

Revision ADN 9.3.4. Summary and Recommendations

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Revision ADN 9.3.4. Summary and Recommendations

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1 Introduction

Design and operation of inland waterway ships carrying dangerous goods are with regard to safety regulated in the European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN). ADN features a section 9.3.4 called Alternative Constructions. This section describes how cargo tanks exceeding the default ADN maximum size of 380 m³ can still be permitted through providing for additional protection against collisions.

Section 9.3.4 was written in 2005 and based on knowledge and know-how available at that time. At some points this knowledge and know-how have become outdated. Therefore an investigation was carried out by TNO together with industrial parties aimed at revising and updating the text of section 9.3.4 in accordance with the current state of the art.

Section 9.3.4 also states a maximum allowable tank size of 1000 m³. At the initiation of the revision/update the question was raised whether this value could be increased. The main reason for this is the introduction of alternative fuels in inland waterway shipping, e.g. LNG and hydrogen, requiring dedicated tankers for transporting these fuels which would benefit from tanks exceeding the 1000 m³ limit. Therefore the investigation also included work on the associated risk implications of exceeding this 1000 m³ limit.

1.1 Issues addressed

There are three categories of issues which have been addressed in this investigation:

1. Collision energy currently available on the river to inflict damage to other ships.
2. Guidelines on how to conduct collision crash calculations.
3. The upper limit of tank size at 1000 m³.

The shipping statistics used for the collision energy cumulative probability density functions used in the current text of section 9.3.4 are from 1999. The functions are now updated based on 2018 shipping statistics.

Over the past two decades much experience has been gained in conducting crash calculations on ship structures. This includes experience with two different explicit finite element packages, which are used for such calculations. This experience is used to formulate an update of the guidelines for crash calculations.

The feasibility of increasing the maximum tank size beyond the current 1000 m³ limit has been investigated through loss of containment effect analyses for tank sizes up to 5000 m³.

These three issues are reported in separate background documents. The summary is provided in this report per issue. The recommendations resulting from the investigations are given Chapter 5.

1.2 References

This work refers to five external documents, while the results are reported in three TNO documents.

1.2.1 External documents

- [1] ADN, European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways as from 1 January 2021, ECE/TRANS/301 (Vol. I & II), <https://unece.org/adn-2019-files>
- [2] Driving Dynamics of Inland Vessels, 2016 Bundesanstalt für Wasserbau (BAW), Karlsruhe, Germany
- [3] EFFECTS version 11.5.1.21121, A computer program to calculate the physical effects and consequences of the escape of hazardous chemicals, Gexcon, 2021
- [4] <https://www.scenarioboekje.nl/> (accessed 2021)
- [5] <https://www.infomil.nl/onderwerpen/veiligheid/basisnet/> (accessed 2021)

1.2.2 TNO reports

- [6] TNO 2022 R12238, Background document: Updated ADN 9.3.4 collision energy statistics
- [7] TNO 2022 R11532, ADN 9.3.4 FE Sensitivity Analysis
- [8] TNO 2022 R10765, Revision ADN 9.3.4 - WP Consequence Analysis

1.2.3 Acknowledgements

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Rensen Driessen
Somtrans
TNO
Victrol

2 Issue 1: Collision energy

In the current ADN section 9.3.4 (ref [1]), the probabilities of a collision exceeding a chosen collision energy level are based on 1999 shipping statistics. Since then the population of ships has increased significantly. Moreover there has been a shift towards ships with larger displacements, due to the introduction of 100 m and 135 m ships. As a consequence, energy available on the river to inflict collision damage has increased. Therefore the cumulative probability density functions for collision energies have to be updated. A full report can be found in [6].

