Maritime and Coastguard Agency

MERCHANT SHIPPING NOTICE

MSN 1715 (M)

Subdivision and Damage Stability of Cargo Ships of 80m in Length and Over

Notice to Shipbuilders, Shipowners, Ship repairers, Naval Architects, Masters and Officers.

This Notice Supersedes Merchant Shipping Notice No. M.1476.

Summary

This Notice advises all Shipbuilders, Shipowners, Shiprepairers, Naval Architects, Masters and Officers of subdivision and damage stability of cargo ships of 80m in length and over.

Key points:-

- Requirements for subdivision and damage stability for cargo ships, using the probabilistic method;
- categories of ship to which these requirements apply; and
- formulae used for calculating the subdivision indices.

1. Part B-1 of Chapter II-1 of the International Maritime Organisation Convention for the Safety of Life at Sea 1974, was amended and adopted by the Maritime Safety Committee of the International Maritime Organisation on the 25th May *1990* (MSC.58(25)) with effect from 1st July 1998 (MSC.47(66)).

2. The Merchant Shipping (Cargo Ship Construction) Regulations 1997 S.I. No.1509, as amended by the Merchant Shipping (Cargo Ship Construction)(Amendment) Regulations 1999, implement and interpret the above named regulations.

3. The regulations introduce requirements for subdivision and damage stability of cargo ships 100m in length and upwards built after 1 February 1992, and cargo ships 80m in length and upwards built after 1 July 1998, based on the probabilistic concept. They do not apply to such ships which comply with subdivision and damage stability requirements of other statutory instruments.

4. Annex 1 to this notice contains formulae for use in calculating the subdivision indices, and other related information.

5. Annex 11 contains explanatory notes prepared by the International Maritime Organisation for the purpose of calculating the subdivision indices. They should be read in conjunction with the following Annex.

6. Annex III contains the text adopted by the MSC resolutions referred to in paragraph 1 above.

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ANNEX I

1. Definitions

For the purpose of this notice, unless expressly provided otherwise:

.1.1 Subdivision Load Line is a waterline used in determining the subdivision of the ship.

.1.2 Deepest subdivision load line is the subdivision load line which corresponds to the summer draught to be assigned to the ship.

.1.3 Partial load line is the light ship draught plus 60% of the difference between the light ship draught and deepest subdivision load line.

.2.1 Subdivision length of the ship (“L_s”) is the greatest projected moulded length of that part of the ship at or below deck or decks limiting the vertical extent of flooding with the ship at the deepest subdivision load line.

.2.2 Mid-length is the mid point of the subdivision length of the ship.

.2.3 Aft terminal is the aft limit of the subdivision length.

.2.4 Forward terminal is the forward limit of the subdivision length.

.3. Breadth (“B”) is the greatest moulded breadth of the ship at or below the deepest subdivision load line.

.4. Draught (“d”) is the vertical distance from the moulded baseline at mid-length to the water line in question.

.5. Permeability (“μ”) of the space is the proportion of the immersed volume of that space which can be occupied by water.

2. Required subdivision index "R"

.1 The degree of subdivision to be provided shall be determined by the required subdivision index "R", as follows:

.1.1 for ships over 100m in length;

$$R = (0.002 + 0.0009L_s)^{1/3}\text{; and}$$

.1.2 for ships of 80m in length and upwards, but not exceeding 100m in length;

$$R=1-\left[1-\left(1+\frac{L_s}{100}\cdot\frac{R_0}{1-R_0}\right)\right],$$

where R_0 is the value R as calculated in accordance with the formula in subparagraph 1.1.1, and “Ls” is the length of the ship in metres.

3. Attained subdivision index "A"

.1 The attained subdivision index "A" shall be calculated for the ship by the following formula:

$$A = \Sigma pisi$$

where:

“i” represents each compartment or group of compartments under consideration,

“pi” accounts for the probability that only the compartment or group of compartments under consideration may be flooded, disregarding any horizontal subdivision,

“si” accounts for the probability of survival after flooding the compartment or group of compartments under consideration, including the effects of any horizontal subdivision.

.2 In calculating “A”, level trim shall be used.

.3 This summation covers only those cases of flooding which contribute to the value of the attained subdivision index “A”.

.4 The summation indicated by the above formula shall be taken over the ship’s length for all cases of flooding in which a single compartment or two or more adjacent compartments are involved.

.5 Wherever wing compartments are fitted, contribution to the summation indicated by the formula shall be taken for all cases of flooding in which wing compartments are involved; and additionally, for all cases of simultaneous flooding of a wing compartment or compartments and the adjacent inboard compartment or compartments, assuming a rectangular penetration which extends to the ship’s centreline, but excludes damage to any centreline bulkhead.

.6 The assumed vertical extent of damage is to extend from the baseline upwards to any watertight horizontal subdivision above the waterline or higher. However, if a lesser extent will give a more severe result, such extent is to be assumed.

.7 If pipes, ducts or tunnels are situated within assumed flooded compartments, arrangements are to be made to ensure that progressive flooding cannot thereby extend to compartments other than those assumed flooded. However, the Administration may permit minor progressive flooding if it is demonstrated that its effects can be easily controlled and the safety of the ship is not impaired.

.8 In the flooding calculations carried out according to the regulations, only one breach of the hull need be assumed.

4. Calculation of the factor “l2i”

.1. The factor "pi" shall be calculated according to paragraph .1.1 (below) as appropriate, using the following notations:

x_1 = the distance from the aft terminal of "Ls" to the foremost portion of the aft end of the compartment being considered;

x_2 = the distance from the aft terminal of "Ls" to the aftermost portion of the forward end of the compartment being considered;

E_1 = x_1 / L_s

E_2 = x_2 / L_s

E = $E_l + E_2 - 1$

J = $E_2 - E_l$

J' = $J - E$, if $E \geq 0$

J' = $J + E$, if $E < 0$

The maximum non dimensional damage length, $J_{rnax} = 48 / L_s$, but not more than 0.24

The assumed distribution density of damage location along the ship's length

a = 1.2 + 0.8E, but not more than 1.2

The assumed distribution function of damage location along the ship's length

F = $0.4 + 0.25\,E\,(1.2 + a)$

y = J / J_{max}

p = $F_1 J_{max}$

q = $0.4\,F_2\,(J_{max})^2$

F_1 = $y^2 - \frac{y^3}{3}$, if $Y < 1$,

F_1 = $y - \frac{1}{3}$ otherwise;

F_2 = $\frac{y^3}{3} - \frac{y^4}{12}$, if $Y < 1$,

F_2 = $\frac{y^3}{2} - \frac{y}{3} + \frac{1}{12}$ otherwise.

.1.1 The factor “pi” is determined for each single compartment:

.1.1.1 Where the compartment considered extends over the entire ship length, “Ls”:

$$p_i = 1$$

.1.1.2 Where the aft limit of the compartment considered coincides with / the aft terminal:

$$p_i = F + 0.5\,ap + q$$

.1.1.3 Where the forward limit of the compartment considered coincides with the forward terminal:

$$p_i = 1 - F + 0.5ap$$

.1.1.4 When both ends of the compartment considered are inside the aft and forward terminals of the ship length, “Ls”:

$$p_i = ap$$

.1.1.5 In applying the formulae of paragraphs 4.1.1.2, 4.1.1.3 and 4.1.1.4, where the compartment considered extends over the “mid-length”, these formulae values shall be reduced by an amount determined according to the formula for “q”, in which “F_2” is calculated taking “y” to be J'/J_{max}.

.2. Wherever wing compartments are fitted, the “pi” – value for a wing compartment shall be obtained by multiplying the value, as determined in paragraph 3, by the reduction factor “r” according to subparagraph .2.2, which represents the probability that the inboard spaces will not be flooded.

.2.1 The “pi” – value for the case of simultaneous flooding of a wing and adjacent inboard compartment shall be obtained by using the formulae of paragraph 3, multiplied by the factor (1 – r).

.2.2 The reduction factor "r" shall be determined by the following formulae:
For $J \geq 0.2\, b/B$:

$$r = \frac{b}{B}\left(2.3 + \frac{0.08}{J + 0.02}\right) + 0.1, \qquad \text{if } b/B \leqslant 0.2$$

$$r = \left(\frac{0.016}{J + 0.02} + \frac{b}{B} + 0.36\right), \qquad \text{if } b/B > 0.2$$

For $J < 0.2\, b/B$ the reduction factor “r” shall be determined by linear interpolation between

$r = 1$, for $J = 0$

and

r = as for the case where $J \geq 0.2b/B$, for $J = 0.2\, b/B$,

where:

b = the mean transverse distance in metres measured at right angles to the centreline at the deepest subdivision load line between the shell and a portion of and parallel to that part of the longitudinal bulkhead which extends between the longitudinal limits used in calculating the factor “p_i”.

.3. To evaluate “p_i” for compartments taken singly the formulae in paragraphs .1 and .2 shall be applied directly.

.3.1 To evaluate the “pi” – values attributable to groups of compartments the following applies:

for compartments taken by pairs:

$p_i = p_{12} - p_1 - p_2$
$p_i = p_{23} - p_2 - p_3$, etc.

for compartments taken by groups of three:

$p_i = p_{123} - p_{12} - p_{23} + p_2$
$p_i = p_{234} - p_{23} - p_{34} + p_3$, etc.

for compartments taken by groups of four:

$p_i = p_{1234} - p_{123} - p_{234} + p_{23}$
$p_i = p_{2345} - p_{234} - p_{345} + p_{34}$, etc.

where:
p_{12}, p_{23}, p_{34}, etc,
p_{123}, p_{234}, p_{345}, etc and
p_{1234}, p_{2345}, p_{3456}, etc

shall be calculated according to the formulae in paragraphs 4.1 and 4.2 for a single compartment whose nondimensional length “J” corresponds to that of a group consisting of the compartments indicated by the indices assigned to “p”.

.3.2 The factor “pi” for a group of three or more adjacent compartments equals zero if the non dimensional length of such a group minus the nondimensional length of the aftermost and foremost compartments in the group is greater than “J_{max}”.

5. Calculation of factor "Si"

.1. The factor “si” shall be determined for each compartment or group of compartments according to the following:

.1.1 in general for any condition of flooding from any initial loading condition “s” shall be

$$S = C\sqrt{0.5\,(GZ_{max})(\text{range})}$$

with C = 1, if $\varnothing e \leq 25°$

with C = 0, if $\varnothing e > 30°$

$$C = \sqrt{\frac{30 - \varnothing e}{5}} \quad \text{otherwise}$$

GZ_{max} = maximum positive righting lever (in metres) within the range given below but not more than 0.1m;

range = range of positive righting levers beyond the angle of equilibrium (in degrees) but not more than 20°; however, the range shall be terminated at the angle where openings not capable of being closed weathertight are immersed;

$\varnothing e$ = final equilibrium angle of heel (in degrees);

.1.2 s = 0 where the final waterline taking into account sinkage, heel and trim, immerses the lower edge of openings through which progressive flooding may take place. Such opening shall include air pipes, ventilators and openings which are closed by means of weathertight doors or hatch covers, and may exclude those openings closed by means of watertight manhole covers and flush scuttles, small watertight hatch covers which maintain the high integrity of the deck, remotely operated sliding watertight doors, access doors and access hatch covers, of watertight integrity, normally closed at sea and sidescuttles of the non-opening type. However, if the compartments so flooded are taken into account in the calculations the requirements of this regulation shall be applied.

.1.3 For each compartment or group of compartments “s_i” shall be weighted according to draught considerations as follows:

$$s_i = 0.5\ S_\ell + 0.5\ S_p$$

where

“se” is the “s”-factor at the deepest subdivision load line
“sp” is the “s”-factor at the partial load line.

.2. For all compartments forward of the collision bulkhead, the “s”-value, calculated assuming the ship to be at its deepest subdivision load line and with assumed unlimited vertical extent of damage is to be equal to 1.

.3. Wherever a horizontal subdivision is fitted above the waterline in question the following applies.

.3.1 The “s”-value for the lower compartment or group of compartments shall be obtained by multiplying the value as determined in subparagraph 5.1.1 by the reduction factor “v” according to subparagraph 5.3.3, which represents the probability that the spaces above the horizontal subdivision will not be flooded.

.3.2 In cases of positive contribution to index “A” due to simultaneous flooding of the spaces above the horizontal subdivision, the resulting “s”-value for such a compartment or group of compartments shall be obtained by an increase of the value as determined by subparagraph 5.3.1 by the “s”-value for simultaneous flooding according to subparagraph 5.1.1, multiplied by the factor (1-v).

.3.3 The probability factor “v_i” shall be calculated according to:

$v_i = \frac{H-d}{H_{max} - d}$, for the assumed flooding up to the horizontal subdivision above the subdivision load line, where "H" is to be restricted to a height of “H_{max}”,

$v_i = 1$, if the uppermost horizontal subdivision in way of the assumed damaged region is below “H_{max}”,

where:

"H" is the height of the horizontal subdivision above the baseline (in metres) which is assumed to limit the vertical extent of damage,

“Hmax” is the maximum possible vertical extent of damage above the baseline (in metres), or

$H_{max} = d + 0.056\ L_s\ (1 - \frac{L_s}{500})$, if $L_s \leq 250$ m;

$H_{max} = d + 7$, if $L_s > 250$m

whichever is less.

