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Accuracy analysis of stowing calculations for securing non-standard cargoes on ships according to IMO CSS Code

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Abstract

The article takes up a subject of effectiveness of securing arrangements while stowing non-standard cargoes on ships. Accuracy analysis of stowing calculations was based on procedures proposed by Code of Safe Practice for Cargo Stowage and Securing – CSS Code. Detailed calculations of forces and moments related to lashings, which prevents non-standard cargo against transverse tipping, were performed. Some simplifications were proven that may result in underestimating or overstating the calculated righting moment, which decides of safety margin of securing non-standard cargoes. The alternative more reliable procedure, without simplifications, was proposed.

Introduction

Stowing general cargoes on ships contains several operations associated with appropriate location of the cargoes and their securing. Contemporary technology used in cargo shipping aims at elimination of stowing errors by standardizing cargo units as well as appropriate adjusting ship structures. It makes possible to expand automation of cargo handling in ports. The most popular have become containers, which have dominated cargo transport by sea. Technology of handling and securing containers on ships makes it possible to considerable limit workforce and achieve this way very high effectiveness. Several millions of containers are yearly handled in sea container terminals, which employ a few dozen percent smaller number of workers as compared with traditional general cargo terminals. This constitutes a huge technological progress but it also possesses its own limitations. A part of cargoes, called non-standard ones, requires - and will require in the future - an individual approach and significant expenditure of human work. Among them heavy cargo units, large dimension loads as well as other loads in non-standard packing, are numbered.

Stowing techniques of non-standard cargoes are rarely described in ship cargo handling documentation, especially in *Cargo Securing Manual*. Therefore persons responsible for loading are forced to rely on other available documents and their knowledge of ship, cargo

and own experience. Their responsibility is high as stowing errors are often associated with high cargo losses and in extreme cases they can cause loss of ship's floatability. The principle is that each unit of non-standard cargo requires separate stowing calculations and selection of a suitable securing technique with the use of appropriate lashing equipment. Appropriate know-how in the area is crucial.

In present, there are a few IMO (International Maritime Organisation) documents useful in preparing stowing plans for non-standard cargoes. *Code of Safe Practice for Cargo Stowage and Securing – CSS Code* [1] is the most important. The Code contains example procedures for stowing calculations, which make it possible to select proper securing equipment. In 2002 during 75th session of MSC/IMO subcommittee some important changes were introduced to Appendix 13, entitled „*Methods to assess the efficiency of securing arrangements for non-standardized cargoes*”¹. In the Appendix formulae and tables are included for calculation of forces and moments designed to protect against shifting and tipping a non-standard cargo. Knowledge of such forces makes it possible to select an appropriate number and quality of securing arrangements.

However, some of formulas given in the Appendix in question propose some relatively important simplifications, which affect results of calculations, that may result in underestimating effectiveness of securing arrangements. The simplifications concern calculations for determination of forces occurring in lashing designed to protect cargo against transverse tipping. The objective of the below presented analysis is a comparison of accuracy of calculations performed with the use of the CSS Code procedures and alternative ones.

Calculations of moments, which prevents non-standard cargo against transverse tipping

The CSS Code recommends to use the below given inequality to control whether the cargo securing devices protect it against tipping to port or starboard side:

$$F_y \cdot d \leq b \cdot m \cdot g + 0,9 \cdot (CS_1 \cdot c_1 + CS_2 \cdot c_2 + \dots + CS_n \cdot c_n) \quad (1)$$

where:

F_y – transverse cargo tipping force [kN],

d – lever of action of tipping force [m] (usually assumed equal to a half of the cargo height $d=h/2$)

¹ Annex 13 Methods to assess the efficiency of securing arrangements for non-standardized cargoes (MSC/Circ.1026).

$b = e/2$ [m], where: e – transverse distance between supports of a cargo unit (cargo breadth),

m – mass of a cargo unit [t],

$g = 9,81 \text{ m/s}^2$ (gravity acceleration),

CS_1, CS_2, \dots, CS_n – forces in lashings,

c_1, c_2, \dots, c_n – levers of action of forces in lashings.

The important assumption given in the CSS Code indicates that the angles α and β , between the lashings and ship's deck (the vertical angle α) and between lashings and perpendicular to ship central line (the horizontal angle β) are to satisfy the following requirement (Fig. 1): $\alpha \geq 45^\circ$ or $\beta \leq 45^\circ$.

