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Economic Commission for Europe

Inland Transport Committee

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) (ADN Safety Committee)

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Implementation of the European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN): Matters related to classification societies

Update and revision ADN 9.3.4, topic: collision energies

Transmitted by the Group of ADN Recommended Classification Societies

Memorandum

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To

Revision ADN 9.3.4 project participants and sponsors

From

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Subject

Update and revision ADN 9.3.4, topic: collision energies

Date

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Contents

Introduction

ADN 9.3.4 prescribes how to demonstrate equivalent safety when a tanker is equipped with cargo tanks which exceed the ADN default maximum size of 380 m^3. For this purpose formulas are given for collision energies which a tanker is likely to be exposed to during a collision. The formulas are based on 1999 shipping statistics, which are outdated. Updated collision energies, based on more recent (2017) statistics have been derived and are reported in this document.

Theoretical background

Typical collision scenarios are shown in Figure 1. A distinction is made between collisions with a V-shaped bow and a push barge bow. The push barge bow is assumed to strike at an angle of 55 degrees while the V-bow strikes at 90 degrees (according current ADN). It is assumed that at those angles the largest penetrating damages will occur.

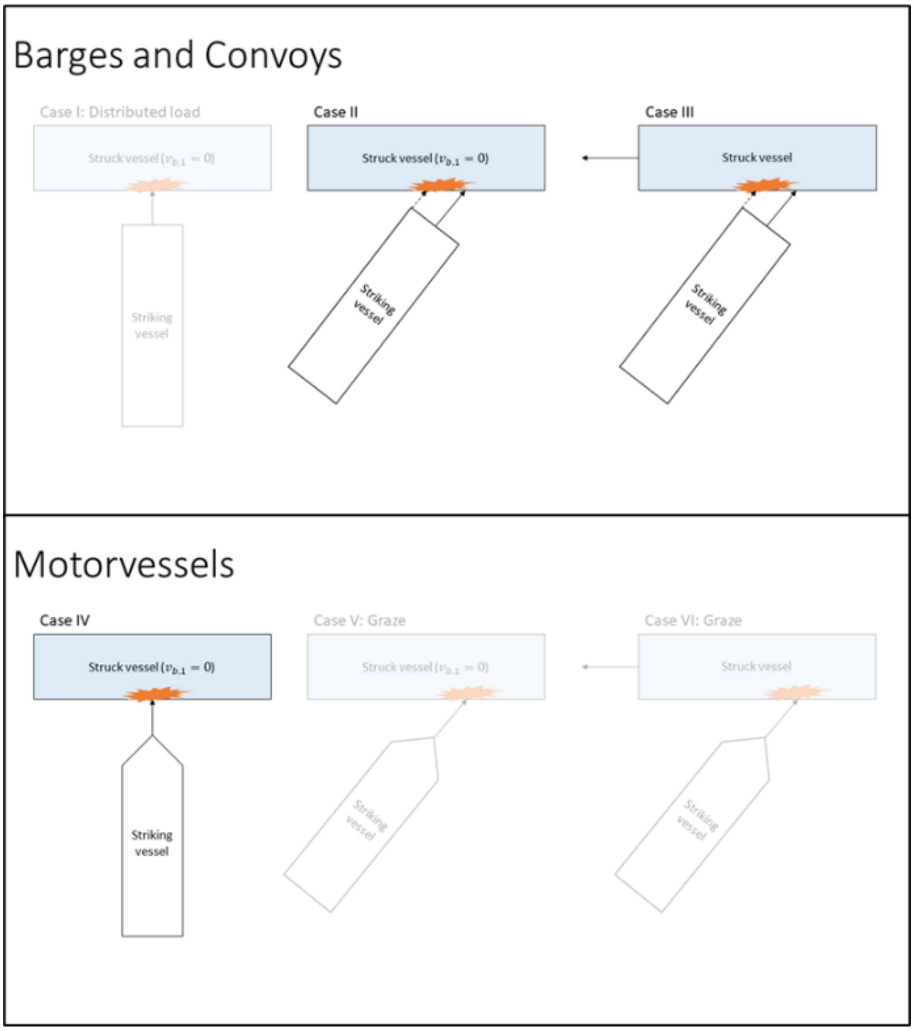

Figure 1 typical collision scenarios

It is also assumed that the struck ship has no velocity. Moreover a fully inelastic collision is assumed, i.e. there is no bouncing back. It is also assumed that the bow of the striking ship does not deform, i.e. the struck ship absorbes all collision energy. These assumptions are according current ADN regulations.