2.1 Approach

The collision energy that a struck ship will absorb in a collision depends on the mass and velocity of the striking ship, its own mass and the collision velocity. It is reasonable to assume a fully inelastic collision and for the struck ship an initially zero lateral velocity. Under these assumptions the absorbed energy equals:

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

With :

E_{diss}	collision energy absorbed by the structure [kJ]
m_a	effective mass of striking ship [tonnes]
m_b	effective mass of struck ship [tonnes]
v_a	velocity of striking ship [m/s]

The displacement of the striking ship is multiplied by 1.1 to obtain the effective mass, i.e. including added mass longitudinal direction. The displacement of the struck ship is multiplied by 1.4 in order to include added mass in lateral direction. In order to determine a probability distribution of collision energies both ship masses and collision velocity must be known.

2.2 Main findings collision energy statistics

2.2.1 Ship masses

Figure 2.1 shows the number of ship passages per effective mass class observed in 2017. The largest effective mass of a single unit observed is 15,500 tonnes (including added mass). Effective mass ranges were chosen in bins of 500 tonnes for a finer distribution of ship masses. The range is extended to the largest registered mass on the river.

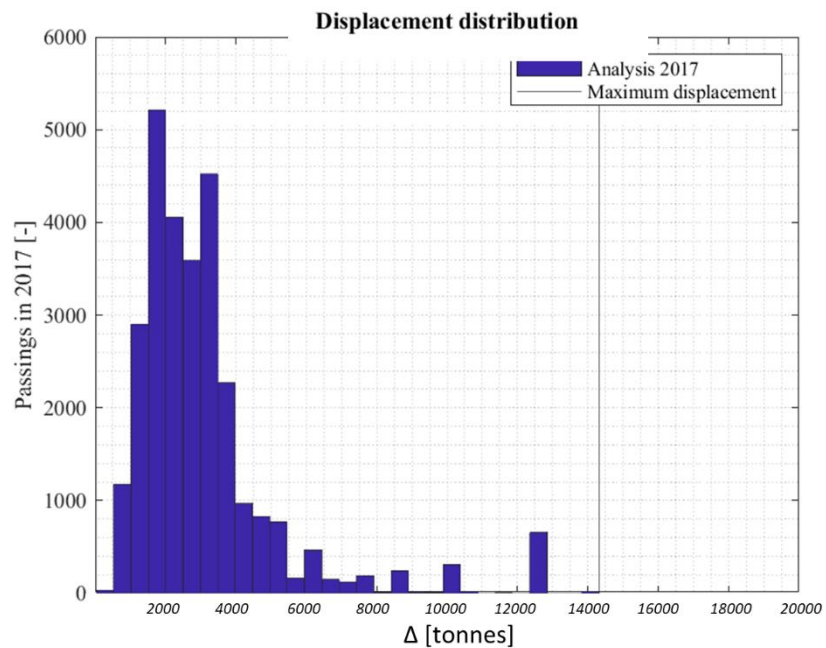


Figure 2.1 Ship passages per effective mass classes, 2017

Most passages are in the effective mass range between 1000 and 5000 tonnes. Additionally, there were slightly under 700 passages in the 12,000 – 14,000 tonnes effective mass range, to be attributed to push barge convoys carrying iron ore and coal.

2.2.2 Collision velocities

Collision velocities in regulation 9.3.4. are based on maximum sailing velocities. For each ship type these are taken from data published by Bundesanstalt für Wasserbau (BAW, ref [2]). It is noted that the ships sailing independently can sail at speeds as high as 18 km/hr. Push convoys tend to sail at 14 km/hr.

2.2.3 Energy distribution

The collision energies for given ship masses and ship velocities can be determined by eq. (1). Figure 2.2 and Figure 2.3 show the results. In this case, an infinite effective mass of the struck ship was assumed (viz. moored alongside a quay). This implies all energy would need to be absorbed by the struck ship in case of a collision. There is no energy in the sway motion of the struck ship. The figures are intended to show the difference between 1999 and 2017. Two histograms are shown. Figure 2.2 depicts the probability density function of kinetic energies available on the river in terms of single ships. Figure 2.3 shows the associated cumulative probability density functions (CPDF) derived for 1999 and 2017 data. 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. Figure 2.2 and Figure 2.3 show that there is a clear need to update ADN regarding collision energy statistics.

