ANNEX 16

RESOLUTION MEPC.110(49)

Adopted on 18 July 2003

REVISED INTERIM GUIDELINES FOR THE APPROVAL OF ALTERNATIVE METHODS OF DESIGN AND CONSTRUCTION OF OIL TANKERS UNDER REGULATION 13F(5) OF ANNEX I OF MARPOL 73/78

THE MARINE ENVIRONMENT PROTECTION COMMITTEE,

RECALLING Article 38(a) of the Convention on the International Maritime Organization concerning the functions of the Marine Environment Protection Committee (the Committee) conferred upon it by international conventions for the prevention and control of marine pollution,

NOTING resolution MEPC.52(32) by which the Committee adopted regulations 13F and 13G and related amendments to Annex I of MARPOL 73/78,

NOTING ALSO resolution MEPC.66(37) by which the Committee adopted the Interim Guidelines for the approval of alternative methods of design and construction of oil tankers under regulation 13F(5) of annex I of MARPOL 73/78,

NOTING FURTHER that by resolution MEPC.66(37), the Committee resolved to keep the Interim Guidelines under review and to develop final guidelines in the light of experience,

HAVING CONSIDERED, at its forty-ninth session, the recommendation made by the Sub-Committee on Bulk Liquids and Gases,

1. ADOPTS the Revised Interim Guidelines for the approval of alternative methods of design and construction of oil tankers under regulation 13F(5) of Annex I of MARPOL 73/78, the text of which is set out in the Annex to the present resolution;

2. INVITES Member Governments to give due consideration to the Revised Interim Guidelines when evaluating other methods of design and construction of oil tankers as alternatives to the requirements prescribed in regulation 13F(5) of Annex I of MARPOL 73/78 for submission of such designs to the Committee for approval;

3. AGREES to keep the Revised Interim Guidelines under review in the light of experience gained;

4. INVITES the Maritime Safety Committee to note the Revised Interim Guidelines;

5. URGES Member Governments to bring the aforementioned Revised Interim Guidelines to the attention of shipbuilders, shipowners, ship operators and other parties concerned with the design, construction and operation of oil tankers with a view to encouraging their use for oil tankers constructed on or after 1 April 2005;

6. REVOKES resolution MEPC.66(37).

ANNEX

REVISED INTERIM GUIDELINES FOR THE APPROVAL OF ALTERNATIVE METHODS OF DESIGN AND CONSTRUCTION OF OIL TANKERS UNDER REGULATION 13F(5) OF ANNEX I OF MARPOL 73/78

Preamble

1 The purpose of these Revised Interim Guidelines, hereunder referred to as "the Guidelines", is to provide an international standard for the evaluation and approval of alternative methods of design and construction of oil tankers under regulation 13F(5) of Annex I of MARPOL 73/78.

2 The basic philosophy of the Guidelines is to compare the oil outflow performance in case of collision or stranding of an alternative tanker design to that of reference double-hull designs complying with regulation 13F(3) on the basis of a calculated pollution-prevention index.

3 The oil outflow performance of double-hull tankers which comply with regulation 13F(3) may be different. The longitudinal subdivision of the cargo tanks has a major influence on the oil outflow in case of inner hull penetration. The selected reference double-hull designs exhibit a favourable oil outflow performance.

4 The calculation of oil outflow is based on the probabilistic methodology and best available tanker accident damage statistics. Reappraisal of the Guidelines may be appropriate when more information on tanker accident damage has become available and more experience with the application of these Guidelines has been gained.

5 Falling tides will have an adverse effect on oil outflow from a stranded tanker and the Guidelines take account of this. The tide values specified in section 5 represent realistic average tidal changes which have been chosen to identify the influence of tidal changes on the oil outflow in case of stranding.

1 **General**

1.1 Regulation 13F of Annex I of MARPOL 73/78 specifies structural requirements for new tankers of 600 dwt and above, contracted on or after 6 July 1993. Paragraph (3) of the regulation requires tankers of 5,000 dwt and above to be equipped with double hulls. Various detailed requirements and permissible exceptions are given in the regulation.

Paragraph (5) of the regulation specifies that other designs may be accepted as alternatives to double hull, provided they give at least the same level of protection against oil pollution in the event of collision or stranding and are approved in principle by the Marine Environment Protection Committee (MEPC) based on Guidelines developed by the Organization.

1.2 These Guidelines should be used to assess the acceptability of alternative oil tanker designs of 5,000 dwt and above with regard to the prevention of oil outflow in the event of collision or stranding as specified in paragraph (5) of regulation 13F.

1.3 For any alternative design of an oil tanker not satisfying regulation 13F(3) or (4), a study of the cargo oil outflow performance should be carried out as specified in sections 4 through 6 of these Guidelines.

1.4 This study should cover the full range of ship sizes with a minimum of four different ship sizes, unless the approval is requested for only a limited range of vessel sizes. Data for four reference double-hull designs are given in section 7.

1.5 Evaluation of the cargo oil outflow performance of the proposed alternative design should be made by calculating the pollution-prevention index E, as outlined in section 4 of these Guidelines.

1.6 The probabilistic methodology for the calculation of oil outflow according to these Guidelines is based on available tanker casualty statistics. With the collection of additional statistical material, the damage density distribution functions specified in paragraph 5.2 should be periodically reviewed.

1.7 In principle, and as far as applicable, the requirements of paragraphs (3)(d)-(f), (6) and (8) of regulation 13F apply also to alternative designs. The requirements of paragraph (9) of regulation 13F also applies to alternative designs. In addition, it should be demonstrated by means of a risk analysis that the new design under consideration provides an adequate safety level. Such analysis should address any specific risks associated with the alternative design and, if there are any, it should be demonstrated that safe solutions exist to cope with them.

2 Applicability

2.1 These Guidelines apply to the assessment of alternative designs of oil tankers to be constructed of steel or other equivalent material, as required by SOLAS regulation II-2/11. Designs for tankers intended to be constructed of other materials or incorporating novel features (e.g. non-metallic materials) or designs which use impact-absorbing devices should be specially considered.

2.2 The approval procedure of these Guidelines applies to oil tankers of sizes up to 350,000 dwt. For larger sizes the approval procedure should be specially considered.

3 Approval procedure for alternative tanker designs

3.1 An Administration which receives a request for approval of an alternative tanker design for the purpose of complying with regulation 13F, should first evaluate the proposed design and satisfy itself that the design complies with these Guidelines and other applicable regulations of MARPOL Annex I. That Administration should then submit the proposal and the supporting documentation, together with its own evaluation report, to the Organization for evaluation and approval of the design concept by the MEPC as an alternative to the requirements of regulation 13F(3). Only design concepts which have been approved in principle by the MEPC are allowed for the construction of tankers to which regulation 13F(5) applies.

3.2 The submission to the Administration and the Organization should at least include the following items:

.1 detailed specification of the alternative design concept;

.2 drawings showing the basic design of the tank system and, where necessary, of the entire ship;

.3 study of the oil outflow performance as outlined in paragraphs 1.3 to 1.5;

.4 risk analysis as outlined in paragraph 1.7;

.5 details of the calculation procedure or computer program used for the probabilistic oil outflow analysis to satisfy the Administration that the calculation procedure used gives satisfactory results. For verification of the computer program see paragraph 6.2.

Any additional information may be required to be submitted if deemed necessary.

3.3 In addition to the approval procedure for the design concept specified in paragraphs 3.1 and 3.2 above, the final shipyard design should be approved by the Flag State Administration for compliance with these Guidelines and all other applicable regulations MARPOL Annex I. This should include survivability considerations as referred to in paragraph 5.1.5.10.

3.4 Any approved design concept will require reconsideration if the Guidelines have been amended.

4 **Oil outflow analysis**

4.1 *General*

4.1.1 The oil pollution prevention performance of a tanker design is expressed by a non-dimensional oil pollution prevention index E which is a function of the three oil outflow parameters: "probability of zero oil outflow", "mean oil outflow" and "extreme oil outflow". The oil outflow parameters should be calculated for all conceivable damage cases within the entire envelope of damage conditions as detailed in section 5.

4.1.2 The three oil outflow parameters are defined as follows:

.1 *Probability of zero oil outflow*. This parameter represents the probability that no cargo oil will escape from the tanker in case of collision or stranding. If, e.g., the parameter equals 0.6, in 60% of all collision or stranding accidents no oil outflow is expected to occur.

.2 *Mean oil outflow parameter*. The mean oil outflow represents the sum of all outflow volumes multiplied by their respective probabilities. The mean oil outflow parameter is expressed as a fraction of the total cargo oil capacity at 98% tank filling.

.3 *Extreme oil outflow parameter*. The extreme oil outflow is calculated - after the volumes of all outflow cases have been arranged in ascending order - as the sum of the outflow volumes between 0.9 and 1.0 cumulative probability, multiplied by their respective probabilities. The value so derived is multiplied by 10. The extreme oil outflow parameter is expressed as a fraction of the total cargo oil capacity at 98% tank filling.

4.1.3 In general, consideration of ship's survivability will not be required for the conceptual approval of an alternative design. This may, however, be required in special cases, depending on special features of the design.

4.2 *Pollution-prevention index*

The level of protection against oil pollution in the event of collision or stranding as compared to the reference double-hull designs should be determined by calculation of the pollution-prevention index E as follows:

$$E = k_1\, P_O/P_{OR} + k_2\, (0.01 + O_{MR})/(0.01 + O_M) + k_3\, (0.025 + O_{ER})/(0.025 + O_E) = 1.0 \quad (4.2)$$

where:

k_1, k_2 and k_3 are weighting factors having the values:

k_1 = 0.5
k_2 = 0.4
k_3 = 0.1

P_O = probability of zero oil outflow for the alternative design
O_M = mean oil outflow parameter for the alternative design
O_E = extreme oil outflow parameter for the alternative design
P_{OR}, O_{MR} and O_{ER} are the corresponding parameters for the reference double-hull design of the same cargo oil capacity as specified in section 7.

4.3 *Calculation of oil outflow parameters*

The oil outflow parameters P_O, O_M and O_E should be calculated as follows:

Probability of zero oil outflow, P_O:

$$P_O = \sum_{i=1}^{n} P_i\, K_i \quad (4.3\text{-}1)$$

where:

i represents each compartment or group of compartments under consideration, running from $i = 1$ to $i = n$
P_i accounts for the probability that only the compartment or group of compartments under consideration are breached
K_i equals 0 if there is oil outflow from any of the breached cargo spaces in i. If there is no outflow, K_i equals 1.

Mean oil outflow parameter, O_M:

$$O_M = \sum^{n} (P_i\, O_i)/C \quad (4.3\text{-}2)$$

$i=1$

where:

O_i = combined oil outflow (m^3) from all cargo spaces breached in *i*
C = total cargo oil capacity at 98% tank filling (m^3)

Extreme oil outflow parameter, O_E:

$$O_E = 10 ?? \sum_{i=1}^{n} (P_{ie} O_{ie})/C? \quad (4.3\text{-}3)$$

where the index "*ie*" represents the extreme outflow cases, which are the damage cases falling within the cumulative probability range between 0.9 and 1.0 after they have been arranged as specified in paragraph 6.1.

5 Assumptions for calculating oil outflow parameters

5.1 *General*

5.1.1 The assumptions specified in this section should be used when calculating the oil outflow parameters.

5.1.2 Outflow parameters should be calculated independently for collisions and strandings and then combined as follows:

.1 0.4 of the computed value for collisions; and

.2 0.6 of the computed value for strandings.

5.1.3 For strandings, independent calculations should be done for 0 m and 2.5 m fall in tide. Outflow parameters for the stranded conditions should be a weighted average, calculated as follows:

.1 .7 for 0 m tide condition; and

.2 0.3 for 2.5 m fall in tide condition.

5.1.4 The damage cases and the associated probability factor P_i for each damage case should be determined based on the damage density distribution functions as specified in paragraph 5.2.

5.1.5 The following general assumptions apply for the calculation of outflow parameters:

.1 The ship should be assumed loaded to the load line draught d_s with zero trim and heel. All cargo tanks should be assumed loaded to 98% of their volumetric capacity. The nominal density of the cargo oil should be calculated as follows:

$$\rho_n = 1000\,(DW)/C\ (kg/m^3) \quad (5.1.5.1)$$

.2 For the purposes of these outflow calculations, the permeability of each space within the cargo block, including cargo tanks, ballast tanks and other non-oil spaces should be taken as 0.99, unless proven otherwise.

.3 For all cases of collision damage, the entire contents of all damaged cargo oil tanks should be assumed to be spilled into the sea, unless proven otherwise.

.4 For all stranded conditions, the ship should be assumed aground on a shelf. Assumed stranded draughts prior to tidal change should be equal to the initial intact draughts. Should the ship trim or float free due to the outflow of oil, this should be accounted for in the calculations for the final shipyard design.

.5 In general, an inert gas overpressure of 0.05 bar gauge should be assumed if an inert gas system is fitted, otherwise the inert gas overpressure should be taken as zero.