The collision energy which a struck ship will need to absorb depends on the mass and velocity of the striking ship and its own mass and velocity. Since a fully inelastic collision and a zero velocity of the struck ship are assumed, the energy to be absorbed by the structure equals:

$$E_{diss} = \frac{1}{2} \boldsymbol{m_a v_a^2} \left(\frac{\boldsymbol{m_b}}{\boldsymbol{m_a + m_b}} \right) \quad (1)$$

With: E_{diss} collision energy absorbed by the structure [J]

m_a effective mass of striking ship [kg]

m_b effective mass of struck ship [kg]

v_a velocity of striking ship [m/s]

The displacement of the striking ship is multiplied by 1.1 to obtain the effective mass, in order to cater for added mass. The displacement of the struck ship is multiplied by 1.4 for the same reason. The above listed formula and figures are according to the current ADN regulations.

Shipping statistics

The main source of information is anonymized AIS data obtained through the Dutch river authority, Rijkswaterstaat. It lists all ship passages at the Boven-Rijn, north-west of Lobith. It is thereby assumed that the traffic intensity at the border between Germany and the Netherlands is indicative for the traffic intensity and hence collision energy density on the European inland waterways.

Displacements and effective masses

Figure 2 shows a histogram of ship passages recorded in 2017 and 1999. It is noted that the current ADN 9.3.4 regulations are based on the 1999 data. The 2017 data in Figure 2 is categorized in the same DWT classes as the ones reported on the 1999 statistics. This illustrates the importance of smaller categories in the higher DWT domain.

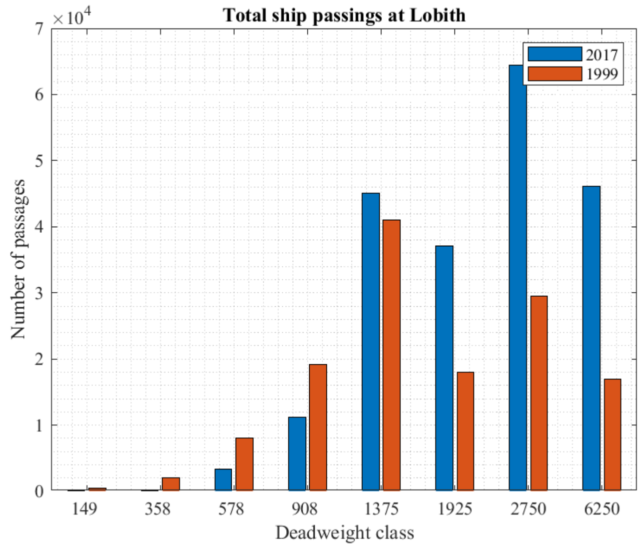

Figure 2 Ship passages per deadweight class, 1999 and 2017

As can be seen, shipping has increased significantly in both amount and size since 1999. This illustrates the need for an update of the collision energy statistics used in ADN 9.3.4.

Figure 3 shows the number of ship passages per effective mass class observed in 2017. The largest effective mass of a single unit observed is 15500 tonnes(including added mass). Effective mass ranges were chosen at a width of 500 tonnes in order to better reflect the increased amount and diversity of high energy vessels in 2017.

