types of cargo, fishing and industrial ships.

Table 3. The values of factor X_1.

B/d	X_1
≤ 2,4	1,0
2,5	0,98
2,6	0,96
2,7	0,95
2,8	0,93
2,9	0,91
3,0	0,90
3,1	0,88
3,2	0,86
3,3	0,84
3,4	0,82
3,5	0,80
3,6	0,79
4,0	0,78
4,5	0,76
5,0	0,72
5,5	0,68
6,0	0,64
≥ 6,5	0,62

It can be seen that using Table 3 for factor X_1 in roll amplitude formulae always leads to decreasing of value θ_r while B/d increases in accordance with physical nature of phenomenon. This decreasing becomes practically sensible starting from $B/d > 4{,}0$. Such ratios between breadth and draught as shown by statistical analysis of main dimensions of ships are typical for cargo ships with standard loading conditions "without cargo with ballast 10% consumables" (dry cargo, tankers), large fishing vessels (fish cannery ship, whale factory ship) with low production in holds and low consumables and for industrial ships during voyage, when B/d

often more than 5,0 – 6,0. The correction of Table 3 for them has the largest value and may reduce calculated roll amplitudes for 15 – 20%.

So, the formulae for roll amplitude from Weather Criterion can be applied for the vessels with ratio *B/d* > 3,5 which typically has excessive accelerations. Gained value of amplitude may be used in calculation of the acceleration.

4. SOME DRAWBACKS OF FORMULAE FOR CALCULATION OF COEFFICIENT *c* IN FORMULAE FOR CALCULATION OF ROLL AMPLITUDE

The following formulae is utilized in calculation of roll amplitude according to IMO method [4]:

$$c = 0{,}373 + 0{,}023B/d - 0{,}043L/100 \qquad (4)$$

It was obtained for ships of unrestricted service which usually have the ratio of breadth to draught *B/d* < 3,5 and relative metacentric height is $\frac{\sqrt{h_0}}{B} < 0{,}08$. Application of this dependence for sea-river ships, which typically have larger ratios *B/d* and metacentric heights leads to significant error.

The formulae (4) gives significantly discrepant values of coefficient *c* and consequently roll period for vessels with different length but with same *B/d*. So for the ship with length L = 100 m, B/d = 2,5, $\frac{\sqrt{h_0}}{B} =$ 0,06 we will obtain: c = 0,399, T = 12,9 s, and for ship with length L = 200 m, with the same B/d = 2,5, $\frac{\sqrt{h_0}}{B} =$ 0,06: c = 0,345, T = 11,5 s. The difference is about 10%. It is obvious that with growth of length the error increases.

Taking into account the drawbacks mentioned above, the formulae for calculation of coefficient *c* also should be revised in order to avoid the above mentioned errors. Besides this, formulae for calculation of *c* does not take into account the influence of z-coordinate of center of gravity at natural roll period.

Natural roll period is defined by known formulae:

$$T = 2\pi\sqrt{\frac{I_{xx} + \lambda_{44}}{Dh}} \qquad (5)$$

Here I_{xx} – moment of inertia of ship's weight about central longitudinal axis;
λ_{44} – associated moment of inertia;
D – displacement.

Coefficient *c* can be defined from equality $T = \frac{2cB}{\sqrt{h}}$ taking into account (5) as follows

$$c = \frac{\pi}{B}\sqrt{\frac{I_{xx} + \lambda_{44}}{D}} \qquad (6)$$

Moment of inertia of ship's weight about central longitudinal axis and associated moment of inertia are necessary to define coefficient *c*.

Moment of inertia of ship's weight I_{xx} about central longitudinal axis *OX* can be determined most accurately by calculation of moments of inertia of the components of weight (shell plating, deck framing, superstructure, cargo, fuel, stores and etc.). The known formulae of theoretical mechanics is used for this purpose:

$$I_{xx} = \sum_i m_i\left[y_i^2 + (z_i - z_g)^2\right] + \sum_i I_{xi}^c \qquad (7)$$

where m_i – weight of each *i* component from the whole weight;
y_i – ordinate of center of gravity of each m_i about centerline;
z_i – z-coordinate of its center of gravity about centerline;
I_{xi}^c – natural moment of inertia of each *i* component of weight.