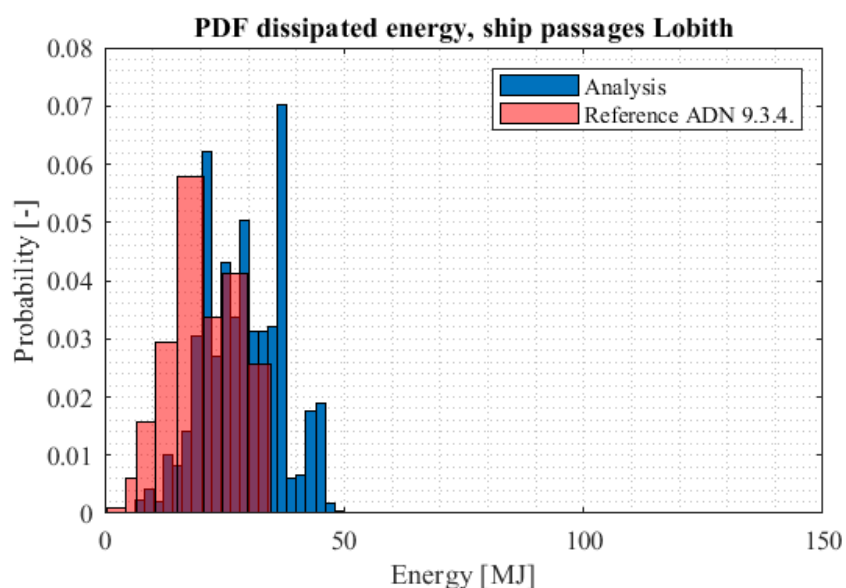


Figure 2.2 Probability density of collision energy river Rhine (1999 and 2017)

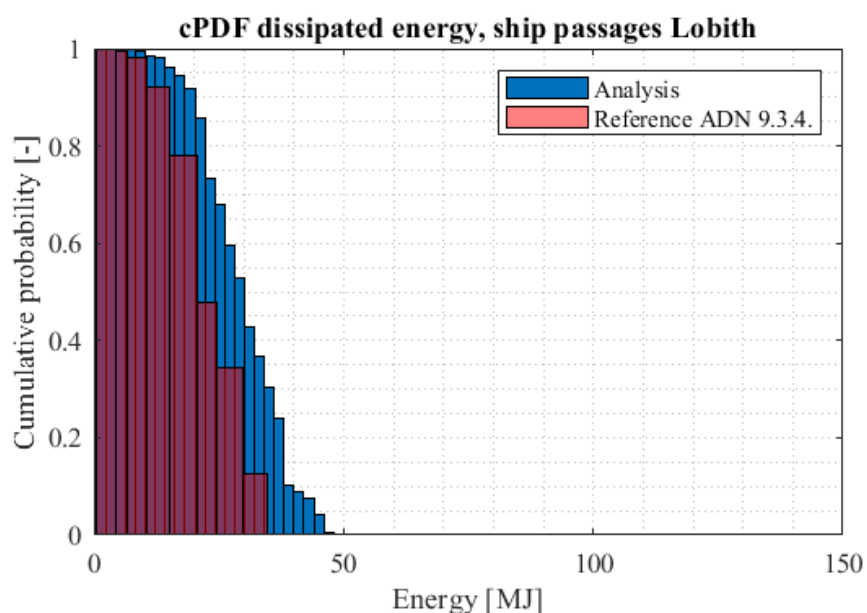


Figure 2.3 Cumulative probability density of collision energy river Rhine (1999 and 2017)

According to 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. Therefore, in order to illustrate the consequences for an actual collision case where the struck ship is allowed to sway, a mass has to be assumed for the struck ship.

Figure 2.4 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 regulation is shown as well.

As expected the available collision energy to inflict damage has increased significantly since 1999.

