Safe Carriage of Ore Concentrates in Double Hull Bulkers

Walter Abicht, TU Hamburg-Harburg[1]

1. Introduction

In January 1966, the MS "Kremsertor" capsized on her voyage to Bremen in the English Channel. The accident occurred eleven days after the vessel had left the port of Novorossijsk, with iron ore concentrate as cargo, just after it had passed the Bay of Biscay in stormy weather.

The casualty was investigated by Prof. Wendel and his associate *Arndt (1966)*. It was found that, after an upward migration of moisture, upper parts of the cargo liquefied, causing progressive cargo shifting and, finally, capsizing of the vessel.

The investigation received notice in Germany as well as at IMO and evoked activities to improve the rules for the shipment of bulk cargo which may liquefy. The first edition of the "Code of safe practice for solid bulk cargoes" (BC Code) was published by IMO in 1965. In the following years, several amendments were made. Nevertheless, the present situation is still unsatisfactory.

In the current version of the bulk carrier code, the mean moisture of a concentrate cargo is taken as a criterion to indicate whether liquefaction is to be expected or not. Other important factors, as ship motions in waves, vibrations, migration of moisture during the voyage, duration of voyage etc. are ignored. Obviously, without observing these additional influences, a reliable prediction cannot be made. Unfortunately, up to now, a better criterion does not exist. Because it is doubtful whether such a criterion – suitable for practical use – can be established, ore concentrate cargo should be generally regarded as liquid. In my opinion, it is more practical to develop an economically efficient bulker design with sufficient stability even if the cargo has totally or partly liquefied, than to try to improve the liquefaction criterion.

The idea for the proposal presented here came during the investigation of the capsizing of the barge-pusher unit "Finn-Baltic". The vessel capsized after downward migration of moisture and shifting of the iron ore concentrate cargo in December 1990 in the Baltic Sea.

2. Existing rules for the shipment of ore concentrates

The relevant rules in the IMO BC code, intended to prevent capsizing due to liquefaction of cargo, are based on the assumption that liquefaction will not occur if the cargo moisture – measured prior to loading – does not exceed the "transportable moisture limit" (TML). TML is defined as 90% of the "flow moisture point" (FMP). FMP indicates the percentage of moisture at which the material starts to flow in a plastic manner when vibrated. The FMP is determined in tests with representative samples of the material. The test procedures are described in detail in the BC Code.

Materials having a higher moisture content must be carried either in cargo ships fitted with specially designed portable divisions or in specially constructed cargo ships with permanent structural boundaries. If TML is not exceeded, no measures must be taken.

These rules are rather ineffective. The reasons for this judgement are:

- For the behavior of the cargo during the voyage several factors are of importance. It is impossible to predict the behavior if only mean moisture content and flow moisture point are known.
- The moisture of the material is not constant, but distributed throughout the consignment. During the voyage, the distribution varies with time, and accordingly, the occurrence of liquefaction depends – among other factors – on the duration of the voyage.

[1]Lämmersieth 90, D-22305 Hamburg

- The TML criterion does not distinguish between upward and downward movement of moisture. At the time the criterion was developed, mainly cases of capsizing after liquefaction at the surface of the cargo were known, *Arndt (1966)*. However, capsizing after liquefaction at the bottom of the cargo may also occur *(Atkinson and Taylor 1994)*. Especially in the latter case, the moisture may rise up to saturation at the bottom, even if the average moisture of the cargo is clearly below TML. The cargo can then easily shift along the steel deck.

The inadequacies of the TML criterion call for an improvement of the existing rules. Because of the difficulties to predict prior to shipment whether a cargo will partly or totally liquefy during the voyage, a new regulation should be based on the worst case scenario. The consequences for the design would be not too severe. As demonstrated in the following, an arrangement of a double hull is the most convincing solution. The benefits attained by a double hull of sufficient width are: no capsizing in case of liquefaction, high probability of surviving small damages occurring from inside by the grab or from outside by being rammed, no cumbersome portable divisions or permanent longitudinal bulkheads within the holds, smooth inner side walls, no troublesome procedures like determination of FMP and measurements of moisture contents.

