

# **Proposed interpretations of and amendments to the Annex 13 of the IMO Code of Safe Practice for Cargo Stowage and Securing**

## **Introduction**

The following article may be of interest for all persons who are engaged with the stowage and securing of all types of cargo and especially of exceptionally large cargo units on sea-going vessels. Such persons are mariners, transport engineers, warranty surveyors and representatives of all commercial parties of the particular transport project, including their underwriters' risk managers.

Since 1995 the proper stowage and securing of cargo items on ships has been supported by the Annex 13 of the IMO Code of Safe Practice for Cargo Stowage and Securing (CSS-Code). This Code does not present mandatory regulations. It is rather classified as an adopted industry standard. But what is more important, it has proved its value compared to the previous uncertainty of opinions, hearsay and casualness sprawling in the wake of globalisation of shipping in the second half of the 20<sup>th</sup> Century.

The Annex 13 contains a concise but flexible calculation method which enables a competent user to assess any semi- and non-standardised securing arrangement. At the time the method was designed, its scope of application had been phrased in a way to exclude cargo units with "unusual characteristics" and the use of "relevant expertise" had been prompted instead. But the past twenty years have shown a considerable increase of such extraordinary shipments together with the trustful habit of users to readily apply the Annex 13 also for them. Therefore it appears advisable to adapt or upgrade the provisions of the Annex 13 by the following topics:

1. Weather dependent load assumptions for cargo securing (A)
2. Speed reduction in head seas as accepted operational parameter (A)
3. Vessel survival criteria in case of a major cargo shift (A)
4. Additional tipping moment due to the rotational inertia of cargo units (A)
5. Balance of longitudinal sliding and tipping (A)
6. Interpretation of "on deck high" (B)
7. Separate consideration of wind moment in tipping balances (B)
8. Homogeneity of securing arrangements (B)

The above topics are marked with the category labels (A) and (B). Category (A) will need the approval of IMO, because the proposals therein require the agreement of new benchmarks. Category (B) may be applied immediately, because the proposals remain within the scope of responsible application of the existing Annex 13.

## **1. Weather dependent load assumptions for cargo securing**

A reduction of load assumptions for navigating in restricted areas, accounting for the season of the year and the weather forecasts for the intended voyage, has been facilitated in principle in the Annex 13, but not explicitly specified. The need for a unified interpretation does not only result from a desirable cost reduction for cargo securing but also from occasional shipments of cargo units which are too sensitive against full scale accelerations and therefore require moderate transport conditions. Restricted sea areas or benign condition weather windows are generally distinguished by a less heavy seaway.

## 1.1 Significant wave height

The actual seaway in a specified area is usually denoted by the oceanographic term "significant wave height" with the acronym  $H_S$ . Figures of  $H_S$  are usually part of ocean and coastal weather forecasts for relevant sea areas and for the time span of one or more days.  $H_S$  is a statistical measure of wave height in a given wave spectrum and corresponds closely to the arithmetical mean of the upper third of wave heights in that spectrum. It further coincides fairly well with the prominent wave height estimated by an experienced local observer. The mathematical definition of  $H_S$  implies, that

- 13.5% of all waves in the actual spectrum are higher than  $H_S$ ,
- 1% of all waves are higher than  $1.5 \cdot H_S$ ,
- 0.03% of all waves are higher than  $2 \cdot H_S$ ,
- 0.01% of all waves are higher than  $2.15 \cdot H_S$ ,
- waves higher than  $2.2 \cdot H_S$  are classified as freak waves related to the actual  $H_S$ .

## 1.2 Long-term statistics

Another more long-term description of seaway conditions in a specified area is the so-called 20-year significant wave height. This height is much greater than the usual day to day figures of  $H_S$ . It is a theoretical construct, derived from long term observations, and denotes a significant wave height that will be exceeded only once within 20 years in this area. Thus the 20-year significant wave height may be used as a yardstick to compare different sea areas in terms of general seaway severity. Examples of 20-year significant wave heights are:

North Atlantic Ocean:  $H_S^{20\text{year}} = 19.6 \text{ m}$

Mid North Sea:  $H_S^{20\text{year}} = 11.9 \text{ m}$

Baltic Sea:  $H_S^{20\text{year}} = 8.5 \text{ m}$

The 20 year significant wave height of 19.6 m on the North Atlantic has been confirmed by repeated measurements of significant wave heights of this magnitude during the last years, results that have been published by the Danish Meteorological Institute DMI.

## 1.3 Significant wave heights assigned to offshore operations

The increase of off-shore marine operations and sensitive ocean shipments during the past decades has gone along with research and wave data collection. One outcome of this effort is a calculation tool that permits to determine a probability based significant wave height for operational purposes. The results are available for a large repertory of sea areas and for an optional number of operation days in that area. This tool is published by DNV-GL in the standard DNV-GL-ST-N001.

The figures of significant wave heights obtained by this calculation tool do not necessarily coincide with those from meteorological institutes because they are matched to vessel response and allowable stress design in the first place, but they might be as well used as parameters in a unified interpretation of the allowance made by the Annex 13.

Area 5 Baltic sea	$H_S^{20\text{year}} = 8.1 \text{ m}$	Area 15 Newfoundland	$H_S^{20\text{year}} = 15.8 \text{ m}$
Area 8 South of Greenland	$H_S^{20\text{year}} = 16.3 \text{ m}$	Area 16 West of Biscay	$H_S^{20\text{year}} = 16.3 \text{ m}$
Area 9 West of Ireland	$H_S^{20\text{year}} = 16.0 \text{ m}$	Area 17 Bay of Biscay	$H_S^{20\text{year}} = 16.0 \text{ m}$
Area 10 South of Ireland	$H_S^{20\text{year}} = 15.0 \text{ m}$	Area 24 Western Atlantic	$H_S^{20\text{year}} = 15.5 \text{ m}$
Area 11 Greater North Sea	$H_S^{20\text{year}} = 16.0 \text{ m}$	Area 25 West of Gibraltar	$H_S^{20\text{year}} = 13.1 \text{ m}$

An extract of the world map shows the reference numbers of sea areas.

