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Working Party on the Transport of Dangerous Goods

Joint Meeting of Experts on the Regulations annexed to the European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN)[*]

Twelfth session
Geneva, 21-25 January 2008
Item 4 (c) of the provisional agenda

PROPOSALS FOR AMENDMENTS TO THE REGULATIONS ANNEXED TO ADN[**]

Miscellaneous proposals for amendments

Alternative constructions (tank vessels)

Transmitted by the Central Commission for the Navigation of the Rhine (CCNR)[***]

1. The CCNR proposes to include in the Regulations annexed to ADN new provisions intended to allow alternative constructions for tank vessels (e.g. for cargo tanks of higher capacity, different intervals between side walls and cargo tanks), as well as provisions concerning the procedures to follow in such cases.

2. The proposals to amend Part. 9 of the Regulations are reproduced below.

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[*] This meeting is organized jointly by the Economic Commission for Europe and the Central Commission for the Navigation of the Rhine (CCNR).
[**] Distributed in German by the CCNR under the symbol CCNR/ZKR/ADN/WP.15/AC.2/2008/5.
[***] In accordance with the programme of work of the Inland Transport Committee for 2006-2010 (ECE/TRANS/166/Add.1, programme activities 02.7 (b)).

9.3.1.11.1 (a)
9.3.2.11.1 (a)
9.3.3.11.1 (a)
9.3.1.11.2 (a)
9.3.2.11.7 Insert the following phrase at the beginning of the paragraphe: "Unless alternative constructions are permitted in accordance with 9.3.4,".

Add a new section 9.3.4 to read as follows:

"9.3.4 Alternative constructions

The maximum permissible capacity of a cargo tank determined in accordance with 9.3.1.11.1, 9.3.2.11.1 and 9.3.3.11.1 may be exceeded and the minimum distances in accordance with 9.3.1.11.2 a) and 9.3.2.11.7 may be deviated from provided that the provisions of this section are complied with. The capacity of a cargo tank shall not exceed 1000 m^3.

When a vessel is built in compliance with this section, a recognized classification society shall document the way in which the calculations made in accordance with subsection 9.3.4.2, steps 1 to 13, have been applied and shall submit its conclusions to the competent authority for approval. The competent authority may request additional calculations and evidence.

The competent authority shall include this construction in the certificate of approval in accordance with section 8.6.1.

9.3.4.1 General

Tank vessels fitted with cargo tanks with a capacity above the maximum allowable capacity as determined according to 9.3.1.11.1, 9.3.2.11.1 or 9.3.3.11.1 may be acceptable from a safety point of view provided that the cargo tanks are sufficiently protected against collisions through a crashworthy side structure.

Tanks vessels, with a distance between the side wall and the cargo tank not complying with the requirements of 9.3.1.11.2 a) or 9.3.2.11.7 may be acceptable from a safety point of view provided that the cargo tanks are sufficiently protected against collisions through a crashworthy side structure.

Sufficient protection can be shown by comparing the risk associated with a conventional design (reference design), complying with the ADN regulations and with the minimum building requirements according to a recognised classification society, to the risk of a crashworthy design (new design) featuring either enlarged cargo tanks or a reduced distance between the side wall and the cargo tank. When the risk associated with the crashworthy design is equal to or lower than the risk associated with the conventional design, equivalent or superior safety is demonstrated.

How the equivalent or superior safety must be demonstrated is explained in the following sub-sections.

9.3.4.2 Approach

The probability of tank rupture due to a collision and the area around the vessel affected by the cargo outflow as a result thereof are the governing parameters.

The following formula is used to describe the risk:

$$R = P\,C$$

wherein: R risk [m^2],

P probability of tank rupture [ ],

C consequence of tank rupture [m^2].

The probability P of tank rupture depends on the probability distribution of the available collision energy represented by vessels, which the victim is likely to encounter in a collision, and the capacity of the struck vessel to absorb this available collision energy without tank rupture.

The physical consequence C of cargo spillage resulting from tank rupture is expressed as an affected area around the vessel.

From the formula it can be concluded that an increase of the area affected by cargo outflow can be compensated by a decrease of the probability of outflow. A decrease of this probability can be achieved by means of a crashworthy side structure.

The following sub-sections show how to calculate tank rupture probabilities, how to predict the collision energy absorbing capacity of a vessel side structure and how to determine a consequence increase due to cargo spillage from enlarged cargo tanks.