.6 For the calculation of oil outflow in case of stranding, the principles of hydrostatic balance should apply, and the location of damage used for calculations of hydrostatic pressure balance and related oil outflow calculations should be the lowest point in the cargo tank.

.7 For cargo tanks bounded by the bottom shell, unless proven otherwise, oil outflow equal to 1% of the volume of the damaged tank should be assumed to account for initial exchange losses and dynamic effects due to current and waves.

.8 For breached non-cargo spaces located wholly or in part below breached cargo oil tanks, the flooded volume of these spaces at equilibrium should be assumed to contain 50% oil and 50% seawater by volume, unless proven otherwise.

.9 If deemed necessary, model tests may be required to determine the influence of tidal, current and swell effects on the oil outflow performance.

.10 For ship designs which incorporate cargo transfer systems for reducing oil outflow, calculations should be provided illustrating the effectiveness of such devices. For these calculations, damage openings consistent with the damage density distribution functions defined in paragraph 5.2 should be assumed.

.11 Where, for the final shipyard design referred to in 3.3 and in the special cases referred to in paragraph 4.1.3, damage stability calculations are required, the following should apply:

A damage stability calculation should be performed for each damage case. The stability in the final stage of flooding should be regarded as sufficient if the requirements of MARPOL regulation I/25(3) are complied with.

Should the ship fail to meet the survivability criteria as defined in MARPOL regulation I/25(3), 100% oil outflow from all cargo tanks should be assumed for that damage case.

5.2 *Damage assumptions*

5.2.1 General, definitions

The damage assumptions for the probabilistic oil outflow analysis are given in terms of the damage density distribution functions specified in paragraphs 5.2.2 and 5.2.3. These functions are so scaled that the total probability for each damage parameter equals 100% (i.e. the area under each curve equals 1.0).

The location of a damage refers always to the centre of a damage. Damage location and extent to an inner horizontal bottom or vertical bulkhead should be assumed to be the same as the statistically derived damage to the outer hull.

The location and extent of damage to compartment boundaries should be assumed to be of rectangular shape, following the hull surface in the extents defined in paragraphs 5.2.2 and 5.2.3.

The following definitions apply for the purpose of paragraphs 5.2.2 and 5.2.3.

x	=	dimensionless distance from A.P. relative to the ship's length between perpendiculars
y	=	dimensionless longitudinal extent of damage relative to the ship's length between perpendiculars
z_t	=	dimensionless transverse penetration extent relative to the ship's breadth
z_v	=	dimensionless vertical penetration extent relative to the ship's depth
z_l	=	dimensionless vertical distance between the baseline and the centre of the vertical extent z_v relative to the distance between baseline and deck level (normally the ship's depth)
b	=	dimensionless transverse extent to bottom damage relative to the ship's breadth
b_l	=	dimensionless transverse location of bottom damage relative to the ship's breadth

5.2.2 Side damage due to collision

Function for longitudinal location:

$f_{S1} = 1.0$ for $0 = x = 0.1$;

Function for longitudinal extent:

$f_{S2} = 11.95 - 84.5y$ for $y = 0.1$
$f_{S2} = 6.65 - 31.5y$ for $0.1 < y = 0.2$
$f_{S2} = 0.35$ for $0.2 < y = 0.3$;

Function for transverse penetration:

$f_{S3} = 24.96 - 399.2z_t$ for $z_t = 0.05$
$f_{S3} = 9.44 - 88.8z_t$ for $0.05 < z_t = 0.1$
$f_{S3} = 0.56$ for $0.1 < z_t = 0.3$;

Function for vertical extent:

$f_{S4} = 3.83 - 11.1z_v$	for $z_v = 0.3$
$f_{S4} = 0.5$	for $z_v > 0.3$

Function for vertical location:

$f_{S5} = z_l$	for $z_l = 0.25$
$f_{S5} = 5z_l - 1.0$	for $0.25 < z_l = 0.5$
$f_{S5} = 1.50$	for $0.5 < z_l = 1.0$.

Graphs of the functions f_{S1}, f_{S2}, f_{S3}, f_{S4} and f_{S5} are shone in figures 1 and 2.

5.2.3 Bottom damage due to stranding

Function for longitudinal location:

$f_{b1} = 0.2 + 0.8x$	for $x = 0.5$
$f_{b1} = 4x - 1.4$	for $0.5 < x = 1.0$;

Function for longitudinal extent:

$f_{b2} = 4.5 - 13.33y$	for $y = 0.3$
$f_{b2} = 0.5$	for $0.3 < y = 0.8$;

Function for vertical penetration:

$f_{b3} = 14.5 - 134z_v$	for $z_v = 0.1$
$f_{b3} = 1.1$	for $0.1 < z_v = 0.3$;

Function for transverse extent:

$f_{b4} = 4.0 - 12b$	for $b = 0.3$
$f_{b4} = 0.4$	for $0.3 < b = 0.9$
$f_{b4} = 12b - 10.4$	for $b > 0.9$;

Function for transverse location:

$f_{b5} = 1.0$	for $0 = b_1 = 1.0$.

Graphs of the functions f_{b1}, f_{b2}, f_{b3}, f_{b4} and f_{b5} are shone in figures 3 and 4.

6 Probabilistic methodology for calculating oil outflow

6.1 *Damage cases*

6.1.1 Using the damage probability distribution functions specified in paragraph 5.2, all damage cases n as per paragraph 4.3 should be evaluated and placed in ascending order of oil outflow. The cumulative probability for all damage cases should be computed, being the running sum of probabilities beginning at the minimum outflow damage case and proceeding to the maximum outflow damage case. The cumulative probability for all damage cases should be 1.0.

6.1.2 For each damage case the damage consequences in terms of penetrations (breaching) of cargo tank boundaries should be evaluated and the related oil outflow calculated. A cargo tank should be considered as being breached in a damage case under consideration if the applied damage envelope reaches any part of the cargo tank boundaries.

6.1.3 When determining the damage cases, it should be assumed for the purpose of these calculations that the location, extent and penetration of damages are independent of each other.

6.2 *Oil outflow calculations*

6.2.1 The probabilistic oil outflow calculations may be done as outlined by the “Example for the Application of the Revised Interim Guidelines” given in the appendix to these Guidelines. Other calculation procedures may be accepted, provided they show acceptable accuracy.

6.2.2 The computer program used for the oil outflow analysis should be verified against the data for oil outflow parameters for the reference double-hull designs given in section 7.

6.2.3 After the final waterline has been determined, the oil outflow from each damaged cargo tank should be computed for each damage case under the assumptions specified in paragraph 5.1.5.

7 *Reference double-hull designs*

7.1 Data for four reference double-hull designs of 5,000 dwt, 60,000 dwt, 150,000 dwt and 283,000 dwt are summarized in tables 7.1 and 7.2 and are illustrated in figures 5 to 8. Table 7.1 also contains the data for the oil outflow parameters P_{OR}, O_{MR} and O_{ER} to be used for the concept approval (ship survivability not considered).

7.2 Table 7.2 contains the corresponding data to be used for the shipyard design approval (ship survivability considered).

Table 7.1 - Oil outflow parameters (ship survivability not considered)

Reference design number	Deadweight Metric Tons	Oil outflow parameters (ship survivability not considered)		
		P_{OR}	O_{MR}	O_{ER}
1	5,000	0.81	0.013	0.098
2	60,000	0.81	0.012	0.089
3	150,000	0.79	0.014	0.101
4	283,000	0.77	0.012	0.077

Table 7.2 - Oil outflow parameters (ship survivability considered)

Reference design number	Deadweight Metric Tons	Oil outflow parameters (ship survivability not considered)		
		P_{OR}	O_{MR}	O_{ER}
1	5,000	0.72	0.110	0.440
2	60,000	0.81	0.019	0.157
3	150,000	0.79	0.016	0.114
4	283,000	0.77	0.014	0.093

(The above tables replace existing tables 7.1 and 7.2)

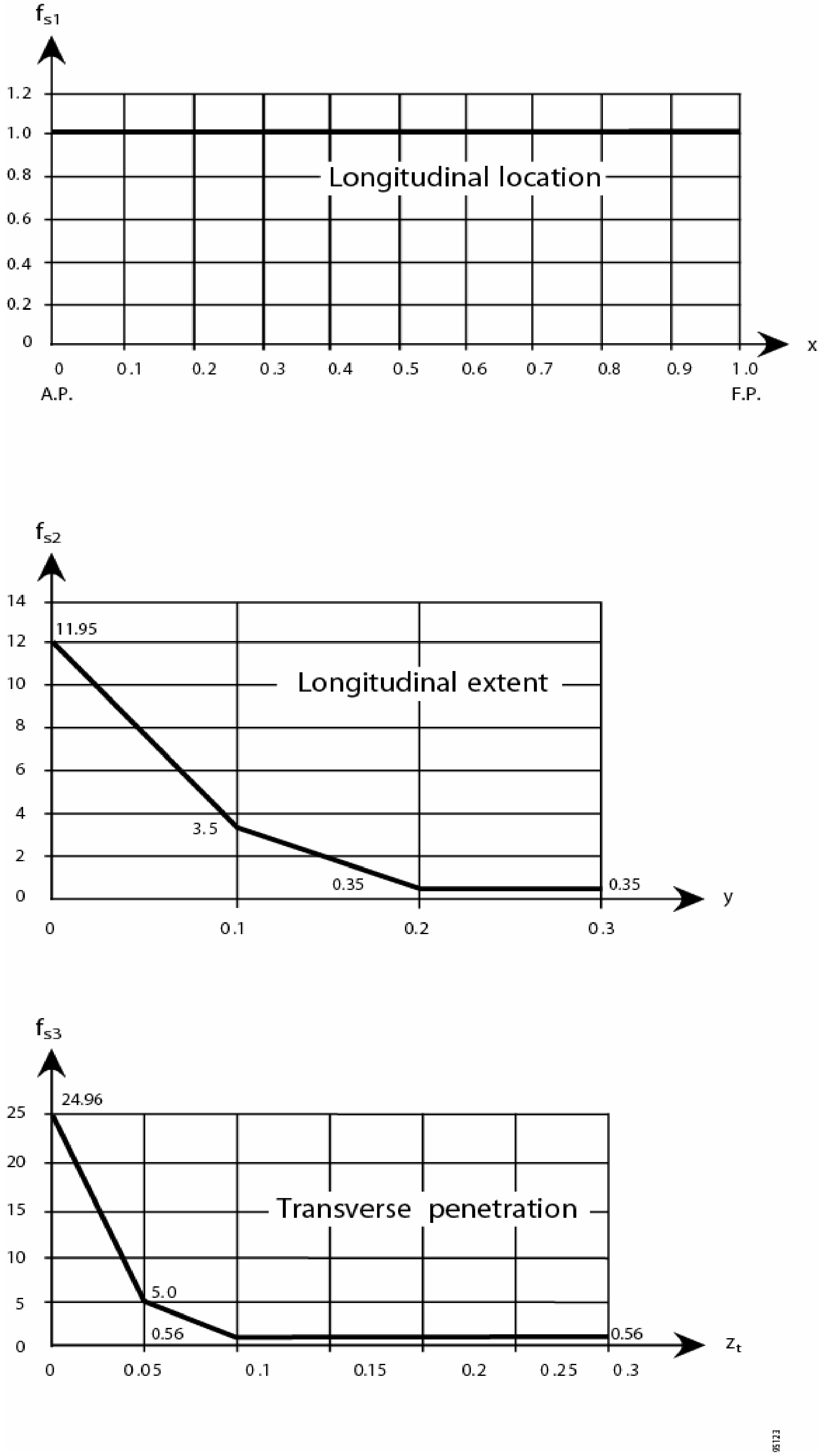

Figure 1 – Side damage due to collision:
density distribution functions f_{s1}, f_{s2} and f_{s3}