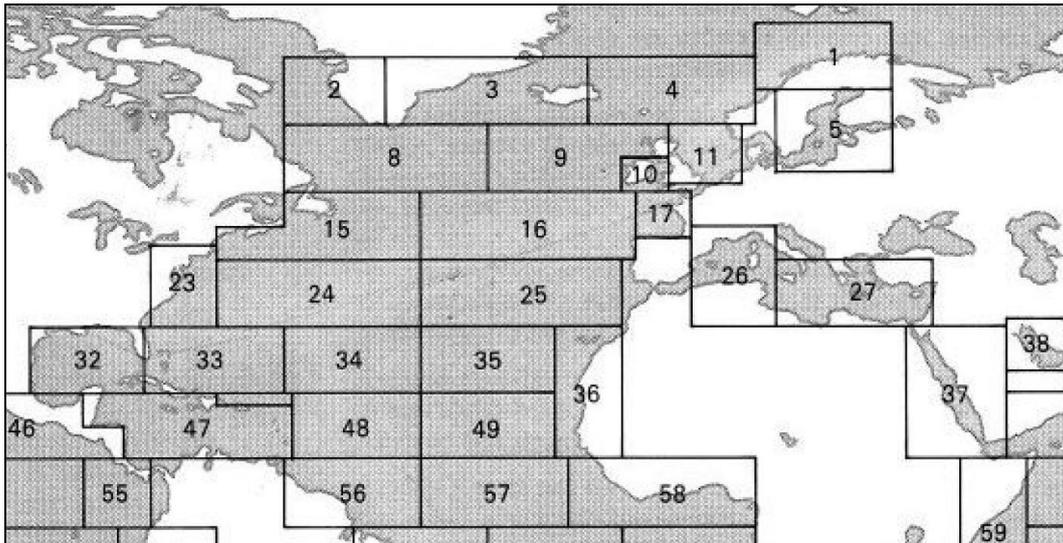


Figure 1.1: Extract of the world map of sea areas

#### 1.4 Reduction of acceleration figures in moderate sea conditions

Although the Annex 13 offers a possible reduction of acceleration assumptions explicitly for operation in a restricted area, this must not necessarily be understood only in a geographic sense but should include time limited operation in a moderate sea state anywhere in the world. Then the predicted significant wave height may be the only essential parameter.

There are presently two different reduction models available. Both models provide a reduction factor for the accelerations when entering with the parameter  $H_M$ , which is the greatest of all predicted significant wave heights  $H_S$  along the intended sea passage.

The first model has been introduced in 1993 in Sweden as a national tool and later in 2011 included into the revised IMO Code of Safe Practice for Ships Carrying Timber Deck Cargoes (TDC Code). This model is also the basis for the acceleration levels presented for different sea area in the IMO/ILO/UNECE Guidelines for Packing of Cargo Transport Units from 1997 and also in the revised IMO/ILO/UNECE Code of Practice for Packing of Cargo Transport Units (CTU Code) from 2014.

The second model has been developed by the International Association of Classification Societies (IACS) in 2013 in the aftermath of the Lashing@Sea project. It has been based on measurements of accelerations on different vessels in identified sea states and on theoretical vessel response models.

The **Swedish reduction model** is represented by the formula for the reduction factor  $f_R$ .

$$f_R = \sqrt[3]{\frac{H_M}{19.6}}$$

The constant 19.6 in this formula denotes the height of the twenty year significant wave in the Northern Atlantic Ocean. Figure 1.3 shows the graph of the formula together with numerous points of sample reduction factors showing the relations of measured accelerations to the calculated Annex 13 acceleration level.

The vast majority of measurements has been collected in sea states with  $H_S$ -values not greater than 8 metres. There were, however, a few observations in greater wave heights. This may be explained by the limited number of ships operating in greater wave heights and by today's weather routing which enables to avoid such areas.

The Swedish model has been successfully used, not only by Swedish flagged vessels, in the Baltic and North Sea shipping, particularly in ro-ro-ships and ferries with semi-standardised stowage and securing systems, and also in the Baltic timber trade. In lack of other models for

reducing the accelerations to a reasonable level in modern shipping the model has been accepted by most Maritime Administrations and Classification Societies.

The **IACS reduction model** is represented by the formula:

$$f_R = 0.3 + 0.1 \cdot H_M \quad \text{with } f_R \leq 1.0$$

This means there is no reduction, if the significant wave height is equal to or greater than 7 metres, while 0.3 will be the minimum reduction factor. Full scale measurements in sea states with significant wave heights of up to 7 metres appear to justify a more stringent reduction policy than offered by the Swedish model. This applies mainly for sea states with significant wave heights of more than 5 metres.