9.3.4.3 Calculation procedure

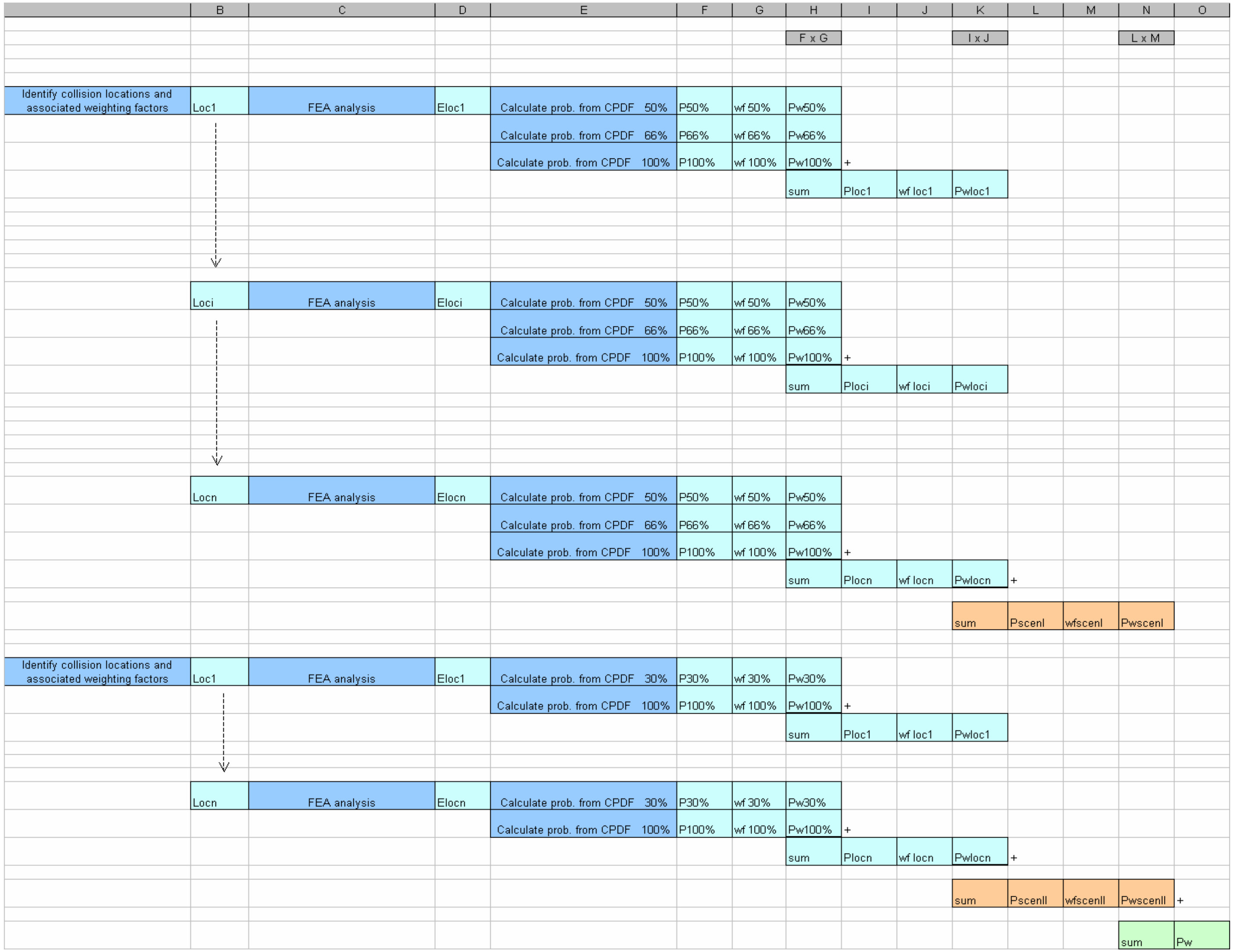
The calculation procedure shall typically follow 13 basic steps. For the following steps it is helpful to refer to the table in Figure 1 which shows how to calculate the weighted probability of tank rupture.

Step 1

Besides the (new) design, featuring enlarged cargo tanks or a reduced distance between the side wall and the cargo tank and a crashworthy side structure, generate a design (reference design) with the same main dimensions. This reference design shall fulfil the requirements specified in section 9.3.1 (Type G), 9.3.2 (Type C) or 9.3.3. (Type N) and shall comply with the minimum requirements with respect to scantlings as issued by a recognised classification society.

Steps 2 through 10 shall be carried out for both the reference design and the crashworthy design.

Figure 1 Scheme to calculate weighted probability of tank failure



Step 2

Determine the relevant, typical collision locations i=1 through n.

Figure 1 depicts the general case where there are 'n' typical collision locations.

The number of typical collision locations depends on the structural arrangement of the vessel structure. The choice of the collision locations shall be agreed upon by a recognised classification society.

Vertical collision locations

<u>Type C tank vessel and Type N tank vessel</u>

The striking locations in the vertical direction are defined by the draught differences of striking and struck vessels. Based on the ballast and design draughts of both striking and struck vessels, the collision locations in the vertical direction are defined in the following way (Figure 2):

T_{1max} is the design draught of the striking vessel and T_{1min} is the ballast draught of the striking vessel, while T_{2max} and T_{2min} are the design and ballast draughts of the struck vessel respectively. The area between $T1=T_{1min}$, $T1=T_{1max}$ and $T2=T_{2min}$, $T2=T_{2max}$ is a measure for all collision possibilities. In this example there are 3 vertical collision locations which are represented by three areas ΔT_1, ΔT_2, ΔT_3 (Figure 2).

The point P_1 is the case where the lower edge of the vertical part of the push barge bow or the V-shaped bow, strikes at deck level (see section 9.3.4.4.6. for bow shapes). The triangular area in Figure 2, below the P_1 diagonal represents the collision case 'collision above deck'.

The point P_2 is the case where the upper part of the push barge bow or the V-shaped bow, strikes at the upper edge of the shear strake. The area in Figure 2, between the P_1 diagonal and the P_2 diagonal represents the collision case 'collision at deck'.

The area above the P_2 diagonal represents the collision case 'collision below deck'.

See also Figure 3, which shows these characteristic vertical collision locations.

Useful weighting factors are obtained for each collision case by dividing the respective areas by the total area representing all collision cases.

For the mass of both striking vessel and struck vessel the maximum values possible at the relative draughts should be chosen, i.e. the highest point on each respective diagonal.