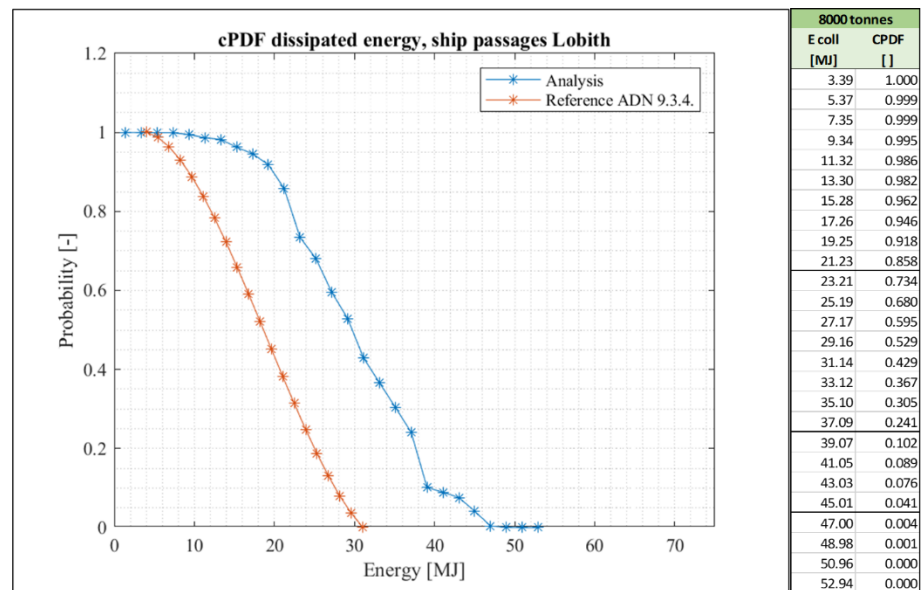


Figure 2.4 CPDF collision energy, struck vessel 8000 Tonne, 2018 statistics vs 1999 statistics

2.3 Discussion collision energies

The consequence of the updated collision energy CPDF is shown in Figure 2.5. As a typical example, the consequence of a ship with 760 m³ tanks is taken. In this case the tank size is double the allowable maximum volume stipulated in ADN.

According to ADN 9.3.4., doubling the tank size requires a ship with a crashworthiness which will reduce the probability tank rupture by half compared to a ship designed in compliance with the prescriptive regulations for scantlings according ADN (the minimum scantlings design or reference design).

Suppose the reference design is able to absorb 20 MJ prior to tank rupture. Based on the 1999 data the probability of tank rupture, given a collision, is approx. 0.43. The new design would therefore require a probability reduction down to $0.43/2 = 0.215$. Based on the 1999 curve an energy absorbing capacity of 24.5 MJ would be required to attain this probability reduction.

The same exercise based on the 2017 curve yields a rupture probability for the reference design of 0.88. So now the probability must be reduced to $0.88/2 = 0.44$ for the new design. The CPDF curve shows that this requires an energy absorbing capacity of at least 31 MJ.