Much can be done in the design stage to keep the necessary width of the double hull small. A remaining loss of cubic capacity of the holds can be avoided by reducing the height of the double bottom, by rising the depth, and by enlarging the hatchways.

3. Residual stability of a bulk carrier after liquefaction of cargo

If a bulker carrying liquid cargo is inclined, the cargo starts to shift creating a heeling moment which increases with angle of inclination. For obtaining the resulting righting arm, this heeling moment has to be subtracted from the initial righting moment of the vessel and the remaining moment to be divided by the weight of the ship. The residual arms must attain the minimum values required in the existing stability rules. This is to be observed if the risk of capsizing shall not exceed the level which is normal for seagoing ships.

Fig. 1 shows the midship section of a bulk carrier of 48,000tdw, *Heldt (1996)*. The initial design is a single hull standard bulker with alternating short and long cargo holds. The total number of holds is seven; the four short holds are assumed to be loaded with iron ore concentrate of 3.6t/m^3. The respective righting arms of this bulker are plotted in Fig. 2. If the cargo has liquefied the vessel will capsize because the residual righting arms are negative throughout the total range of angles of inclination up to 80°.

Heldt (1996) investigated to what extent the stability after liquefaction can be improved by the arrangement of a double hull of 2m in width (case a), of 4m in width (case b), and by the arrangement of a centreline division (case c). The centreline division improves stability most, Fig. 2. For practical reasons, however, a centreline division should be avoided because it hampers the handling and stowage of cargo. From this point of view, the double hull is better. Though the residual righting arms are smaller, the stability rules can be fulfilled if the width of the wing space is broad enough. For the bulk carrier under consideration the width of the double hull should be 3m to fulfill IMO stability requirements.

The residual metacentric height which corresponds with the dotted righting arm curve of Fig. 2, is $\overline{GM}' \approx 1.20$m (the prime indicates that the free surface effect of the cargo is included). This result is not only valid for the bulk carrier presented in Fig. 1, but for all bulk carriers of normal shape. Generally, sufficient residual stability is to be expected if after liquefaction the metacentric height of the vessel does not fall below $\overline{GM}' \approx 1.20$m.

$L_{pp} = 208.80\text{m}$
$B = 28.00\text{m}$
$D = 16.20\text{m}$
$\Delta = 60539\text{t}$
$C_B = 0.85$
$T = 11.87\text{m}$

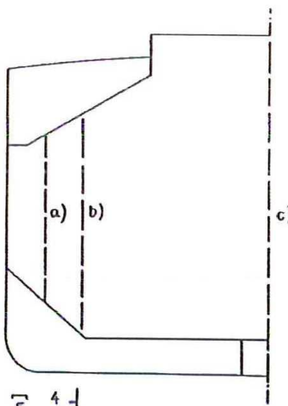

Fig. 1: Variation of the midship section of a bulk carrier of 48,000tdw, *Heldt (1996)*: a) 2m wide double hull, b) 4m wide double hull, c) single hull bulker with centreline division.

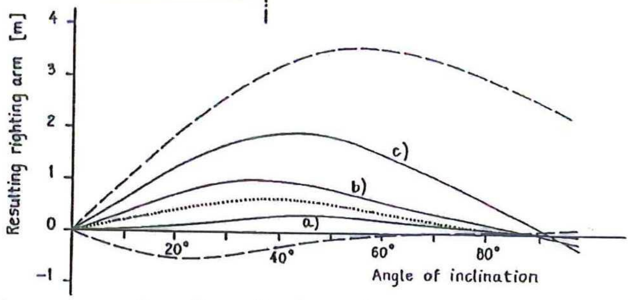

Fig. 2: Residual righting arms after liquefaction of concentrate cargeo for the variations a), b) and c) of the bulk carrier in Fig. 1. The dotted line between curves a) and b) indicates the limit below which the residual lever arms must not fall if the intact stability rules of the "Seeberufsgenossenschaft", *SBG (1984)* – which are equivalent to the IMO "Code of Intact Stability" (Res. A 749) – shall be satisfied. Broken lines for original bulk carrier without longitudinal bulkheads. Upper broken line for solid cargo, lower broken line for liquefied cargo.