Additionally, force in lashing (calculated strength CS) is calculated as a fraction of the maximum securing load MSL according to the formula:

$$CS = \frac{MSL}{1,35} [kN] \quad (1)$$

The CSS Code also indicates a way to simplification of calculations by assuming that values of levers of forces in lashings are approximately equal to the cargo breadth e :

$$c_1 \approx c_2 \approx \dots \approx c_n \approx e$$

Hence, the inequality (1) can be substituted by the following:

$$F_y \cdot d \leq b \cdot m \cdot g + 0,9 \cdot e \cdot (CS_1 + CS_2 + \dots + CS_n) \quad (2)$$

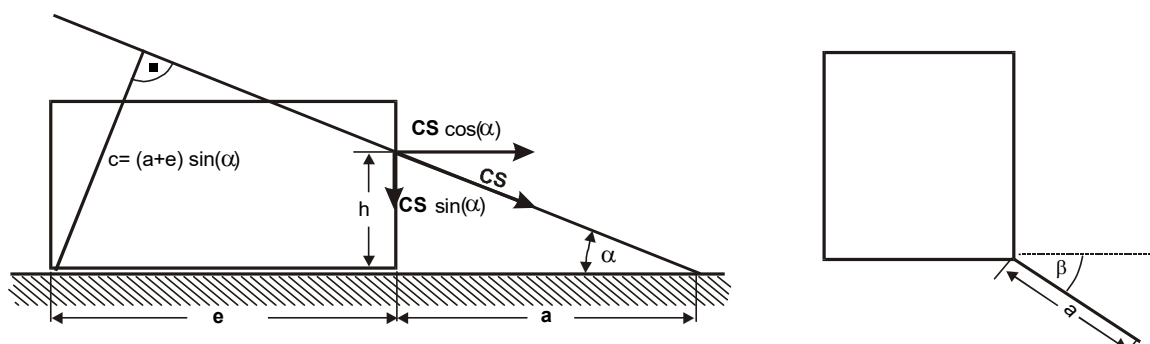


Fig. 1. Moment of single lashing which prevents against cargo tipping
(According to the authors' elaboration).

Course of calculations, which led to formulation of the inequality (2) which describes moments acting in the case of transverse tipping the cargo, can be analyzed by using simple calculations. The inequality illustrates the relation between the cargo tipping moment, which acts crosswise the ship, and the moment which resist the former. This is the moment associated with action of the gravity force mg and sum of the moments associated with forces in oblique cargo securing devices, M_y . The lashings must be directed towards the opposite side relative to direction of action of the tipping moment.

$$F_y \cdot d \leq b \cdot m \cdot g + M_{y1} + M_{y2} + \dots + M_{yn} \quad (3)$$

The moment related to a single lashing, which resist the tipping, is equal to:

$$M_y = CS \cdot c = CS \cdot (a + e) \cdot \sin \alpha, \quad (4)$$

where:

CS – force in single lashing [kN],

c – lever of force [m],

a – vertical projection of the lashing line onto the deck plane [m].

The formula is correct only for the angle β equal to 0° (i.e. when the lashing is perpendicular to ship's central plane). Otherwise, at determining the moment M_y , the parameter a should be substituted by the product $a \cdot \cos \beta$, and the formula in question finally takes the form as follows (Fig. 2):

$$M_y = CS \cdot (e + a \cdot \cos \beta) \cdot \sin \alpha \quad (5)$$

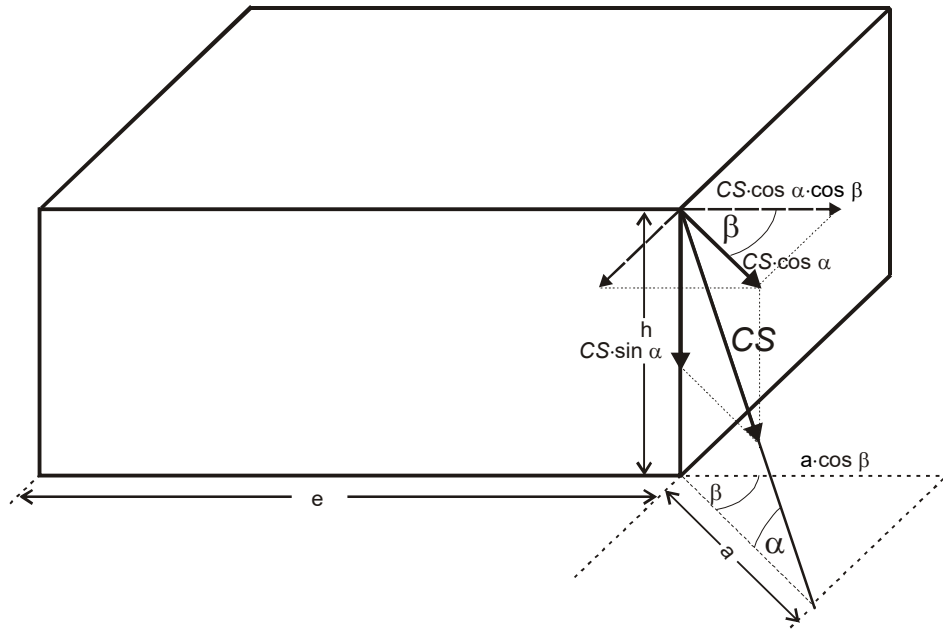


Fig. 2. Decomposition of the force acting in lashing which resist the tipping of cargo
(According to the authors' elaboration).