6. Permeability

For the purpose of the subdivision and damage stability calculations of the regulations, the permeability of each space or part of a space shall be as follows:

Spaces	Permeability
Appropriated to stores	0.60
Occupied by accommodation	0.95
Occupied by machinery	0.85
Void spaces	0.95
Dry cargo spaces	0.70
Intended for liquid	0 or 0.95[1]

7. Stability Information

.1 In providing the information and when determining the overall GM (or KG) values:

.1.1 in the case where intact stability requirements are more onerous they shall apply.

.1.2 in the case where values determined from considerations solely related to the subdivision index are more onerous then:

- .i the limiting GM value shall be varied linearly between the deepest subdivision load line and the partial load line; and
- .ii for draughts below the partial load line the GM value shall be assumed constant.

.1.3 in the case where values determined from both intact stability and the subdivision index apply then:

- .i the limiting GM shall be varied linearly between the deepest subdivision load line and the partial load line; and
- .ii for draughts below the partial load line the GM value shall be assumed constant where the subdivision index is more onerous otherwise intact stability requirements apply.

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[1] Whichever results in the more severe requirements.

ANNEX II

EXPLANATORY NOTES TO THE SOLAS REGULATIONS ON SUBDIVISION AND DAMAGE STABILITY OF CARGO SHIPS OF 100 METRES IN LENGTH AND OVER

These explanatory notes are divided into two parts. Part A describes the background to the method used whilst Part B contains explanation and amplification of individual regulations.

PART A

In this part of the explanatory notes, the background of the subdivision index is presented and then the calculation of the probability of damaged is developed.

Finally, the development of the calculation of the probability that a damaged ship will not capsize or sink is demonstrated.

1 INTRODUCTION

These regulations are based on the probabilistic concept which takes the probability of survival after collision as a measure of ship's safety in the damaged condition, hereinafter referred to as the "attained subdivision index A".

This is an objective measure of ship safety and therefore there is no need to supplement this index by any deterministic requirements. These new regulations, therefore, are primarily based on the probabilistic approach, with only very few deterministic elements which are necessary to make the concept practicable.

The philosophy behind the probabilistic concept is that two different ships with the same index of subdivision are of equal safety and therefore there is no need for special treatment for specific parts of the ship. The only areas which are given special attention in these regulations are the forward and bottom regions which are dealt with by special rules concerning subdivision, provided for the cases of ramming and grounding.

In order to develop the probabilistic concept of ship subdivision, it is assumed that the ship is damaged. Since the location and size of the damage is random, it is not possible to state which part of the ship becomes flooded. However, the probability of flooding a space can be determined if the probability of occurrence of certain damages is known. The probability of flooding a space is equal to the probability of occurrence of all such damages which just open the considered space. A space is a part of the volume of the ship which is bounded by undamaged watertight structural divisions.

Next, it is assumed that a particular space is flooded. In addition to some inherent characteristics of the ship, in such a case there are various factors which influence whether the ship can survive such flooding; they include the initial draught and GM, the permeability of the space and the weather conditions, all of which are random at the time when the ship is damaged. Provided that the limiting combinations of the aforementioned variables and the probability of their occurrence are known, the probability that the ship will not capsize or sink, with the considered space flooded, can be determined.

The probability of survival is given by the formula for entire probability as the sum of the products for each compartment or group of compartments of the probability that a space is flooded multiplied by the probability that the ship will not capsize or sink with the considered space flooded.

Although the ideas outlined above are very simple, their practical application in an exact manner would give rise to several difficulties. For example, for an extensive but still incomplete description of the damage, its longitudinal and vertical location as well as its longitudinal, vertical and transverse extent is necessary. Apart from the difficulties in handling such a five-dimensional random variable, it is impossible to determine its probability distribution with the presently available damage statistics. Similar conditions hold for the variables and physical relationships involved in the calculation of the probability that a ship with a flooded space will not capsize or sink.

In order to make the concept practicable, extensive simplifications are necessary. Although it is not possible to calculate on such a simplified basis the exact probability of survival, it is possible to develop a useful comparative measure of merit of the longitudinal, transverse and horizontal subdivision of the ship.

2 DETERMINATION OF THE PROBABILITY OF FLOODING OF SHIP SPACES

.1 Consideration of longitudinal damage location and extent only.

The simplest case is to consider the location and length of damage in the longitudinal direction. This would be sufficient for ships with no longitudinal and horizontal watertight structural divisions.

With the damage location “x” and damage length “y” as defined in figure 1, all possible damages can be represented by points in a triangle which is also shown in this figure.

All damages which open single compartments of length “ℓ_i" are represented in figure 1 by points in triangles with the base “ℓ_i”. Triangles with the base “ℓ_i” + “ℓ_i” (where j = i + 1) enclose points corresponding to damages opening either compartment “i”, or compartment “j”, or both of them. Correspondingly, the points in the parallelogram “ij” represent damages which open both the compartments “i” and “j”.

Damage location “x” and damage length “y” are random variables. Their distribution density f(x,y) can be derived from the damage statistics. The meaning of f(x,y) is as follows (see figure 2): the total volume between the x-y plane and the surface given by f(x,y) equals one and represents the probability that there is damage (this has been assumed to be certain). The volume above a triangle corresponding to damage which opens a compartment represents the probability that this compartment is opened. In a similar manner for all areas in the x-y plane which correspond to the opening of compartments or group of compartments, there are volumes which represent the probability that the considered compartments or group of compartments are opened.

The probability that a compartment or a group of adjacent compartments is opened is expressed by the factor “pi” as calculated according to regulation 25-5.

Consideration of damage location “x” and damage length “y” only would be fully correct in the case of ships with pure transverse subdivision. However, there are very few, if any, such ships – all normally have a double bottom, at least.

In such a case, the probability of flooding a compartment should be split up into the following three components: probability of flooding the double bottom only, probability of flooding the space above the double bottom only and probability of flooding both the space above and the double bottom itself (see figure 3). For each of these cases there may be a different probability that the ship will survive in the flooded condition. A way out of this dilemma, which may be used in applying these new regulations, is to assume that the most unfavourable vertical extent of damage (out of the three possibilities) occurs with the total probability “p”. Therefore the contribution to survival probability made by more favourable cases is neglected. That the concept is still meaningful for comparative purposes follows from the fact that the error made by neglecting favourable effects of horizontal subdivision is not great and the more important influence of longitudinal damage location and extension is fully covered.

Some examples for dealing with other cases of horizontal subdivision are given in appendix 1.

.2 Consideration of horizontal subdivision above a water line.

In the case where the ship has as a horizontal subdivision above a water line, the vertical extent of damage may be limited to the depth of that horizontal subdivision. The probability of not damaging the horizontal subdivision is represented by the factor “vi”, as calculated according to regulation 25-6. This factor represents the assumed distribution function of the vertical extent of damage and varies from zero for subdivision at the level of the waterplane, linearly upwards to the value of one at the level conforming to the minimum bow height according to the 1966 Load Line Convention (see figure 4).

.3 Consideration of damage penetration in addition to longitudinal damage location and extent.

With the simplifying assumption that the damage is rectangular and with the vertical extent of damage according to 2.2, the damage can be described by the damage location “x”, the damage length “y” and the damage penetration “z” (see figure 5). These variables can be represented in a three-dimensional co-ordinate system, as shown in figure 6. Each point in the prism, with triangular base, represents a damage.

All damages which open a side compartment correspond to the points of a smaller prism with height “b” equal to the distance of the longitudinal bulkhead from the ship's side, which is erected above a triangle with the base “i” equal to the length of the side compartment under consideration. It is not difficult to identify in figure 5 the volumes which correspond to such damage which flood other parts of the ship bounded by transverse and longitudinal watertight structural subdivisions.

Damage location “x”, damage length “y” and damage penetration “z” are random variables. The distribution density f(x,y,z) can be derived from damage statistics. This distribution density can be illustrated by assuming it to be a density which varies from point to point of the volume shown in figure 6. The “weight” of the total volume is one and represents the probability that there is a damage (which is assumed to be certain). The "weight" of a partial volume (representing the flooding of certain spaces) represents the probability that the spaces under consideration are opened.

The probability that a side compartment is opened can be expressed as “p_ir” where “p_i” is to be calculated according to regulation 25-5.1 and “r” according to regulation 25-5.2. The probability that a centre compartment (extending at least to the ship centrelines) is opened, in addition to the adjacent side compartment, can be expressed as $P_i(1-r)$.

Some examples for the calculation of the probability that side or side plus centre spaces are opened are given in appendix 2.

Again, it must be stated that the probability calculated on the basis of the simplifying assumptions mentioned above is not exact. Nevertheless, it gives a comparative measure of how the probability of opening spaces depends on transverse and longitudinal structural subdivisions, and thus takes account of the most essential influences, whilst neglecting secondary effects. Neglecting the random variation of longitudinal and transverse damage extent would be a much greater error than that which is caused by neglecting these secondary effects.

3. DAMAGE STATISTICS

.1 Source of data

The following considerations are based on the information contained in various IMO documents. They summarise casualty data reported to IMO on 811 damage cards. There are 296 cases of rammed ships which contained information on each of the following characteristics:

Ship length - L
Ship breadth - B
Damage location - x
Damage length - y
Damage penetration - z

In order to omit inconsistencies in the results derived from the data, which may be caused by the use of different samples, the following investigations have been based only on the aforementioned 296 cases. However, further investigations have been made using, in addition, the information given for other cases. Despite the random scatter, which is to be expected because of the use of different samples composed at random, they lead to the same conclusion. A different sample, which comprised 209 cases in which "L", "y" and year of collision are given, was used for the investigation of the dependency of damage length on the year of collision.

.2 General consideration of damage extent.

It is clear that the principal factors affecting damage extent are:

.2.1 Structural characteristics of the rammed ship

.2.2 Structural characteristics of the ramming ship

.2.3 Mass of the rammed ship at time of collision

.2.4 Mass of the ramming ship at time of collision

.2.5 Speed of the rammed ship at time of collision

.2.6 Speed of the ramming ship at time of collision

.2.7 Relative course angle between rammed and ramming ship

.2.8 Location of damage relative to the ship's length

From the point of view of the rammed ship only item .1 is predetermined; all other items are random. An investigation of the damage length of ships with different numbers of decks has shown that there is no significant influence. This does not prove that there is no influence. It is, however, valid to conclude that the influence of structural characteristics is relatively small. It therefore seems justifiable to neglect this influence.

The mass of the rammed ship depends on its size and its loading condition. The influence of the latter is small and therefore for the sake of simplicity it has been neglected. To account for the size of the rammed ship, damage length has been related to the ship and damage penetration to the ship breadth.

The following will show that the damage does not depend significantly on the place at which it occurs in the ship's length. From this it is concluded that the damage extent does not depend on the location of the damage, except at the ends of the ship, where damage length is bounded according to the definition of damage location as the centre of the damage.

Some comments on the mass of the ramming ship are given below.

.3 Distribution of damage length.

Preliminary investigations have lead to the conclusion that the distribution of the ratio damage length to ship length y/L is approximately independent of the ship length. A proof will be given below. As a consequence, y/L can be taken as independent of "L".

From theoretical considerations (using the central limit theorem) it follows that $y/L + \in_y$ (where "$\in_y$" is constant) is approximately log-normally distributed. This is confirmed by figures 7 and 8, in which good agreement is shown between the log-normal distribution function and distribution density on the one hand and the corresponding results of the damage statistics on the other.

Figure 9 shows the regression of y/L on "L" for $L \leq 200$m (five damages relate to ships with $L > 200$m). The regression line has a small negative slope which proved to be insignificant, and may be caused by samples taken at random. There might be a small dependence of y/L on the ship length, but if is so small that it cannot be derived from the given sample. It is therefore certainly no significant error to assume y/L to be independent of ship size for $L \leq 200$m.

An explanation of this independence might be that small vessels are more likely to meet mainly small vessels and large vessels are more likely to meet mainly large vessels. However, this reasoning cannot be extended to very large vessels because of the small total number of such ships. Because of the very few damage cases concerning ships with $L > 200$m, nothing can be said about the damage distribution of such ships. **It** seems reasonable to assume, as an approximation for ships with $L > 200$m, that the median *of* the damage length is constant and equal to the median for $L = 200$m. The latter equals $200*(y/L)_{50}$ where $(y/L)_{50}$ is the median *of* the non-dimensional damage length for ships with $L = 200$m.

The regression of the non-dimensional damage length y/L on the non-dimensional damage location is given in figure 10. This shows that there is no significant difference between the damage distribution in the forward and aft half of the ship, but simple geometric reasoning indicates that the damage length at the ends *of* the ship – forward as well as aft – is limited to smaller values than the central part of the ship. Therefore the log-normal distribution found for all values for y/L – independent of damage location -is the marginal distribution. The corresponding conditional distribution of y/L, on the condition that the damage location is given, does not need to be considered as for the practical application an approximation will be used, which allows establishment of a very simple relationship between the conditional and marginal damage length distribution.

.4 Dependence of damage length on year of collision.

The tendency in increasing speed and size of ships during recent years suggests that the average size of damage in cases of collision also is growing. In order to investigate this, a regression analysis of the logarithm of the non-dimensional damage length on the year of collision has been made. The result is shown in figure 11. This figure shows a significant positive slope of the regression line, which proves that, on average, the damage length increase with year of collision.

It therefore seems prudent not to use the distribution which results from all damage data independent of the year of collision. Assuming that the variance about the regression line is constant, it is possible to derive from the regression analysis the distribution function of non-dimensional damage length for any arbitrarily chosen year; such a function is determined by the mean (which is given by the regression line) and the variance about the regression line *of* the logarithm of $y/L + \in_y$. Some samples are given in figures 12 and 13.