4. Reduction of the metacentric height of a double hull bulker due to liquefaction of cargo

The assumption that the total cargo moves like a liquid, is an extreme statement. In reality, liquefaction does not start simultaneously in all cargo holds. However, because it cannot be excluded that after some time the total cargo has become easily movable, it appears advisable to consider the worst case. An additional advantage of this assumption is that it will make a ship generally able to carry liquid cargoes without any stability problems.

The effect of a free liquid on the metacentric height can be assessed by assuming that the centre of gravity of the fluid is shifted from the centre of the fluid to the metacentre of the fluid in the hold. Fig. 3 shows the cross section of a double hull bulker.

$$\overline{b_o m} = \frac{i}{v} = \frac{l \cdot w^3}{12v} \tag{1}$$

i is the transverse moment of inertia of the free surface, v the volume of the liquid, l the length of the hold partly filled with liquid cargo, and w the inside width of the hold.

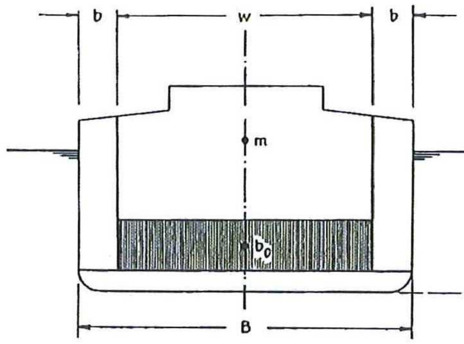

Fig. 3: Free liquid effect: the effective point of attack of the fluid weight moves from the centre of gravity of the fluid b_0 to the metacentre of the fluid m

The shift of the centre of gravity of the fluid from b_o to m shifts the centre of gravity of the ship from G to G'. The distance $\overline{GG'}$ is identical with the loss of metacentric height $\Delta\overline{GM}$

caused by the liquid. By comparing the moments of mass, we get:

$$\overline{b_o m} \cdot \rho_c \cdot v = \overline{GG'} \cdot \rho_w \cdot C_B \cdot L \cdot B \cdot T \longrightarrow \Delta\overline{GM} = \overline{GG'} = \frac{\rho_c}{\rho_w} \cdot \frac{\overline{b_o m} \cdot v}{C_B \cdot L \cdot B \cdot T} \tag{2}$$

v is the volume of the cargo liquid, ρ_c its mass density, ρ_w the mass density of the sea water, C_B the block coefficient, L the length, B the breadth, and T the draft of the ship. Because of the aim to present the influence of the double hull width b on the loss of stability, the inside width of the cargo hold is expressed as:

$$w = \left(1 - 2\frac{b}{B}\right) \cdot B \tag{3}$$

Combining Eqs. (1) to (3), we get for the loss of metacentric height:

$$\frac{\Delta\overline{GM}}{B} = \frac{1}{12} \cdot \frac{\rho_c}{\rho_w} \cdot \frac{1}{C_B} \cdot \frac{l}{L} \cdot \frac{B}{T} \cdot \left(1 - 2\frac{b}{B}\right)^3 \tag{4}$$

This formula demonstrates that the loss of stability due to liquefaction decreases with decreasing ρ_c/ρ_w, l/L, B/T, and with increasing block coefficient C_B and b/B.