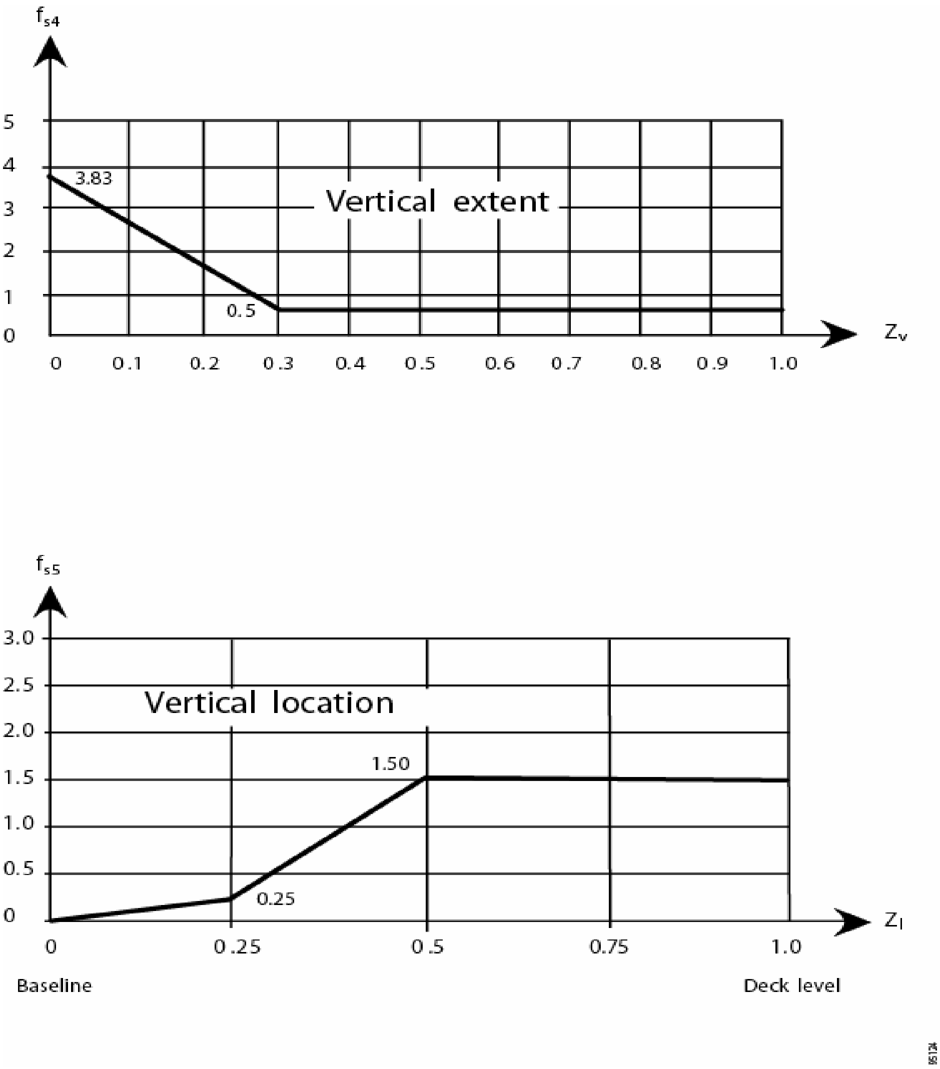

Figure 2 – Side damage due to collision:
density distribution functions f_{s4} and f_{s5}

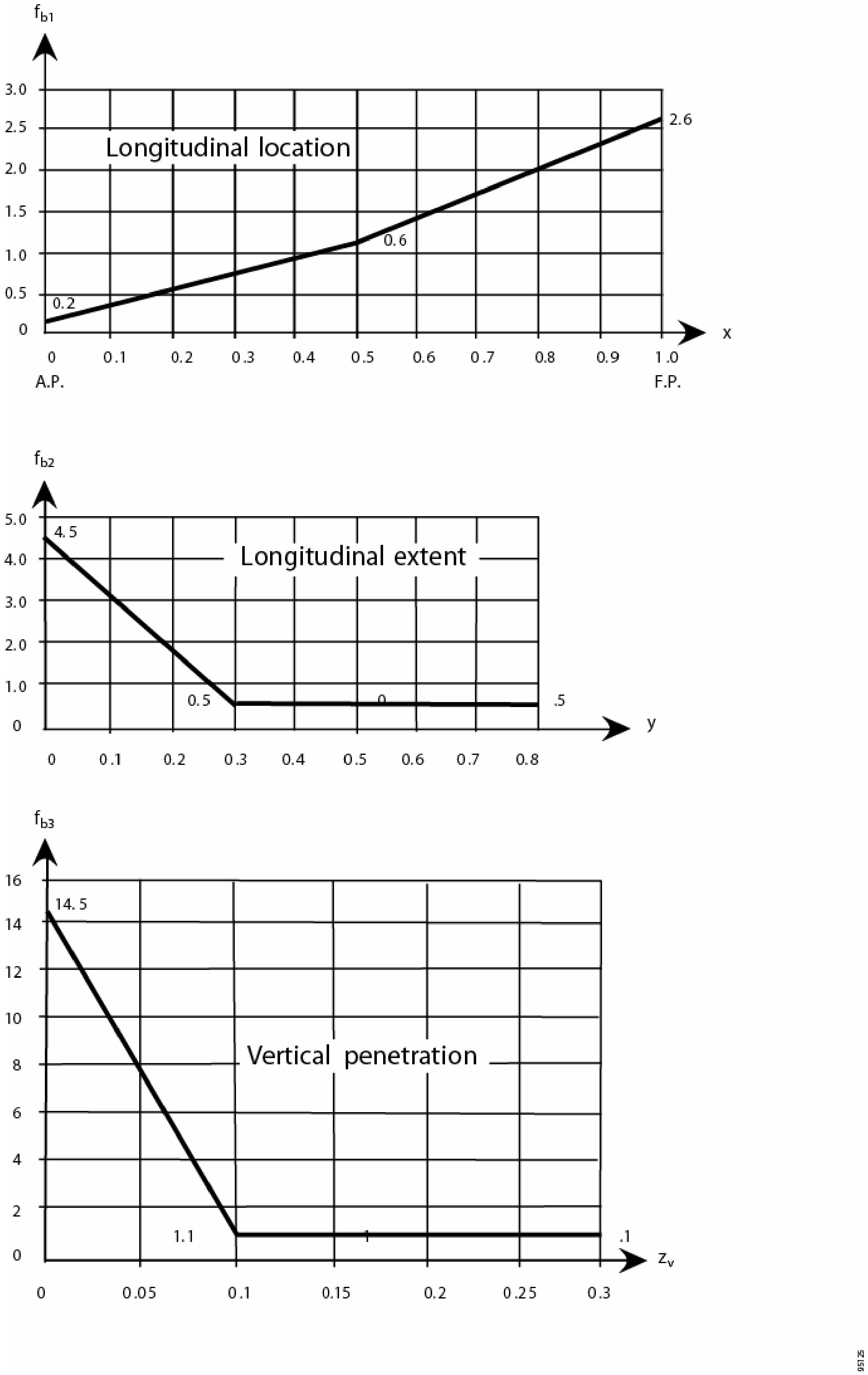

Figure 3 – Bottom damage due to stranding:
density distribution functions f_{b1}, f_{b2} and f_{b3}

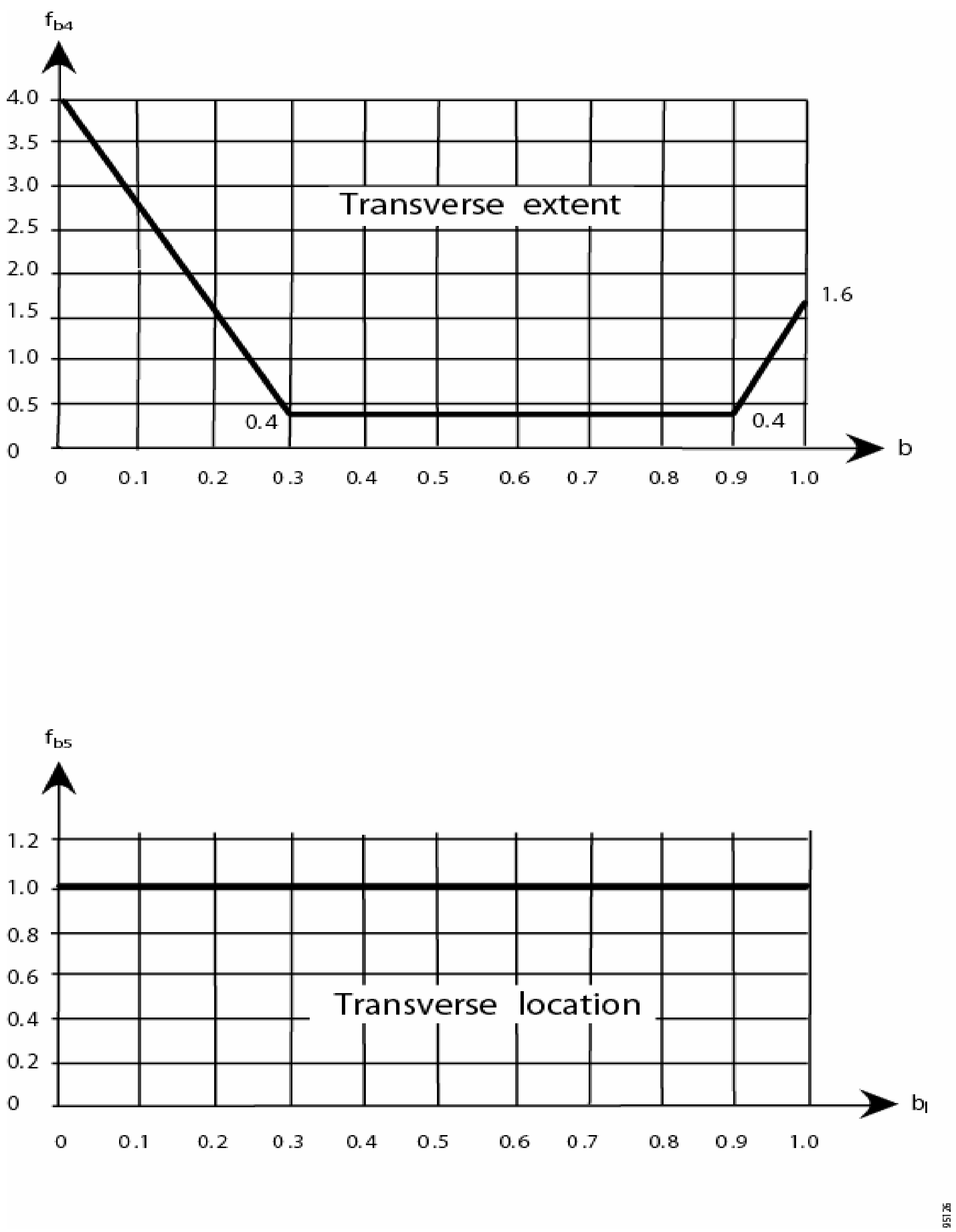

Figure 4 – Bottom damage due to stranding: density distribution functions f_{b4}, and f_{b5}