.5 Distribution of damage penetration.

Similar consideration as in the case of the damage length lead to the conclusion that $z/B + \in_z$ is approximately log-normally distributed and does not depend on the ship size, which in this connection is represented by the breadth "B" of the ship. Figures 14 and 15 show good agreement between the log-normal distribution and the corresponding values obtained from the damage statistics. Figure 16 proves that there is, in fact, no significant dependence of z/B on "B".

As is to be expected, there is a strong correlation between z/B and y/L. Figures 17 and 18 show that z/B increases on the average with increasing y/L. The joint distribution of the logarithm of ($y/L + \in_y$) and ($z/B + \in_z$) is a bivariate normal distribution. From that distribution the conditional distribution of zlB on the condition that the damage length assumes certain values y /L can be derived.

.6 Distribution of damage location.

Inspection of the histogram (figure 19) of the non-dimensional damage location show that damages in the forward half of the ship are more frequent than in the aft part. The only explanation which can be offered for the peaks of the histogram at approximately x/L = 0.45 and x/L = 0.95, is that they are random because of the limited sample.

Because the damage location is defined as distance from the aft terminal of “L” to the centre of the damage, it is always a distance of y/2L from the ends of the ship. Starting with a simple assumption for the conditional distribution of x/L on the condition that y/L assumes certain values, the marginal distribution density has been derived and is shown as a curve in figure 19. The corresponding distribution function is given in figure 20.

4. PROBABILITY OF CAPSIZE

(Determination of the probability that a damaged ship will not capsize or sink -calculation of the "si' value)

.1 Criteria proposed to avoid capsizing or sinking.

It is not possible with the present state of knowledge to determine, with any degree of accuracy, criteria related to the probability of capsize of ships in waves. Therefore the formulae contained in these regulations are simplified and based on common standards used for damaged stability calculations.

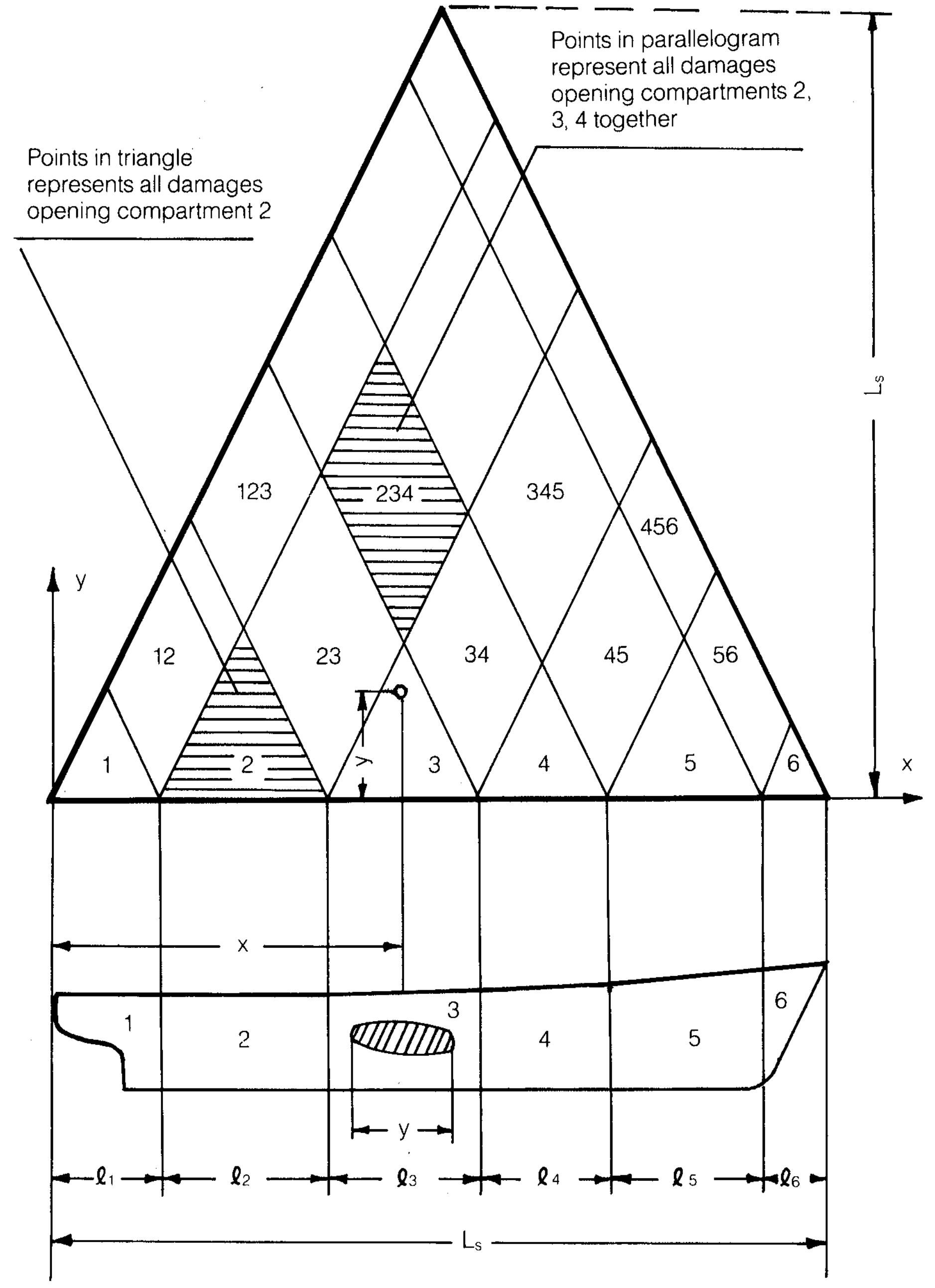
Points in parallelogram represent all damages opening compartments 2, 3, 4 together
Points in triangle represents all damages opening compartment 2
123
234
345
456
12
23
34
45
56
1
2
3
4
5
6
y
x
y
L_s
x
1
2
3
4
5
6
y
ℓ_1
ℓ_2
ℓ_3
ℓ_4
ℓ_5
ℓ_6
L_s

FIGURE 1

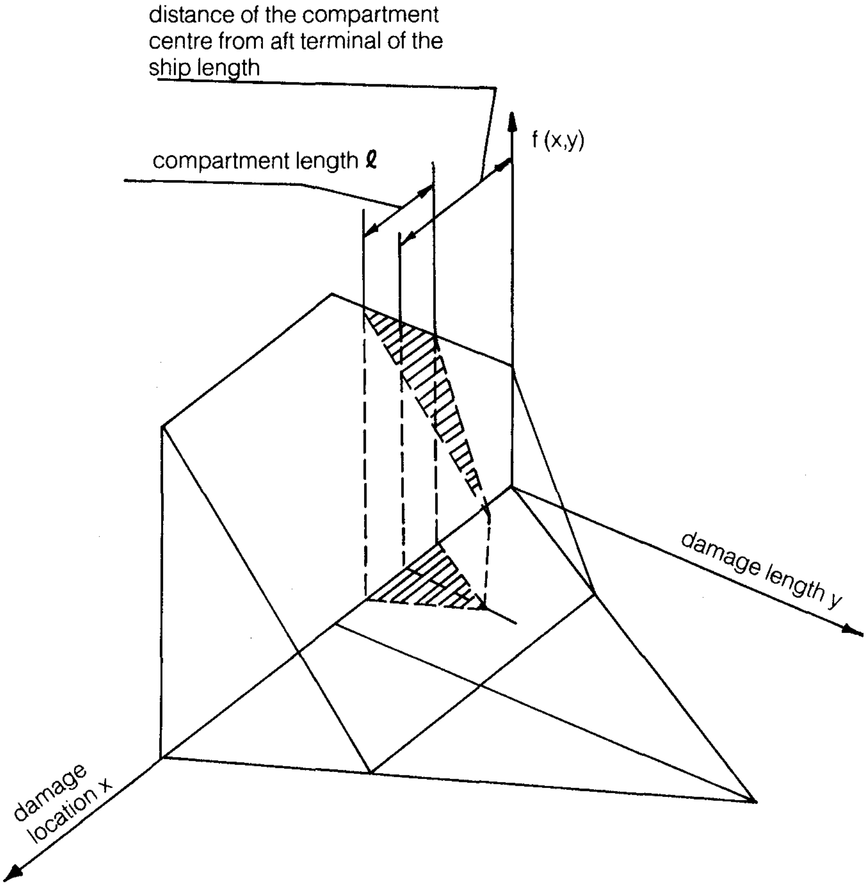
distance of the compartment centre from aft terminal of the ship length
compartment length ℓ
f (x,y)
damage length y
damage location x

FIGURE 2

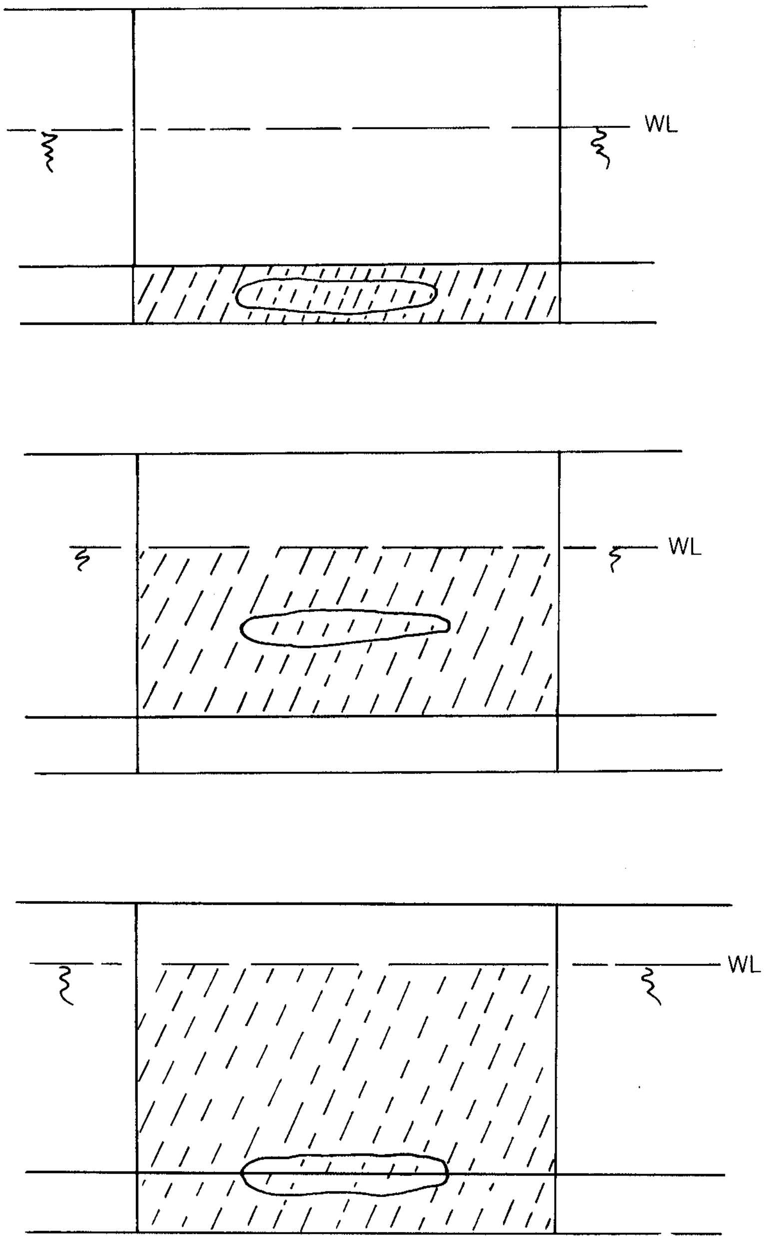

FIGURE 3

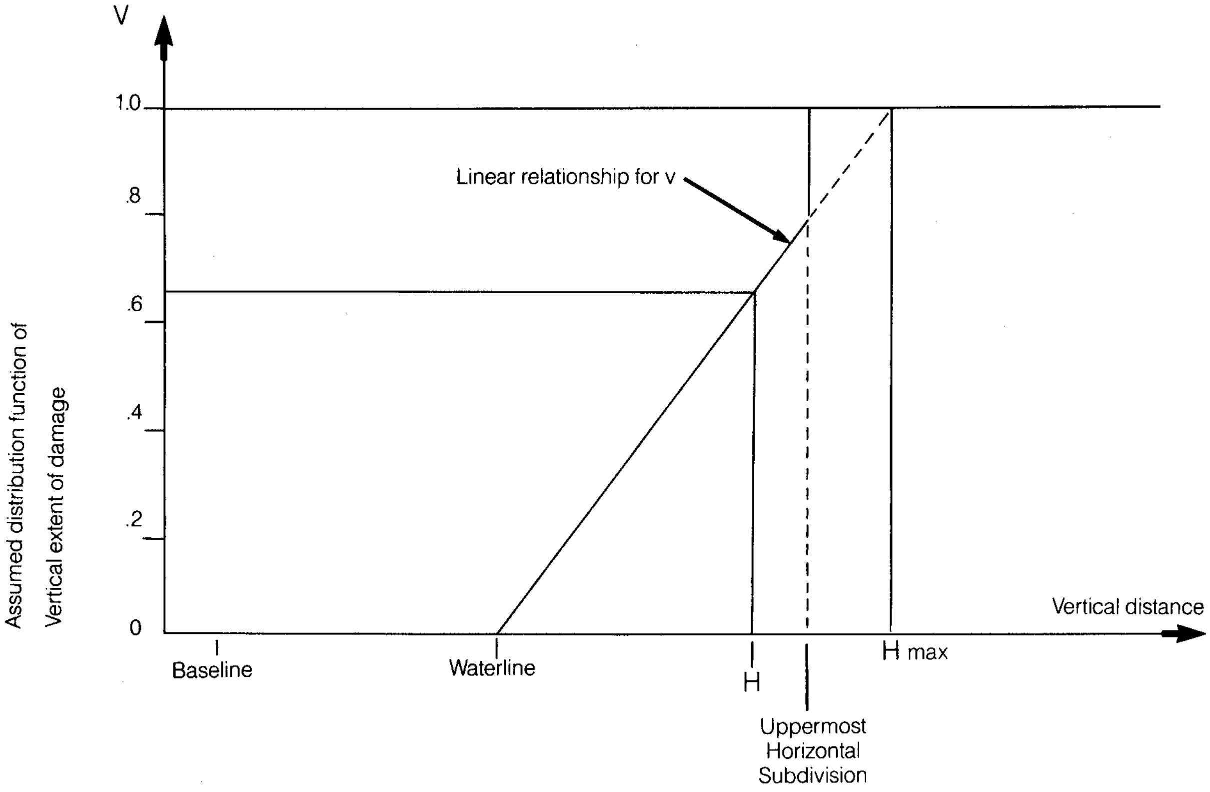
V
1.0
.8
.6
.4
.2
0
Assumed distribution function of
Vertical extent of damage
Linear relationship for v
Vertical distance
Baseline
Waterline
H
Uppermost
Horizontal
Subdivision
H max