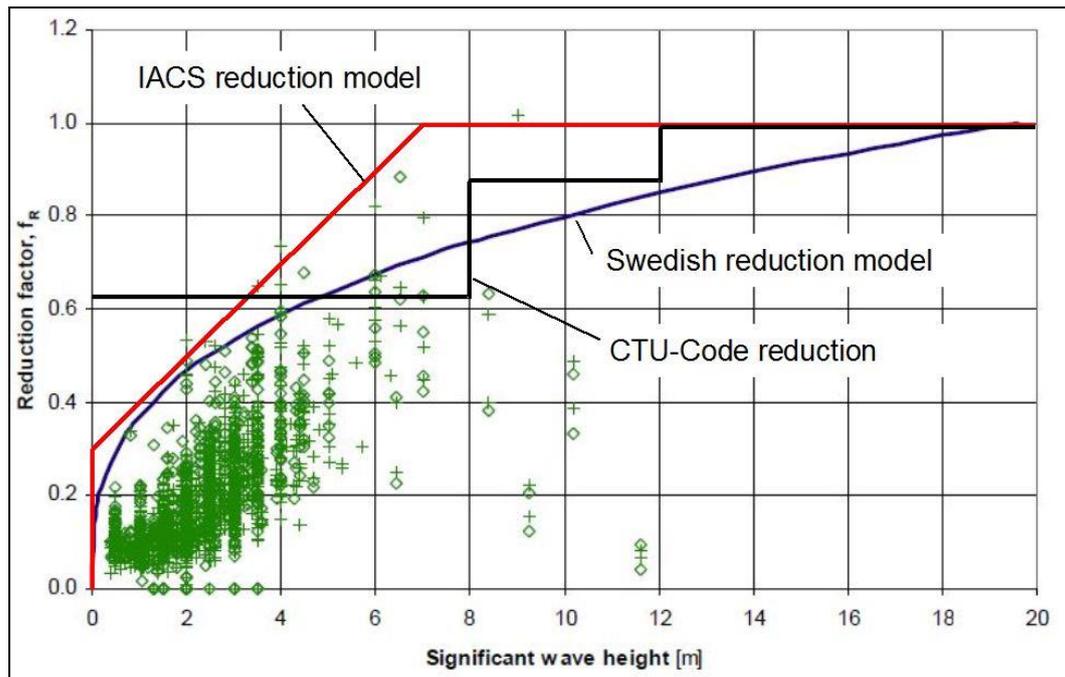


Figure 1.2: Swedish reduction model, IACS reduction model and CTU requirements

### 1.5 Unified interpretation of the "reduction clause" in the Annex 13

The utilisation of a reduction factor would be simply its multiplication with the specific longitudinal, transverse and vertical forces obtained from the Annex 13 tables. The subsequent balance calculations for the prevention of sliding or tipping of the cargo unit in question would be satisfied with correspondingly less securing effort.

Another practical application of the reduction factor would be the preparation of tables or diagrams for a distinguished vessel in its Cargo Securing Manual. Such tables or diagrams would show the necessary securing effort in different stowage positions in the vessel, depending on the forecasted sea state in terms of significant wave height. This practice has been employed successfully for many years in the Baltic and North Sea trades.

At the time being it is still open, which of the two models or what compromise solution may be given the IMO recommendation status in the form of a unified interpretation of the reduction clause in the Annex 13. Whatever model is used, the essential parameter  $H_M$  should be specified in terms of reliability, which may be made dependent on the prediction period and/or possible ports of refuge underway.

One possible solution may be to distinguish different modes of cargo transport according to the following:

1. The assumed accelerations shall be taken from the Annex 13.

2. The assumed accelerations may be reduced using the Swedish (TDC) model for vessels with standardized (excluding containers) and semi-standardized stowage and securing systems as well as for vessels carrying timber deck cargoes.
3. For vessels carrying cargoes in a non-standardise mode of transport the assumed accelerations may be reduced according to the IACS model.

This solution should be complemented by a definition of the positive properties of standardised and semi-standardised stowage and securing systems in order to guarantee the appropriate world-wide application. Good Cargo Securing Manuals will contain this already.

## 2. Speed reduction in head seas as accepted operational parameter

The present Annex 13 requires to assume the full nominal service speed of the vessel for assessing external forces to the cargo. There are situations however, where the sensitivity of certain cargo units or the restricted feasibility of securing measures limit the endurable forces. Therefore it seems advisable to include a deliberate speed reduction, exclusively in head seas, into the operational parameters. That means in clear words that speed reduction would become a legal measure of cargo securing which should be specified and approved in the ship's Cargo Securing Manual, as has been practiced by certain flag states already. In general, this measure may be limited to distinguished cargoes like timber on deck or pipes on deck or to unusual and sensitive cargo items.

The problem of securing against longitudinal sliding and tipping arises predominantly in stowage positions at the forward and aft parts of the vessel and increases with the vertical level of stowage. The mathematical model of ship behaviour in the Annex 13 assigns a gentle random influence of the speed of the vessel on the magnitude of forces. Lower speed means a certain reduction of all forces. In the case of longitudinal securing a twofold relief is obtained by speed reduction, namely the direct drop of longitudinal forces and the drop in temporary loss of weight. This provides a better friction or a better tilting stability than with high speed.

Another possible revision of the Annex 13 regards the worst case approach within the longitudinal sliding and tipping balances. This is addressed in chapter 5 below and may justify a modification of the assumed weight reduction by 80% of  $F_z$ , concurrent with the maximum longitudinal force  $F_x$ .

Experience has indeed shown that certain cargoes, where longitudinal securing is difficult, like timber or pipes on deck, do not move longitudinally in head-on sea, if the vessel's speed is reduced accordingly, a fact which cannot be reflected by the present Annex 13 calculation model. The following example demonstrates the modelled effect of a speed reduction and of the modified weight reduction.

**Example:** The demand of longitudinal securing of a distinguished cargo unit is checked with two different ship's speeds according to the algorithm of the Annex 13. Ship:  $L_{pp} = 160$  m. Cargo:  $m = 100$  t, stowed on deck low at  $0.8 L$ , cargo dimensions  $l \times b \times h = 10 \times 8 \times 4$  m.

### Service speed $v = 18$ kn

$$F_x = 2.9 \cdot 0.82 \cdot 100 + 48 = 286 \text{ kN} \quad (48 \text{ kN} = \text{impact forces from wind and spray})$$

$$F_z = 7.6 \cdot 0.82 \cdot 100 = 623 \text{ kN}$$

$$\begin{aligned} \text{Longitudinal securing demand} &= F_x - \mu \cdot (m \cdot g - F_z) \\ &= 286 - 0.3 \cdot (100 \cdot 9.81 - 623) = \mathbf{179 \text{ kN}} \end{aligned}$$

### with 80% vertical force $F_z$ :

$$\begin{aligned} \text{Longitudinal securing demand} &= F_x - \mu \cdot (m \cdot g - 0.8 \cdot F_z) \\ &= 286 - 0.3 \cdot (100 \cdot 9.81 - 498) = \mathbf{141 \text{ kN}} \end{aligned}$$

**Reduced speed  $v = 12$  kn**

$$F_x = 2.9 \cdot 0.65 \cdot 100 + 48 = 237 \text{ kN}$$

$$F_z = 7.6 \cdot 0.65 \cdot 100 = 494 \text{ kN}$$

$$\begin{aligned} \text{Longitudinal securing demand} &= F_x - \mu \cdot (m \cdot g - F_z) \\ &= 237 - 0.3 \cdot (100 \cdot 9.81 - 494) = \mathbf{91 \text{ kN}} \end{aligned}$$