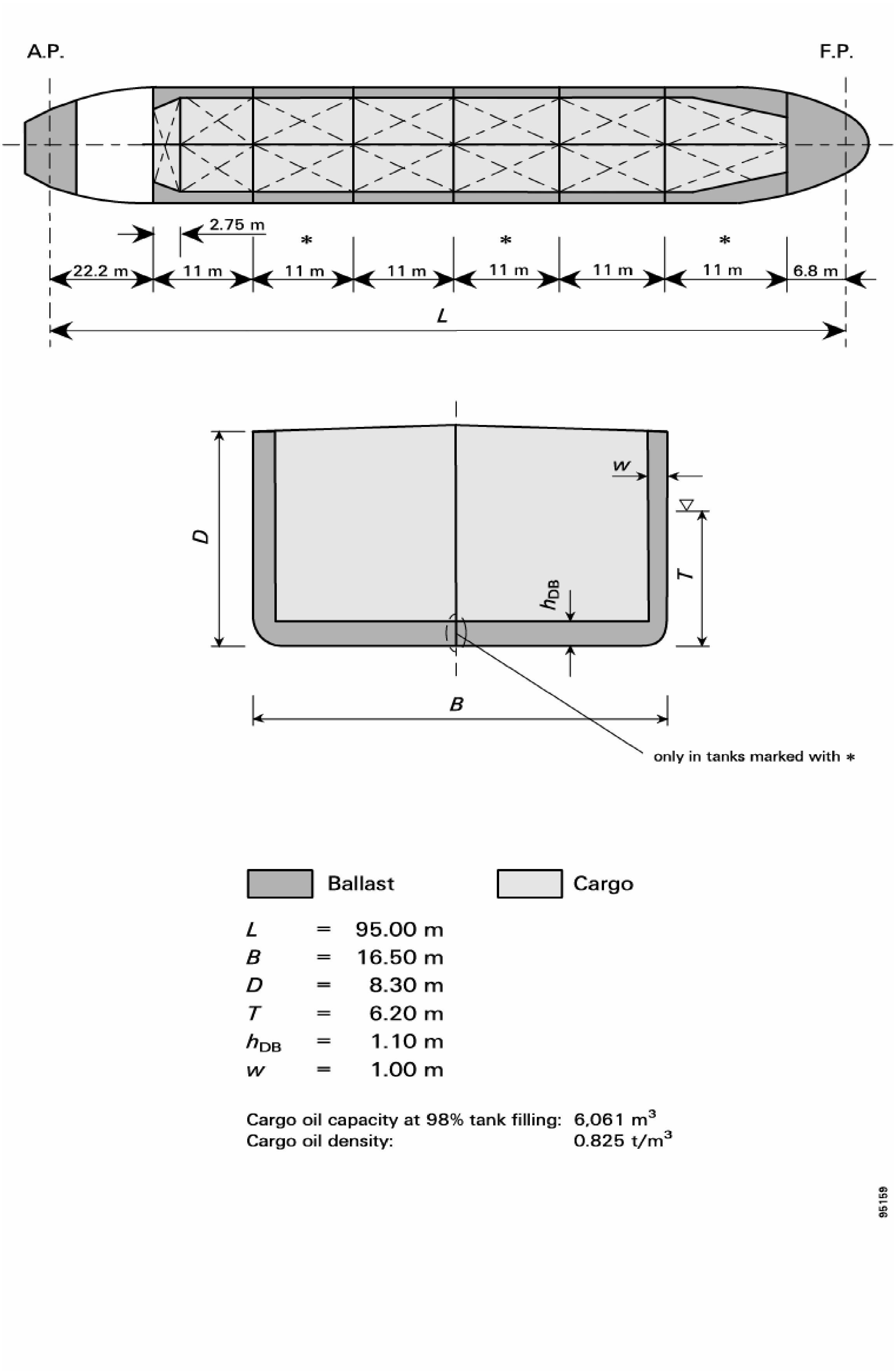

Figure 5 – Reference double hull design no. 1
Deadweight: 5,000 dwt

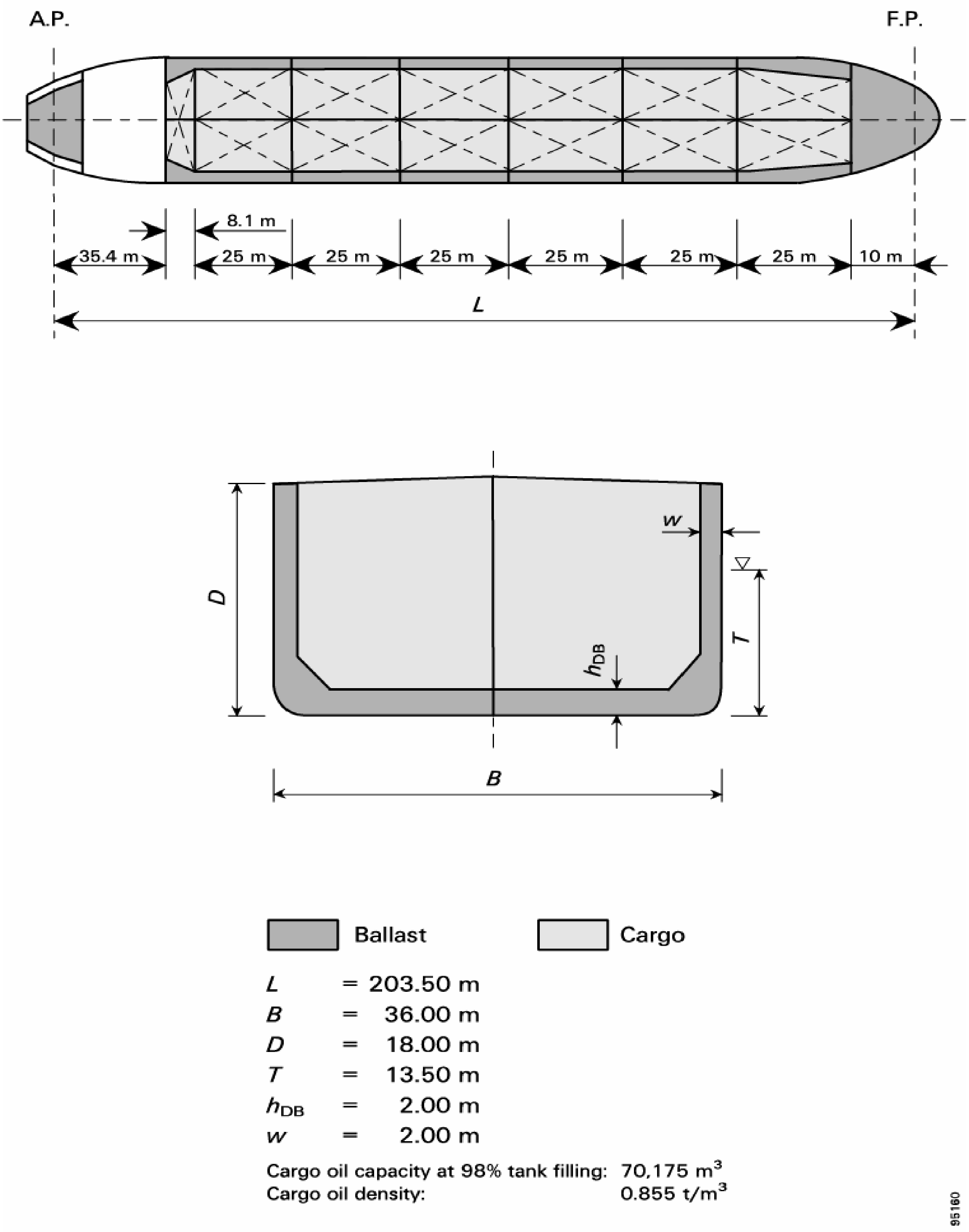

Figure 6 – Reference double hull design no. 2
Deadweight: 60,000 dwt

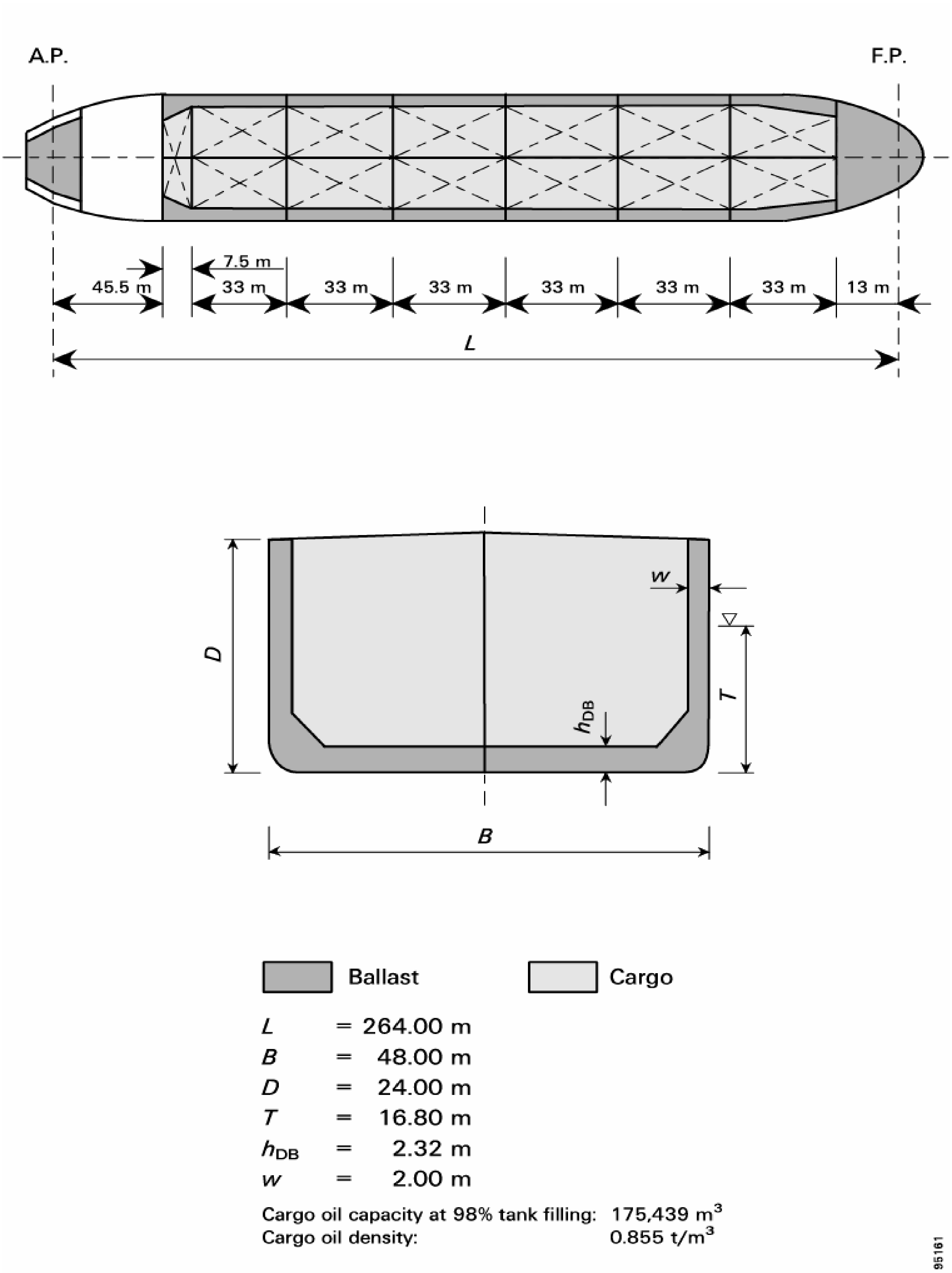

Figure 7 – Reference double hull design no. 3
Deadweight: 150,000 dwt

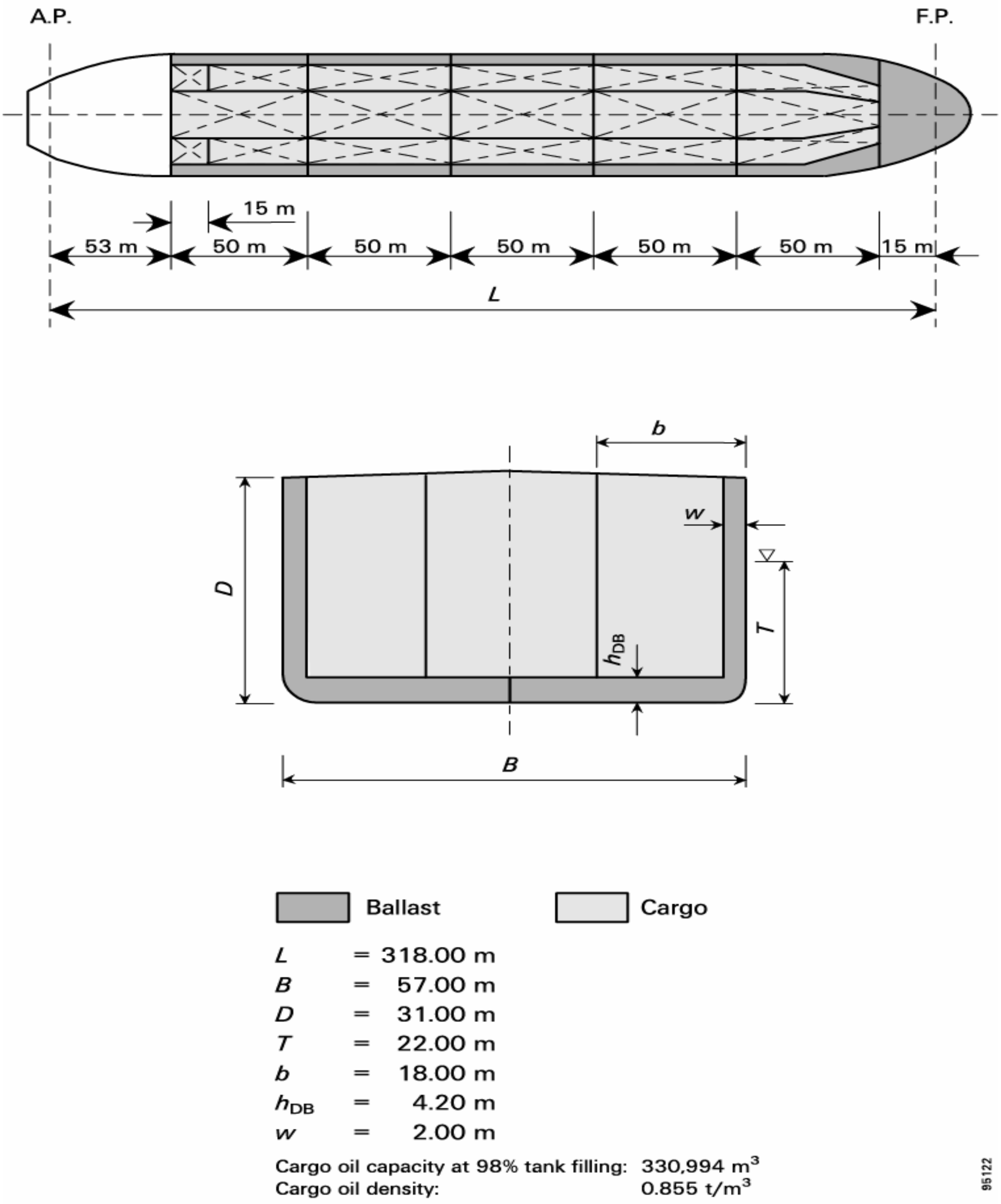

Figure 8 – Reference double hull design no. 4
Deadweight: 283,000 dwt

APPENDIX

EXAMPLE FOR THE APPLICATION OF THE REVISED INTERIM GUIDELINES

1 General

1.1 The application of the Revised Interim Guidelines, hereunder referred to as "the Guidelines", is shown in the following worked example illustrating the calculation procedure of the oil outflow parameters for a tank barge. For presentation purposes, a simplified hull form and level of compartmentation have been assumed. The procedures described herein are readily adaptable as a computer application, which will be necessary as more complicated arrangements are evaluated. This example is evaluated in accordance with the requirements for "concept approval". Additional requirements for a shipyard design approval are noted where applicable.