FIGURE 4

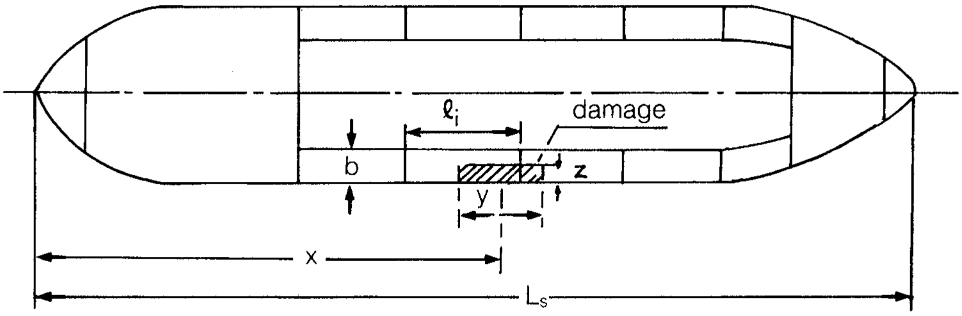

FIGURE 5

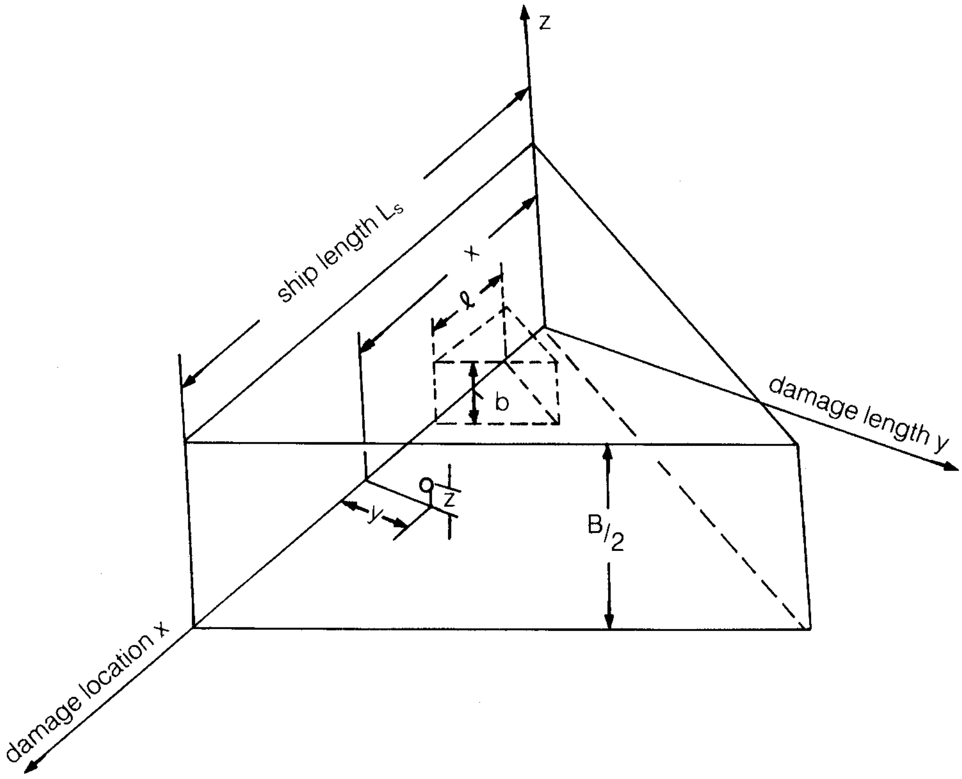

FIGURE 6

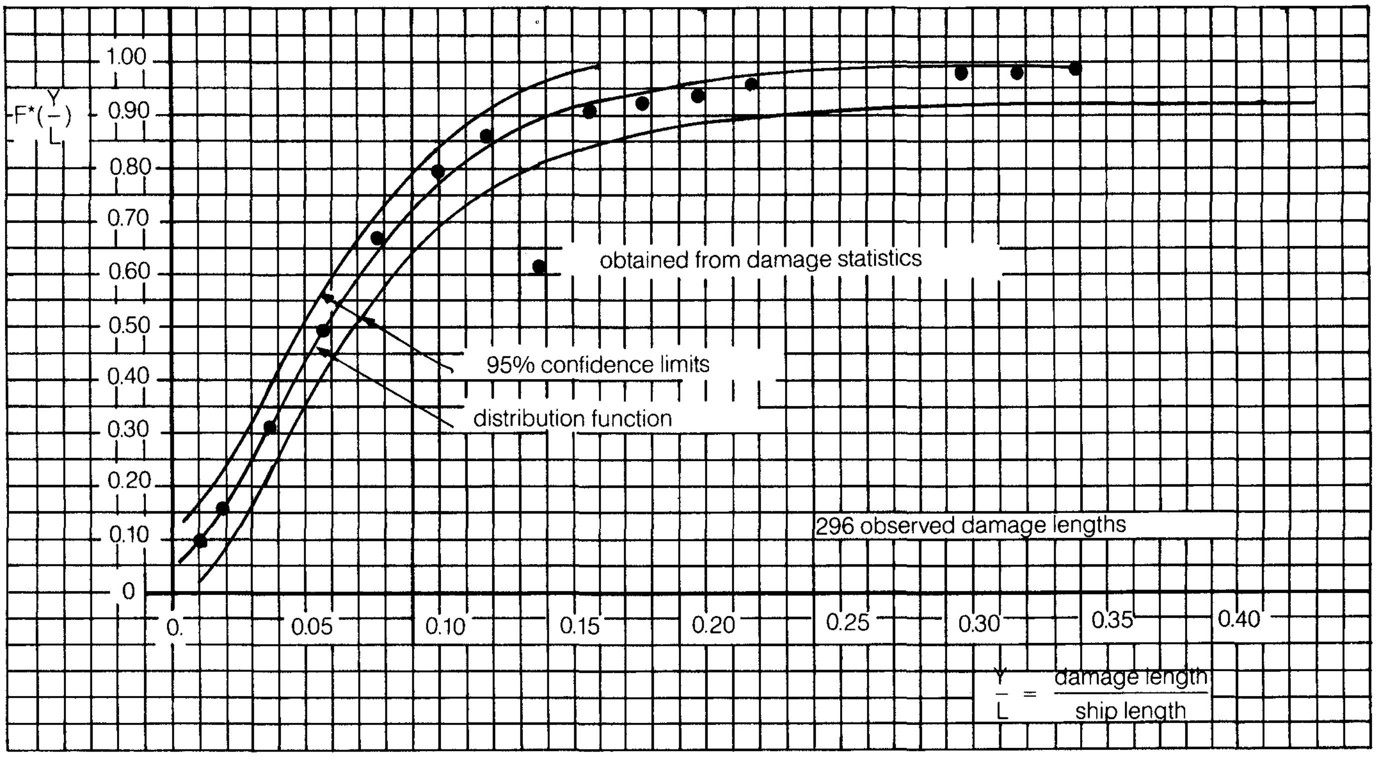

FIGURE 7 - DISTRIBUTION FUNCTION OF NON-DIMENSIONAL DAMAGE LENGTH

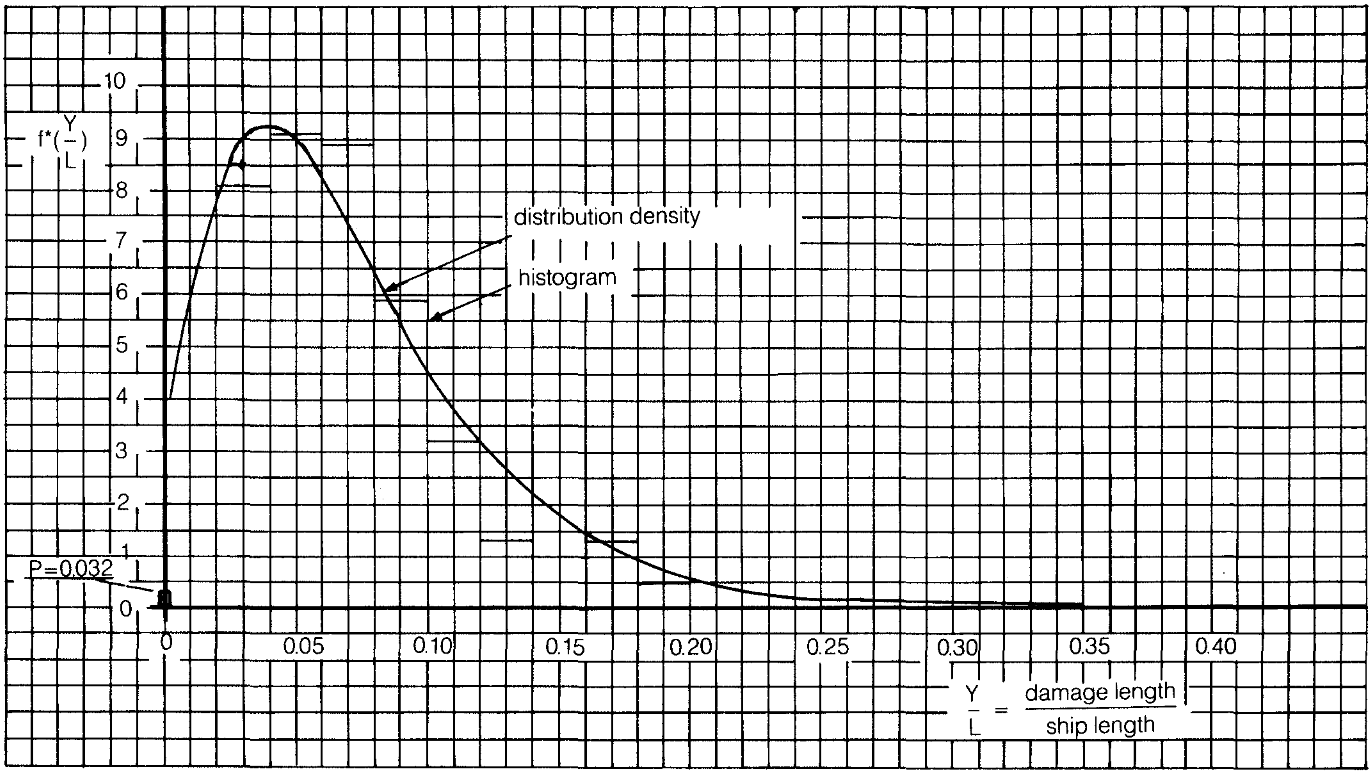

FIGURE 8 - DISTRIBUTION DENSITY OF NON-DIMENSIONAL DAMAGE LENGTH

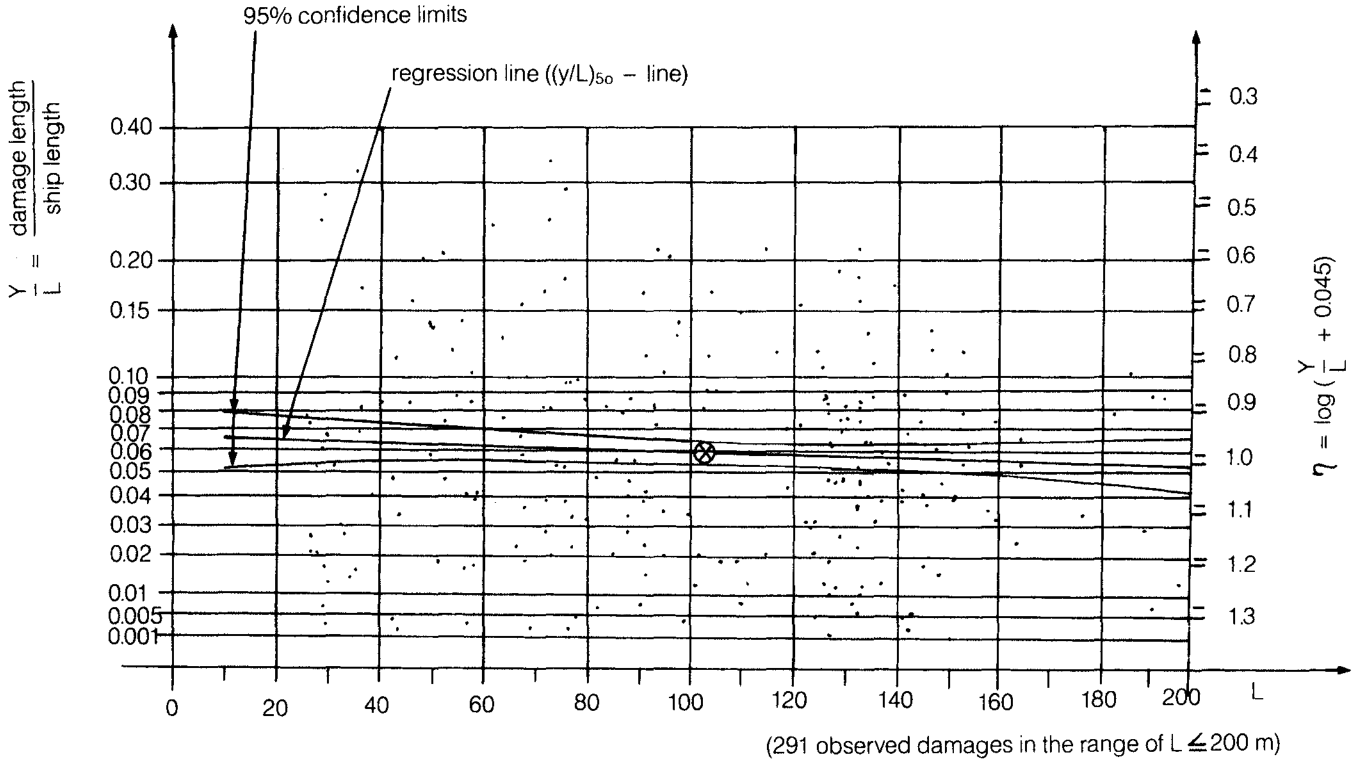

FIGURE 9 - REGRESSION OF NON-DIMENSIONAL DAMAGE LENGTH ON SHIP LENGTH

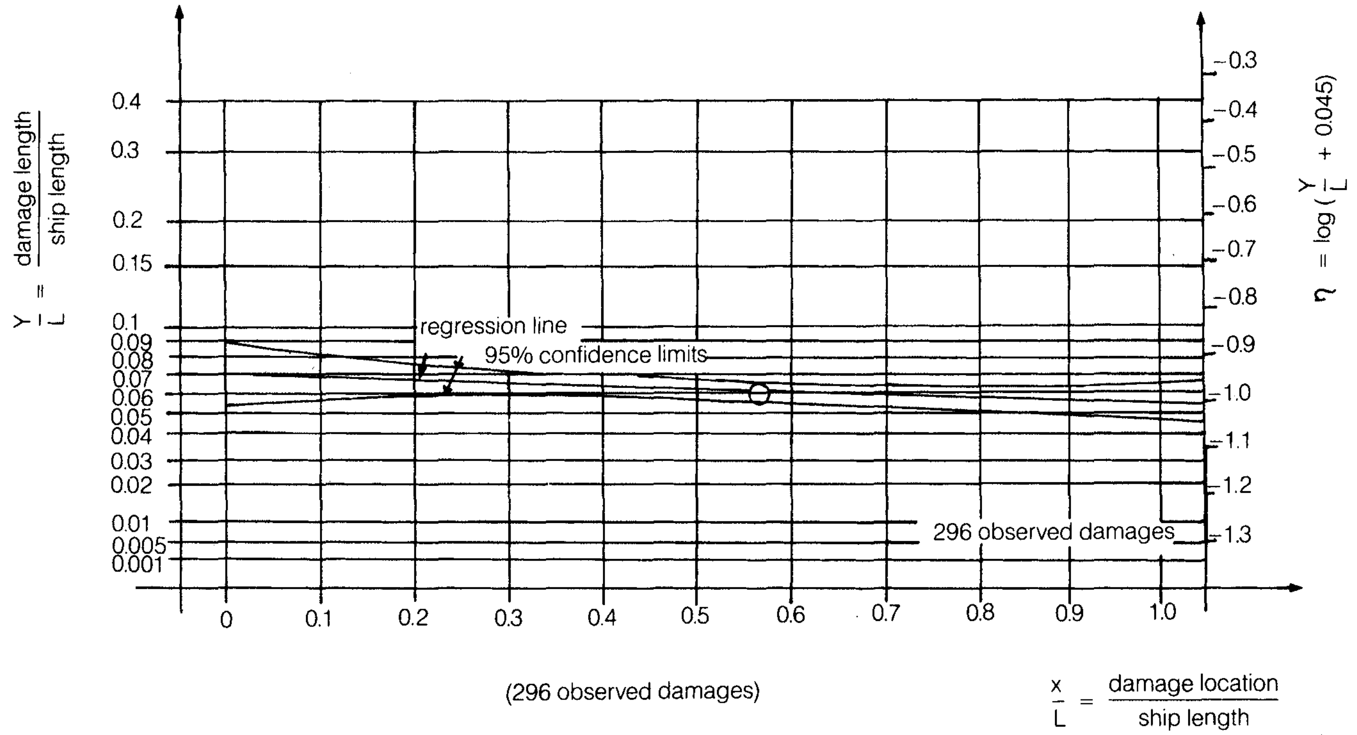