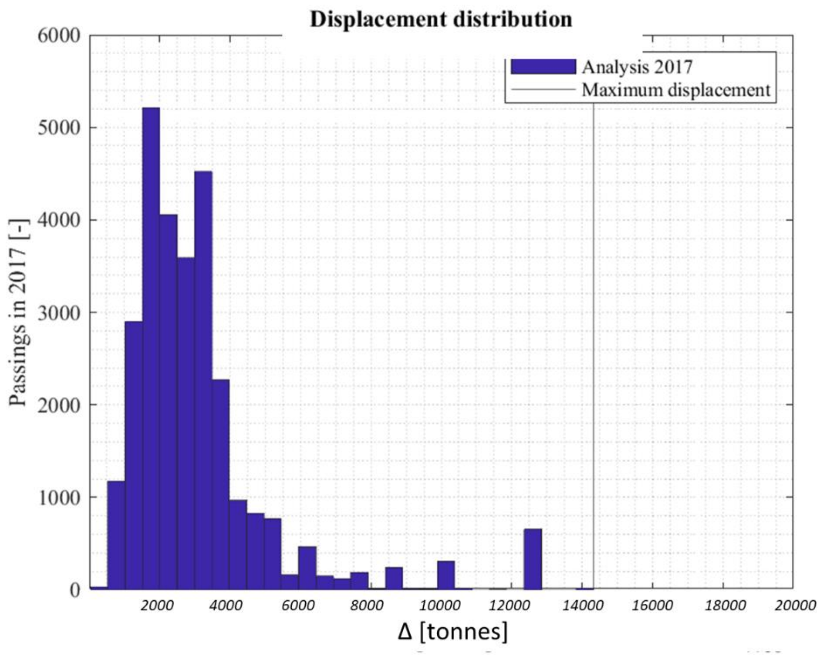

Figure 3 Ship passages per effective mass classes, 2017

Most passages are in the effective mass range between 1000 and 5000 tonnes. In 2017 there were slightly under 700 passages in the 12000 - 14000 tonne effective mass range, to be attributed to push barge convoys carrying iron ore and coal (Figure 4).

Figure 4 Pushed convoy [photo: Imperial Shipping Holding GmbH, source: BAW[1]]

It is noted that the PS row of a typical push barge convoy is connected to the SB row of the convoy's barges through steel cables. Therefore the connection between the PS barge row and SB barge row is not rigid. Hence, when a collision at an angle occurs (case II and Case III in Figure 1) only the mass of one row of three barges will participate fully in the collision whereas the other row will only participate partially if not at all. In the energy analysis this mechanism has been ignored. Instead the full mass of the convoy is assumed which is considered conservative.

Sailing speed

Ship speeds through water (STW) were attributed to each ship type as listed in the table below. The classification of inland ship types includes both the SK code and CEMT class according Rijkswaterstaat[2] The length L and width B, are presented as the average of the SK code category. The maximum speed is taken from data published by Bundesanstalt für Wasserbau (BAW[1]). Bold font numbers indicate reported values. The non-bold font values are copied from values in previous (above) or following (below) cells.

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[1] Driving Dynamics of Inland Vessels, 2016 Bundesanstalt für Wasserbau (BAW), Karlsruhe, Germany

[2] Rijkswaterstaat, Adviesdienst Verkeer en Vervoer, "Classificatie en kenmerken van de Europese vloot en de Actieve vloot in Nederland," Rijkswaterstaat, Rotterdam, 2002