5. Minimum double hull width for sufficient stability after liquefaction of cargo

The $\overline{GM}$ of a bulker as shown in Fig. 1 is relatively high if it carries solid concentrate cargo. For solid iron ore concentrate e.g., $\overline{GM}$ amounts to some metres even if only every second cargo hold is loaded. The residual metacentric height after liquefaction of cargo, $\overline{GM}' = \overline{GM} - \Delta\overline{GM}$ should be about 1.20m. Eq. (4) shows the parameters influencing $\Delta\overline{GM}$. If in the stage of a double hull bulker design $\overline{GM}$ can be assessed and also the parameters ρ_c/ρ_w, C_B, l/L, and B/T are given, the necessary double hull width b/B can be calculated to get the required $\overline{GM}'$:

$$\frac{b}{B} = \frac{1}{2}\left(1 - \sqrt[3]{\frac{12C_B \cdot (\Delta\overline{GM}/B)}{(\rho_c/\rho_w) \cdot (l/L) \cdot (B/T)}}\right) \tag{5}$$

This equation shows what must be done to keep the double hull width small. The only parameter which cannot be influenced by the designer, is the mass density ratio ρ_c/ρ_w. Therefore, a maximum mass density for concentrate cargo should be specified for each ship. For the other parameters is to be aimed at: a high C_B, a small B/T, a small l/L by filling cargo only into some of the holds, and – above all – a high $\Delta\overline{GM}/B$. For a high $\Delta\overline{GM}/B$, it is important to try to get a high $\overline{GM}$ without making the vessel too broad and too stiff. Unfortunately, some of these points have also opposite effects. E.g., if l/L is kept small, the cargo must be stowed higher with the result that $\overline{GM}$ becomes smaller. Therefore, in each individual case, it must be well considered which solution is more effective.

All factors contributing to this goal must be observed to get a small double hull width. Of course, the range of variation for the individual parameters is limited. This applies also to $\overline{GM}$. For the highest $\overline{GM}$ which may be tolerated, the shortest rolling periods of existing standard bulk carriers give some orientation. For iron ore concentrate cargo, the lower limit may be set between 8 and 9 seconds, which is around one second and a half less than the average rolling period of around 10 seconds. This means that e.g. for a bulker with B =24m, the maximal acceptable $\overline{GM}$ is about 5.15m.

In the design stage, it will be helpful to have a diagram which shows for each individual case how wide the double hull must be. Such a diagram is presented in Fig. 4. A family of curves is plotted; each curve is based on a constant product of C_B and $\Delta\overline{GM}/B$. The other relevant parameters are to be found as a product of ρ_c/ρ_w, B/T, and l/L on the vertical axis. The minimum double hull width b/B needed for sufficient residual stability is to be read from the abscissa. Example: A double hull bulker of 30,000tdw is subdivided as shown in Fig. 5. The concentrate cargo is carried in the four shorter of the seven holds. The stowage factor is assumed to be $0.27\text{m}^3/\text{t}$, ρ_c/ρ_w =3.6, B =24m, T =10.50m, $C_B = 0.82$, $\overline{GM} = 5.15$m, $\Delta\overline{GM} = 3.95$m, and $l/L = 0.34$. This yields $C_B \cdot \Delta\overline{GM}/B = 0.135$. The corresponding curve is plotted in Fig. 4 (dashed line). For $\rho_c/\rho_w \cdot B/T \cdot l/L = 3.6 \cdot 2.286 \cdot 0.34 = 2.80$ we get $b/B = 0.083$. Hence, the minimum double hull width being necessary for sufficient residual stability is $b = 0.083 \cdot 24\text{m} = 2.00\text{m}$. It may be interesting that this is just the same double hull width required for an oil tanker of the same size – not for stability reasons but for reasons of oil pollution minimization.

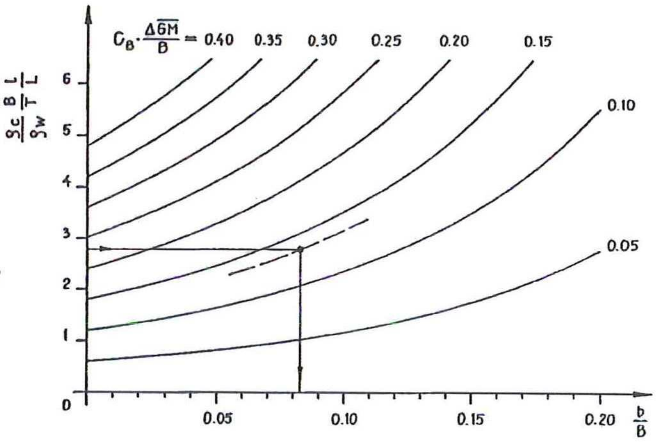

Fig. 4: Diagram for the determination of the minimum double hull width. Example: $C_B \cdot \Delta\overline{GM}/B = 0.135$ and $\rho_c/\rho_w \cdot B/T \cdot l/L = 2.8$. The double hull width must be $b/B = 0.083$.

