Freeboard calculation - traditional and future approach
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Abstract
The earliest requirement related to the safety of ships at sea was probably the requirement to assign freeboard. This requirement was included in the early regulations of the British Board of Trade. International requirements were included in the 1930 Load Lines Convention, revised in 1966. The early concept of freeboard was based on the assurance of a sufficient amount of reserve buoyancy. This concept was criticised in the 1966 LL Conference and it was proposed that freeboard should be based on the concept of deck wetness and protection of crew.
IMO recently initiated work towards this end and a research programme has been started in Poland. The deck wetness approach to freeboard concept and its implications are discussed in the paper.

1 Introduction
Freeboard was considered long ago as an important element of ship safety. It was recognised that in order to maintain seaworthiness ships must possess some amount of reserve buoyancy, i.e. some volume above the waterplane and below the watertight deck. In a document from about 100 BC found in Tunisia containing a contract for transport of goods the master of a cargo ship solemnly promised not to overload his ship. The freeboard mark was known in the middle ages. The Venetian maritime code from the fifteenth century required placing the load line mark in the form of an iron cross fixed to the side of the ship [1].
In the second half of the eighteenth century Lloyd's Register recommended that the freeboard should not be less than 2 to 3 inches.
In view of the increasing number of casualties the British Board of Trade issued the Merchant Shipping Act in 1873 requiring a load line mark placed on the ship's side on all British ships. This was the result of a campaign by Samuel Plimsoll (1824 - 1899) and form that time the load line mark was often referred to as the Plimsoll Disc.

International rules regarding freeboard were established by the first International Conference on Load Lines in 1930. The second Conference in 1966 was organised by IMO and introduced important changes to the freeboard tables. In 1988 the Protocol to the 1966 Load Lines Convention was adopted, where amendments to the articles and conditions of assignment were introduced.

In the mid-eighties the SLF Sub-Committee of IMO received proposals from Argentina [2] and China [3] to revise freeboard tables and method of freeboard estimation as in the 1966 Convention on the basis of deck wetness. It was then that the Sub-committee started work towards this aim and in 1993 it established a working group with the purpose to propose revision of technical requirements of the 1966 LL Convention. The working group is now continuing its efforts towards achieving this aim and it is assumed that the new Load Line Convention could be adopted in the year 2000.

The reasons for aiming at the revision of the LL Convention are summarised as follows [4]:

" 1. since 1966 SOLAS 74 and MARPOL Convention have been adopted and a number of amendments to these Conventions have been adopted, the requirements of the LL Convention should be reviewed to keep the requirements consistent with other conventions,
2. new technology and scientific findings which could not have been applied in 1966 should now be available and could be employed to define the requirements of the LL Convention in a more rational manner,
3. new types of ships, e.g. high speed craft have been developed,
4. recent research indicates that economical benefit for freeboard may be given to larger ships, for example tankers, when new direct calculation methods are applied, and
5. concern for the safety of small ships "

2 The development of the principles of freeboard estimation

The concept of reckoning of the freeboard from the beginning was based on the assumption that the ship should posses a certain amount of reserve buoyancy which is the volume of the intact ship hull between the waterplane and the uppermost deck exposed to the weather in which all openings should be securely closed. Freeboard was considered to be a measure of the reserve buoyancy and its amount was related principally to the length of the ship with several corrections taking into account the block coefficient, depth, position of the deck
line, superstructures, trunks and sheer. Corrections were calculated using approximate formulae derived from an analysis of proportions of ship types being in service at the beginning of century. The above principles formulated the basis for freeboard tables in 1930 and also in 1966 LL Conventions. Both conventions include also chapters on conditions of assignment of load lines, where requirements concerning constructional features of doors, hatchways, machinery space and other openings, ventilators etc. were specified. Those principles of calculation of the freeboard were not changed in the 1988 Protocol relating to the 1966 LL Convention.

The development of shipbuilding technology, particularly after World War II caused that during the 1966 International Conference on Load Lines doubts were expressed as to the rationality of the principles of reckoning of freeboards. The point was stressed that formerly because of the lack of specific requirements regarding stability, intact or damage, subdivision, and strength of the hull the purpose if assigning adequate freeboard was to maintain sufficient degree of overall safety against capsizing, foundering and hull breaking. With the advent of separate requirements concerning stability, subdivision and strength (the last because of the rules of classification societies), the freeboard lost its meaning and the only purpose of its assignment is to provide sufficient height of the working deck above water in order to avoid excessive deck wetness and consequences of trapping too much water on the deck.