FIGURE 10 - REGRESSION OF NON-DIMENSIONAL DAMAGE LENGTH ON NON-DIMENSIONAL DAMAGE LOCATION

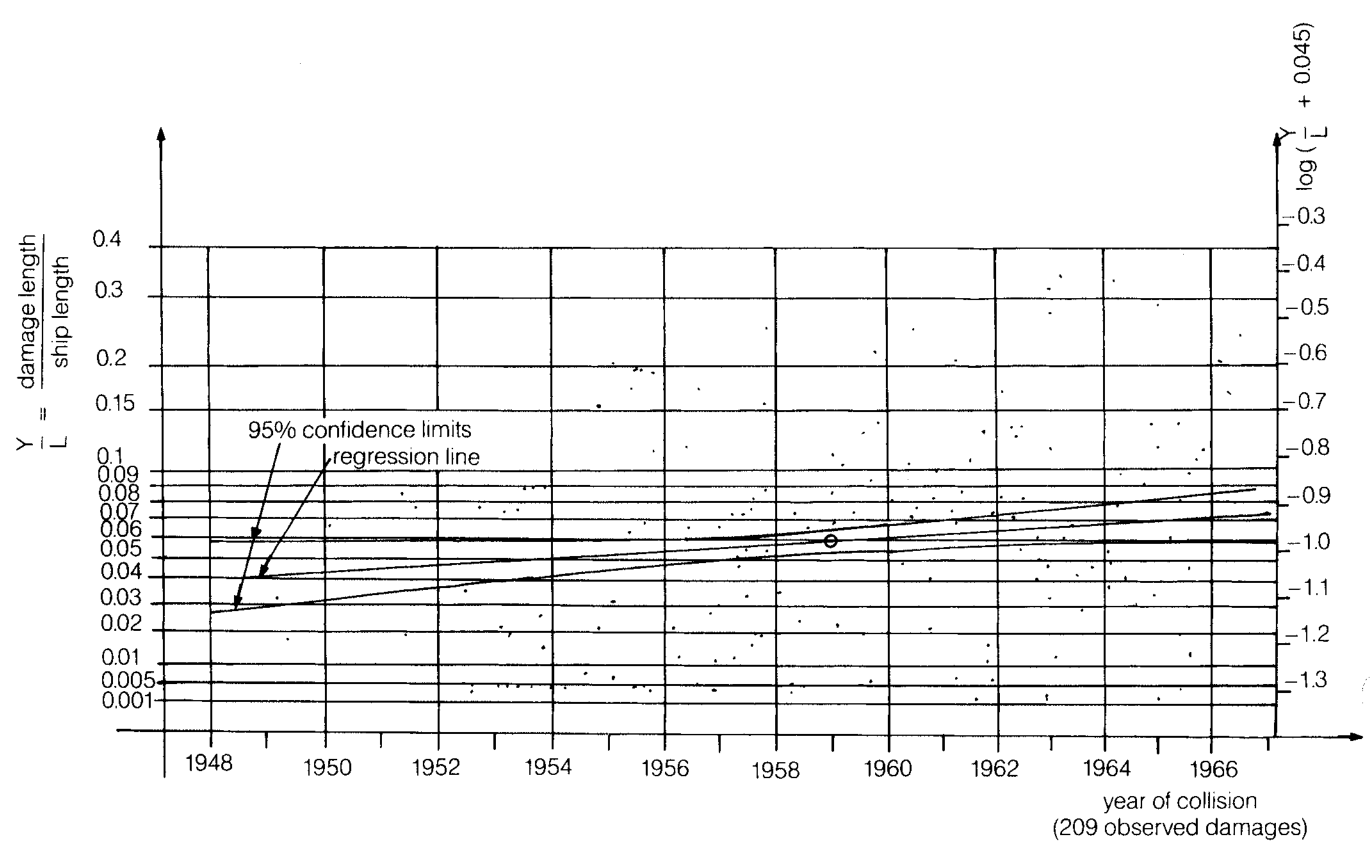

FIGURE 11 - REGRESSION OF NON-DIMENSIONAL DAMAGE LENGTH ON YEAR OF COLLISION

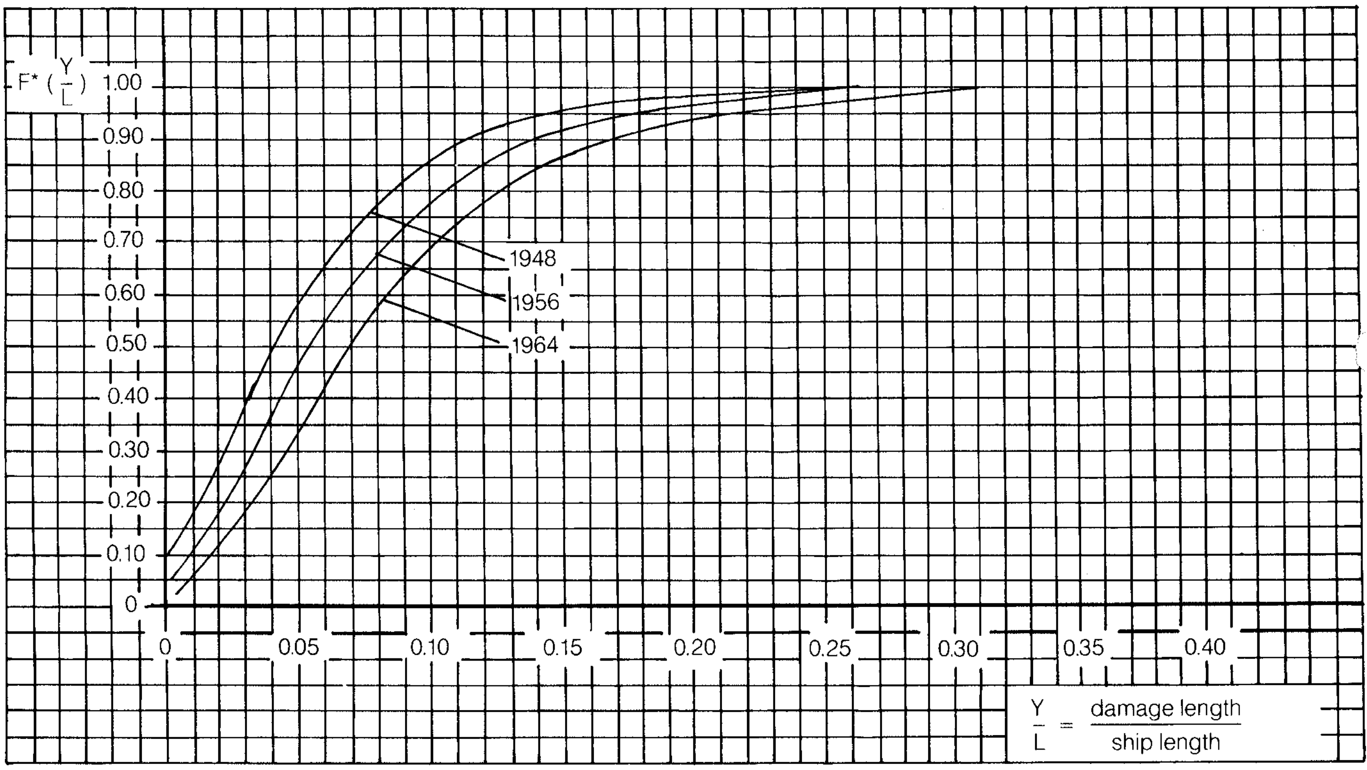

FIGURE 12 - DISTRIBUTION FUNCTION OF NON-DIMENSIONAL DAMAGE LENGTH FOR RESPECTIVE YEAR OF COLLISION

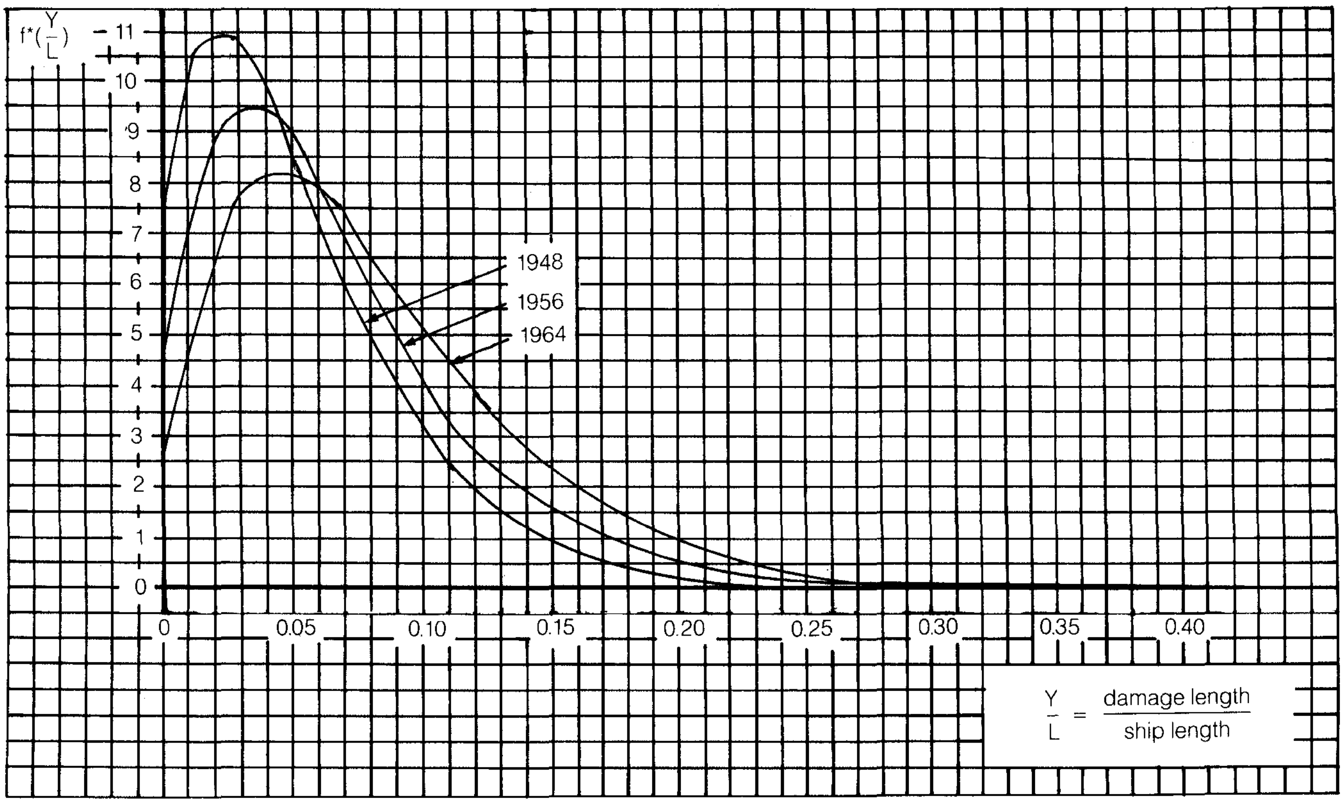

FIGURE 13 - DISTRIBUTION DENSITY OF NON-DIMENTSONAL DAMAGE LENGTH FOR RESPECTIVE YEAR OF COLLISION

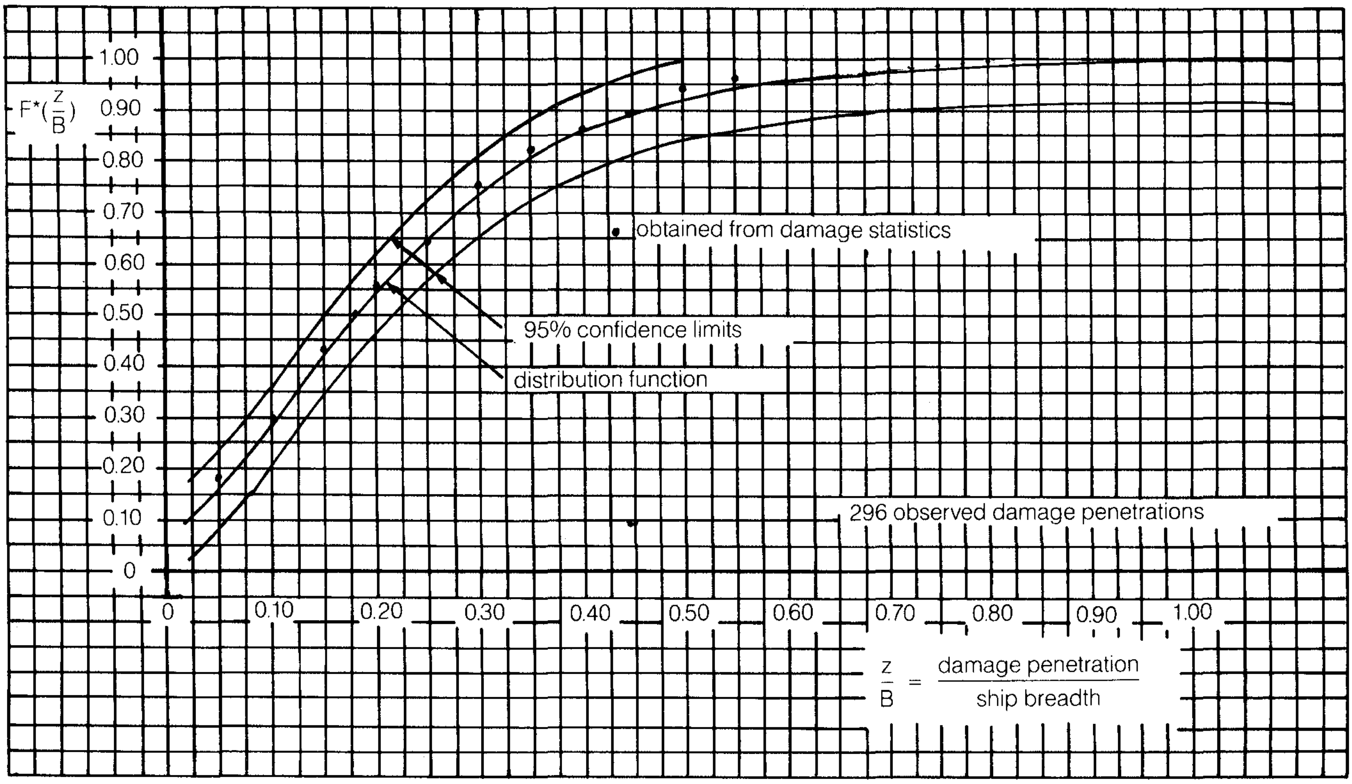