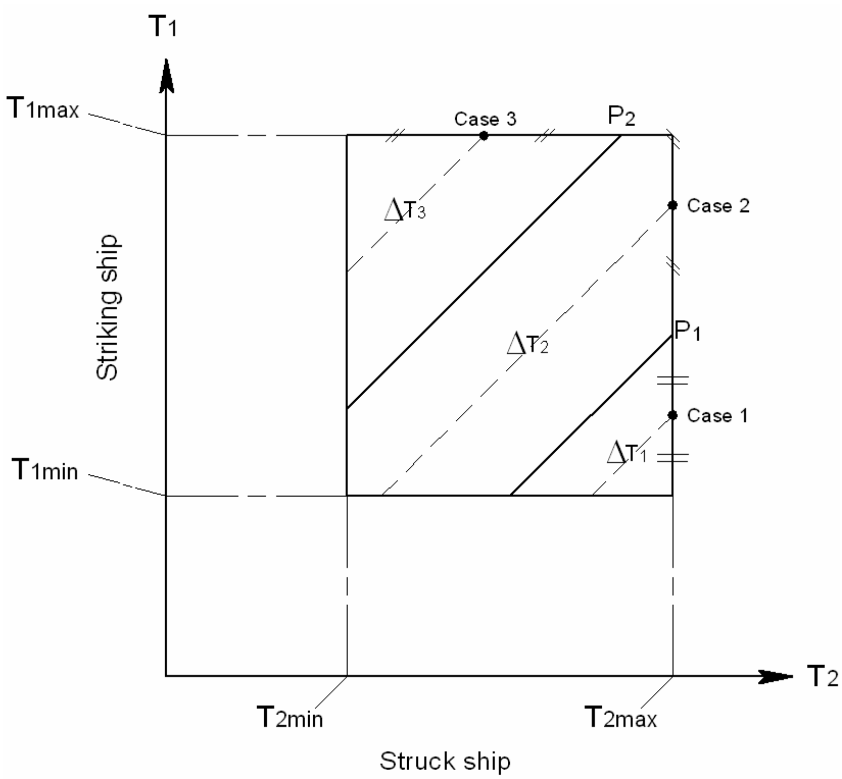


Figure 2: Definition vertical striking locations

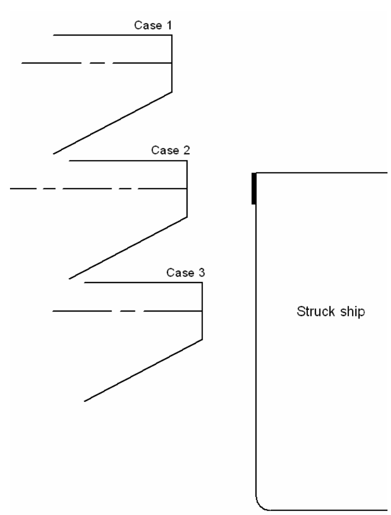


Figure 3: Example vertical collision locations

Type C and Type N tank vessels

Depending on the vessel's structural arrangement, the classification society may require additional collision locations.

Type G tank vessel

Usually only collisions at half tank height need to be considered. However the classification society may require additional collision locations.

Longitudinal collision location

Type C and Type N tank vessels

Usually there are at least three typical longitudinal collision locations:

Location 1 at bulkhead,

Location 2 between webs,

Location 3 at web.

Type G tank vessel

There are usually at least three typical collision locations:

Location 1 at cargo tank end,

Location 2 between webs,

Location 3 at web.

Number of collision locations

Type C and Type N tank vessels

The combination of collision locations in the example shown here yields 3 x 3 = 9 collision locations.

Typ G tank vessel

The combination of collision locations in the example shown here yields 1 x 3 = 3 cases.

Additional locations for Type G tank vessel

Two more locations need to be taken into consideration, i.e. striking at tank seating and striking at tank anti-floating devices. These locations shall be agreed upon by a recognised classification society.

Step 3

Determine, for each typical collision location, a weighting factor, which reflects the relative probability that such a typical location will be struck. In Figure 1 these factors are named *wfloc(i)* (column J). The choice should be submitted to a recognised classification society for approval.

The weighting factor for each location is a multiplication of the factor associated with the vertical location by the factor associated with the horizontal location.

Vertical collision locations

Type C and Type N tank vessels

The weighting factors for the various vertical collision locations are equal to the ratio between the partial areas and the total area as shown in Figure 1. For collision case 1 the weighting factor equals the ratio between the area of the triangle described by P_1, the maximum draught of the struck vessel (T_{2max}) and the minimum draught of the striking vessel (T_{1min}) and the area of the rectangle between minimum and maximum draughts of striking and struck vessels.

Type G tank vessel

The weighting factor equals 1.0, since there is only one striking location.

Longitudinal collision locations

Type C and Type N tank vessels

The weighting factors for the longitudinal collision locations are equal to the ratio between the characteristic length associated with the typical collision location and the tank length.

Characteristic lengths are defined below:

- collision on bulkhead: 0.2 x web frame spacing aft and/ or forward of bulkhead but not larger than 450 mm,

- collision on web:0.2 x web frame spacing aft and/ or forward of web but not larger than 450 mm,

- collision between webs: Tank length minus lengths associated with “collision on bulkhead” and lengths associated with "collision on web".

Type G tank vessel

The weighting factors for the longitudinal collision locations are equal to the ratio between the characteristic length associated with the typical collision location and the tank length.

Characteristic lengths are defined below:

- collision at tank end: distance between transverse bulkhead and the start of the cylindrical part of the tank,

- collision on web: 0.2 x web frame spacing aft or forward of web but not larger than 450 mm,

- collision between webs: Tank length minus lengths associated with “collision at tank end” and lengths associated with "collision on web".

Step 4

Calculate the energy absorbing capacity for each collision location. The energy absorbing capacity is defined as the internal energy plus the sliding energy absorbed by the struck vessel during penetration by a colliding bow, up to a penetration where the cargo tank shows an initial fracture. These energies are to be calculated through explicit finite element calculations, in accordance with 9.3.4.4.1.