Calculation according to the formulae (7) is rather laborious. So, approximate formulas are often used in practice. They are based on some facilitating assumptions about the hull form and its load distribution. The most appropriate formulae for many known authors is Duayer formulae [13]:

$$I_{xx} = \frac{D}{12g}(B^2 + 4z_g^2), \tag{8}$$

and also formulae of Y. A. Shimanskiy, [13]:

$$I_{xx} = \frac{D}{g}\left(B^2 \frac{C_W^2}{11{,}4C_B} + \frac{H^2}{12}\right), \tag{9}$$

where H – depth;
C_W – water plane area coefficient;
C_B – block coefficient.

Duayer formulae is more preferable because it gives the results close to calculation data according to (7) and describes the dependence from z-coordinate of ship's center of gravity.

Roll period of displacement ships which have large ratios *L/B* and small block coefficients can be calculated using data of V. A. Morenshildt which are obtained as a result of tests of systematic series of ship models [14]. Associated moment of inertia in dependence of *B/d, L/B,* C_W and C_B can be easily defined by nomograms for fishing vessels and transport ships proposed by V. V. Lugovskiy on the basis of tests of two systematic series (20 models in total), that were carried out in test basin of SPbSMTU [13, 6]. Later S. M. Panenko carried out model tests with larger block coefficients and ratios of *B/d* that are typical for industrial ships and proposed the nomogram for defining of λ_{44} [13, 9]. According to this data the associated moment of inertia is defined by the following expression:

$$\lambda_{44} = \frac{0{,}314}{C_B} I_{xx} \frac{\lambda_{44}}{I_{xe}} \quad , \tag{10}$$

where I_{xe} – moment of inertia of underwater part of the ellipsoid, which has the same main dimensions, as the vessel under consideration (model).

The magnitude of λ_{44}/I_{xe} is defined by nomograms depending on *B/d, L/B,* C_W and C_B. The limits of changing of ships' characteristics for which those nomograms are provided in Table 4.

Table 4

No	Type of vessel	*L/B*	*B/d*	C_B	C_w
1	Transport ships	*≈7,3*	*2,4-3,5*	*0,59-0,74*	*0,7-0,82*
2	Fishing vessels and tugs	3,5-6,5	2,4-3,5	0,44-0,56	0,7-0,82
3	Industrial ships	4,5-6,5	3-5,6	-	0,75-0,9

The empirical formulae of G. K. Avdeev which is obtained by processing of the same results of model tests of different vessels in test basin of SPbSMTU can be utilized for defining of the associated moment of inertia for wide range of ships and inland-navigation vessels [1, 7].

$$I_{xx} + \lambda_{44} = \frac{I_{xx}}{0{,}28 + \dfrac{1{,}8}{BC_W\left(1 + \dfrac{1}{6}\dfrac{B}{d}\right)}\sqrt{\dfrac{I_{xx}g}{D}}}. \tag{11}$$

It is necessary to know moment of inertia of ship's weight and associated moment of inertia to define natural roll period. Calculation of this moments are preferably to be carried out by approximate empirical methods.

The associated moment of inertia λ_{44} mainly depends on *B/d* and water plane area coefficient C_W and also moment of inertia of ship's weight I_{xx}. The formulae of G. K. Avdeev (11) and nomograms of V. V. Lugovskiy and S. M. Panenko most fully meets such dependences for wide range of ships and inland-navigation vessels.

Substitution of (11) in expression for coefficient c (6) will give us the following formulae:

$$c = \pi \sqrt{\frac{\left(1+4z_g^2/B^2\right)}{12g\left[0{,}28+\dfrac{1{,}8}{C_W\left(1+0{,}167\,B/d\right)}\sqrt{\dfrac{\left(1+4z_g^2/B^2\right)}{12}}\right]}}. \tag{14}$$

To facilitate calculations it can be reduced with enough for practice degree of accuracy (Fig. 4) to the form:

$$c = 0{,}114 + 0{,}012\frac{B}{d} + 0{,}26\frac{z_g}{B} + 0{,}195C_W \tag{15}$$

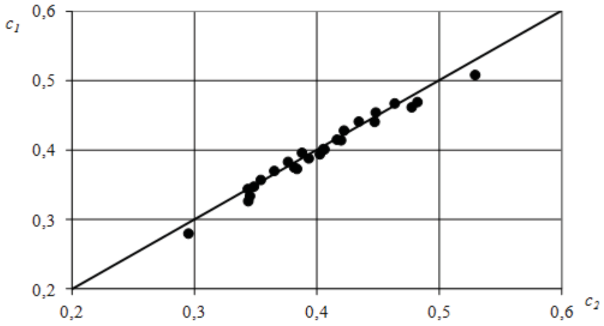

Fig.4 The comparison of the calculation results according to formulas (15) and (14)