FIGURE 14 - DISTRIBUTION FUCTION OF NON-DIMENSIONAL DAMAGE PENETRATION

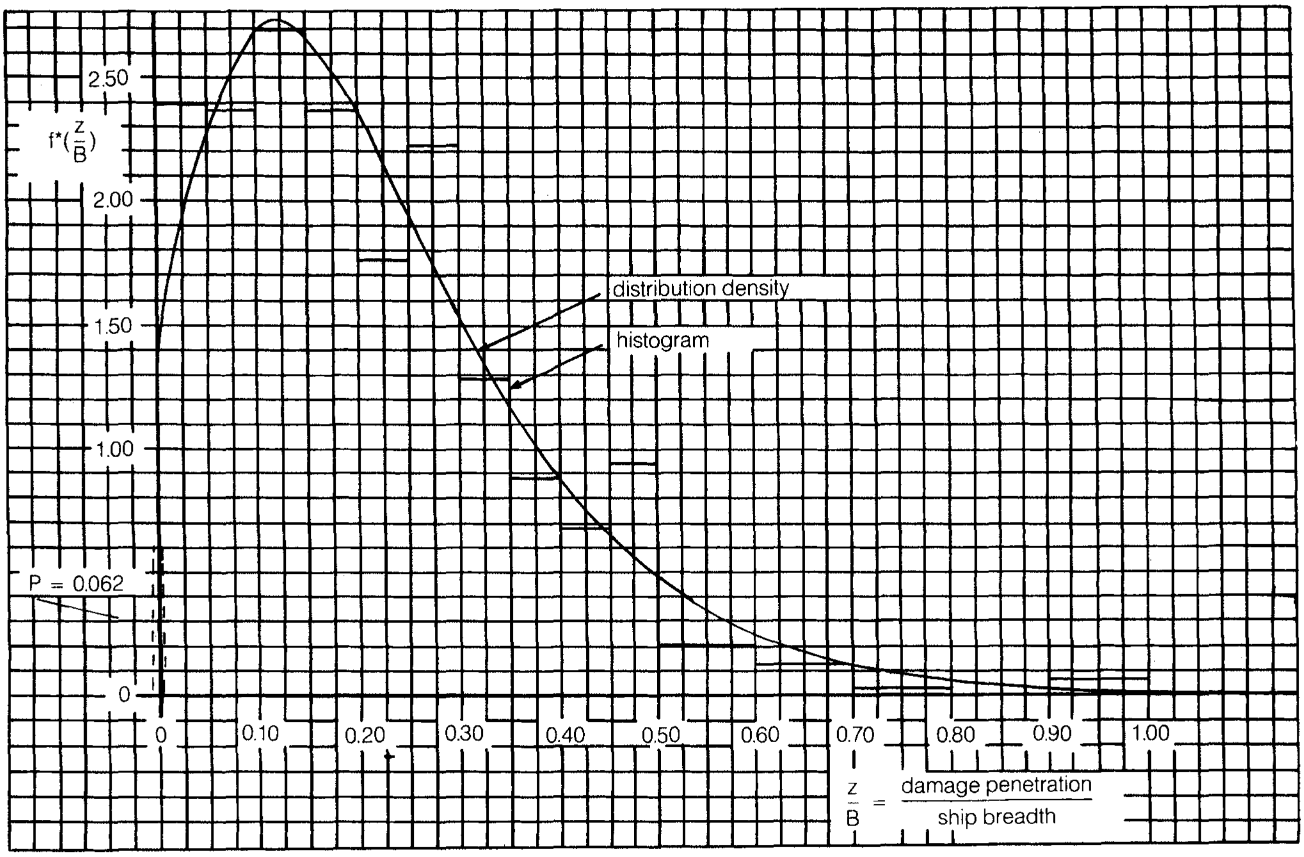

FIGURE 15 - DISTRIBUTION DENSITY OF NON-DIMENSIONAL DAMAGE PENETRATION

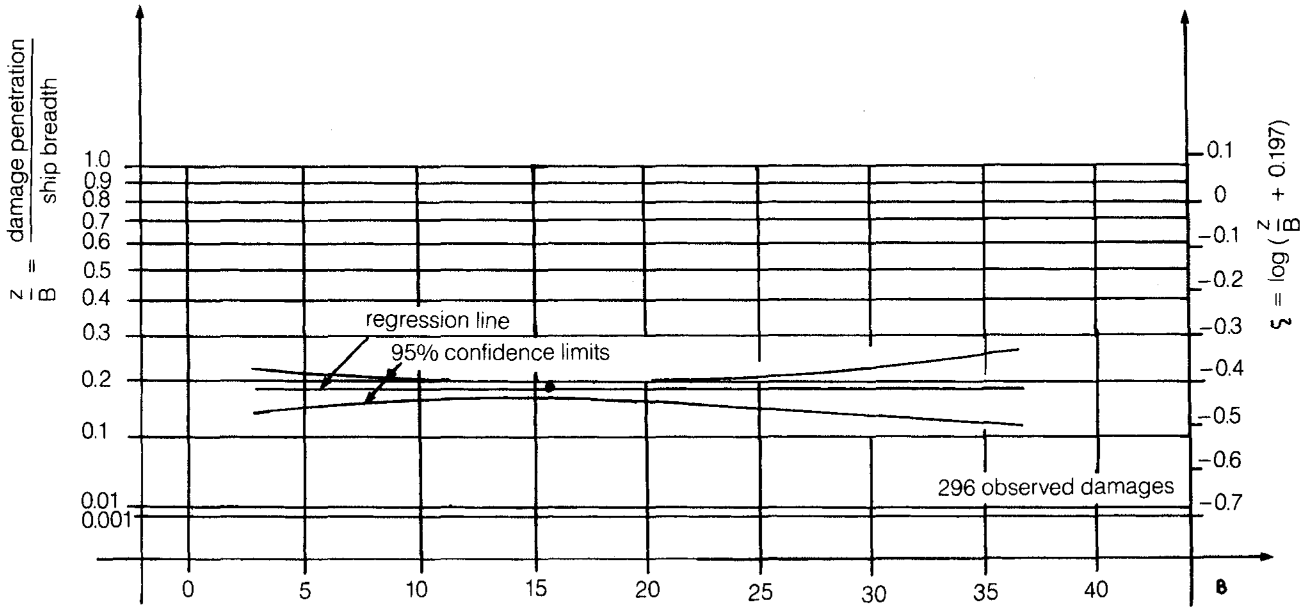

FIGURE 16 - REGRESSION OF NON-DIMENSIONAL DAMAGE PENETRATION ON SHIP BREADTH

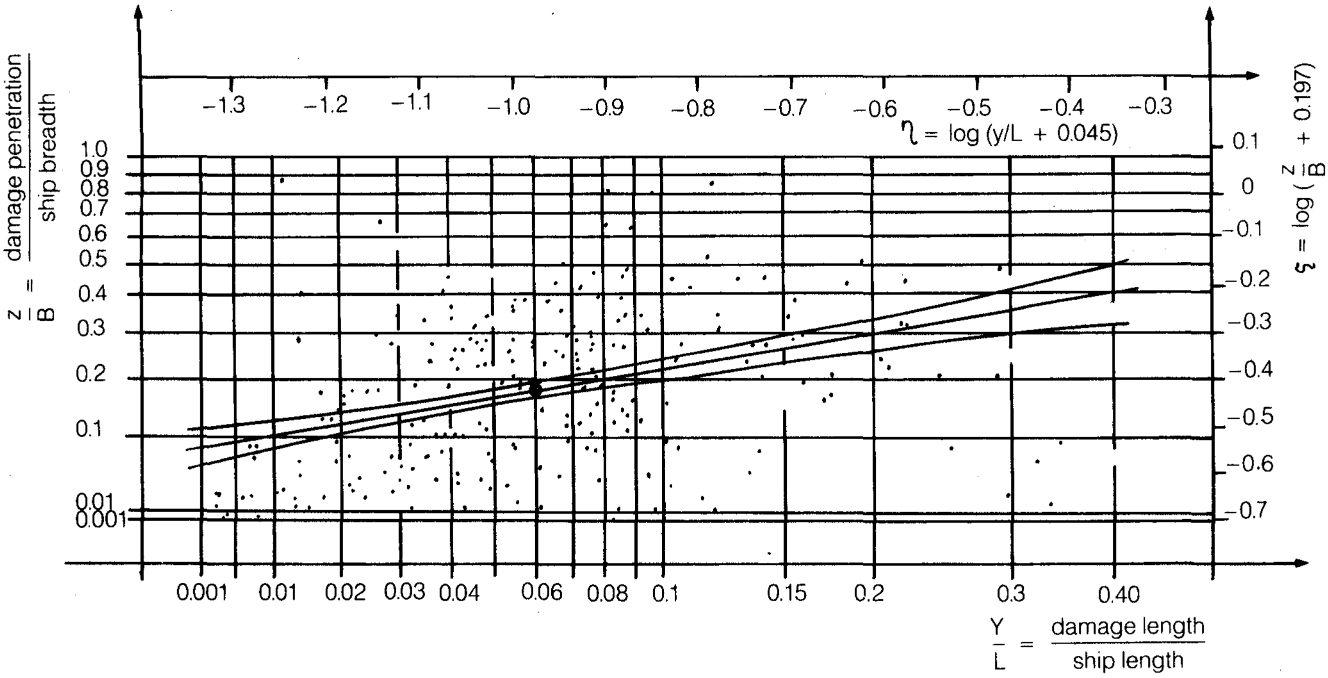

FIGURE 17

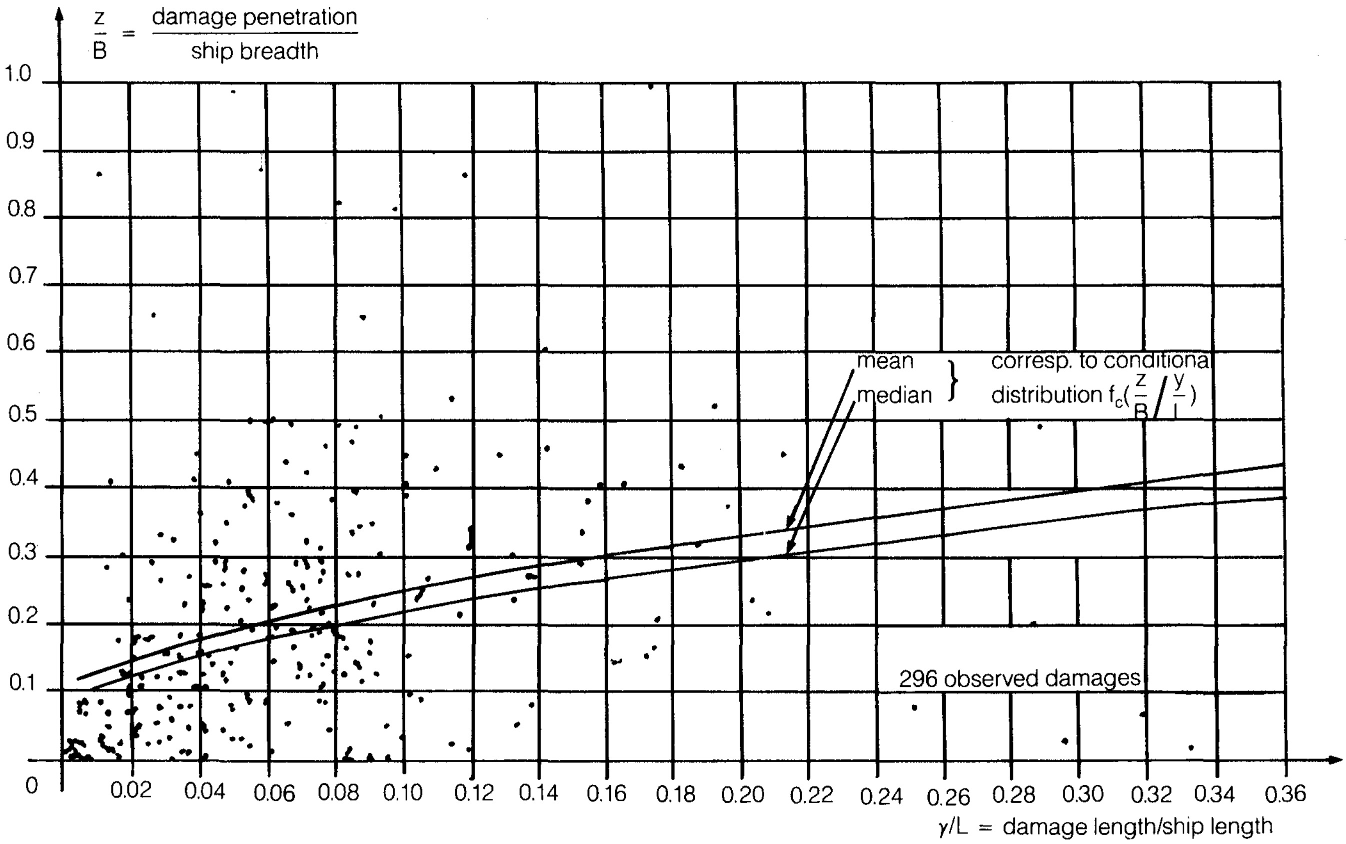

FIGURE 18

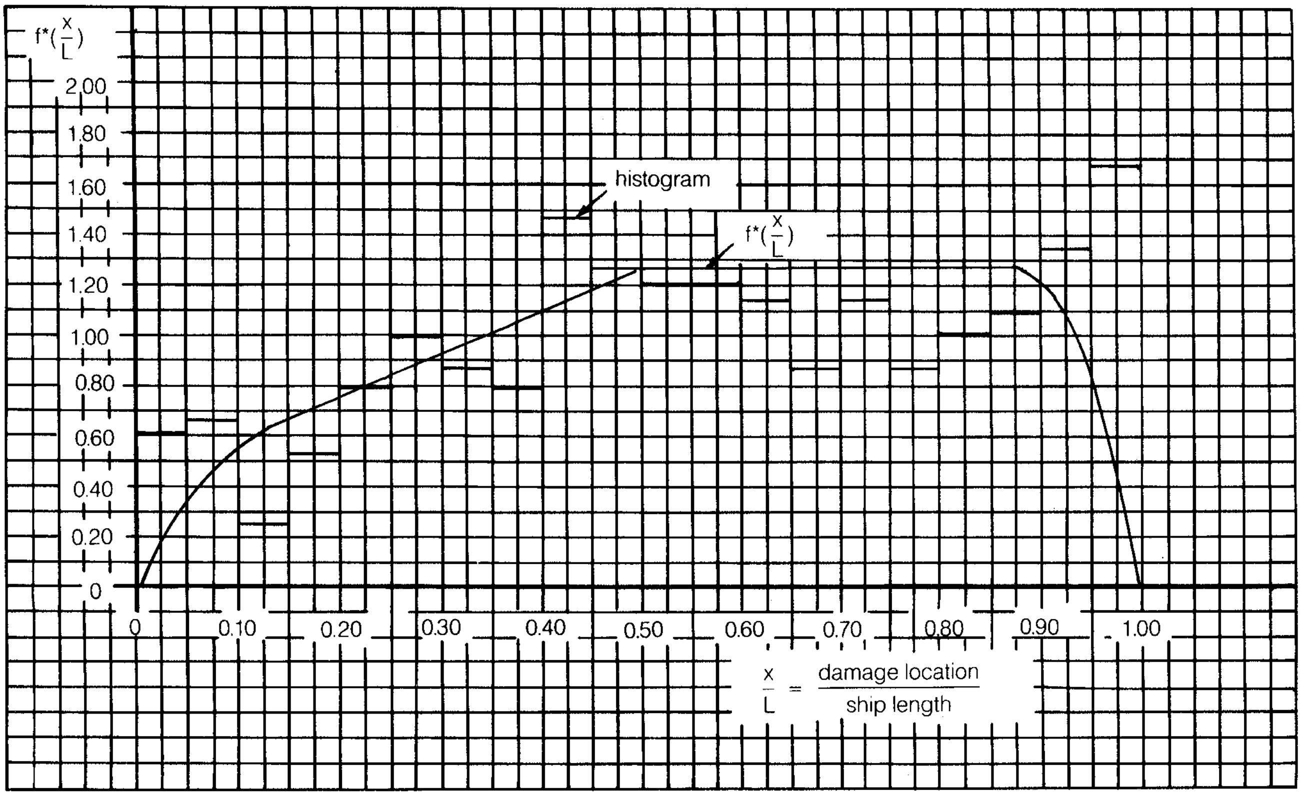

FIGURE 19 - DISTRIBUTION OF NON-DIMENSIONAL DAMAGE LOCATION