These calculations are to be done for two different collision scenarios:

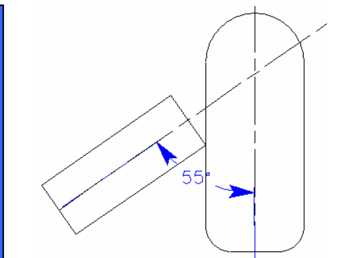
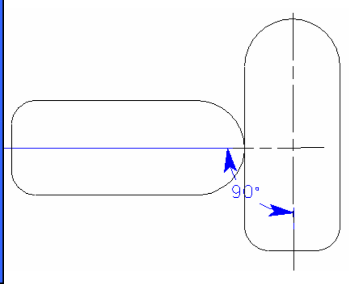
scenario I, refers to a push barge bow penetrating the struck vessel,

scenario II, refers to a V-shaped bow penetrating the struck vessel.

The bow shapes are defined in 9.3.4.4.6.

In Figure 1 these energies are called E_{loci}, and are indicated in column D.

Table 1: Speed reduction factors for scenario I or scenario II

					Causes		
					Communication error and poor visibility	**Technical error**	**Human error**
					0,50	0,20	0,30
Worst case scenarios	I		Push barge-bow, striking angle 55°	0,80	0.66	0.50	1.00
	II		V-shaped-bow, striking angle 90°	0,20	0.30		1.00

Step 5

For each collision absorption capacity *Eloc(I)*, the associated probability of exceedance is to be calculated, i.e. the probability of tank fracture.

For this purpose, the formula for the cumulative probability density functions (CPDF) below shall be used. The appropriate coefficients shall be selected from Table for the effective mass of the struck vessel.

$$P_{x\%} = C_1 E^3_{loc(i)} + C_2 E^2_{loc(i)} + C_3 E_{loc(i)} + C_4$$

with: $Px\%$ probability of tank rupture,
$C_{1\text{-}4}$ coefficient from Table,
$E_{loc(i)}$ Energy absorbing capacity.

The effective mass equals the maximum displacement of the vessel multiplied by a factor of 1.4. Both collision scenarios (Table 1) are to be considered.

In the case of scenario I (push barge bow at 55°), three CPDF curves shall be considered:

CPDF 50% (velocity 0.5 V_{max}),

CPDF 66% (velocity 2/3 V_{max}),

CPDF 100% (velocity V_{max}).

In the case of scenario II (V-shaped bow at 90°), two CPDF curves shall be considered:

CPDF 30% (velocity 0.3 V_{max}),

CPDF 100% (velocity V_{max}).

In Figure 1 (column F), these probabilities are called *P50%*, *P66%*, *P100%* and *P30%*, *P100%* respectively.

Table 2: Coefficients for the CPDF-curves

effective mass struck vessel Tonnes	velocity = 1 x Vmax				
	coefficients				
	C_1	C_2	C_3	C_4	range
14000	4.106E-05	-2.507E-03	9.727E-03	9.983E-01	4<E<39
12000	4.609E-05	-2.761E-03	1.215E-02	9.926E-01	4<E<36
10000	5.327E-05	-3.125E-03	1.569E-02	9.839E-01	4<E<33
8000	6.458E-05	-3.691E-03	2.108E-02	9.715E-01	4<E<31
6000	7.902E-05	-4.431E-03	2.719E-02	9.590E-01	4<E<27
4500	8.823E-05	-5.152E-03	3.285E-02	9.482E-01	4<E<24
3000	2.144E-05	-4.607E-03	2.921E-02	9.555E-01	2<E<19
1500	- 2.071E-03	2.704E-02	-1.245E-01	1.169E+00	2<E<12

effective mass struck vessel Tonnes	velocity = 2/3 x Vmax				
	coefficients				
	C_1	C_2	C_3	C_4	range
14000	4.638E-04	-1.254E-02	2.041E-02	1.000E+00	2<E<17
12000	5.377E-04	-1.427E-02	2.897E-02	9.908E-01	2<E<17
10000	6.262E-04	-1.631E-02	3.849E-02	9.805E-01	2<E<15
8000	7.363E-04	-1.861E-02	4.646E-02	9.729E-01	2<E<13
6000	9.115E-04	-2.269E-02	6.285E-02	9.573E-01	2<E<12
4500	1.071E-03	-2.705E-02	7.738E-02	9.455E-01	1<E<11
3000	-1.709E-05	-1.952E-02	5.123E-02	9.682E-01	1<E<8
1500	-2.479E-02	1.500E-01	-3.218E-01	1.204E+00	1<E<5

effective mass struck vessel Tonnes	velocity = 0,5 x Vmax				
	coefficients				
	C_1	C_2	C_3	C_4	range
14000	2.621E-03	-3.978E-02	3.363E-02	1.000E+00	1<E<10
12000	2.947E-03	-4.404E-02	4.759E-02	9.932E-01	1<E<9
10000	3.317E-03	-4.873E-02	5.843E-02	9.878E-01	2<E<8
8000	3.963E-03	-5.723E-02	7.945E-02	9.739E-01	2<E<7
6000	5.349E-03	-7.407E-02	1.186E-01	9.517E-01	1<E<6
4500	6.303E-03	-8.713E-02	1.393E-01	9.440E-01	1<E<6
3000	2.628E-03	-8.504E-02	1.447E-01	9.408E-01	1<E<5
1500	-1.566E-01	5.419E-01	-6.348E-01	1.209E+00	1<E<3

effective mass struck vessel	velocity = 0,3 x Vmax				
	coefficients				
Tonnes	C_1	C_2	C_3	C_4	range
14000	5.628E-02	-3.081E-01	1.036E-01	9.991E-01	1<E<3
12000	5.997E-02	-3.212E-01	1.029E-01	1.002E+00	1<E<3
10000	7.477E-02	-3.949E-01	1.875E-01	9.816E-01	1<E<3
8000	1.021E-02	-5.143E-01	2.983E-01	9.593E-01	1<E<2
6000	9.145E-02	-4.814E-01	2.421E-01	9.694E-01	1<E<2
4500	1.180E-01	-6.267E-01	3.542E-01	9.521E-01	1<E<2
3000	7.902E-02	-7.546E-01	5.079E-01	9.218E-01	1<E<2
1500	-1.031E+00	2.214E-01	1.891E-01	9.554E-01	0.5<E<1

The range where the formula holds is given in column 6,

below the range the probability $P_{x\%} = 1$,

above the range $P_{x\%} = 0$.