On substitution of a by:

$$a = \frac{h}{\tan \alpha}$$

the following was obtained:

$$\begin{aligned} M_y &= CS \cdot \sin \alpha \cdot \left(e + \frac{h}{\tan \alpha} \cdot \cos \beta \right) = CS \cdot e \cdot \sin \alpha \cdot \left(1 + \frac{R}{\tan \alpha} \cdot \cos \beta \right) = \\ &= CS \cdot e \cdot (\sin \alpha + R \cdot \cos \alpha \cdot \cos \beta) = CS \cdot e \cdot fm_y \end{aligned}$$

$$M_y = CS \cdot e \cdot fm_y \quad (6)$$

where:

α – vertical angle of lashing

β – horizontal angle of lashing,

R – ratio of the lashing's fixing point height h and the cargo breadth e , h/e ,

$fm_y = \sin \alpha + R \cdot \cos \alpha \cdot \cos \beta$ – a coefficient.

On introduction of the developed form of the parameter $\square M_y$ into the inequality (3) it takes the form:

$$F_y \cdot d \leq b \cdot m \cdot g + e \cdot (CS_1 \cdot fm_{y_1} + CS_2 \cdot fm_{y_2} + \dots + CS_n \cdot fm_{y_n}) \quad (7)$$

By making use of the relation (6) a table was elaborated which gives the coefficients fm_y for various values of R and the lashing's angles α and β .

Tab. 1. Values of the coefficient fm_y

	$\beta \backslash \alpha$	-30	-10	0	10	30	50	70	90
R=1,0	10	0,35	0,80	0,98	1,14	1,35	1,40	1,28	1,00
	30	0,25	0,68	0,87	1,03	1,25	1,32	1,24	1,00
	50	0,06	0,46	0,64	0,81	1,06	1,18	1,16	1,00
	70	-0,20	0,16	0,34	0,51	0,80	0,99	1,06	1,00
	90	-0,50	-0,17	0,00	0,17	0,50	0,77	0,94	1,00
R=1,2	10	0,52	0,99	1,18	1,34	1,52	1,53	1,34	1,00
	30	0,40	0,85	1,04	1,20	1,40	1,43	1,30	1,00
	50	0,17	0,59	0,77	0,93	1,17	1,26	1,20	1,00
	70	-0,14	0,23	0,41	0,58	0,86	1,03	1,08	1,00
	90	-0,50	-0,17	0,00	0,17	0,50	0,77	0,94	1,00
R=1,4	10	0,69	1,18	1,38	1,53	1,69	1,65	1,41	1,00
	30	0,55	1,02	1,21	1,37	1,55	1,55	1,35	1,00
	50	0,28	0,71	0,90	1,06	1,28	1,34	1,25	1,00
	70	-0,09	0,30	0,48	0,65	0,91	1,07	1,10	1,00
	90	-0,50	-0,17	0,00	0,17	0,50	0,77	0,94	1,00
R=1,6	10	0,86	1,38	1,58	1,73	1,86	1,78	1,48	1,00
	30	0,70	1,19	1,39	1,54	1,70	1,66	1,41	1,00
	50	0,39	0,84	1,03	1,19	1,39	1,43	1,29	1,00
	70	-0,03	0,37	0,55	0,71	0,97	1,12	1,13	1,00
	90	-0,50	-0,17	0,00	0,17	0,50	0,77	0,94	1,00
R=1,8	10	1,04	1,57	1,77	1,92	2,04	1,91	1,55	1,00
	30	0,85	1,36	1,56	1,71	1,85	1,77	1,47	1,00
	50	0,50	0,97	1,16	1,31	1,50	1,51	1,34	1,00
	70	0,03	0,43	0,62	0,78	1,03	1,16	1,15	1,00
	90	-0,50	-0,17	0,00	0,17	0,50	0,77	0,94	1,00
R=2,0	10	1,33	1,90	1,97	2,11	2,21	2,03	1,61	1,00
	30	1,11	1,65	1,73	1,88	2,00	1,88	1,53	1,00
	50	0,69	1,18	1,29	1,44	1,61	1,59	1,38	1,00
	70	0,13	0,55	0,68	0,85	1,09	1,21	1,17	1,00
	90	-0,50	-0,17	0,00	0,17	0,50	0,77	0,94	1,00
	$\beta \backslash \alpha$	-30	-10	0	10	30	50	70	90

(According to the authors' elaboration).