Table 1 Ship types and velocities

SK code	Amount	Description (Dutch)	CEMT class	B [m]	L [m]	V max [km/h]
B01	0	Duwstel	I	5.2	55	**14**
B02	0	Duwstel	II	6.6	65	14
B03	0	Duwstel	III	7.5	80	14
B04	3	Duwstel	III	8.2	85	14
BI	15	Europa I duwstel	IV	9.5	95	14
BII-1	45	Europa II duwstel	V a	11.4	102.5	14
BII-2b	1	2-baksduwstel breed	VI a	22.8	120	**14**
BII-2L	4	2-baksduwstel lang	V b	15.1	180	**16**
BII-4	655	4-baksduwstel	VI b	22.8	190	**14**
BII-6b	1417	6-baksduwstel lang (incl 5-baks breed)	VII a	34.2	195	13
BII-6l	34	6-baksduwstel lang (incl 5-baks lang)	VI c	22.8	270	**13**
BIIa-1	2	Europa IIa duwstel	V a	11.4	101	14
BIIL-1	58	Europa II Lang	V a	11.4	130	14
C1b	0	2 spitsen breed	I	10.1	38.5	14
C1l	0	2 spitsen lang	I	5.05	78.5	14
C2b	3	Klasse IV + Europa I breed	VI a	19	95	14
C2l	15	Klasse IV + Europa I lang	IV b	9.5	177.5	14
C3b	111	Klasse Va + Europa II breed	VI a	22.8	102.5	14
C3l	1155	Klasse Va + Europa II lang	V b	11.4	180	14
C4	949	Klasse Va + 3 Europa II	VI b	22.8	185	14
M1	1	Spits	I	5.05	38.5	**12**
M10	351	Maatgevend schip 13,5 * 110 m	VI a	13.5	110	18
M11	1700	Maatgevend schip 14,2 * 135 m	VI a	14.2	135	18
M12	1401	Rijnmax Schip	VI a	17	135	18
M2	340	Kempenaar	II	6.6	52.5	**16**
M3	63	Hagenaar	III	7.2	62.5	**18**
M4	128	Dortmund Eems	III	8.2	70	18
M5	453	Verlengde Dortmund	III	8.2	82.5	18
M6	3416	Rijn-Herne Schip	IV	9.5	92.5	18
M7	548	Verlengde Rijn-Herne	IV	9.5	105	18
M8	11762	Groot Rijnschip	V a	11.4	111	**18**
M9	4049	Verlengd Groot Rijnschip	V a	11.4	135	**18**

It is noted that the ships sailing independently (SK codes starting with M) can sail at speeds as high as 18 km/hr. Push convoys tend to sail at 14 km/hr.

Collision energies

There are two topics regarding collision energy available on the river to inflict damage;

1. Determine if the available collision energy on the river has increased significantly since ADN section 9.3.4 came into force,
   and if this is the case,
2. Develop updated cumulative probability density functions for collision energies.

Topic 1.

Figure 5 shows two histograms, the one on the right hand side depicts the probability density function of kinetic energies available on the river in terms of single ships according to the ½ m v^2 formula. This implies that were a ship to collide with a victim all energy would need to be absorbed by the ship structures involved. Data is shown for both the 1999 situation (red) and the 2017 situation (blue). As can be seen, higher collision energies are available in the 2017 case. The left hand side histogram depicts the cumulative probability density functions derived for 1999 and 2017 data.