Step 6

The weighted probabilities of tank fracture shall be calculated by multiplying each fracture probability *P(##)%* (Figure 1 column F) by the weighting factors as given in Table 3.

Table 3: Weighting factors for each characteristic collision speed

			weighting factor
Scenario I	CPDF 50%	wf50%	0.2
	CPDF 66%	wf66%	0.5
	CPDF 100%	wf100%	0.3
Scenario II	CPDF 30%	wf30%	0.7
	CPDF 100%	wf100%	0.3

In Figure 1 (column H), these probabilities are referred to as *Pw50%*, *Pw66%* etc.

Step 7

Add all weighted probabilities Pw(##)% (Figure 1 column H) for each collision location considered. This gives the resulting probabilities Ploc(i) (Figure 1 column I).

Step 8

Multiply the tank fracture probabilities for each collision location, by the weighting factors wfloc(i) (Figure 1 column J) related to the collision locations. Add all weighted probabilities for both collision scenarios I and II. This gives the weighted fracture probabilities for both collision scenarios.

Step 9

Add the weighted probabilities Pwloc(i) for both collision scenarios I and II. This gives PscenI and PscenII (Figure 1 column L).

Step 10

The final probability of tank fracture is to be calculated by the formula below (Figure 1 column O):

$$P_w = 0{,}8 \quad PscenI + \quad 0{,}2 \quad PscenII$$

Step 11

P_w for the new design is called P_n.

P_w for the reference structure is called P_r.

Step 12

Calculate the effect increase, in case of tank fracture, due to enlarged cargo tanks.

For cargo tanks with capacities between 380 m^3 and 1000 m^3 containing flammable, toxic and acid liquids or gases it shall be assumed that the effect increase relates linearly to the increased tank capacity (proportionality factor 1.00).

The following formula is to be used:

$$\frac{C_n}{C_r} = \frac{V}{V_r}$$

With: C_n consequence related to the new design, featuring enlarged cargo tanks,
C_r consequence related to the reference design, featuring 380 m^3 cargo tanks,
V maximum capacity of the enlarged cargo tank,
V_r maximum capacity of cargo tank reference vessel.

This formula was calculated for characteristic cargoes as listed in the table below..

Table 4: Characteristic cargoes

	UN	**Description**
Benzene	1114	Flammable liquid Packing group II Hazardous to health
Acrylonitrile Stabilised ACN	1093	Flammable liquid Packing group I Toxic, stabilised
n-Hexane	1208	Flammable liquid Packing group II
Nonane	1920	Flammable liquid Packing group III
Ammonia	1005	Toxic, corrosive gas Liquefied under pressure
Propane	1978	Flammable gas Liquefied under pressure

If it is expected that the affected area related to the outflow of a specific cargo will have a proportionality factor larger than 1.0, as stated in step 12, the affected area shall be determined through a separate calculation. With this calculated affected area, the comparison as described in step 13 shall be carried out.

Step 13

Compare the probability ratio $\frac{P_r}{P_n}$ with the consequence ratio $\frac{C_n}{C_r}$.

When $\frac{C_n}{C_r} \leq \frac{P_r}{P_n}$, the new design complies with the requirements.

9.3.4.4. Calculation of energy absorbing capacity

The calculation of collision energy absorbing capacity shall be done by means of a Finite Element Analysis (FEA). The analysis shall be carried out using a recognized finite element code (e.g. LS-DYNA, PAM-CRASH, ABAQUS etc.) capable of dealing with both geometrical and material non-linear effects. The code shall also be able to simulate rupture realistically.

The actual program and the level of detail of the calculations shall be agreed upon with a recognised classification society.

9.3.4.4.1 Finite element models

First of all, two FE models shall be generated, one for the crashworthy structure and one for the reference structure. Principally, the generation of the FE models shall catch all plastic deformations relevant for all collision cases considered. In principle the whole length of the cargo zone shall be modelled. At both ends of the cargo zone the translational degrees of freedom are to be restrained. Because in most collision situations the global bending of the vessel sections is not significant for evaluation of plastic deformation energy it is sufficient that only half of the vessel sections be considered. In these cases the transverse displacements at the CL (centreline) shall be constrained. After generating a FE model, a test collision calculation shall be carried out to ensure that there is no occurrence of plastic deformations near the constraint boundaries. Otherwise the FE modelled area has to be increased.

Generally, structural areas involved during collisions shall be sufficiently finely idealized, while other parts may be modelled coarsely. The density of the element mesh shall be suitable for a reasonable description of local folding deformations and for determination of realistic rupture of elements, based on a suitable failure criterion. From calculation experience it is known that the maximum element size is generally less than 200 mm in collision areas. The shell element shape shall have an aspect ratio of at least 1/3. The element size L for a shell element is defined as the maximum length of both sides of the element: $L=\max\{L_1,L_2\}$. The ratio between element length and element thickness should be larger than 5. Other values shall be discussed with a recognised classification society. Usually plate structures, such as shell, inner hull (tank shell in case of tank vessels for gas), webs as well as stringers can be idealized as shell elements and stiffeners can be represented as beam elements. Cut outs and manholes in collision areas shall be taken into account.

The 'node on segment penalty' method shall be used:

- contact_automatic_single_surface	LS-DYNA,
- self impacting	PAMCRASH,
- similar contact types	other FE-programs.