Coefficient c can be determined utilizing nomograms of V. V. Lugovskiy and S. M. Panenko (moment of inertia of ship's weight is determined according to Duayer formulae):

$$c = 0{,}289\sqrt{\left(1+4\frac{z_g^2}{B^2}\right)\left(1+\frac{0{,}314}{C_B}\frac{\lambda_{44}}{I_{x\text{э}}}\right)} \tag{16}$$

Here the ratio λ_{44}/I_{xe} is determined by nomograms depending on ship's characteristics B/d, L/B, C_W, C_B. Based on the results of processing of these calculations the approximate dependence is obtained:

$$c = 0{,}121 + 0{,}10C_W + 0{,}025\frac{B}{d} + 0{,}35\frac{z_g}{B} + 0{,}001\frac{L}{B} \tag{17}$$

Calculations according to (17) give the results close to data that was obtained directly by nomograms. The error for all values of B/d, L/B, C_W, C_B does not exceed 5 – 7 % excluding C_W = 0,9. The error can reach 15 % for industrial ships where formulae gives understated results.

The results of calculation of coefficient c for determination of natural roll period by different methodologies are provided on Fig. 6:

1. IMO methodology, (2).
2. By formulae (15).
3. By formulae (17).

The calculations are carried out for sea-river vessel with different loading conditions. The ratio B/d is varied from 3.58 to 7,43; ratio z_g/B from 0,19 to 0,38; water plane area coefficient varied slightly ($C_W \approx 0{,}70 – 0{,}90$).

Analysis of provided dependences shows that nature of varying coefficient from $\frac{\sqrt{h_0}}{B}$ is practically the same for a number of methods: the value of coefficient c droningly reduces while $\frac{\sqrt{h_0}}{B}$ grows. The exclusion is method (2) (IMO) because coefficient c does not depend from $\frac{\sqrt{h_0}}{B}$.

The dependences of coefficient c which was calculated according to IMO formulae and proposed method (17) with widely varying parameters B/d, z_g/B, C_W are compared on Fig. 7. The range of varying of parameters B/d, z_g/B, C_W practically covers the whole varying range for real vessels: B/d = 2– 8; z_g/B = 0,2 – 0,6; C_W = 0,70 – 0,90. It can be seen from the provided dependences that proposed method of determination of coefficient c is practically in agreement with IMO method with $B/d \geq 4$ but has some advantages because it takes into account the influence of z-coordinate of center of gravity on natural roll period and takes into account more fully the ratio B/d.

Test calculations were carried out for 79 vessels of different types with different loading conditions (289 variants in total).

The difference in natural roll periods between IMO method and proposed method is small and does not exceed 11 % and when $z_g/B \approx 0{,}33 - 0{,}35$ they give practically the same results. When $z_g/B < 0{,}33$ roll period is less according to proposed method and when $z_g/B > 0{,}35$ it is larger than for IMO method.

Calculation method of natural roll period practically does not affect roll amplitudes for all loading conditions under consideration. It's obvious that Weather Criterion practically does not change when calculating period according to the proposed method.

The revised formulae (17) can be applied for vessels with ratio $B/d > 3{,}5$ and takes into account z-coordinate of center of gravity, but it practically does not affect roll amplitudes. So the existing formula for calculation of coefficient c can be applied to calculate roll amplitudes that are used for acceleration calculation for vessels with ratio $B/d > 3{,}5$.