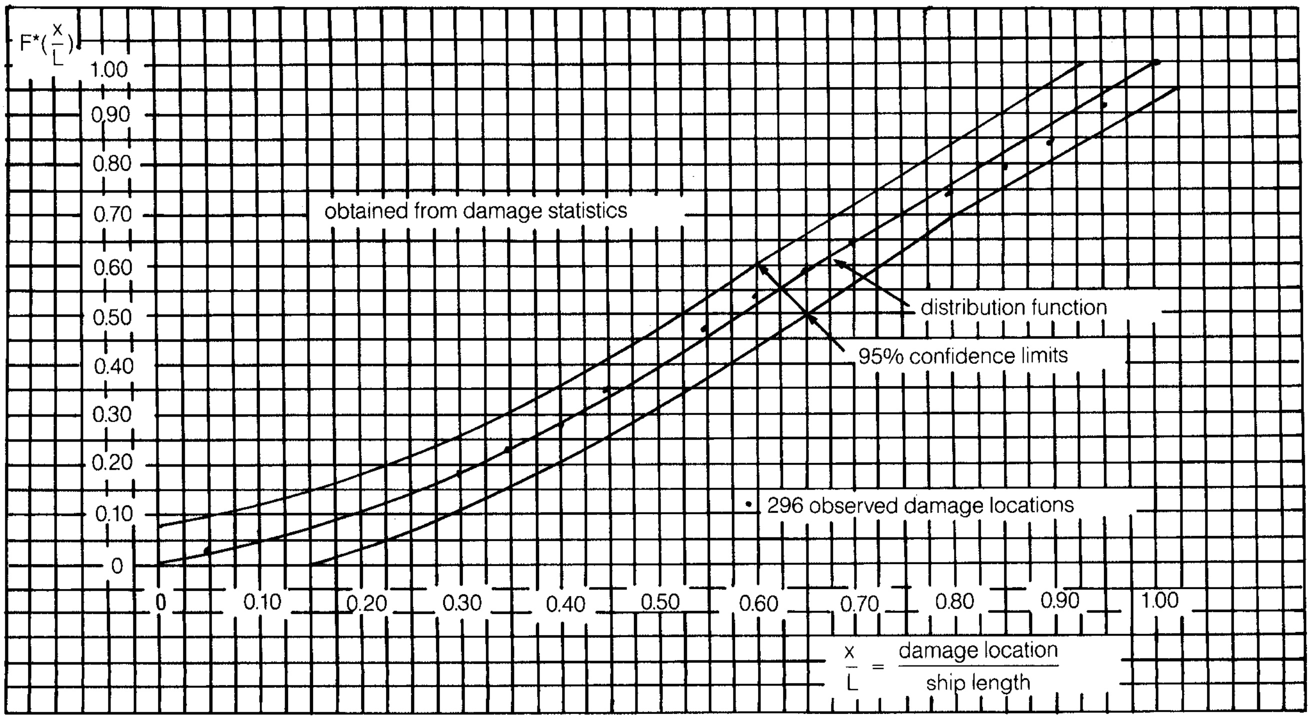

FIGURE 20 - DISTRIBUTION FUNCTION OF NON-DIMENSIONAL DAMAGE LOCATION

APPENDIX 1

TRANSVERSE SUBDIVISION

This Appendix illustrates, by means of examples, how to divide the ship length “L_s” into discrete damage zones. The subdivision of “L_s” into damage zones should not only take account of existing tranverse bulkheads, but also separate smaller local watertight compartments, the flooding of which have significant influence on the damage stability results.