9.3.4.4.2 ***Material properties***

Since a crash calculation involves extreme structural behaviour with both geometrical and material non-linear effects, the input of material properties up to ultimate tensile stress has a significant influence on the extent of collision energy absorbing capacity. It is generally recommended to use the true stress-strain relationship, which can be obtained from a tensile test in the following way:

$$\sigma = C \cdot \varepsilon^n , \qquad 4$$

where

$$n = \ln(1 + A_g) \qquad 5$$

and

$$C = R_m \cdot \left(\frac{e}{n}\right)^n . \qquad 6$$

A_g is the maximal uniform strain related to the ultimate tensile stress R_m. Both values can be measured from a tensile test. e is the natural logarithmic constant. However, in many cases only the ultimate stress R_m is available.

In these cases the following approximation may be used for shipbuilding steel with a maximum R_{eH} of 355 N/mm² to obtain the proper A_g value from a known R_m ([MPa]) value:

$$A_g = \frac{1}{0.24 + 0.01395 \cdot R_m} . \qquad 7$$

Often, the material properties from tensile tests are not available when starting the calculations. If this is the case, minimum values of A_g and R_m, as defined in the rules, shall be used. For steel with a yield stress higher than 355 N/mm² or materials other than steel, material properties shall be discussed with a recognised classification society.

9.3.4.4.3 ***Failure Criteria***

As mentioned, the most important specified measurement for the energy equivalence for different structural designs is the critical energy value at which the tank shell of the struck vessel ruptures. In a FEA this critical situation is represented by the first rupture of a finite element, which has an extremely large plastic strain at this moment.

Usually the first rupture of an element in a FEA is defined with a failure strain value. If the calculated strain, such as plastic effective strain, principal strain or for a shell element the strain in the thickness direction of this element exceeds its defined failure strain value, the element shall be deleted from the FE model and the deformation energy in this element will no longer change in the following calculation steps.

From evaluation of the thickness measurements towards cracks, the following definition of failure strain is recommended:

$$\varepsilon_f\left(l_e\right) = \varepsilon_g + \varepsilon_e \cdot \frac{t}{l_e}$$

where ε_g is the uniform strain and ε_e is the necking, t and l_e is the plate thickness and an individual element length respectively.

The values of uniform strain and the necking achieved from the thickness measurements for shipbuilding steel with a maximum R_{eH} of 355 N/mm² are related to the calculated stress states and are assigned in the following table:

stress states	1-D	2-D
ε_g	0.079	0.056
ε_e	0.76	0.54
element type	beam, truss	shell, plate

Much more realistic ε_g and ε_e values can be achieved by more additional thickness measurements from prototype damage cases and experiments.

Other failure criteria may be used when sufficient proof can be provided showing their adequacy.

Type G tank vessel specific

The fracture criterion for the gas tank itself shall be based on equivalent strain. A typical strain of 0.15 shall be assumed for fracture. Equivalent plastic strain associated with compression is to be ignored.

9.3.4.4.4 ***Determination of the energy absorbing capacity***

The energy absorbing capacity is the summation of internal energy, i.e. energy associated with deformation of structural elements, and friction energy.

The friction coefficient shall be calculated with the following formula:

$$\mu_c = FD + (FS - FD) \cdot e^{-DC|v_{rel}|},$$

with FD = 0.1,
FS = 0.3,
DC = 0.01
$|v_{rel}|$ = relative friction velocity.

A calculated force penetration curve shall be supplied to a recognised classification society.

Type G tank vessel specific

The energy absorbing capacity of a type G tank vessel shall include the energy absorbed through compression of the vapour in the tank.

The following formula shall be used to calculate this energy:

$$E = \frac{p_1 \cdot v_1 - p_0 \cdot v_0}{1 - \gamma}$$

with:

γ c_p/c_v (1.4)
c_p specific heat at constant pressure [J/(kgK)]
c_v specific heat at constant volume [J/(kgK)]
p_0 pressure at start of compression [Pa]
p_1 pressure at end of compression [Pa]
v_0 volume at start of compression [m^3]
v_1 volume at end of compression [m^3]

9.3.4.4.5 ***Definition of striking vessel and definition of striking bow***

It is required that two types of striking bow shapes be used for calculating collision energy absorbing capacities:

- bow shape I: push barge bow (*see 9.3.4.4.6 for details and dimensions*),
- bow shape II: V-shape bow without bulb (*see 9.3.4.4.6 for details and dimensions*).

Because in most collision cases the striking bow shows only slight deformations compared to the side structure of a struck vessel, a striking bow will generally be defined as rigid. Only for special situations, where the struck vessel has a very strong side structure compared to the striking bow and the structural behaviour of the struck vessel is influenced by the plastic deformation of the striking bow, shall the striking bow be considered as deformable. In this case the structure of the striking bow should also be modelled and recognised classification society shall be consulted prior to the calculations.

9.3.4.4.6 ***Definition of collision cases***

With respect to the finite element collision crash calculations, the following shall be assumed:

(a) In case of a collision with the V-shaped bow, the collision angle equals 90° and, in case of the push barge bow, the collision angle equals 55°; and

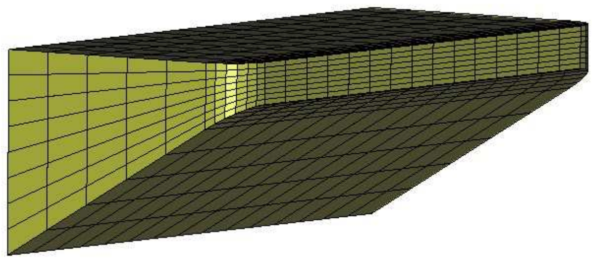
(b) The struck vessel has zero speed, while the striking vessel penetrates with a constant speed of 10 m/s.