1.2 An application of the Guidelines will typically follow these seven basic steps:

.1 ***Vessel design***: In accordance with paragraph 3.1 of the Guidelines, the vessel is designed to meet all applicable regulations of MARPOL Annex I.

.2 ***Establishing of the full load condition***: In accordance with paragraph 5.1.5 of the Guidelines, a full load condition is developed.

.3 ***Assembling of the damage cases***: By applying the damage density distribution functions provided in the Guidelines, determine each unique grouping of damaged compartments and the probability associated with that damage condition. Independent sets of damage cases are derived for side (collision) and bottom (stranding) damage.

.4 ***Computation of the equilibrium condition for each damage case***: Compute the final equilibrium condition for all side and bottom damage conditions. This step is only required for the final shipyard design, in accordance with paragraph 5.1.5.10 of the Guidelines.

.5 ***Computation of the oil outflow for each damage case***: Calculate the oil outflow for each damage case. Separate calculations are done for side damage and for bottom damage at 0.0 m and 2.5 m fall in tide conditions. For side damage, all oil is assumed to escape from damaged tanks. For bottom damage, a hydrostatic balance method is applied. For the final shipyard design, survivability is evaluated in accordance with the requirements of MARPOL regulation I/25(3).

.6 ***Computation of the oil outflow parameters***: The cumulative probability of occurrence of each level of oil outflow is developed. This is done for the side damage and for each bottom damage tide condition. The associated oil outflow parameters are then computed. The bottom damage tidal parameters are combined in accordance with paragraph 5.1.3 and the side and bottom damage parameters are then combined in accordance with paragraph 5.1.2 of the Guidelines.

.7 ***Computation of the Pollution Prevention Index E***: The new design has satisfactory characteristics if index E, as defined in paragraph 4.2 of the Guidelines, is greater than or equal to 1.0.

2 Analysis procedure

The basic steps 1 through 6 below are described in this section.

2.1 *Step 1: Vessel design*

The arrangement and dimensions of the example barge are as shown in figure A1 (Barge arrangement). For clarity purposes, a simple arrangement has been selected which does not meet all MARPOL 73/78 requirements. However, for actual designs submitted for approval as an alternative to double hull, the vessel must meet all applicable regulations of Annex I of MARPOL 73/78.

2.2 *Step 2: Establishing of the full load condition*

An intact load condition shall be developed with the vessel at its maximum assigned load line with zero trim and heel. Departure quantities of constants and consumables (fuel oil, diesel oil, fresh water, lube oil, etc.) should be assumed. Capacities of cargo oil tanks should be based on actual permeabilities for these compartments. All cargo oil tanks shall be assumed to be filled to 98% of their capacities. All cargo oil shall be taken at a homogeneous density.

For this example, it is assumed that the permeability of the cargo oil tanks is 0.99 and 0.95 for the double bottom/wing tank ballast spaces. The 100% capacity of the cargo oil tanks CO1 and CO2 is:

CO1:	9,623 m^3
CO2:	28,868 m^3
Total:	38,491 m^3

Cargo tank capacity at 98% filling: $C = 0.98 \text{ x } 38{,}491 = 37{,}721 \text{ m}^3$.

For this barge, for simplicity reasons, zero weight for the constants and consumables has been assumed. At the 9.0 m assigned load line the following values for the cargo oil mass (*W*) and density ($?_C$) are obtained:

W = displacement - light barge weight = 33,949 t

$?_C = 33{,}949 \text{ t}/C = 0.90 \text{ t/m}^3$

2.3 *Step 3: Assembling of the damage cases*

In this step the damage cases have to be developed. This involves applying the probability density distribution functions for side damage (figures 1 and 2) and the probability density distribution functions for bottom damage (figures 3 and 4). Each unique grouping of damaged compartments is determined together with its associated probability. The sum of the probabilities should equal 1.0 for both the side and the bottom damage evaluations.

There are different methods available for developing the compartment groupings and probabilities, each of which should converge on the same results.

In this example, the compartment groupings and the use of the probability density functions is shown by a "step-wise" evaluation method. This method involves stepping through each damage location and extent at a sufficiently fine increment. For instance, it is assumed (for the side damage) to step through the functions as follows: longitudinal location = 100 steps, longitudinal extent = 100 steps, transverse penetration = 100 steps, vertical location = 10 steps, and vertical extent = 100 steps. You will then be developing 10^9 damage incidents. The probability of each step is equal to the area under the probability density distribution curve over that increment. The probability for each damage incident is the product of the probabilities of the five functions. There are many redundant incidents which damage identical compartments. These are combined by summing their probabilities. For a typical double-hull tanker, the 10^9 damage incidents reduce down to 100 to 400 unique groupings of compartments.

2.3.1 *Side damage evaluation*

The damage density distribution functions provide independent statistics for location, length, and penetration. For side damage, the probability of a given damage longitudinal location, longitudinal extent, transverse penetration, vertical location and vertical extent is the product of the probabilities of these five damage characteristics.

To maintain the example at a manageable size, fairly coarse increments have been assumed:

Longitudinal location at 10 steps	=	$L/10$	=	$0.10L$ per step
Longitudinal extent at 3 steps	=	$0.3L/3$	=	$0.10L$ per step
Transverse penetration at 6 steps	=	$0.3B/6$	=	$0.05B$ per step.

To further simplify the evaluation, each damage is assumed to extend vertically without limit. Therefore, the probabilities of vertical location and vertical extent are taken as 1.0 for each damage case. This is a reasonable assumption as the double bottom height is only 10% of the depth. Taking the area under the density distribution function for vertical location up to $0.1D$ (see figure 2, function f_{S5}) yields a value of 0.005. This means that the probability of the centre of damage location falling within the double bottom region is 1/200.

Figure A2 (Side damage definition) shows the steps for longitudinal location, longitudinal extent and transverse penetration in relation to the barge. Table A1 (Increments for step-wise side damage evaluation) gives the range for each step, the mean or average value over the step, and the probability of occurrence of that particular step. For instance, Z_1 covers the range of transverse penetration beginning at the side shell and extending inboard 5% of the breadth. The average penetration is $0.025B$ or 2.5% of the breadth. The probability of occurrence is the likelihood that the penetration will fall within the range of 0% to 5% of the breadth. The probability equals 0.749, which is the area under the density distribution function for transverse penetration (figure 1, function f_{S3}) between $0.0B$ and $0.05B$. The area under each probability density function is 1.0, and therefore the sum of the probabilities for all increments for each function is 1.0.

A total of ten longitudinal locations, three longitudinal extents and six transverse penetrations will be evaluated. All combinations of damages must be considered for a total of $(10)\times(3)\times(6) = 180$ separate incidents. The damaged compartments are found by overlaying each combination of location/extent/penetration onto the barge. These damage boundaries define a rectangular box. Any compartment which extends into this damage zone is considered damaged. Each of the 180 incidents results in damage to one or more compartments. Incidents with identical damaged compartments are collected into a single damage case by summing the probabilities of the individual damage incidents.

Let us begin at the aft end of the barge and proceed forward. The first damage location X_1 is centred 0.05L forward of the transom. The first damage extent Y_1 has an average length of 0.05L. The average value for the first transverse penetration Z_1 is 0.025B. The resulting damage box lies entirely within the WB1 compartment and therefore damages that compartment only. The probability of this incident is:

$$P_{111}(X_1 Y_1 Z_1) = (0.1000) \text{ x } (0.7725) \text{ x } (0.7490) = 0.05786$$

If we step through the transverse penetrations Z_2 through Z_6, we find that only the WB1 compartment is damaged for each of these cases. The probabilities for these cases are 0.01074, 0.00216, 0.00216, 0.00216, 0.00216, and 0.00216 respectively. The combined probability for the six cases at longitudinal damage location X_1 is:

$$P_{111\text{-}6}(X_1 Y_1 Z_{1\text{-}6}) = 0.05786 + 0.01074 + 0.00216 + 0.00216 + 0.00216 + 0.00216 = 0.07725$$

Next, we move to damage extent Y_2. The damage box $X_1 Y_2 Z_1$ once again falls within the WB1 compartment. Likewise, transverse penetrations Z_2 through Z_6 fall within this compartment. We compute the probability for these cases and find that: $P_{121\text{-}6}(X_1 Y_2 Z_{1\text{-}6}) = 0.01925$.

Similarly, the damage boxes defined by $X_1 Y_3 Z_{1\text{-}6}$ lie within the WB1 compartment and have a combined probability $P_{131\text{-}6}(X_1 Y_3 Z_{1\text{-}6}) = 0.00350$.

We now move to the next longitudinal location, X_2. With longitudinal extent Y_1, the damage stays within the WB1 compartment. The combined probability is $P_{211\text{-}6}(X_2 Y_1 Z_{1\text{-}6}) = 0.07725$.

The forward bound of the damage box $X_2 Y_2 Z_1$ extends forward of the transverse bulkhead located 20.0 m from the transom, damaging compartments both fore and aft of this bulkhead. Transverse penetration Z_1 extends to a point just outboard of the longitudinal bulkhead. Therefore, this combination damages both the WB1 and WB2S compartments. The probability is $P_{221}(X_2 Y_2 Z_1) = 0.01442$.

We find that the damage box $X_2 Y_2 Z_2$ extends inboard of the longitudinal bulkhead, damaging compartments WB1, WB2S and CO1. A cargo oil tank has been damaged and oil outflow will occur. Similarly, damage penetrations Z_3 through Z_6 result in breaching of the three compartments. The combined probability for these five incidents is:

$$P_{222\text{-}6}(X_2 Y_2 Z_{2\text{-}6}) = 0.00268 + 0.00054 + 0.00054 + 0.00054 + 0.00054 = 0.00483$$

By stepping through the barge for all 180 incidents and combining unique damage compartment groupings, we obtain the compartment grouping and probability values shown in table A2 (Probability values for side damage). Each compartment group represents a unique set of compartments. The associated probability is the probability that each particular group of compartments will be damaged in a collision which breaches the hull. For instance, the probability of damaging the WB1 compartment is 0.17725. This means there is approximately a 17.7% likelihood that only this compartment will be damaged. Likewise, the probability of concurrently damaging the WB1 and WB2S compartments is 0.03408 or about 3.4%. Note that the cumulative probability of occurrence for all groups equals 1.0.

2.3.2 *Bottom damage evaluation*

For bottom damage, the probability of a given damage longitudinal location, longitudinal extent, vertical penetration, transverse location and transverse extent is, analogously to the side damage evaluation, the product of the probabilities of these five damage characteristics.

The following increments are assumed for the bottom damage evaluation:

Longitudinal location at 10 steps	=	$L/10$	$= 0.10L$ per step
Longitudinal extent at 8 steps	=	$0.8L/8$	$= 0.10L$ per step
Vertical penetration at 6 steps	=	$0.3D/6$	$= 0.05D$ per step.

To further simplify the evaluation, all damage is assumed to extend transversely without limit. Therefore, the probabilities of transverse extent and transverse location are taken as 1.0 for each damage case.

Compartment groupings are developed using the same process as previously described for side damage.

Analogously, a total of ten longitudinal locations, eight longitudinal extents and six vertical penetrations need to be evaluated. The damage incidents to be taken into account for groundings sum up to a total of (10) x (8) x (6) = 480 separate incidents.

Figure A3 (Bottom damage definition) shows the steps for longitudinal location, longitudinal extent and vertical penetration in relation to the barge. Table A3 (Increments for step-wise bottom damage definition) gives the range for each step, the mean or average value over the step, and the probability of occurrence of that particular step.

Again, putting the aftmost compartment WB1 together in terms of damage increments, the following probabilities have to be summed up:

$P_{111\text{-}6}\ X_1Y_1\ Z_{1\text{-}6}) = (0.0240) \times (0.38333) \times (1.0) = 0.00920$
$P_{121\text{-}6}(X_1Y_2\ Z_{1\text{-}6}) = (0.0240) \times (0.2500) \times (1.0) = 0.00600$
$P_{131\text{-}6}(X_1Y_3\ Z_{1\text{-}6}) = (0.0240) \times (0.11677) \times (1.0) = 0.00280$
$P_{211\text{-}6}(X_2Y_1\ Z_{1\text{-}6}) = (0.0320) \times (0.38333) \times (1.0) = 0.01227.$

Therefore the likelihood of damaging the WB1 compartment sums up to:

$$P_{WB1} = P_{11} + P_{12} + P_{13} + P_{21} = 0.03027.$$

By addressing each of the 480 incidents to the relevant compartment (or groups of compartments) the likelihood of a damage to these resulting from a grounding is obtained. This is shown in table A4 (Probability values for bottom damage).

2.4 *Step 4: Computation of the equilibrium condition for each damage case*

This example describes the concept analysis only. Damage stability analyses to determine the equilibrium conditions are only required for the final shipyard design, in accordance with paragraph 5.1.5.10 of the Guidelines.

2.5 *Step 5: Computation of the oil outflow for each damage case*

In this step the oil outflow associated with each of the compartment groupings is calculated for side and bottom damage as outlined below.