Several papers were published prior to the 1966 Conference the authors of which pointed out that the existing freeboard regulations based on the reserve buoyancy idea were obsolete. Papers by Krappinger [1], Barenhus [5] and Puchstein [6] may be quoted in this context in which the authors pursued the idea of using deck wetness principle as a basis for estimation of the minimum freeboard.

On the other hand during the 1966 LL Conference principles and methods of calculations were already available basing on ship theory, and several papers covering both the theoretical approach as well as model tests were published, e.g. papers by Newton [7], Fick [8], Goodrich [9] and others.

The idea of estimating freeboard on the basis of the probability of deck wetness was in general accepted by the 1966 LL Conference and working out of the regulatuions based on this principle was delegated to the technical committee of the Conference. The task assigned to the technical committee was, however, unfeasible in the short time available and the committee after some discussion decided to adhere to the old principles with only re-adjusting of freeboard tables. The development of the new principles of the reckoning of the freeboard was left for future consideration.

In spite of the general feeling in favour of the deck wetness principle nothing happened in IMO during the following 20 years, untill the mid-eighties when proposals to revise technical requirements of the 1966 LL Convention on the basis of deck wetness were advanced. In the meantime, however, following
recommendation of the 1966 LL Conference to develop freeboard requirements for fishing vessels another IMO Subcommittee (PFV) considered and finally agreed the formula for calculation of the minimum distance from the deepest operating waterline to the lowest point of the top of the bulwark or to the edge of the working deck. The formula was based on systematic calculations of deck wetness of fishing vessels and derived from regression analysis by the Polish delegation [10]. Ultimately this formula was included as the attachment to the Torremolinos Convention.

In the studies conducted by the SLF - Subcommittee the basis for future methods of reckoning of the freeboard is assumed to be deck wetness. Considerable effort is, however, needed in order to work out new freeboard regulations on this basis.

3 The general framework of the LL 2000 Convention

The general framework of the LL 2000 Convention was discussed by the working group established at the 38th and 39th session of the SLF- Subcommittee of IMO. Despite some divergence of opinions it was agreed that there should be two options of calculation of freeboard in the future convention:

1. freeboard tables
2. direct calculation method

Reckoning of freeboard using tables where freeboard is given as the function of ship's length with some correcting factors is an easy process which should not be abandoned. It is assumed, however, that tables existing in the 1966 LL
Convention should be revised and new tables (or formulae) developed on the basis of deck wetness principle.

The usage of tables for calculation of the freeboard will be restricted to ships of conventional type mainly. For non conventional ships where tables could not be used direct calculation method should be applied consists of calculation of probability of deck wetness using appropriate mathematical model (or models tests) under certain assumptions, which are discussed later.

The general framework of the new convention is shown in Fig. 1. This diagram was proposed by the author at the 38th session of SLF and agreed with minor amendments [4].

4 A review of freeboard tables based on deck wetness

A revision of freeboard tables will be done applying regression analysis to the systematic calculations of probability of deck wetness.

Certain assumptions regarding such calculations gave to be made. Although the assumptions are not yet finally agreed, the SLF Subcommittee at its 32nd session in 1987 [11] agreed the recommendations regarding preliminary studies to be performed by its members. It was agreed that preliminary studies to modernise the freeboard tables do not necessarily require an accurate long term prediction of deck wetness. Rather the studies are to permit comparative evaluations of existing freeboard tables with a view to modify them. It was agreed that deck wetness and the reserve buoyancy studies should be conducted concurrently, using the following criteria for deck wetness studies:

- sea spectrum - ITTC, 2 parameter
- significant wave height - $H_s=10, 7, 4$ m
- direction of waves - head seas only

These studies were restricted to monohull ships of all sizes. The ships were considered for $H_s=10$ m at zero speed, for $H_s=7$ m and 4 m at 60% and 90% of full speed respectively.

At the 39th session of the SLF Subcommittee the working group proposed a methodology of revision of the tables (or formulae as it might be).