**with 80% vertical force  $F_z$ :**

$$\begin{aligned} \text{Longitudinal securing demand} &= F_x - \mu \cdot (m \cdot g - 0.8 \cdot F_z) \\ &= 237 - 0.3 \cdot (100 \cdot 9.81 - 0.8 \cdot 494) = \mathbf{61 \text{ kN}} \end{aligned}$$

The longitudinal securing demand drops to about 34% by a speed reduction of 1/3 in this case and with the modified weight reduction. But there is no simple rule about this relation because of the various influences from stowage position and impact forces to deck cargo. Each case must be investigated individually. An amendment to the Annex 13 in paragraph 7.1 under the Table 3 might read:

*Table 3 should be entered with the full service speed in principle. However, for cargoes with a particular sensitivity against vertical accelerations in head seas or for which longitudinal securing creates substantial difficulties, a deliberate reduction of speed in head seas may become part of the longitudinal securing concept. Such cargoes and the appropriate parameters and evidence procedures of speed reduction should be specified in the ship's Cargo Securing Manual.*

**3. Vessel survival criteria in case of a major cargo shift**

There have been innumerable ship losses and near losses due to a major cargo shift. Thus it suggests itself that well established regulations are in place for avoiding such accidents with cargoes where the risk of shifting is evident, like fine-grained bulk cargoes. For other solid cargoes such regulations do not exist and any regulations on intact stability are based on the assumption that the cargo does not move during the voyage.

However, severe accidents with total shift of the cargo onboard Ro-Ro vessels have produced considerable heeling angles which disabled the ship and finally caused sinking. Therefore the Lashing@Sea consortium has proposed to evaluate a total cargo shift criterion for cases where cargo securing shall be deliberately reduced according to favourable environmental conditions. The evaluation should be guided by the ship's Cargo Securing Manual and ensure the compliance with specific criteria, before the reduced securing arrangement is accepted.

Possible arguments against such a safeguarding may refer to the basic aim of the CSS-Code, which is to avoid shifting of cargo in the first place, and express the inherent fear that the fulfilment of a survival criterion might lead to conceding a higher risk of shifting. This would be indeed unacceptable with the carriage of dangerous goods. On the other hand, weather dependent securing of cargo has been practiced for years and the application of a survival criterion for certain ships should be looked at as an additional and valuable safety measure. The accommodation of such a survival criterion in an appropriate Code should be left to the decision of IMO bodies.

The evaluation of a total cargo shift incident should be based on the assumption that all cargo units on board move to one side until they are packed tightly to each other without any void space in between. For this ultimate condition the curve of the total heeling levers should be drawn and intersected with the currently actual curve of righting levers. The intersection shows the static heeling angle and the residual righting levers used for the compliance assessment.

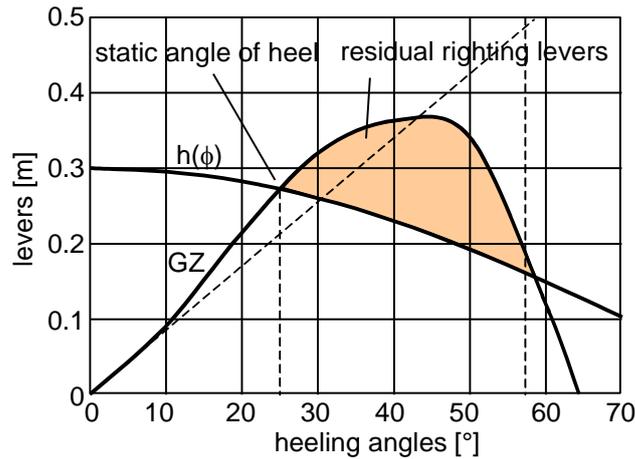


Figure 3.1: Heeling levers  $h(\phi)$  versus righting levers GZ

The curve of the total heeling lever follows the function

$$h(\phi) = \frac{M_0}{DISM} \cdot \cos \phi \text{ [m]}$$

$h(\phi)$  = heeling levers [m]

$M_0$  = total heeling moment at  $\phi = 0^\circ$  [t·m]

DISM = actual mass displacement [t]

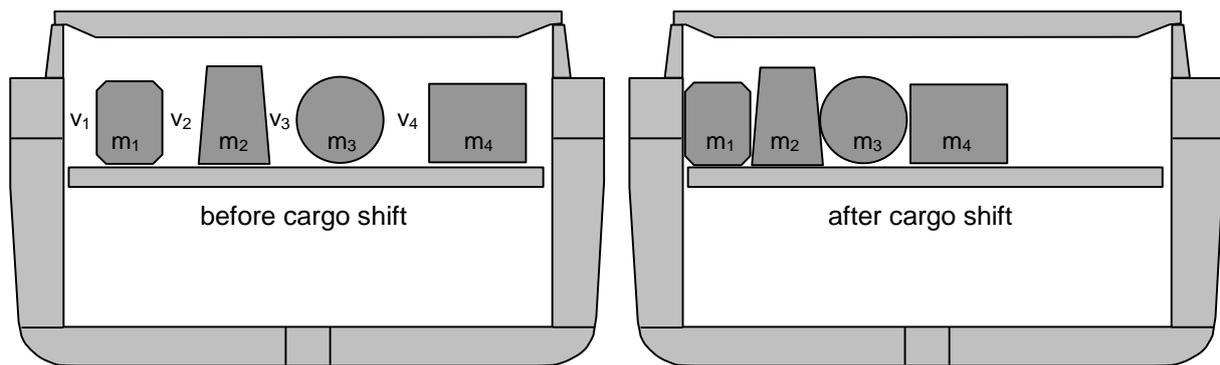


Figure 3.2: Heeling moment from shifting of break bulk cargo

The total heeling moment  $M_0$  is the sum of the sectional heeling moments in all cargo sections of the vessel. The sectional moment in Figure 3.2 is obtained by:

$$M_{\text{section}} = m_1 \cdot v_1 + m_2 \cdot (v_1 + v_2) + m_3 \cdot (v_1 + v_2 + v_3) + m_4 \cdot (v_1 + v_2 + v_3 + v_4) \text{ [t·m]}$$

In **Ro-Ro vessels**, where the mass of cargo with intermediate voids is fairly homogeneously spread over the width  $b$  of cargo spaces, the shifting distance  $d$  of the common cargo centre of gravity is obtained by the approximation:  $d = b/2 - (b - v)/2 = v/2$ .