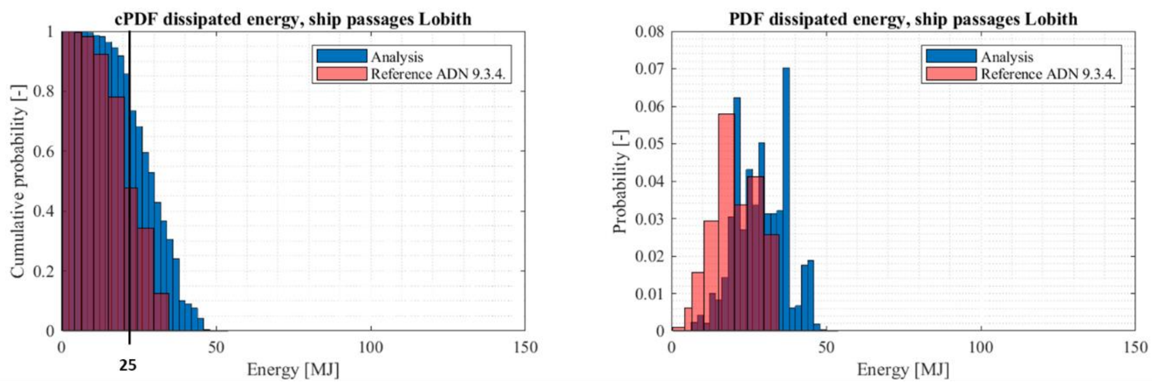
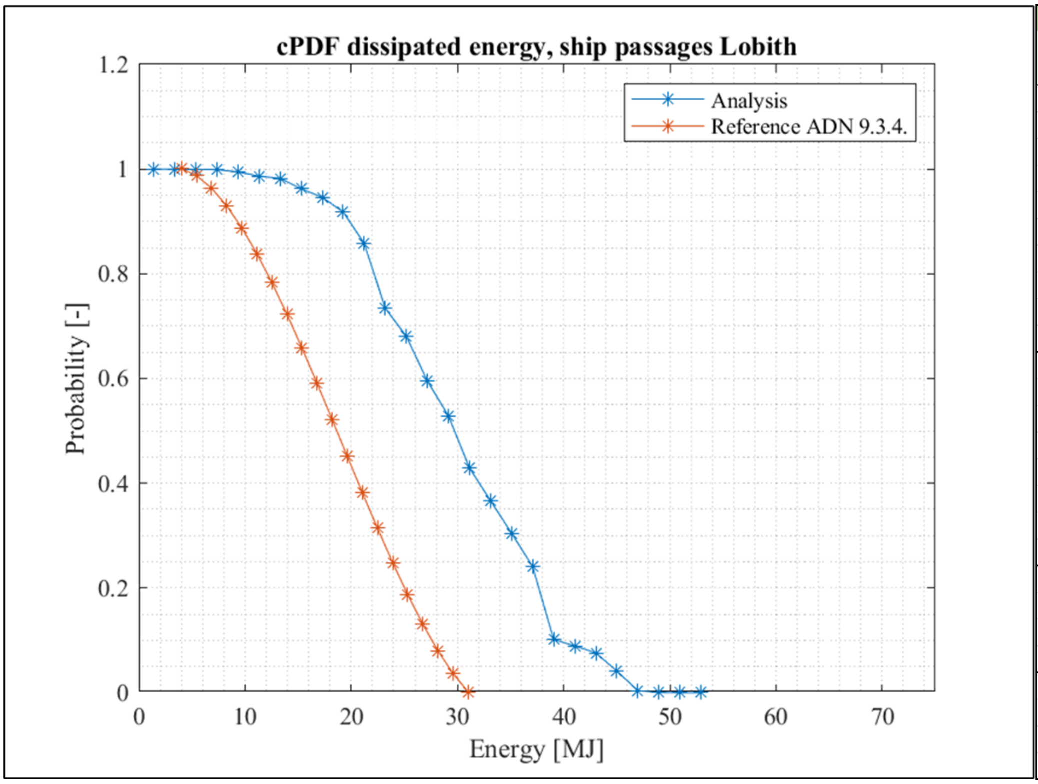


Figure 5 Cumulative probability density and probability density of collision energy river Rhine (1999 and 2017)

This data representation is convenient if one wished to determine the probability of collision energy exceeding a given value, given a collision takes place. For example the probability of exceeding 25 MJ is 0.5 in case of 1999 and 0.75 in case of 2017. The results from this task justified work on topic 2.

Topic 2.

The number of ship passages per effective mass range in conjunction with typical ship velocities, again per effective mass range, have been worked into probability density functions (PDF) for the collision energies available at the river Rhine. These in turn were used to calculated cumulative probability density functions (CPDF). According equation (1) the collision energy available to cause damage to a struck ship also depends on the mass of the struck ship. Hence the CPDF for collision energy depends on the mass of the struck ship as well. Figure 6 shows an example of such a curve (including tabulated figures) for a struck ship with an effective mass of 8000 tonnes. For comparison purposes the curve used in de current ADN 9.3.4 regulations is shown as well.