2.5.1 Side damage evaluation

For side damage, 100% of the oil in a damaged cargo oil tank is assumed to outflow into the sea. If we review the eleven compartment groupings for side damage, we find that oil tank damage occurs in three combinations: CO1 only, CO2 only, and concurrent damage to CO1 and CO2.

The oil outflow for these tanks is as follows:

CO1 (98% full volume)	=	9,430 m^3
CO2 (98% full volume)	=	28,291 m^3
CO1 + CO2 (98% full volume)	=	37,721 m^3.

2.5.2 Bottom damage evaluation

For bottom damage, a pressure balance calculation must be carried out. The vessel is assumed to remain stranded on a shelf at its original intact draught. For the concept analysis, zero trim and zero heel are assumed. An inert gas overpressure of 5 kPa gauge is assumed in accordance with paragraph 5.1.5.5 of the Guidelines. The double bottom spaces located below the cargo oil tanks "capture" some portion of the oil outflow. In accordance with paragraph 5.1.5.8 of the Guidelines, the flooded volume of such spaces should be assumed to contain 50% oil and 50% seawater by volume at equilibrium. When calculating the oil volume captured in these spaces, no assumptions are made on how the oil and seawater is distributed in these spaces.

The calculations are generally carried out for two tidal conditions: 0.0 and 2.5 m fall in tide.

The actual oil volume lost from a cargo tank is calculated for each of the two tidal conditions, assuming hydrostatic balance as follows:

$$g\, z_C\, ?_C + 100?\, p = z_S\, ?_S\, g$$

where:

z_C	=	height of remaining oil in the damaged tank (m)
$?_C$	=	cargo oil density (0.9 t/m? 3•)
g	=	gravitational acceleration (9.81 m/s^2)
$?p$	=	set pressure of cargo tank pressure/vacuum valves (5 kPa gauge)
z_S	=	external seawater head above inner bottom (m)
z_S	=	T - 2 = 7.00 m
$?_S$	=	seawater density (1.025 t/m^3)

See also figure A4.

From the above equation one obtains for the height of remaining oil z_c for the zero-tide condition:

z_C = 7.40 m.

Thus, the height of lost oil (h_l =0.98 h_C - z_C) is:

h_l = 17.64 -- 7.40 = 10.24 m.

The volume of lost oil (V_l) of cargo tank CO1 is:

V_l = 10.24 x 36 x 15 x 0.99 = 5,474 m^3.

In this case the total volume (V_{WO}) of oil and water in the water ballast tanks is:

V_{WO} = 2 x [20 x 2 + V_{WO} x 2] x 60 x 0.95 = 6,202 m^3

where:

z_{wo} = $0.5(z_C + z_S)$ = 7.20 m.

If one assumes that 50% of V_{WO} is occupied by captured oil, one obtains for the total oil outflow ($V_{outflow}$) of cargo tank CO1:

$V_{outflow}$ = V_l - $0.5V_{WO}$ = 2,373 m^3.

The oil outflow of cargo tank CO2 is:

$V_{outflow}$ = 10.24 x 36 x 45 x 0.99 - 0.5 x 6,202 = 13,322 m^3

and the total oil outflow of cargo tanks CO1 and CO2 is:

$V_{outflow}$ = 10.24 x 36 x 60 x 0.99 - 0.5 x 6,202 = 18,796 m^3.

Step-wise application of the damage extents and assumed increments results in fourteen compartment groupings for bottom damage. Oil tank and double bottom damage occurs in three combinations. The oil outflows for these tanks at 0.0 m and 2.5 m fall in tide are summarized in the table below:

Tank combination	**Oil outflow [m^3] at**	
	0.0 m tide	**2.5 m fall in tide**
WB2S + WB2P + C01	2,373	3,862
WB2S + WB2P + C02	13,322	17,244
WB2S + WB2P + CO1 + C02	18,796	23,935

2.6 *Step 6: Computation of the oil outflow parameters*

In this step the oil outflow parameters are computed in accordance with paragraph 4.3 of the Guidelines. To facilitate calculation of these parameters, place the damage groupings in a table in ascending order as a function of oil outflow. A running sum of probabilities is computed, beginning at the minimum outflow damage case and proceeding to the maximum outflow damage case. Tables A5 and A6 (Cumulative probability and oil outflow values) contain the outflow values for the side damage and bottom damage for the two tide conditions.

Probability of zero oil outflow, P_O: This parameter equals the cumulative probability for all damage cases for which there is no oil outflow. From table A5, we see that the probability of zero outflow for the side damage condition is 0.83798, and the probability of zero outflow for the bottom damage (0.0 m tide) condition is 0.84313.

Mean oil outflow parameter, O_M: This is the weighted average of all cases, and is obtained by summing the products of each damage case probability and the computed outflow for that damage case.

Extreme oil outflow parameter, O_E: This represents the weighted average of the damage cases falling within the cumulative probability range between 0.9 and 1.0. It equals the sum of the products of each damage case probability with a cumulative probability between 0.90 and 1.0 and its corresponding oil outflow, with the result multiplied by 10.

For this example, the computed outflow values are as shown in tables A5 and A6. In accordance with paragraph 5.1.3 of the Guidelines, the bottom damage outflow parameters for the 0.0 m and 2.5 m fall in tides are combined in a ratio of 0.7: 0.3, respectively. In accordance with paragraph 5.1.2, the collision (side damage) and stranding (bottom damage) parameters are then combined in a ratio of 0.4: 0.6, respectively. In table A7 (Summary of oil outflow parameters) the oil outflow parameters P_O, O_M and O_E for the example tank barge are listed.

Table A1 – Increments for step-wise side damage evaluation

Longitudinal location (step = 0.1*L*)

	Range of increments			
	minimum	maximum	midpoint	probability
X_1	0.0*L*	0.1*L*	0.05*L*	0.1000
X_2	0.1*L*	0.2*L*	0.15*L*	0.1000
X_3	0.2*L*	0.3*L*	0.25*L*	0.1000
X_4	0.3*L*	0.4*L*	0.35*L*	0.1000
X_5	0.4*L*	0.5*L*	0.45*L*	0.1000
X_6	0.5*L*	0.6*L*	0.55*L*	0.1000
X_7	0.6*L*	0.7*L*	0.65*L*	0.1000
X_8	0.7*L*	0.8*L*	0.75*L*	0.1000
X_9	0.8*L*	0.9*L*	0.85*L*	0.1000
X_{10}	0.9*L*	1.0*L*	0.95*L*	0.1000
				1.0000

Longitudinal extent (step = 0.1*L*)

	Range of increments			
	minimum	maximum	midpoint	probability
Y_1	0.0*L*	0.1*L*	0.05*L*	0.7725
Y_2	0.1*L*	0.2*L*	0.15*L*	0.1925
Y_3	0.2*L*	0.3*L*	0.25*L*	0.0350
				1.0000

Transverse penetration (step = 0.05*B*)

	Range of increments			
	minimum	maximum	midpoint	probability
Z_1	0.0*B*	0.05*B*	0.025*B*	0.7490
Z_2	0.05*B*	0.10*B*	0.075*B*	0.1390
Z_3	0.10*B*	0.15*B*	0.125*B*	0.0280
Z_4	0.15*B*	0.20*B*	0.175*B*	0.0280
Z_5	0.20*B*	0.25*B*	0.225*B*	0.0280
Z_6	0.25*B*	0.30*B*	0.275*B*	0.0280
				1.0000

Table A2 – Probability values for side damage

	Unique compartment groupings	Damage extents and probabilities							Group Probability
1	WB1	$X_1Y_1Z_{1-6}$ 0.07725	$X_1Y_2Z_{1-6}$ 0.01925	$X_1Y_3Z_{1-6}$ 0.00350	$X_2Y_1Z_{1-6}$ 0.07725				0.17725
2	WB1 + WB2S	$X_2Y_2Z_1$ 0.01442	$X_2Y_3Z_1$ 0.00262	$X_3Y_3Z_1$ 0.00262	$X_3Y_2Z_1$ 0.01442				0.03408
3	WB1 + WB2S + CO1	$X_2Y_2Z_{2-6}$ 0.00483	$X_2Y_3Z_{2-6}$ 0.00088	$X_3Y_2Z_{2-6}$ 0.00483					
4	WB2S	$X_3Y_1Z_1$ 0.05786	$X_4Y_1Z_1$ 0.05786	$X_4Y_2Z_1$ 0.01442	$X_4Y_3Z_1$ 0.00262	$X_5Y_1Z_1$ 0.05786	$X_5Y_2Z_1$ 0.01442	$X_5Y_3Z_1$ 0.00262	0.41532
		$X_6Y_1Z_1$ 0.05786	$X_6Y_2Z_1$ 0.01442	$X_6Y_3Z_1$ 0.00262	$X_7Y_1Z_1$ 0.05786	$X_7Y_2Z_1$ 0.01442	$X_7Y_3Z_1$ 0.00262	$X_8Y_1Z_1$ 0.05786	
5	WB2S + CO1	$X_3Y_1Z_{2-6}$ 0.01939							0.01939
6	WB2S + CO1 + CO2	$X_4Y_1Z_{2-6}$ 0.01939	$X_4Y_2Z_{2-6}$ 0.00483	$X_4Y_3Z_{2-6}$ 0.00088	$X_5Y_3Z_{2-6}$ 0.00088				0.02598
7	WB1 + WB2S + CO1 + CO2	$X_3Y_3Z_{2-6}$ 0.00088							0.00088
8	WB2S + CO2	$X_5Y_1Z_{2-6}$ 0.01939	$X_5Y_2Z_{2-6}$ 0.00483	$X_6Y_1Z_{2-6}$ 0.01939	$X_6Y_2Z_{2-6}$ 0.00483	$X_6Y_3Z_{2-6}$ 0.00088	$X_7Y_1Z_{2-6}$ 0.01939	$X_7Y_1Z_{2-6}$ 0.00483	0.09381
		$X_7Y_3Z_{2-6}$ 0.00088	$X_8Y_1Z_{2-6}$ 0.01939						
9	WB2S + WB3	$X_8Y_2Z_1$ 0.01442	$X_8Y_3Z_1$ 0.00262	$X_9Y_2Z_1$ 0.01442	$X_9Y_3Z_1$ 0.00262				0.03408
10	WB2 + CO2 + WB3	$X_8Y_2Z_{2-6}$ 0.00483	$X_8Y_3Z_{2-6}$ 0.00088	$X_9Y_2Z_{2-6}$ 0.00483	$X_9Y_3Z_{2-6}$ 0.00088				0.01142
11	WB3	$X_9Y_1Z_{1-6}$ 0.07725	$X_{10}Y_1Z_{1-6}$ 0.07725	$X_{10}Y_2Z_{1-6}$ 0.01925	$X_{10}Y_3Z_{1-6}$ 0.00350				0.17725
									1.0000

Table A3 – Increments for step-wise side bottom damage definition

Longitudinal location (step = 0.1*L*)

	Range of increments			
	minimum	maximum	midpoint	probability
X_1	0.0*L*	0.1*L*	0.05*L*	0.0240
X_2	0.1*L*	0.2*L*	0.15*L*	0.0320
X_3	0.2*L*	0.3*L*	0.25*L*	0.0400
X_4	0.3*L*	0.4*L*	0.35*L*	0.0480
X_5	0.4*L*	0.5*L*	0.45*L*	0.0560
X_6	0.5*L*	0.6*L*	0.55*L*	0.0800
X_7	0.6*L*	0.7*L*	0.65*L*	0.1200
X_8	0.7*L*	0.8*L*	0.75*L*	0.1600
X_9	0.8*L*	0.9*L*	0.85*L*	0.2000
X_{10}	0.9*L*	1.0*L*	0.95*L*	0.2400
				1.0000

Longitudinal extent (step = 0.1*L*)

	Range of increments			
	minimum	maximum	midpoint	probability
Y_1	0.0*L*	0.1*L*	0.05*L*	0.3833
Y_2	0.1*L*	0.2*L*	0.15*L*	0.2500
Y_3	0.2*L*	0.3*L*	0.25*L*	0.1167
Y_4	0.3*L*	0.4*L*	0.35*L*	0.0500
Y_5	0.4*L*	0.5*L*	0.45*L*	0.0500
Y_6	0.5*L*	0.6*L*	0.55*L*	0.0500
Y_7	0.6*L*	0.7*L*	0.65*L*	0.0500
Y_8	0.7*L*	0.8*L*	0.75*L*	0.0500
				1.0000

Vertical penetration (step = 0.05*D*)

	Range of increments			
	minimum	maximum	midpoint	probability
Z_1	0.0*D*	0.05*D*	0.025D	0.5575
Z_2	0.05*D*	0.10*D*	0.075D	0.2225
Z_3	0.10*D*	0.20*D*	0.125D	0.0550
Z_4	0.15D	0.15D	0.175D	0.0550
Z_5	0.20*D*	0.25*D*	0.225D	0.0550
Z_6	0.25*D*	0.30*D*	0.275D	0.0550
				1.0000