The sectional heeling moment is then:

$$M_{\text{section}} = \frac{m \cdot v}{2} \text{ [t·m]}$$

$m$  = mass of all cargo units in a particular section [t]

$b$  = width of cargo space [m]

$v$  = sum of all transverse voids [m]

The following **functional issues** should be considered before accepting the pre-calculated heeling angle:

- On-board systems getting out of order at the obtained heeling angle.

- Openings on board being submerged at the obtained heeling angle.
- Possible measures to save human lives, the ship and the cargo.

The following **stability criteria** should be fulfilled immediately after the heel has been obtained and before any counter-ballasting measures are taken:

1. The static angle of heel after a total cargo shift shall not exceed 25°. This may be increased to 30° if the deck edge is not submerged.
2. The righting lever GZ has at least 20° positive range beyond the static angle of heel.
3. The maximum GZ reaches at least 0.1 m within 10° beyond the static angle of heel.

The following **stability criteria** should be fulfilled after counter-ballasting measures are completed:

1. The static angle of heel shall not exceed 15°. This may be increased to 17° if the deck edge is not submerged.
2. The righting lever GZ has at least 35° positive range beyond the static angle of heel.
3. The maximum GZ reaches at least 0.2 m within 20° beyond the static angle of heel.
4. The area between the heeling lever curve and the righting lever curve beyond the static angle of heel shall be at least 0.075 m·rad.

The necessary computations for obtaining the total heeling moment and the parameters of residual stability may be facilitated by suitable computer software associated to the on-board stability computer.

#### 4. Additional tipping moment due to the rotational inertia of cargo units

The mathematical model used in the Annex 13 for assessing the suitability of a securing arrangement describes a physical cargo unit by its mass concentrated in its centre of gravity. This is fairly accurate as long as the spatial dimensions of the unit remain below about 10 metres. Any tipping moment will then be determined by the vertical distance of this centre of gravity to the edge of the footprint, i.e. the tipping axis of the unit. Larger units, however, will develop a substantial additional tipping moment by their rotational inertia against the rotational acceleration of the ship in rolling or pitching motions. This additional threat should be included into tipping balances for extra large cargoes by a simple algorithm.

The ordinary transverse tipping moment  $M_y$ , analogous to the algorithm of the Annex 13, but without the contribution of wind and spray forces, reads:

$$M_y = m \cdot [(g + a_z) \cdot \sin \phi + z \cdot \ddot{\phi}] \cdot a \quad [\text{kN}\cdot\text{m}]$$

In this simple approach the mass  $m$  is concentrated in the centre of gravity of the cargo item. The real spatial mass distribution requires the compilation of infinitesimal mass elements with their individual distances from the centre of gravity. This is indicated in Figure 3.1. The differential tipping moment  $dM_y$  of each infinitesimal mass element  $dm$  reads:

$$dM_y = [(g + a_z) \cdot \sin \phi \cdot (a + e) + (z + e) \cdot \ddot{\phi} \cdot (a + e) + f \cdot \ddot{\phi} \cdot (b + f)] \cdot dm \quad [\text{kN}\cdot\text{m}]$$

The integration of all differential tipping moments over the full mass  $m$  of the cargo item with  $g$ ,  $a_z$ ,  $z$ ,  $a$ ,  $b$  as constants and  $e$ ,  $f$  as variables results in the true tipping moment:

$$M_y = \underbrace{m \cdot [(g + a_z) \cdot \sin \phi + z \cdot \ddot{\phi}] \cdot a}_{\text{ordinary tipping moment}} + \underbrace{\ddot{\phi} \cdot \int (i^2 \cdot dm)}_{\text{additional tipping moment}} \quad [\text{kN}\cdot\text{m}]$$