As indicates Tab. 1, the coefficient fm_y takes the values from the interval $[-0,50; 2,21]$. This is so much important that from comparison of the inequalities (2) and (5) results that the

value of the coefficient fm_y , used in the procedure of the CSS Code is equal to 0,9. Even if the Code's limitations of applicability of its procedures to positive values of the angles α and β ($\alpha \geq 45^\circ$ lub $\beta \leq 45^\circ$)² are satisfied they are contained within the interval [0,87; 2,21]. It is worth to show how large practical importance the just demonstrated difference in values of the assumed coefficient, has.

Example calculations

In the CSS Code some example calculations complying with recommended procedures are shown. The example concerned securing a heavy cargo unit of 68 t mass and the dimensions: height $h=2,4$ m, breadth $e=1,8$ m, under action of the external transverse force $F_y=312$ kN. The securing arrangement consist of 4 lashings on each ship side, external two on each side (no.1, 4, 5 and 8) were of $CS=80$ kN, and the remaining four (internal) were of $CS=67$ kN (Fig. 3).

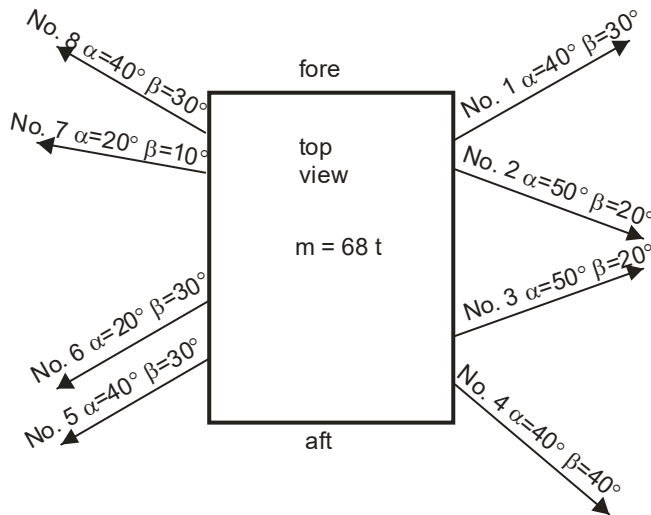


Fig. 3. Arrangement of lashings to secure cargo unite

(According to Annex 13 to CSS Code).

The calculations presented in the CSS Code with application of the inequality (2) yield the following result:

$$F_y \cdot d \leq b \cdot m \cdot g + 0,9 \cdot e \cdot (CS_1 + CS_2 + CS_3 + CS_4)$$

$$312 \cdot 2,4 / 2 \leq 68 \cdot 9,81 \cdot 1,8 / 2 + 0,9 \cdot 1,8 \cdot (80 + 67 + 67 + 80)$$

² The values of the coefficient fm_y , which satisfy the limitation of the CSS Code are presented in Tab. 1 on gray background.

$$374 \leq 600,4 + 476,3$$

$$\underline{374 \leq 1076,7}$$

The inequality is satisfied and takes the same form for both ship sides. It means that the applied securing system is sufficient to resist the cargo tipping moment.

Based on the same data similar calculations with the use of the inequality (7) and the coefficients fm_y can be performed. For comparison the calculations based on the initial inequality (3) with the use of the expression $M_y = CS \cdot (e + a \cdot \cos \beta) \cdot \sin \alpha$, were performed.

The latter calculations are more exact as they are free of errors involved by reading values of the coefficient fm_y from the table.

1) Calculations for starboard side

$$R = h/e = 2,4/1,8 = 1,3$$

Tab. 2. Calculations for starboard side

No. of lashing	CS	α	β	$a=h/tga$	$c=(e+a \cdot \cos \beta) \sin \alpha$	$M_y=CS \cdot c$	fm_y	$CS \cdot fm_y$
1	80	40	30	2,86	2,75	220,0	1,48	118,4
2	67	50	20	2,01	2,83	189,6	1,54	103,2
3	67	50	20	2,01	2,83	189,6	1,54	103,2
4	80	40	40	2,86	2,56	204,8	1,37	109,6
						804,0		434,4

(According to the authors' elaboration).