8000 tonnes	
E coll [MJ]	CPDF [ ]
3.39	1.000
5.37	0.999
7.35	0.999
9.34	0.995
11.32	0.986
13.30	0.982
15.28	0.962
17.26	0.946
19.25	0.918
21.23	0.858
23.21	0.734
25.19	0.680
27.17	0.595
29.16	0.529
31.14	0.429
33.12	0.367
35.10	0.305
37.09	0.241
39.07	0.102
41.05	0.089
43.03	0.076
45.01	0.041
47.00	0.004
48.98	0.001
50.96	0.000
52.94	0.000

Figure 6 CPDF collision energy, struck vessel 8000 Tonne, 2018 statistics vs 1999 statistics

As expected the available collision energy has clearly increased since 1999. When an owner wants to build a tanker with cargo tanks exceeding the default maximum size according ADN of 380 m^3, he needs to decrease the probability of tank rupture in case of a collision. Should he want to use tanks of say 760 m^3, i.e. 2 times 380, the probability of tank rupture must be reduced by a factor 2 compared to a ship designed in compliance with the prescriptive regulations for scantlings according ADN (the minimum scantlings design or reference design).

For example suppose the reference design can absorb 22 MJ up to tank rupture. According 1999 data the probability of tank rupture, given a collision, is approx. 0.32.

The new design would require a probability reduction down to 0.16. According the 1999 curve an energy absorbing capacity of 26 MJ would be required to attain this probability reduction. The same exercise based on the 2017 curve yields; (i) rupture probability reference design 0.8, (ii) required probability reduction down to 0.4, i.e. (iii) a required energy absorbing capacity of 32 MJ.

Discussion, conclusion and way forward

Discussion and conclusion

As expected the collision energy available on the river Rhine to inflict damage given a collision takes place has increased significantly since 1999. The consequence in terms of required additional crashworthiness to keep complying with the intention of ADN regulation 9.3.4. is significant. For a single example, an 8000 tonnes tanker (effective mass, i.e. 1.4 displacement), the required increase of crashworthiness is 6 MJ. The current regulations requires for this example an increase from 22 MJ to 26 MJ, i.e. 4 MJ, whereas with the updated CPDF data the required increase would be from 22 MJ to 32 MJ, i.e. 10 MJ.

It is noted that the CPDF based on updated (2017) data shows a remarkable knuckle (in the 8000 tonne example at 39 MJ). This is caused by the presence of ships in the 10000 - 15000 tonne effective mass range. This cannot be described conveniently with a simple formula, as is currently used in ADN 9.3.4. Therefore it is proposed to express these curves in the updated ADN 9.3.4 text through tabled values instead of a formula. Intermediate values can be determined through linear interpolation.

Way forward

Besides collision energy statistics, the ADN 9.3.4 revision project is considering two other main topics;

a) Crash analysis for determining energy absorbing capacity,
b) Effect of increasing tanks size beyond current ADN maximum of 1000 m^3.

Ad. a)

The work on this topic is in progress. The table below summarises the current status.