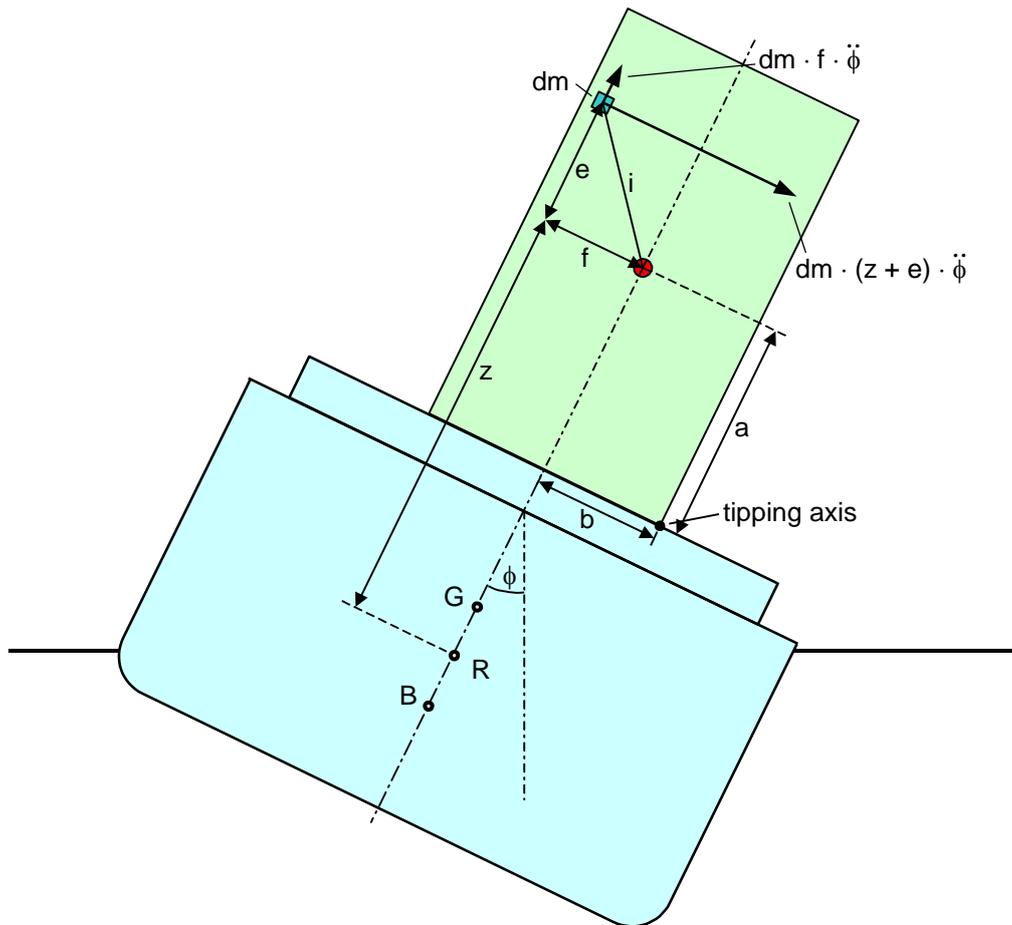


Figure 4.1: Integration of differential mass moments

The additional tipping moment is independent from the position of the tipping axis and the level of stowage in the ship. The figures of a and z have no influence.

The term  $\int(i^2 \cdot dm)$  represents the rotational moment of inertia J about an axis through the centre of gravity. Its numerical value is measured in  $t \cdot m^2$ . It should be provided by the manufacturer of the cargo unit about the longitudinal axis (rolling) and the transverse axis (pitching). However, these data are generally not available and may be approximated.

For a box-shaped unit of the length l, width w, height h and homogeneous mass distribution the rotational moment of inertia about an axis through the centre of gravity is:

For rolling: 
$$J = m \cdot \left( \frac{w^2 + h^2}{12} \right) [t \cdot m^2]$$

For pitching: 
$$J = m \cdot \left( \frac{l^2 + h^2}{12} \right) [t \cdot m^2]$$

The rotational accelerations for seagoing ships may be approximated as follows:

For rolling: 
$$\ddot{\phi} = \frac{36 \cdot GM}{B^2} [s^{-2}] \quad (GM \text{ and } B \text{ entered in metres})$$

For pitching: 
$$\ddot{\psi} = \frac{24}{L_{pp}} [s^{-2}] \quad (L_{pp} \text{ entered in metres})$$

m = mass of cargo unit [t]  
 dm = mass element of cargo unit [t]  
 g = gravity acceleration [ $m/s^2$ ]

$a_z$  = temporary vertical acceleration, which virtually increases the gravity [ $m/s^2$ ]

$\phi$  = roll amplitude [rad]

$z$  = vertical distance of cargo centre of gravity from roll axis of vessel [m]

$a$  = tipping lever [m]

$e$  = vertical distance of mass element from axis through centre of gravity [m]

$f$  = transverse distance of mass element from axis through centre of gravity [m]

$i$  = direct distance of mass element from axis through centre of gravity [m]

$J$  = rotational moment of inertia [ $t \cdot m^2$ ]

$GM$  = metacentric height of the ship [m]

$B$  = breadth moulded of the ship

$L_{pp}$  = length between perpendiculars of the ship [m]

$l$  = length of cargo unit [m]

$w$  = width of cargo unit [m]

$h$  = height of cargo unit [m]

$\ddot{\phi}$  = maximum rotational acceleration of the vessel from rolling [ $s^{-2}$ ]

$\ddot{\psi}$  = maximum rotational acceleration of the vessel from pitching [ $s^{-2}$ ]

**Example:** A huge piece of structural framework of 125 t and the dimensions  $l = 5$  m,  $w = 7$  m and  $h = 14$  m is loaded on the hatch top of a heavy lift vessel (Figure 3.2). Vessel data are  $L_{pp} = 128$  m,  $B = 22.5$  m,  $GM = 2.8$  m. The additional tipping moments  $M_{add}$  are:

About the longitudinal axis (rolling):

$$M_{add} = \frac{36 \cdot GM}{B^2} \cdot m \cdot \frac{w^2 + h^2}{12} = \frac{36 \cdot 2.8}{22.5^2} \cdot 125 \cdot \frac{7^2 + 14^2}{12} = 508 \text{ kN}\cdot\text{m}$$

About the transverse axis (pitching):

$$M_{add} = \frac{24}{L_{pp}} \cdot m \cdot \frac{l^2 + h^2}{12} = \frac{24}{128} \cdot 125 \cdot \frac{5^2 + 14^2}{12} = 432 \text{ kN}\cdot\text{m}$$

## 5. Balance of longitudinal sliding and tipping

There is no doubt among experts that longitudinal and vertical accelerations may coincide with their maximum values on a vessel, because both are direct results of heaving and pitching motions in head-on seas. But their phase relation needs some consideration.

The present calculation method in the Annex 13 requires to assume the most critical phase relation with a full longitudinal force and a full negative (upward) vertical force. The upward vertical force reduces the weight of the cargo and causes thereby the unfavourable reduction of friction as well as reduction of tilting stability of the cargo. This increases the necessary longitudinal securing effort, particularly in stowage positions at the ends of the vessel, where vertical forces are substantial. This approach bears a contradiction, because the full longitudinal force incorporates the deck-parallel component of a full positive (downward) force, which is not there at this phase of motion by definition. The inherent error may be roughly corrected, if only 80% of the calculated vertical (upward) force were deducted from the cargo weight in a balance calculation. This would lead to an slightly modified balance of longitudinal sliding.

$$F_{x \leq} \mu \cdot (m \cdot g - 0.8 \cdot F_z) + CS_1 \cdot f_1 + CS_2 \cdot f_2 + \dots + CS_n \cdot f_n \text{ [kN]}$$

The assessment of the risk of longitudinal tipping to forward or aft is not explicitly lined out in the present Annex 13. The authors at that time were of the opinion that cargo tipping is a subordinate risk in general compared to the risk of sliding and where relevant, transverse tipping would occur in the first place. This is still true, but there are increasingly shipments of odd shaped cargo items, which may tip also longitudinally. Therefore this balance should be included into the Annex 13.