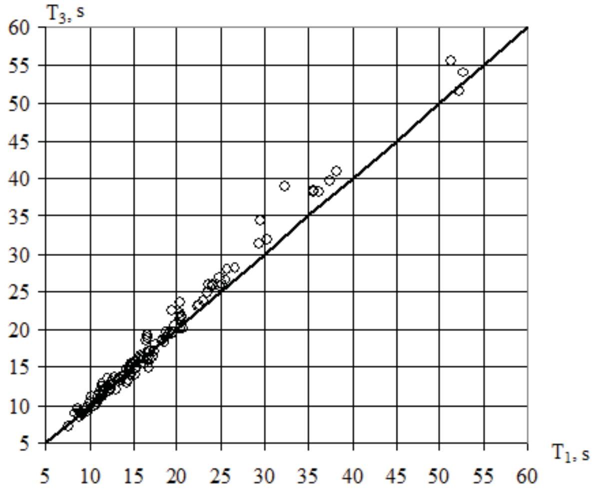

Fig. 5. Roll periods of ships of unrestricted service:
T_1 – IMO , T_3 – proposed method

5. INFLUENCE OF NONLINEAR COMPONENTS ON THE VALUE OF ACCELERATION, DURING ROLLING

Calculation method for acceleration for other types of ship motions should be considered because of the influence of angular accelerations from roll and horizontal accelerations from sway on people health ("human element" in ship operation and carrying out of different work) [15].

Calculation method for acceleration for all types of roll except surge and yaw in linear and nonlinear formulation on regular waves is proposed in work [2]. This work notes that significant lateral horizontal accelerations are occurred because of the nonlinearity of roll especially at range of low frequencies $\omega < 0{,}8$. Herewith the acceleration amplitude can be greater on 30 – 50 % of the appropriate amplitudes that are calculated according to the linear theory.

The influence of nonlinear second order factors on the values of accelerations when sway occurs can reach 20 – 40 % at range of frequencies $\omega < 0{,}5$. The results of acceleration (from sway and roll) calculation in accordance with nonlinear theory at cross point of side and deck is also significantly differs from the same results in accordance with linear theory.

Contribution of roll in common balance of horizontal accelerations for usual loading cases (h_0 below 2 m) constitutes 15 – 20%. Accelerations themselves are 0,15 – 0,20g, but if metacentric height is greater it can reach 60% and summary accelerations significantly exceeds permissible values for horizontal accelerations.

The influence of nonlinear factors on accelerations in different points of vessel first of all depends on value of metacentric height h_0. Roll amplitudes for vessels with $h_0 < 1$ m which are calculated in accordance with nonlinear theory can exceed 50 – 60 % the appropriate amplitudes which are calculated according to linear theory at range of main resonance. The influence of nonlinear factors at range of main resonance mode of rolling is practically absent for vessels with $h_0 > 2$ m, but it appears at range of super harmonic resonance.