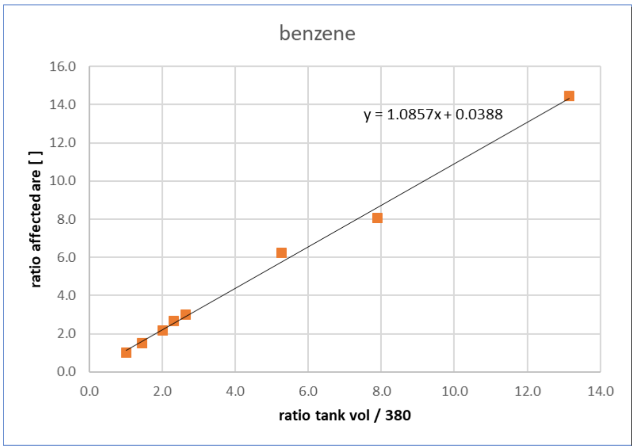
Table 2 Crash analysis status summary

		aspect investigated	
Item #	Priority	***title***	***further description***
1	1	**analyse (gas) tank rupture separately from ship structure**	We now see the shipstructure puncturing the gas tank. With element sizes ranging between 100 and 200 mm we won't describe actual plate folding deformations realistically. Angles between two adjacent elements can easiliy be 90 degrees or more. This causes unrealistic hard spots which unrealistic puncturing capability. Should we calculate deformation of the ship structure plus tank in terms of penetration first and then determined in another way at which penetration the tank will fracture? Proposal: (i) Max. penetration until tank fracture by (a) collision analysis without hull failure criterion (Mesh refinement iwo bow contact area) and (b) collision analysis without hull structure, (ii) Energy absorption until max. penetration (i) by analysis with hull failure criterion (Uniform mesh size)
2	6	element size (25, 50, 100, 200)	see item 12
3	2	**friction (0, 0.1, 0.3)**	This aspect has not attracted much attention in literature. We just assume an 'appropriate' value. From material tests where we push a die into a specimen we know friction is very important, but it is uncertain what is conservative for structures. Proposal: Investigate effect of friction coefficients on penetration depth where tank rupture occurs and crash energy absorbed by structure seperately as described under item 1.
4	8	inertia striking ship included vs rigid imposed penetration	Won't be investigated.
5	8	inertia struck and striking ship included	Won't be investigated.
6	8	inertia struck ship included vs rigid model boundaries	Especially in oblique collision cases the global mechanics will allow the struck ship to move. Won't be investigated.
7	7	manufacturing tolerances, e.g. misalignment, plating slightly curved btwn stiffeners, stiffeners slightly tilted	Won't be investigated.
8	2	**stress-straincurve description, bi-linear, multi-linear**	Demonstrate effect, which will show that multi-linear is required.
9	2	**striking angle**	Small variation (1 deg), sensitivity. Hopefully approach described under item 1 will reduce this sensitivity.
10	2	**striking location, long., vert.**	Small variation (centimeters), sensitivity. Hopefully approach described under item 1 will reduce this sensitivity.
11	2	Struck ship also has velocity	Addressed in scenario selection and statistics.
12	3	**tank pressure, gas tankers only**	Sensitivity to 0, 8, 16 barg. Hopefully approach described under item 1 will reduce this sensitivity.
13	3	**failure criterium (ADN/GL, FLFC)**	Stress state dependency, element size, element size related to ship deformations (converged mesh?)
14	3	**liquid-full tanks**	Tank deformations exceeding liquid full, pressure-volume relation. Check if this occurs in most analyses. If so propose calculation routine to cater for this.

In-kind participants will be requested to contribute in the work described.

Ad. b)

The work on this topic is also in progress. The figure shows a typical result for benzene.



tank volume [m3]	aff. area ratio	tank vol. ratio
380	1.0	1.0
550	1.5	1.4
760	2.2	2.0
880	2.7	2.3
1000	3.0	2.6
2000	6.2	5.3
3000	8.1	7.9
5000	14.5	13.2

Figure 7 Affected area ratios tanks sizes 380 m^3 to 5000 m^3 (380 m^3 tank is 1)

As can be seen in this example the affected area increases approximately proportional to the tank size increase, with a gradient of 1. This suggest that, at least for the benzene case, also beyond 1000 m^3, increasing the tank size by a factor of two increase the affected area also by a factor of 2.

In principle one can therefore maintain the current ADN 9.3.4 reasoning, i.e. risk does not increase by increasing thank size when probability of tank rupture decreases by the same ratio as the tank volume increase. However from a safety point of view one must also observe the number of persons exposed to the hazard. Especially in case the affected area exceeds beyond the river banks. In such cases the required probability reduction may be larger.

Other hazardous cargos and the issue of the affected area exceeding beyond the riverbanks are currently being investigated.