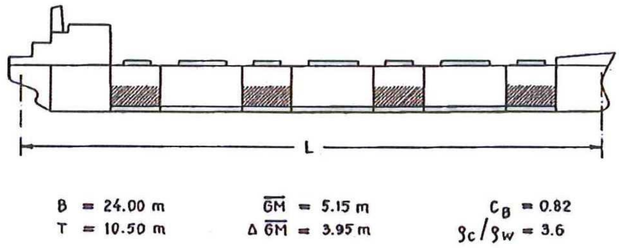

Fig. 5: Example plotted in Fig. 4: double hull bulker of 30,000tdw with concentrate cargo in the four shorter holds; total length of holds filled with cargo is $l/L = 0.34$.

A smaller width than b=2.00m will be obtained, if the mass density of the cargo or the total length of the loaded holds are below the values given above. Also a minimum $\overline{GM}' < 1.20$m reduces the width. Provided that the other data are left unchanged, we get e.g. $b = 1.60$m for $\rho_c/\rho_w = 3.2$. The necessary b will become even smaller if liquefaction is assumed to occur in only three of the four holds filled with cargo. We then get $b = 0.99$m for $\rho_c/\rho_w = 3.6$ and $b = 0.55$m for $\rho_c/\rho_w = 3.2$. If instead of $\overline{GM}' = 1.20$m a value of $\overline{GM}' = 0.76$m is accepted, we get $b = 1.64$m for $\rho_c/\rho_w = 3.6$ and $l/L = 0.34$. However, the assumption of a partial liquefaction of cargo or the allowance of a smaller $\overline{GM}'$ reduces safety. Moreover, the ability of the safe carriage of cargoes which are already liquid prior to loading, will be lost.

6. Concluding remarks

Cargoes liable to liquefy should be generally carried in double hull bulkers. Such a regulation seems all the more acceptable, since the double hull width can be kept small and the loss of hold capacity can be compensated by omitting the lower and upper wing tanks, by a lower double bottom, by larger hatchways etc. Tankers must be fitted with a double hull to minimize oil pollution. Just the same, bulkers should be fitted with a double hull to avoid capsizing. Safety of life at sea is an argument which is at least as serious as protecting the marine environment!

References

ABICHT, W. (1996), *Sicherer Transport von breiartigen Erzkonzentraten*, HANSA 10, p. 28

ABICHT, W. (1997), *Bulk carrier with double hull for the safe carriage of ore concentrates, Int. Maritime Conf. Indonesia 1997, Jakarta*

ABICHT, W. (1998), *Transport von breiartiger Ladung in Doppelhüllenbulkern*, Jahrbuch STG 91 (to be published)

ARNDT, B. (1966), *Kentern durch Übergehen von Schüttladung*, HANSA No. 24, p.2113

ATKINSON, J.H.; TAYLOR, R.N. (1994) *Moisture migration and stability of iron ore concentrate cargoes*, Int. Conf. "Centrifuge 94", Singapore

HELDT, H.P. (1996), *Stabilität und Laderaumgeometrie von Massengutschiffen in bezug auf die Problematik des Transports breiartiger Ladungen*, IfS-Diplomarbeit, Univ. Hamburg

SBG (1984), *Bekanntmachung über die Anwendung der Stabilitätsvorschriften für Fracht-, Fahrgast- und Sonderschiffe vom 24. Oktober 1984*, Seeberufsgenossenschaft, Hamburg