The same principle of coincidence of longitudinal and vertical forces must be adopted for a balance of longitudinal tipping. The tipping balance formula accordingly reads:

$$F_x \cdot a \leq b \cdot (m \cdot g - 0.8 \cdot F_z) + CS_1 \cdot c_1 + CS_2 \cdot c_2 + \dots + CS_n \cdot c_n \quad [\text{kN}\cdot\text{m}]$$

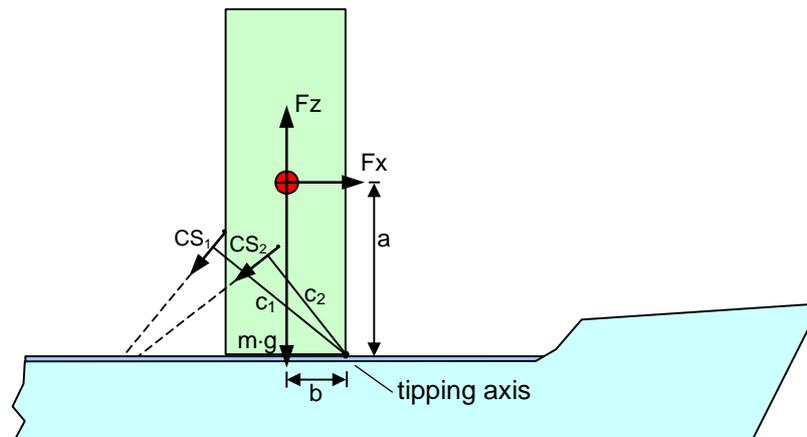


Figure 5.1: Balance of longitudinal tipping to forward

## 6. Interpretation of "on deck high"

The higher the level of stowage above the waterline of a vessel the greater are the expected longitudinal and transverse forces to a cargo item. The desired handiness of the Annex 13 securing assessment method and its applicability to a certain range of ship sizes had caused the introduction of four distinguished stowage levels instead of using the specific vertical position of the cargo unit in question. While the stowage levels "lower hold", "tween deck" and "on deck low" are easy to identify by users, the level of "on deck high" has quite often provoked disputes among parties.

With extremely large cargo items the category "on deck high" appears to be ambiguous. In order to avoid uncertainties in the determination of transverse and longitudinal accelerations in such cases, it is recommended, to use the original mathematical model, which has been the basis for the Annex 13 acceleration tables. This model may be less convenient to use, but is worth to be programmed, e.g. in a suitable spread sheet. Classification societies are prepared to assess and certify such programs. An outline of the relevant mathematical model is shown below and should be included in an appendix to the Annex 13.

The longitudinal, transverse and vertical accelerations acting on a cargo unit may be obtained alternatively by the set of formulas as follows:

$$a_x, a_y, a_z = c_1 \cdot c_2 \cdot c_3 \cdot (a_{x0}, a_{y0}, a_{z0}) \cdot g \quad [\text{m/s}^2]$$

$a_x$ : longitudinal acceleration (gravity component of pitch included)

$a_y$ : transverse acceleration (gravity component of roll included)

$a_z$ : vertical acceleration (component due to static weight not included)

$c_1$ : correction factor for navigation area, taken as 1.0 = worldwide in the Annex 13

$c_2$ : correction factor for season, taken as 1.0 = whole year in the Annex 13

$c_3$ : correction factor for 25 navigation days,  $c_3 = 0.6 + 0.1 \cdot \log_{10}25 = 0.74$  in the Annex 13

$$a_{x0} = \pm a_0 \cdot \sqrt{0.06 + A^2 - 0.25 \cdot A}$$

$$a_{y0} = \pm a_0 \cdot \sqrt{0.6 + 2.5 \cdot \left(\frac{x}{L} + 0.05\right)^2 + K \cdot \left(1 + 0.6 \cdot K \cdot \frac{z}{B}\right)^2}$$

$$a_{z0} = \pm a_0 \cdot \sqrt{1 + \left(5.3 - \frac{45}{L}\right)^2 \cdot \left(\frac{x}{L} + 0.05\right)^2 \cdot \left(\frac{0.6}{C_b}\right)^{3/2}}$$

therein:

$$a_0 = 0.2 \cdot \frac{v}{\sqrt{L}} + \frac{34 - 600/L}{L}$$

$$A = \left( 0.7 - \frac{L}{1200} + \frac{5 \cdot z}{L} \right) \cdot \left( \frac{0.6}{C_b} \right)$$

$$K = \frac{13 \cdot GM}{B}, \text{ but never less than } 1.0$$

L = length of ship [m] ( $L_{pp}$  in the Annex 13)

B = breadth of ship [m] (moulded breadth in the Annex 13)

GM = metacentric height of the vessel [m]

$C_b$  = block coefficient of ship

x = longitudinal distance from amidships to calculating point, positive forward [m]

z = vertical distance from actual waterline to calculating point, positive upward [m]

v = service speed [knots]

g = gravity acceleration = 9.81 m/s<sup>2</sup>

Length Lpp [m]	137,00	$a_0 =$	0,498	
Breadth moulded B [m]	22,60	K =	1,381	
Service speed v [knots]	16,50	X =	27,50	m
Metacentric height GM [m]	2,40	Z =	9,90	m
Mean draught Tm [m]	7,90	A =	0,812	
CB	0,70	$a_x =$	2,598	m/s <sup>2</sup>
Cargo LCG [m]	96,00	$a_y =$	6,590	m/s <sup>2</sup>
Cargo VCG [m]	17,80	$a_z =$	5,404	m/s <sup>2</sup>

Figure 6.1: Sample spread sheet

The sample spread sheet in Figure 6.1 consists of the essential entry data in the green boxes on the left side and the three accelerations on the right side. The sheet can be easily expanded by entering the cargo mass and the cargo dimensions (for deck cargo only) and to show results in terms of forces including the effects of wind and spray.

The example presents a cargo unit that is stowed on the hatch top with VCG = 17.8 m above the ship's keel (base). This is equivalent to about 4 metres above the stowage ground on the hatch and therefore somewhere between "on deck low" and "on deck high".