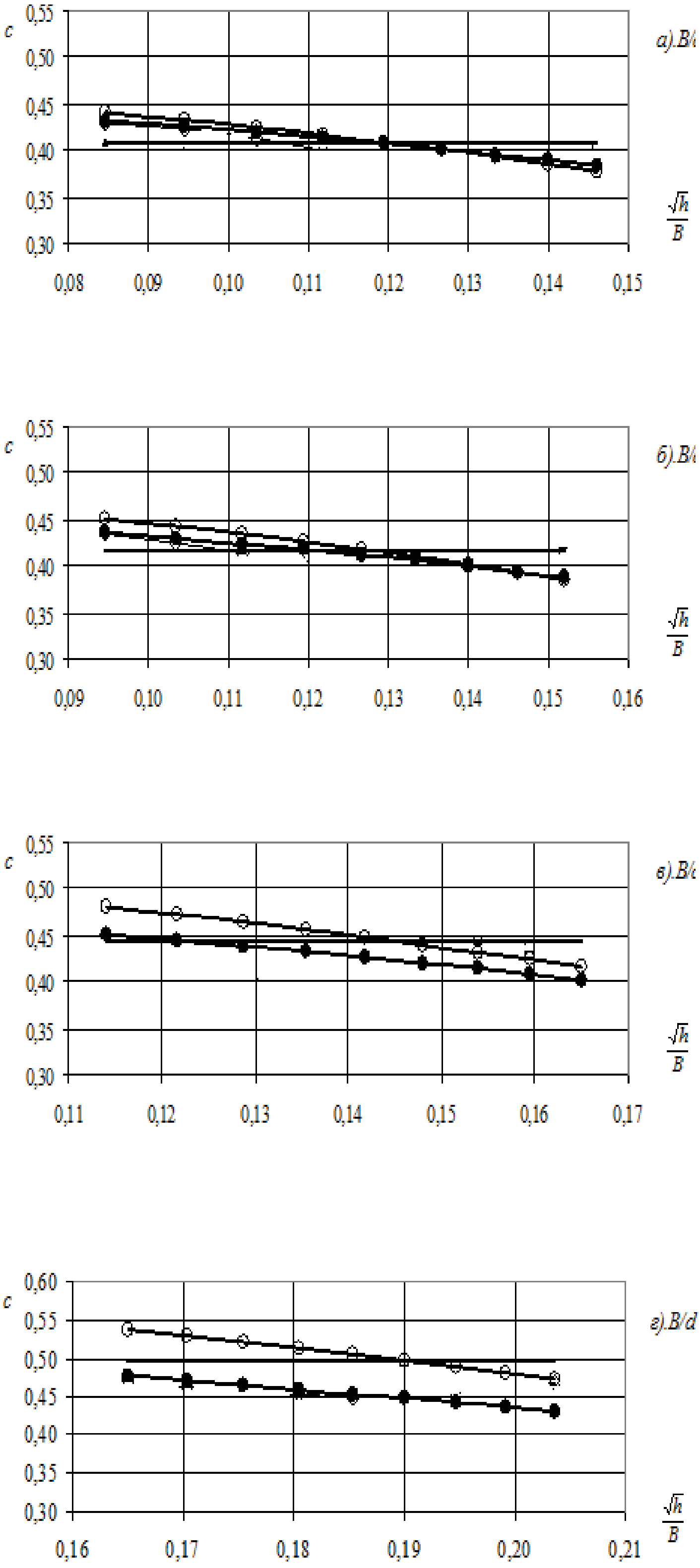

Fig. 6. Coefficient c, calculated according to methodologies:

—1, —◆—2, —○—3,

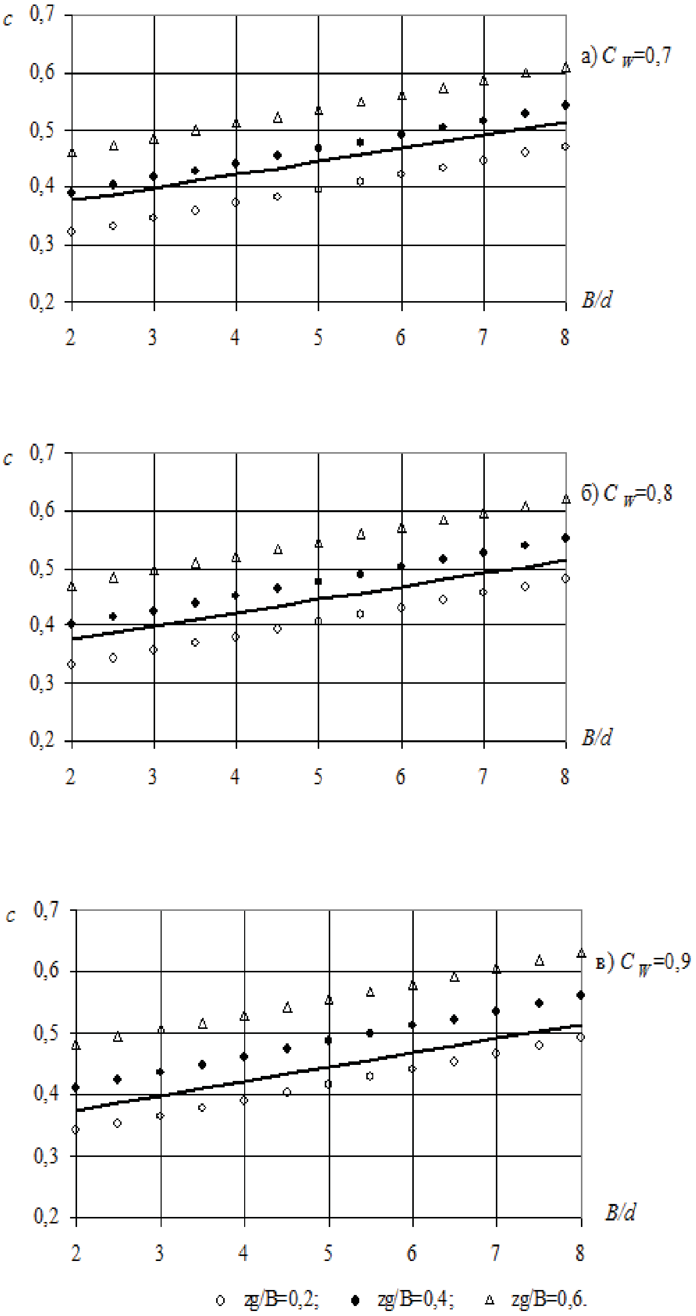

Fig. 7. Coefficient c

Main contribution to vertical accelerations at fore perpendicular is made by pitching (up to 80%) and contribution that is made by heaving is much less (up to 20%).