1. Figure A-I shows the elevation of part of a ship containing two compartments named A and B. Compartment A is divided by local subdivision into the spaces Al and A2. For the purpose of calculating the products p*s, which contribute most favourably to the attained subdivsion index, three fictitious compartments or damage zones are considered. The basis for calculations of the ”p” and “s” values are given below:

.1	Zone 1 of length “ℓ_1”:	“p” based on “ℓ_1” “s” based on flooding of Space A1
.2	Zone 2 of length “ℓ_2”:	“p” based on “ℓ_2” “s” based on flooding of space A1 only or of A2 only, or of Al and A2, whichever results in the least “s” value “p” based on “ℓ_3”
.3	Zone 3 (or space B) of length “ℓ_3”:	“s” based on flooding of space B

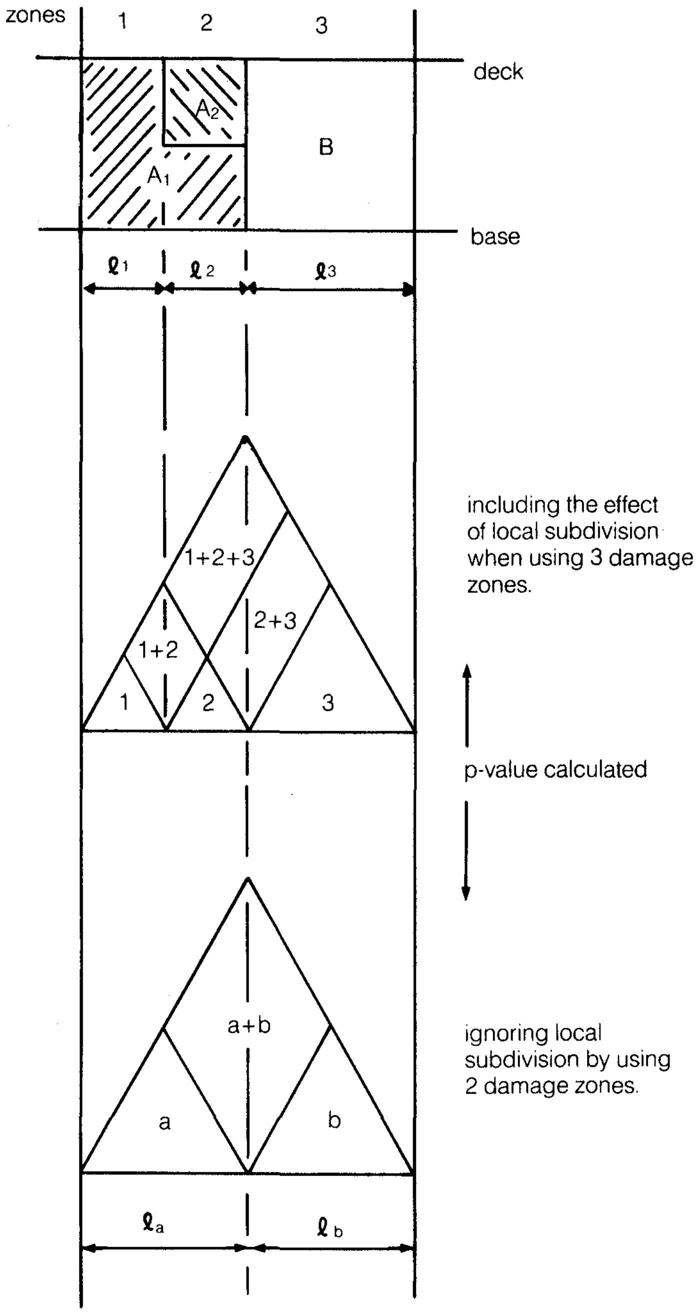
zones
1
2
3
deck
A2
A1
B
base
ℓ1
ℓ2
ℓ3
1+2+3
2+3
1+2
1
2
3
including the effect of local subdivision when using 3 damage zones.
p-value calculated
a+b
a
b
ignoring local subdivision by using 2 damage zones.
ℓa
ℓb

FIGURE A-1

.4 Zones 1 + 2: "p" based on "ℓ_1" and "ℓ_2"

"s" based on flooding of A_1 <u>or</u> of A_1 and A_2, whichever results in the lesser "s" value

.5 Zones 2 + 3: "p" based on "ℓ_2" and "ℓ_3"

"s" based on flooding of A_1 and A_2 and B <u>or</u> of A_1 and B <u>or</u> of A_2 and B, whichever results in the least "s" value

.6 Zones 1 + 2 + 3: "p" based on "ℓ_1", "ℓ_2" and "ℓ_3"

"s" based on flooding of A_1 and B <u>or</u> of A_1 and A_2 and B, whichever results in the lesser "s" value

2. It would also be compatible with the regulations to ignore the local subdivision with respect to the calculation of the "p" value. In this case, the following compartments and group of compartments would be considered.

.1 Zone a of length $\ell_3 = \ell_1 + \ell_2$: "p" based on "ℓ_a"

"s" based on flooding of space A_1 <u>or</u> of space A_2, <u>or</u> of spaces A_1 and A_2, whichever results in the least "s" value

.2 Zone b of length "ℓ_b" (=ℓ_3): "p" based on "ℓ_b"

"s" based on flooding of space B

.3 Zones a + b: "p" based on "ℓ_a" and "ℓ_b"

"s" based on flooding of A_1 and B <u>or</u> of A_2 and B <u>or</u> of A_1 and A_2 and B, whichever results in the least "s" value

3. Obviously, the approach given in paragraph 1 above will generally lead to a higher (but at least the same) attained subdivision index than the approach of paragraph 2. Also, the error made by neglecting the actual distribution of damage in the vertical direction is much smaller in the first case.

4. Another example of local subdivision is shown in Figure A-2. The following tables illustrate how this can be handled.

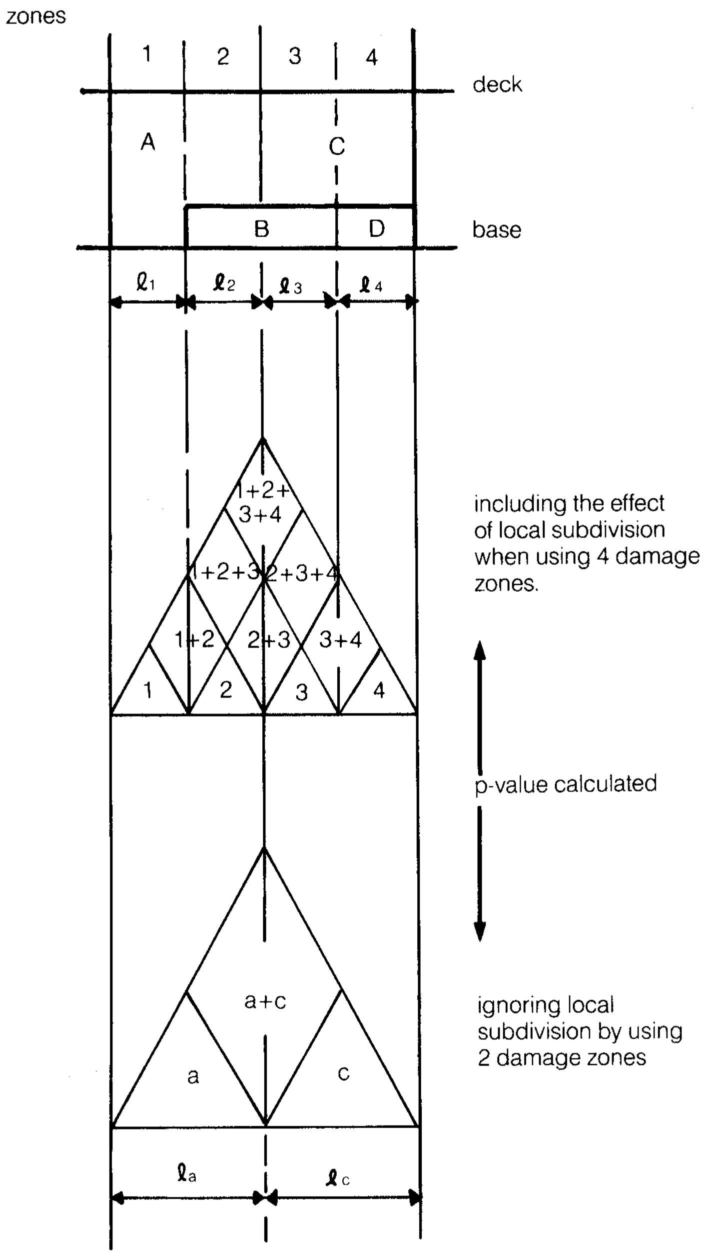
zones
1
2
3
4
deck
A
C
B
D
base
ℓ1
ℓ2
ℓ3
ℓ4
1+2+3+4
1+2+3
2+3+4
1+2
2+3
3+4
1
2
3
4
including the effect of local subdivision when using 4 damage zones.
p-value calculated
a+c
a
c
ignoring local subdivision by using 2 damage zones
ℓa
ℓc

FIGURE A-2

TABLE Al

P -value calculated including the effect of local subdivision

Damage zones measuring length of space opened	p based on length(s)	S based on the flooding of space(s) resulting in the poorest stability
1	ℓ_1	space A
2	ℓ_2	space A or space B or spaces A and B*
3	ℓ_3	space B or space C or spaces Band C*
4	ℓ_4	space C or space D or spaces C and D*
1+2	ℓ_1, ℓ_2	space A or spaces A and B*
2+3	ℓ_2, ℓ_3	space B or spaces A and C or spaces A and Band C*
3+4	ℓ_3, ℓ_4	space C or spaces Band D or spaces Band C and D*
1+2+3	ℓ_1, ℓ_2, ℓ_3	spaces A and B or A and C or A and Band C*
2+3+4	ℓ_2, ℓ_3, ℓ_4	spaces A and C or Band D or A and Band C and D*
1+2+3+4	$\ell_1, \ell_2, \ell_3, \ell_4$	spaces A and C or A and Band D or A and Band C and D*

* – whichever results in a smaller ‘s’ value

TABLE A-2

p – value calculated ignoring local subdivision

Damage zones measuring length of space opened	P based on length(s)	S based on the flooding of space(s) resulting in the poorest stability
A	$\ell_A = \ell_1, + \ell_2$	space A or space B or spaces A and B*
C	$\ell_C = \ell_3 + \ell_4$	space C or space B or spaces D or spaces C and B or spaces Band D or spaces C and D spaces Band C and D*
A+C	ℓ_A, ℓ_C	space B or spaces A and C or spaces Band D or spaces A and B and or spaces A and Band D or spaces A and Band C and D*

* -whichever results in a smaller's' value

APPENDIX 2

I COMBINED TRANSVERSE, HORIZONTAL AND LONGITUDINAL SUBDIVISION

1. Provision has been included in the new regulations to permit evaluation and acceptance of ships with combined longitudinal and transverse subdivision. To facilitate a full understanding and correct and uniform application of the new provisions, some illustrative material is contained in this Appendix. The examples given are based on three different arrangements of combined longitudinal and transverse subdivision as shown in Figures A-3, A-4 and A-5.

2. The following nomenclature is used in this section:

$\ell_1, \ell_2, \ell_3 \ldots$	distance between bulkheads bounding either inboard or wing compartments as shown in Figures A-3, A-4 and A-5

$\ell_{12} = \ell_1 + \ell_2$; + $\ell_{23} = \ell_2 + \ell_3$; $\ell_{34} = \ell_3 + \ell_4$, etc.

$\ell_{1-3} = \ell_1 + \ell_2 + \ell_3$; $\ell_{2-4} = \ell_2 + \ell_3 + \ell_4$, etc.

$\ell_{2-5} = \ell_2 + \ell_3 + \ell_4 + \ell_5$; $\ell_{3-6} = \ell_3 + \ell_4 + \ell_5 + \ell_6$, etc.

p_1, p_2, p_3 etc.	are "p" calculated according to regulation 25-5.1 using ℓ_1, ℓ_2, ℓ_3 etc, as "ℓ".
p_{12}, p_{23}, p_{34}, etc.	are "p" calculated according to regulation 25-5.1 using $\ell_{12}, \ell_{23}, \ell_{34}$ (1'34 etc, as "ℓ".
p_{1-3}, p_{2-4}, etc.	are "p" calculated according to regulation 25-5.1 using ℓ_{1-3}, ℓ_{2-4}, etc, as "ℓ".
p_{2-5}, p_{3-6}, etc.	are "p" calculated according to regulation 25-5.1 using ℓ_{2-5}, ℓ_{3-6}, etc, as "ℓ".
r_1, r_2, r_3, etc.	are "r" calculated according to regulation 25-5.2 using ℓ_1, ℓ_2, ℓ_3 etc, as "ℓ" and "b" defined in regulation 25-5.2.
r_{12}, r_{23}, r_{34}, etc.	are "r" calculated according to regulation 25-5.2 using ℓ_{12}, ℓ_{23}, ℓ_{34} etc, as "ℓ" and "b" defined in regulation 25-5.2.
r_{2-5}, r_{3-6}, etc.	are "r" calculated according to regulation 25-5.2 using ℓ_{2-5}, ℓ_{3-6}, etc, as "ℓ" and "b" as defined in regulation 25-5.2.
b	as defined in regulation 25-5.2

In calculating "r" values for a group of two or more adjacent compartments, the "b" value is common for all compartments in that group, and equal to the smallest "b" value in that group:

$$b = \min \{b_l, b_2 \ldots\ldots.. b_n\}$$

Where: "n" = number of wing compartments in that group;
"b_l", "b_2" ……. "b_n" are the mean values of "b" for individual wing compartments contained in the group.