The respective flow chart explaining the above methodology is shown in fig. 2.
5 Direct calculation method

The phrase "direct calculation method" is interpreted as the calculation of the probability of deck wetness using a computer programme based on an adequate mathematical model of ship motions. In many countries computation programmes of the seakeeping characteristics of ships including deck wetness have been developed and several of them are commercially available. They are based on linear equations of motions and on an analysis in the frequency domain. With regard to ship motions a majority of these programmes provide reliable results at least for hulls of conventional form. Some doubts exist, however, regarding reliability of application of the linear approach based on strip theory to computation of deck wetness, even for conventional forms. This is because the strip theory does not take into account:

- above water hull shape (local flase)
- 3-D effects
- disturbances of the incoming waves because of wave direction and wave radiation
- bow swell-up
- forward speed

The study [12] revealed discrepancies between deck wetness predicted by the linear approach and measured on models.

The inclusion of all the above factors and the resulting non-linear approach might require simulation in the time domain with all the resulting difficulties. Therefore the linear approach has to be retained with some correction factors included, possibly taking into account linear diffraction and potential radiation effects in the determination of the wave height along the ship and / or including...
empirical correction factor for bow swell-up. Currently research programmes were established in order to investigate those possibilities [13].

Upon request of the subcommittee Poland developed the first draft of the guidelines for estimating freeboard by direct calculation method [14]. The guidelines are based on the linear theory, where the freeboard is estimated by calculating the probability of deck wetness which should be smaller than the accepted standard value \( p^* \), i.e. by calculating the probability that

\[
P(s_i \geq FB) \leq p^*
\]

\( P \) defines frequency at which amplitude \( s_i \) of the relative motion of water level \( s \) exceeds freeboard \( FB \). Minimum required freeboard is calculated as a value of reverse function of the above equation.

The flow chart for calculation of freeboard is shown in fig. 3.

The mathematical model is based on linear theory of ship motions, i.e. strip theory and superposition principle. [Hydrodynamic coefficients in equations of motions are estimated assuming flow in the transverse plane of cross-sections of the ship. Correction factors taking into account three-dimensionality of flow at ship ends may be applied.]

Probability of deck wetness at chosen point \( A(x,y) \) of the deck is calculated by the following formula

\[
P(s_i \geq FB) = \exp \left( \frac{FB^2}{2r^2} \right)
\]

Standard deviation \( r \) of the relative motion of point \( A \) is calculated by the formula:
where \( Y(\omega) \) = response amplitude operator
\( S(\omega) \) = wave spectrum

Freeboard is then calculated from the formula

\[
FB = \sqrt{2r_v^2 \ln(\frac{1}{p^*})}
\]

Freeboard is calculated from the above equation for assumed probability of deck wetness \( p^* \) and for assumed wave conditions with standard deviation of amplitude of relative vertical motion of a chosen point A on deck \( r_v \) known. Minimum required freeboard is taken as the maximum value of all FB values calculated for the point A located amidships.

Standard deviation \( r_v \) of the relative motion of point A is calculated for ship courses relative to the oncoming waves and associated ship speeds [as a minimum] as follows:

<table>
<thead>
<tr>
<th>Ship relative course</th>
<th>Ship speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 deg following seas</td>
<td>minimum speed required for course keeping</td>
</tr>
<tr>
<td>45, 315 deg quartering seas</td>
<td>as above</td>
</tr>
<tr>
<td>90, 270 deg beam seas</td>
<td>zero speed</td>
</tr>
<tr>
<td>135, 225 deg oblique seas</td>
<td>full service speed corresponding to sea state</td>
</tr>
<tr>
<td>180 deg head seas</td>
<td>as above</td>
</tr>
</tbody>
</table>

Irregular two-dimensional long crested waves should be assumed. ITTC standard two parameters spectrum is recommended. Six values of mean wave periods equal to 6, 8, 10, 12, 14 and 16 s. should be assumed. The significant wave height \( H_{1/3} \) used in calculations should depend on the zone where the ship is intended to operate.

The standard value of probability of deck wetness \( p^* \) should be assumed depending on the ship type. No specific values of \( p^* \) are recommended at this stage. As a result of calculations depending on the metacentric height, two values of metacentric height of the ship have to be adopted as follows:
- minimum metacentric height required to satisfy IMO Res. A.167 and A.562
- maximum metacentric height resulting from anticipated load conditions
6 Concluding remarks

Although the framework of the future LL Convention was in general approved by the Subcommittee its fulfilment will require extensive research and legislative work. Therefore it is not realistic to expect that the new convention as it was anticipated a few years ago, could be adopted really in the year 2000. From the legal point of view it is also not certain if there will be a new convention of protocol to the 1966 Convention. Not entering into legal matters it might be only mentioned that adoption of the new convention requires denouncing the old convention by parties to it. Otherwise a complicated situation from the legal point of view might arise.

References

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