Significant influence of speed on acceleration should be noted. Its growth leads to drastic increase of amplitude of vertical accelerations and accelerations from surge at range of main resonance and super harmonic resonance. So the values of acceleration from heaving and surge when Fr = 0,306 are higher for 75% and 40% accordingly than when Fr = 0,2. The increment of the above mentioned values for 33 – 35 % occurs at range of super harmonic resonance modes.

6. CONCLUSION

Vulnerability criterion for excessive acceleration 1 level is proposed. The possibility of appliance of present formulae for roll calculation from Weather Criterion during acceleration calculation is showed. Data about the influence of nonlinear component on accelerations during rolling are presented. Formulae for calculation of coefficient c is proposed. Information that is contained in this paper can be used for additional work of vulnerability criterion for excessive accelerations 1 level.

7. REFERENCES

Anfimov V. N., Avdeev G. K. Hydrodynamic characteristics and calculation of roll amplitudes of inland-navigation vessels // Tr. CRI RF. – Ed. XXX. – L., 1955.

Borisov R. V., Kuteynikov M. A. Semenova V. Y., Luzyanin A. A. About the problem of standardizing of accelerations caused by roll. UDK 629.12.073.243.4 // Scientific and technical compilation No. 27. – SPb.: Russian Maritime Register of Shipping, 2004.

Borisov R. V., Kuteynikov M. A., Luzyanin A. A. Method of calculation assessment of natural roll period of marine vessels of different types. UDK 629.12.001.11 // Scientific and technical compilation No. 27. – SPb.: Russian Maritime Register of Shipping, 2004.

Code of Intact Stability for All Types of Ships. IMO Res. MSC.267(85). – 2008.

Kuteynikov M. A. The development and researching of theoretical basic foundation for setting of operational limitations when standardizing of marine vessels seaworthiness // Abstract for thesis for competition of Ph. D. science degree. – SPb.: SPbSMTU, 2001.

Lugovskiy V. V. Nonlinear tasks of seaworthiness. – L.: Shipbuilding, 1966.

Lugovskiy V. V. Roll of the ship. Text-book. – SPb.: Pub. Center SPbSMTU, 1999.

Nieuwenhuysen J. N. Experimental investigations on seasickness. Diss. Utrecht, 1958.

Panenko S. M. Hydrodynamic characteristics of roll of hopper dredgers // Scientific and technical compilation of USSR. Book 2. – L.: Transport, 1972.

Rules for the Classification and Construction of Sea-Going Ships. – SPb.: Russian Maritime Register of Shipping, 2015. – T. 1.

Semenov-Tyan-Shanskiy V. V., Blagoveshenskiy S. N., Holodilin A. N. Roll of the ship. L.: Shipbuilding, 1971.

Semenova V. Y. Research and development of programs for calculation of nonlinear hydrodynamic forces which are occurred due to roll of contour of ship form on the free surface of liquid // Thesis for competition of Ph. D. science degree. – SPb.: SPbSMTU, 1999.

Ship theory guide / Ed. Y. I. Voytkunskiy. – L.: Shipbuilding, 1985. – T.2.

Shmirev. A. N., Morenshildt V. A., Ilyina S. G. Anti-rolling devices of vessels. – L.: Transport, 1972.

Skorohodov D. A. Navigation and control of vessel movement. – SPb.: Almor, 2002.

Borisov R. V., Luzyanin A. A. The development of theoretical basic foundation for ships of different types when rolling //Report on theme. Baltic Engineering Center. – 2002.

Anfimov V. N., Vasilev A. I., Egorov G. A., Mamontov Y. N. The researching of seaworthiness of marine vessels with excessive stability and large block coefficient // Final report on theme 73-632. – L.: LIWT (Leningrad Institute of Water Transport), 1974.