Table A4 – Probability values for bottom damage

	Unique compartment groupings	Damage extents and probabilities								Group Probabilities
1	WB1	$X_{1-2} Y_1 Z_{1-6}$ 0.02147	$X_1 Y_2 Z_{1-6}$ 0.006	$X_1 Y_3 Z_{1-6}$ 0.0028						0.03027
2	WB1 + WB2S + WB2P		$X_{2-3} Y_2 Z_{1-2}$ 0.01404	$X_{2-3} Y_3 Z_{1-2}$ 0.00655	$X_{1-4} Y_4 Z_{1-2}$ 0.00562	$X_{1-4} Y_5 Z_{1-2}$ 0.00562	$X_{1-5} Y_6 Z_{1-2}$ 0.0078	$X_{1-5} Y_7 Z_{1-2}$ 0.0078	$X_{1-4} Y_8 Z_{1-2}$ 0.00562	0.05305
3	WB2S + WB2P + WB3		$X_{8-9} Y_2 Z_{1-2}$ 0.0702	$X_{8-9} Y_3 Z_{1-2}$ 0.03276	$X_{7-10} Y_4 Z_{1-2}$ 0.02808	$X_{7-10} Y_5 Z_{1-2}$ 0.02808	$X_{6-10} Y_6 Z_{1-2}$ 0.0312	$X_{6-10} Y_7 Z_{1-2}$ 0.0312	$X_{7-10} Y_8 Z_{1-2}$ 0.02808	0.24960
4	WB1 + WB2S +WB2P +WB3								$X_{5-6} Y_8 Z_{1-2}$ 0.00530	0.00530
5	WB2S + WB2P	$X_{3-8} Y_1 Z_{1-2}$ 0.1507	$X_{4-7} Y_2 Z_{1-2}$ 0.05928	$X_{4-7} Y_3 Z_{1-2}$ 0.02766	$X_{5-6} Y_4 Z_{1-2}$ 0.0053	$X_{5-6} Y_5 Z_{1-2}$ 0.0053				0.24824
6	WB3	$X_{9-10} Y_1 Z_{1-6}$ 0.16867	$X_{10} Y_2 Z_{1-6}$ 0.06	$X_{10} Y_3 Z_{1-6}$ 0.0028						0.25667
7	WB1 + WB2S + WB2P + CO1		$X_{2-3} Y_2 Z_{3-6}$ 0.00396	$X_2 Y_3 Z_{3-6}$ 0.0082	$X_{1-2} Y_4 Z_{3-6}$ 0.00062	$X_1 Y_5 Z_{3-6}$ 0.00026	$X_1 Y_6 Z_{3-6}$ 0.00026			0.00592
8	WB2S + WB2P+ CO1	$X_3 Y_1 Z_{3-6}$ 0.00337								0.00337
9	WB2S + WB2P+ CO2	$X_{5-8} Y_1 Z_{3-6}$ 0.03508	$X_{5-7} Y_2 Z_{3-6}$ 0.01408	$X_{6-7} Y_3 Z_{3-6}$ 0.00513	$X_6 Y_4 Z_{3-6}$ 0.00088					0.05517
10	WB2S + WB2P + WB3 + CO2		$X_{8-9} Y_2 Z_{3-6}$ 0.0198	$X_{8-9} Y_3 Z_{3-6}$ 0.00924	$X_{7-10} Y_4 Z_{3-6}$ 0.00792	$X_{7-10} Y_5 Z_{3-6}$ 0.00792	$X_{7-10} Y_6 Z_{3-6}$ 0.00792	$X_{8-10} Y_7 Z_{3-6}$ 0.0066	$X_{8-10} Y_8 Z_{3-6}$ 0.0660	0.0660
11	WB1 + WB2S + WB2P + CO1 + CO2			$X_3 Y_3 Z_{3-6}$ 0.00098	$X_{3-4} Y_4 Z_{3-6}$ 0.00098	$X_{2-4} Y_5 Z_{3-6}$ 0.00132	$X_{2-5} Y_6 Z_{3-6}$ 0.00194	$X_{1-5} Y_7 Z_{3-6}$ 0.0022	$X_{1-4} Y_8 Z_{3-6}$ 0.00158	0.00903
12	WB2S + WB2P + WB3+ CO1 + CO2						$X_6 Y_6 Z_{3-6}$ 0.00088	$X_{6-7} Y_7 Z_{3-6}$ 0.0022	$X_7 Y_8 Z_{3-6}$ 0.00132	0.00440
13	WB1+WB2S +WB2P +WB3+ CO1 + CO2								$X_{5-6} Y_8 Z_{3-6}$ 0.0015	0.00150
14	WB2S + WB2P + CO1 + CO2	$X_4 Y_1 Z_{3-6}$ 0.00405	$X_4 Y_2 Z_{3-6}$ 0.00264	$X_{4-5} Y_3 Z_{3-6}$ 0.00267	$X_5 Y_4 Z_{3-6}$ 0.00062	$X_{5-6} Y_5 Z_{3-6}$ 0.0015				0.01148

Table A5 – Cumulative probability and oil outflow values

Side damage

	Compartment groups	Oil outflow O_i (m^3)	Probability P_i	Cumulative probability [sum of P_i]	Mean oil outflow P_i x O_i (m^3)	Probability P_{ie}	Extreme outflow O_{ie} x P_{ie} x 10 (m^3)
	WB1	0.00	0.17725	0.17725	0.00		
	WB1 + WB2S	0.00	0.03408	0.21133	0.00		
	WB2S	0.00	0.41532	0.62665	0.00		
	WB2S + WB3	0.00	0.03408	0.66073	0.00		
	WB3	0.00	0.17725	0.83798	0.00		
	WB1 + WB2S +CO1	9430.00	0.01054	0.84852	99.39		
	WB2S+CO1	9430.00	0.01939	0.86791	182.85		
	WB2S+CO2	28291.00	0.09381	0.96172	2653.98	0.06172	17461.2052
	WB2S+CO2 + WB3	28291.00	0.01142	0.97314	323.08	0.01142	3230.8322
	WB1 + WB2S +CO1 + CO2	37721.00	0.00088	0.97402	33.19	0.00088	331.9448
	WB2S +CO1 + CO2	37721.00	0.02598	1.00000	979.99	0.02598	9799.9158
					4272.48	0.10000	30823.898

Table A5 – Cumulative probability and oil outflow values (continued)

Bottom damage (0.0 metre tide)

	Compartment groups	Oil outflow O_i (m^3)	Probability P_i	Cumulative probability [sum of P_i]	Mean oil outflow P_i x O_i (m^3)	Probability P_{ie}	Extreme outflow O_{ie} x P_{ie} x 10 (m^3)
1	WB1	0.00	0.0302	0.03027	0.00		
2	WB1 + WB2S + WB2P	0.00	0.05304	0.08331	0.00		
3	WB1 + WB2S + WB2P + WB3	0.00	0.00530	0.08861	0.00		
4	WB2S + WB2P	0.00	0.24825	0.33686	0.00		
5	WB2S + WB2P+ WB3	0.00	0.24960	0.58646	0.00		
6	WB3	0.00	0.25667	0.84313	0.00		
7	WB1 + WB2S + WB2P + CO1	2373.00	0.00592	0.84905	14.05		
8	WB2S +WB2P + CO1	2373.00	0.00337	0.85242	8.00		
9	WB2S +WB2P + CO2	13322.00	0.05518	0.90760	735.11	0.00760	1012.4720
10	WB2S +WB2P + WB3 + CO2	13322.00	0.06600	0.97360	879.25	0.06600	8792.5200
11	WB1 + WB2S + WB2P + CO1 + CO2	18796.00	0.00903	0.98263	169.73	0.00903	1697.2788
12	WB3 + WB2S + WB2P + CO1 + CO2	18796.00	0.00150	0.98413	28.19	0.00150	281.9400
13	WB1 + WB2S + WB2P + WB3 + CO1 + CO2	18796.00	0.00440	0.98853	82.70	0.00440	827.0240
14	WB2S +WB2P + CO1 + CO2	18796.00	0.01147	1.00000	215.59	0.01147	2155.9012
					2132.62	0.10000	14767.1360

Table A6 – Cumulative probability and oil outflow values (existing table for 2.5 m is replaced by table below).

Bottom damage (~~2.0~~ 2.5 metre tide)

	Compartment groups	Oil outflow O_i (m^3)	Probability P_i	Cumulative probability [sum of P_i]	Mean oil outflow P_i x O_i (m^3)	Probability P_{ie}	Extreme outflow O_{ie} x P_{ie} x 10 (m^3)
1	WB1	0.00	0.03027	0.03027	0.00		
2	WB1 +WB2P+WB2S	0.00	0.05304	0.08331	0.00		
3	WB1+WB2P+WB2S+WB3C	0.00	0.00530	0.08861	0.00		
4	WB2P+WB2S	0.00	0.24825	0.33686	0.00		
5	WB2P+WB2S+WB3	0.00	0.24960	0.58646	0.00		
6	WB3	0.00	0.25667	0.84313	0.00		
7	WB1 + WB2P + WB2S + CO1	3862.00	0.00592	0.84905	22.86		
8	WB2P+WB2S+CO1	3862.00	0.00337	0.85242	13.01		
9	WB2P+WB2S+CO2	17244.00	0.05518	0.90760	951.52	0.00760	1310.5440
10	WB2P+WB2S+WB3 + CO2	17244.00	0.06600	0.97360	1138.10	0.06600	11381.0400
11	WB1+WB2P+WB2S+CO1+CO2	23935.00	0.00903	0.98263	216.13	0.00903	2161.3305
12	WB3+WB2P+WB2S+CO1+CO2	23935.00	0.00150	0.98413	35.90	0.00150	359.0250
13	WB1+WB2P+WB2S+WB3+CO1+CO2	23935.00	0.00440	0.98853	105.31	0.00440	1053.1400
14	WB2P+WB2S+CO1+CO2	23935.00	0.01147	1.00000	274.53	0.01147	2745.3445
					2757.39	0.10000	19010.4240

Table A7 – Summary of oil outflow parameters

Bottom damage	**(70%) 0.0 m tide**	**(30%) 2.5 m tide**	**Combined**
Probability of zero outflow P_o	0.8431	0.8431	0.8431
Mean outflow (m^3)	2133	2757	2320
Extreme outflow (m^3)	14767	19010	16040

Combined side and bottom damage	**(40%) Side damage**	**(60%) Bottom damage**	**Combined**
Probability of zero outflow P_o	0.8380	0.8431	0.8411
Mean outflow (m^3)	4272	2320	3101
Extreme outflow (m^3)	30824	16040	21954
Mean outflow parameter O_M			0.0822
Extreme outflow parameter O_E			0.5820