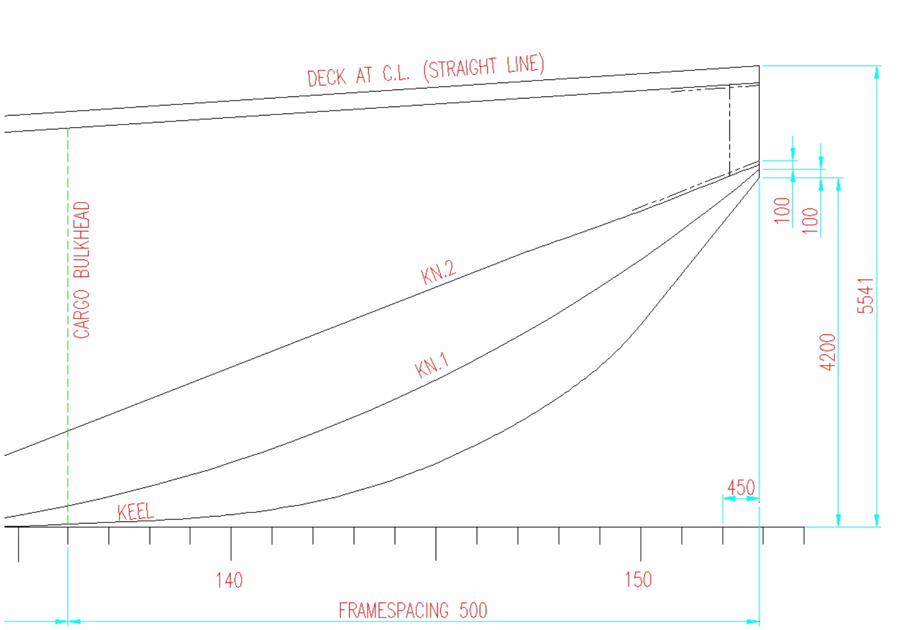
The deformation energy, absorbed by the struck vessel, depends on the collision location. Refer to step 2 of this sub-section, which describes which locations are to be considered.

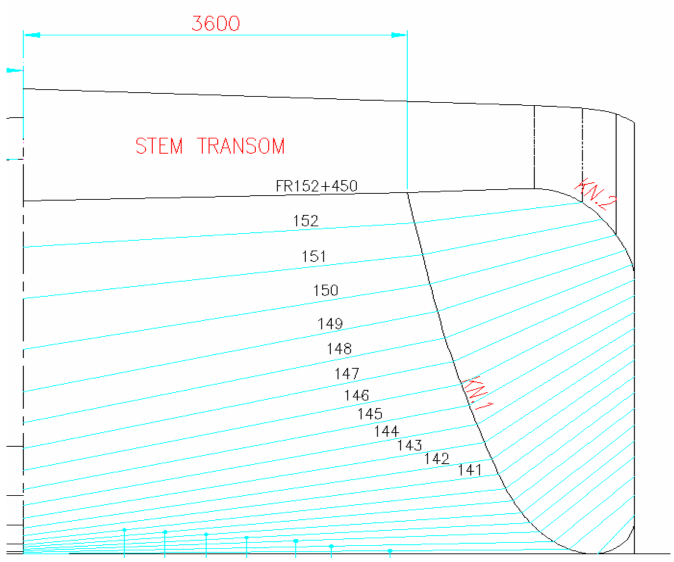
The collision velocity of 10 m/s is a calculation value to be used in the FE analysis only.