The calculations with taking into account the coefficients fm_y yield the following relationship:

$$F_y \cdot d \leq b \cdot m \cdot g + e \cdot (CS_1 \cdot fm_{y1} + CS_2 \cdot fm_{y2} + + CS_n \cdot fm_{yn})$$

$$374 \leq 600,4 + 1,8 \cdot 434,4$$

$$\underline{374 \leq 1382,3}$$

The exact calculations, i.e. without simplifications, yield the following relationship:

$$F_y \cdot d \leq b \cdot m \cdot g + M_{y1} + M_{y2} + ... + M_{yn}$$

$$374 \leq 600,4 + 804,0$$

$$\underline{374 \leq 1404,4}$$

2) Calculations for port side.

Tab. 3. Calculations for port side

No. of lashing	CS	α	β	$a=h/tga$	$c=(e+a\cdot\cos\beta)\sin\alpha$	$M_y=CS\cdot c$	fm_y	$CS\cdot fm_y$
5	80	40	30	2,86	2,75	220,0	1,48	118,4
6	67	20	30	6,59	2,57	172,2	1,38	92,5
7	67	20	10	6,59	2,83	189,6	1,47	98,5
8	80	40	30	2,86	2,75	220,0	1,48	118,4
						801,8		427,8

(According to the authors' elaboration).

The calculations with taking into account the coefficients fm_y yield the following relationship:

$$374 \leq 600,4 + 1,8 \cdot 427,8$$

$$\underline{374 \leq 1370,4}$$

The exact calculations, i.e. without simplifications, yield the following relationship:

$$374 \leq 600,4 + 801,8$$

$$\underline{374 \leq 1402,2}$$

The obtained inequalities for port and starboard side differ to each other only a little. All the results indicate that the applied securing system is sufficient to resist the cargo tipping moment. In all variants the securing safety margin, i.e. the difference between tipping moment and righting moment, is much greater than that calculated according to the CSS Code.

Conclusions

Basing on the performed accuracy analysis concerning the securing devices for non-standard cargo units, the following detail conclusions may be offered:

- 1) The procedure for calculations of the moment resisting the transverse force, which tends to tip the non-standard cargo units, recommended by the CSS Code, is simple in use but contains some inaccuracy resulting from the applied simplifications.

- 2) The first important simplification in the CSS Code is the application of the constant coefficient equal to 0,9 in the inequality (1) whereas in reality it takes values from the interval $[-0,50; 2,21]$.
- 3) Successive simplification proposed in the CSS Code is the assumption that values of levers of forces acting in lashings are approximately equal to the cargo breadth e , that results in the recommendation on using the inequality (2) to calculations.
- 4) The presented method gives the possibility to calculate also moments in securing devices, which do not meet the requirements mentioned in the CSS Code referring to the α and β angles.
- 5) The calculations performed in presented example according to CSS Code with all simplifications underestimate the final results by about 300 kNm. Comparing this value with righting moment (about 1400 kNm), it means that the safety margin was increased by over 20%.
- 6) In practice, the application of the CSS Code procedures may be connected with underestimating or overstating the calculated moment as the procedure takes into account only number and nominal strength of lashings and does not differentiate them regarding the angle which they form with ship's deck and straight line perpendicular to ship's central line. This is why the same result was obtained for the same number of lashings on port and starboard side.

Application of the inequality (7) together with Tab. 1, which enables to determine the coefficient fm_y for various values of R and the angles α and β of securing devices, is proposed as an alternative procedure for calculation of moments in lashings, which prevent the non-standard cargo unit from tipping.

Results obtained by means of the procedure only a little differ from those accurate calculated with the use of trigonometric functions. The observed differences result from application of linear interpolation to reading values of the coefficient fm_y from Tab. 1, whereas in reality values of the coefficient vary non-linearly.

Application of the alternative procedure should not be limited to any range of the angles α and β formed by lashings. However, it is important to observe that for certain lashings which are characterized by negative values of the angle α , force in such lashings, instead to prevent the cargo against transverse tipping, can co-operate with the tipping force. It can so happen if the coefficient fm_y takes negative values. Therefore as a rule the system of securing the cargo by means of lashings directed upwards from the level of their fixing points at the cargo, should be avoided.

The proposed alternative procedure would improve safety of securing non-standard cargoes. Accurate calculations of moments resisting transverse tipping the cargo would be transformed to stowing decisions, i.e. choice of number and strength of lashings as well as a way of their fixing.

Bibliography

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2. *Guidelines For The Preparation Of The Cargo Securing Manual*, 1997 Edition, International Maritime Organization (IMO I298E).

Nomenclature: safety of transportation, stowing, cargo securing, non-standard cargoes, lashing

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