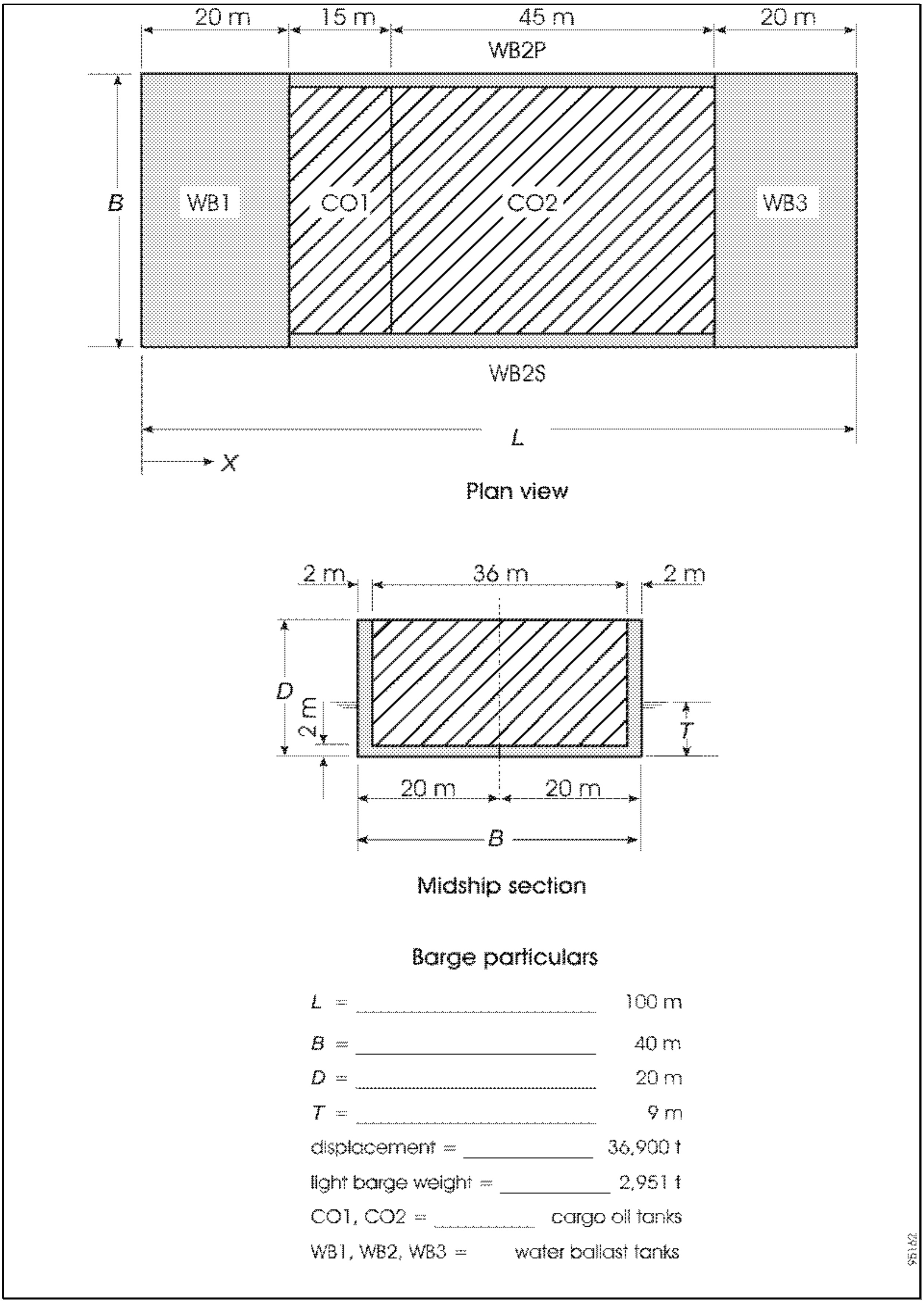

Figure A1 – Barge arrangement

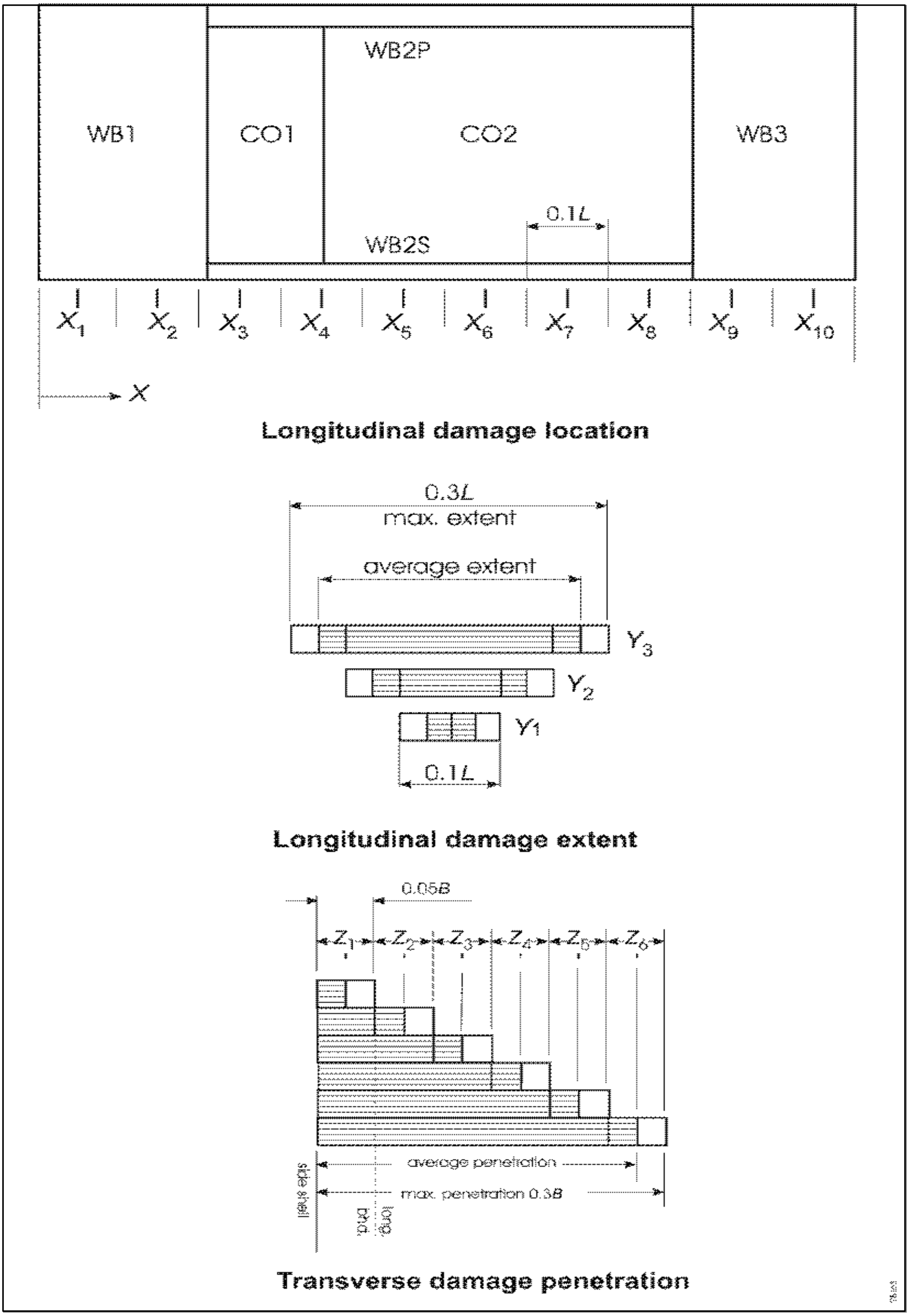

Figure A2 – Side damage definition

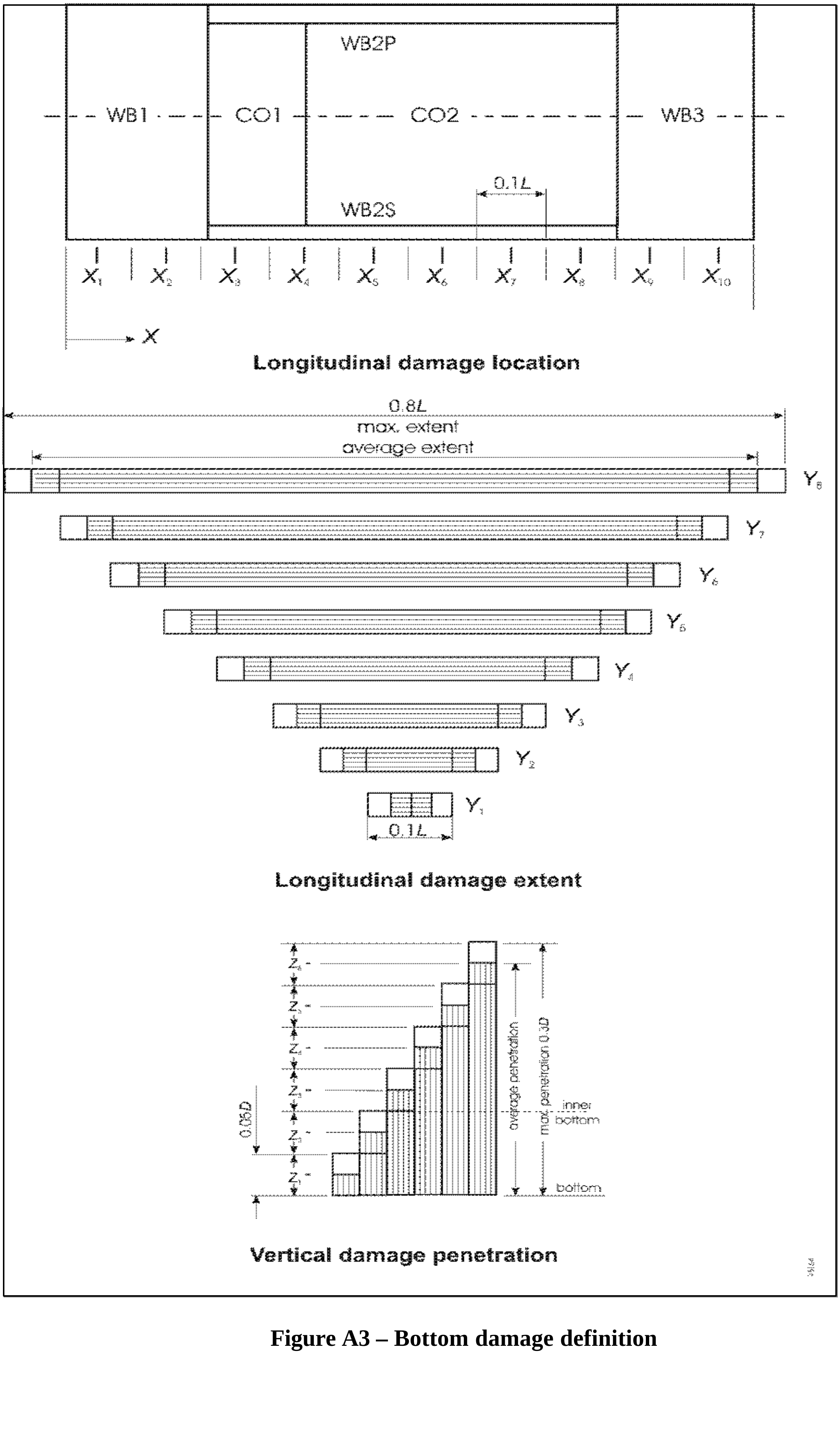

Figure A3 – Bottom damage definition

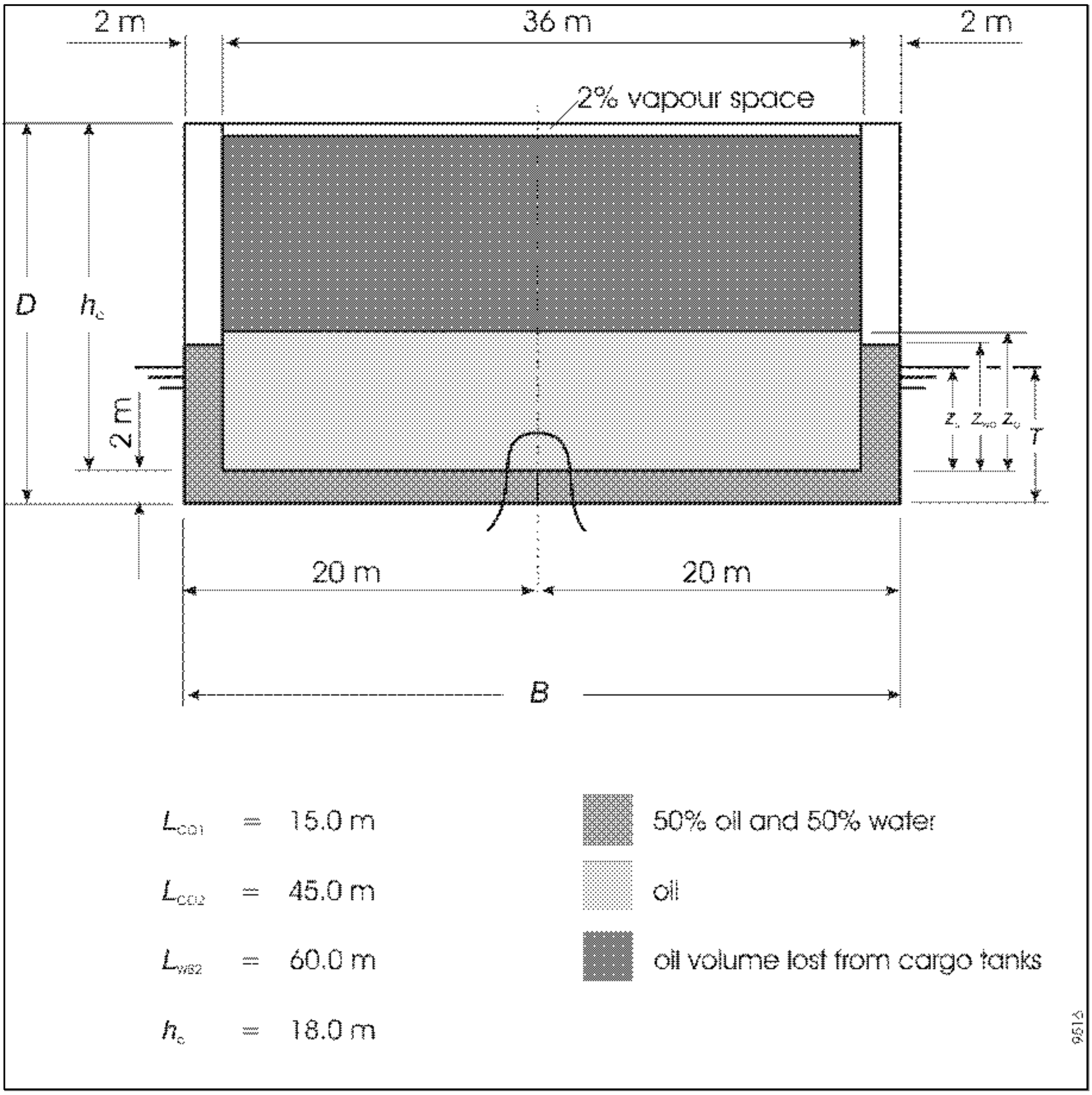

Figure A4 – Oil outflow scheme for bottom damage

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