9.3.4.4.7 ***Drawings***

Pushbarge bow

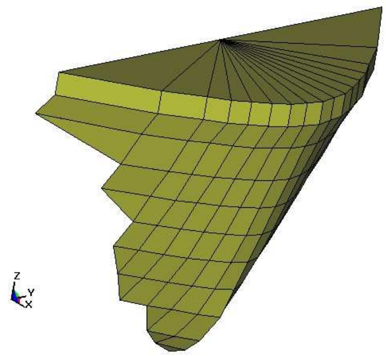


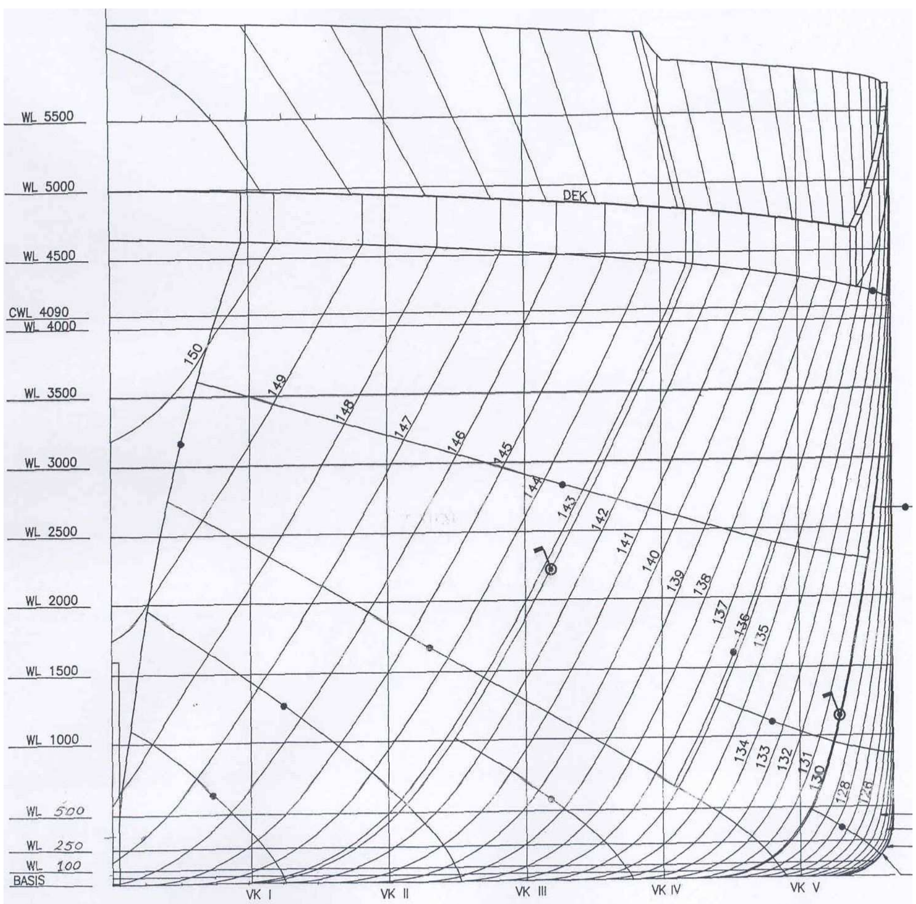



3600
STEM TRANSOM
FR152+450
152
151
150
149
148
147
146
145
144
143
142
141
KN.1
KN.2

Width: 11,50 m

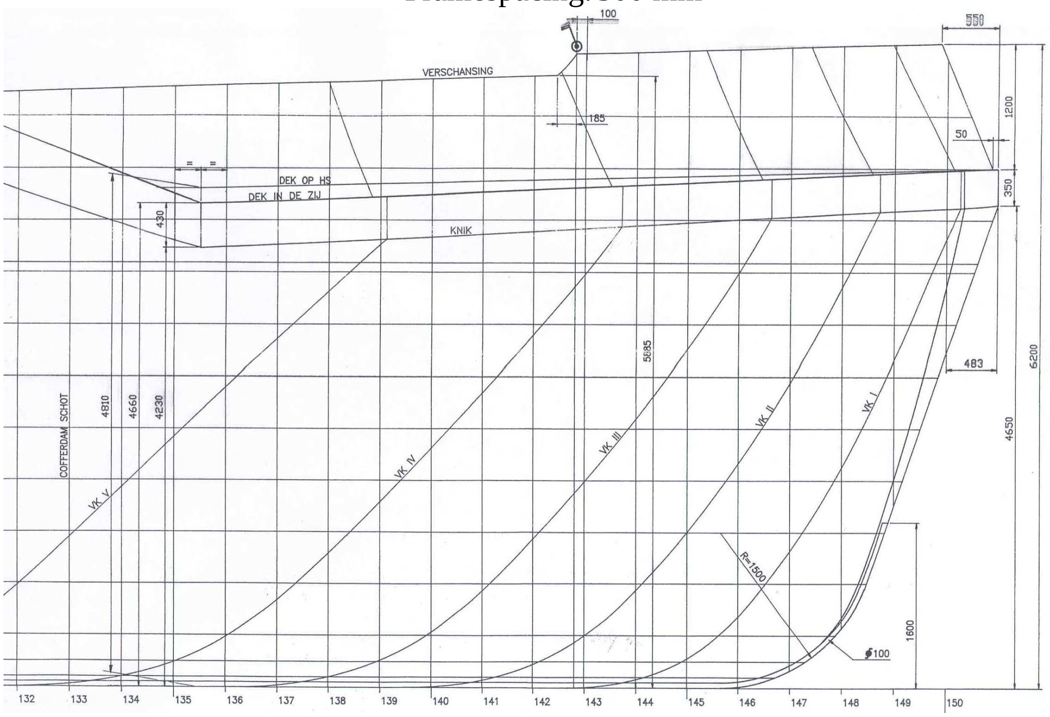
V-shaped bow

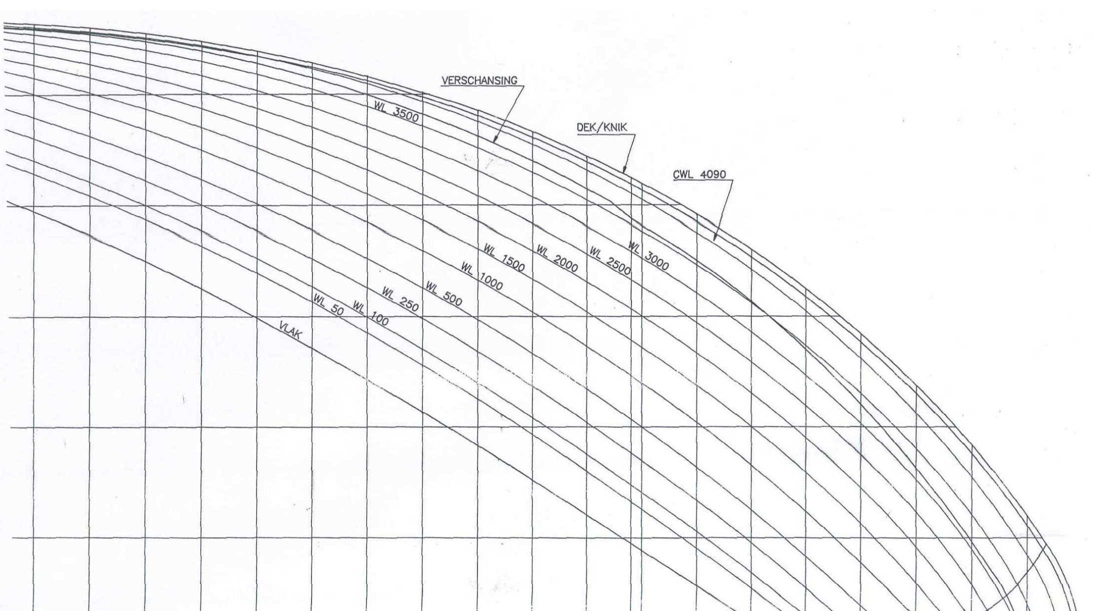




Width: 11,35 m

Framespacing: 500 mm





Buttock spacing: 1000 mm"