## 7. Separate consideration of wind moment in tipping balances

In the present Annex 13 horizontal weight components, inertia forces and wind/spray forces to a deck cargo, for reasons of simplification, are combined as acting in the centre of gravity of the cargo item. This is correct for the balance of sliding, however an approximation only for the balance of tipping. Particularly high deck cargo units with their major wind exposed area well above the centre of gravity should be given a separate compilation of moments from wind forces, spray forces and gravity/inertia forces in order to get a more realistic tipping moment. This option should be included in the Annex 13 by an amendment in its paragraph 7 as follows:

*The tipping moment of high deck cargo units with a centre of wind attack deviating from the centre of gravity should be determined by compilation of the individual moments from gravity/inertia, wind and sea-sloshing.*

**Example:** Figure 7.1 relates to the shipment of a huge portal harbour crane. The crane is shown in the ship-longitudinal view. The centres of attack by wind and spray deviate remarkably from the centre of gravity. A compilation of the individual tipping moment reads:

	<b>F<sub>x</sub></b>	<b>a</b>	<b>F<sub>x</sub> · a</b>
gravity/inertia	1373 kN	13.0 m	17849 kN·m
wind	170 kN	20.0 m	3400 kN·m
spray	4 kN	1.0 m	4 kN·m
<b>Total</b>	<b>1547 kN</b>		<b>21253 kN·m</b>

The conventionally computed tipping moment would be only:

<b>Total</b>	<b>1547 kN</b>	<b>13.0 m</b>	<b>20111 kN·m</b>
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The surplus against the conventional tipping moment is about 6% in this example.

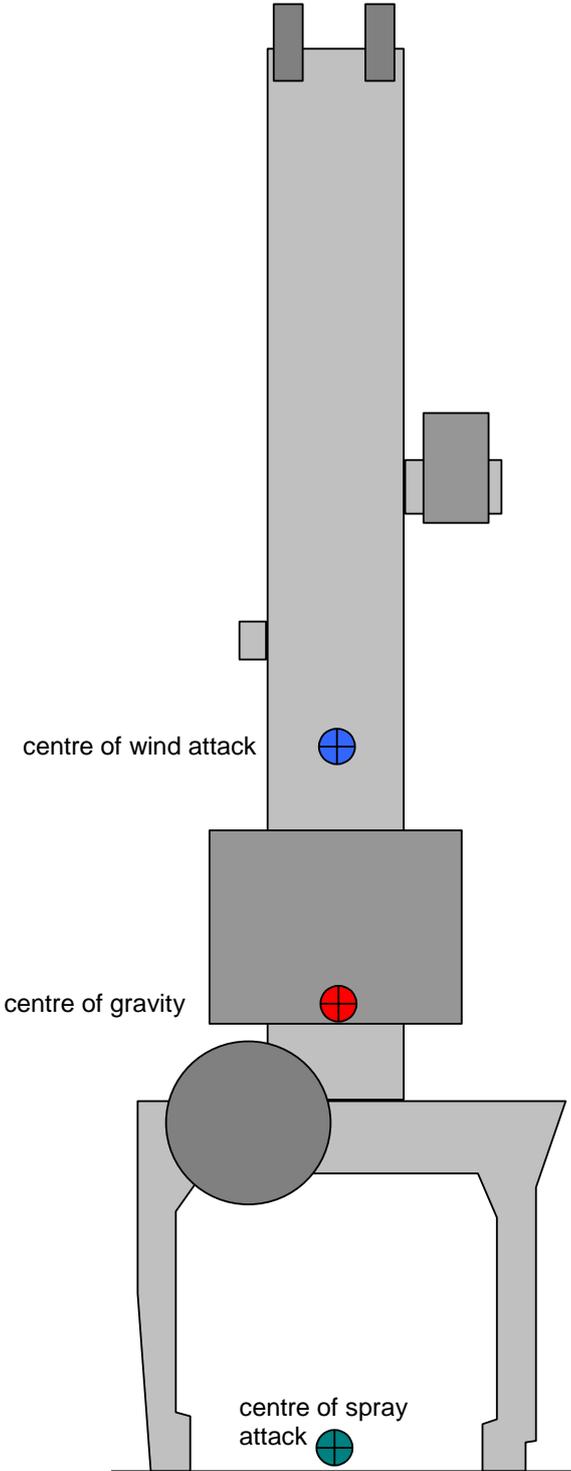


Figure 7.1: Tipping moment from impact forces and weight/inertia forces

## 8. Homogeneity of securing arrangements

The Annex 13 assigns strength capacity values to securing elements and materials by declaring the "maximum securing load" (MSL) as a percentage of the nominal breaking strength. However, these MSL figures shall be reduced by a safety factor, in order to get the so-called "calculation strength" (CS) when used in a balance calculation. The reason for this reduction is, in the first place, the risk of inhomogeneous distribution of forces among securing devices when it comes to the assumed extreme load case. This is an effective safeguard against overloading individual securing devices.

It appears nowadays, that increasingly fibre belts are used to secure heavy cargo units. These fibre belts have an allowable elastic elongation of 7% when loaded to their MSL. This is much more than the elastic elongation of wire rope lashings (about 1.6%), long link chains (about 1%) or short link chains (about 1,5%). The elastic deformation of welded stoppers or steel stanchions for the carriage of pipes on deck would be even less than that.

The combination of fibre belts with chains or moreover, the combination of fibre belts with welded stoppers may create a securing arrangement that is extremely inhomogeneous, in that the more stiff securing devices have to take the "lion-share" of the load. This will no longer be compensated by the above mentioned safety factor. The Annex 13 should therefore be amended by an appropriate warning under its paragraph 6 as follows:

*If securing devices of diverse elasticity are used in parallel, e.g. welded stoppers and fibre belts or steel stanchions and long wire lashings, the stiff devices, i.e. the stoppers or the stanchions in the above examples, must be able to keep the cargo in place alone. The more flexible securing devices in such an arrangement should be excluded in a sliding balance calculation or be taken into account in the tipping balance only.*