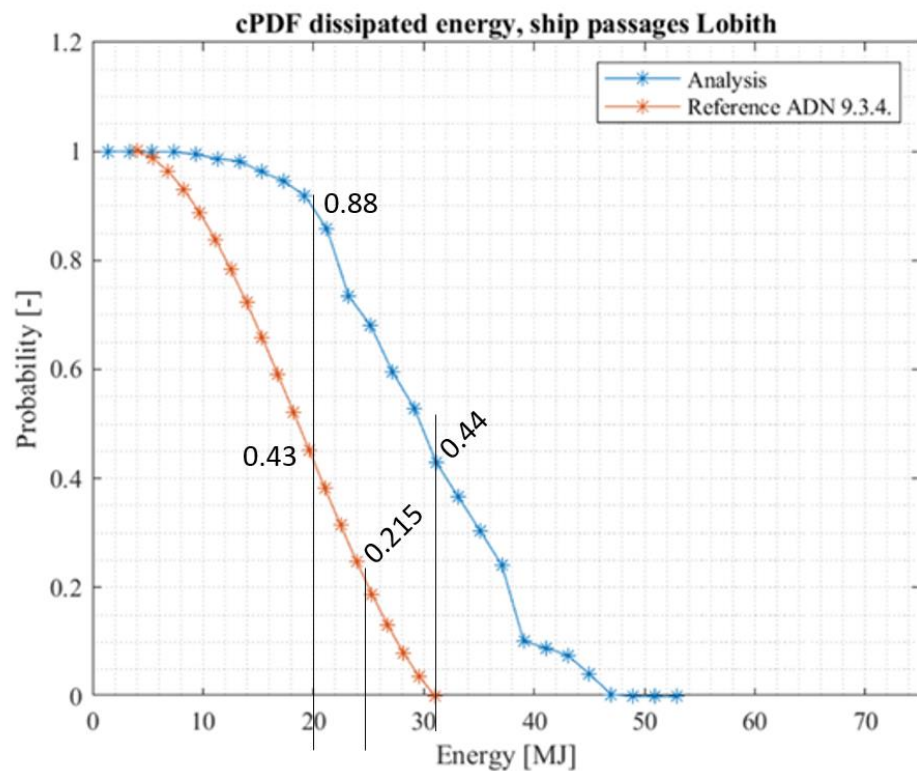


Figure 2.5 Consequence of updated energy statistics

2.4 Recommendations

From the updated energy statistics, the following recommendations arise:

- Update the cumulative probability density curves as indicated in this section.
- List the values of the cumulative probability density curves in tables instead of formulas.
- Give tabled values for effective ship mass classes from 1500 to 14,000 tonnes, with 500 tonnes steps up to 4000 tonnes, larger steps between 5000 and 14,000 tonnes.

3 Issue 2: Guidance on crash calculations

Section 9.3.4 from the ADN prescribes how the crash calculations to obtain the energy absorbing capacity of the ship structure need to be carried out. Calculations must be done by explicit finite element methods such as Abaqus and LS-Dyna. For running these analyses many assumptions and choices have to be made for which recommendations are given. The validity of these recommendations has been investigated further in this project.

Experience with crash calculations in the past shows that sometimes structural material trapped between the striking bow and tank causes unconvincing tank ruptures. An effort has been made to find a way of dealing with this issue.

The work done on issue 2 also addresses some errors in the current ADN 9.3.4 text and provides recommendations to remedy some ambiguities.

The following paragraphs give a summary of the results of the investigation. The full report on crash calculations can be found in the TNO report (ref [7]).

3.1 Approach

In order to investigate the sensitivity of the calculated results to the many choices and assumptions that need to be made for doing crash calculations, a systematic study has been carried out. For this purpose an inland waterway gas tanker was selected on which crash calculations were done. More than 35 simulations have been carried out in a combined effort by four different parties; Annmar Engineering, Damen Naval Engineering, Femto Engineering and TNO. The sensitivity study includes the following topics:

1. Friction.
2. Plasticity model.
3. Striking angle.
4. Striking location.
5. Tank pressure.
6. Failure criterion.
7. Mesh size.
8. Separate analysis of energy absorbing capacity and tank rupture.
9. The effect of the choice of software.

The ‘trapped structural material’ issue which manifests itself in case of topic 4, has been investigated by considering rupture of the tank and crashing of the ship structure separately. The idea is that this will yield more consistent results.

3.2 Main findings crash calculations

As an example, topic 4 (Striking location) is reported here. Figure 3.1 shows a typical collision scenario, in this example a V-shaped bow striking a gas tanker. The

picture on the left shows the striking location in height. The picture on the right shows the observed damage at a penetration of 3.0 m. In the latter the striking bow and tank have been blanked. The point of view is looking from the inner side of the tank hold towards the lower half of the shell and the bottom.

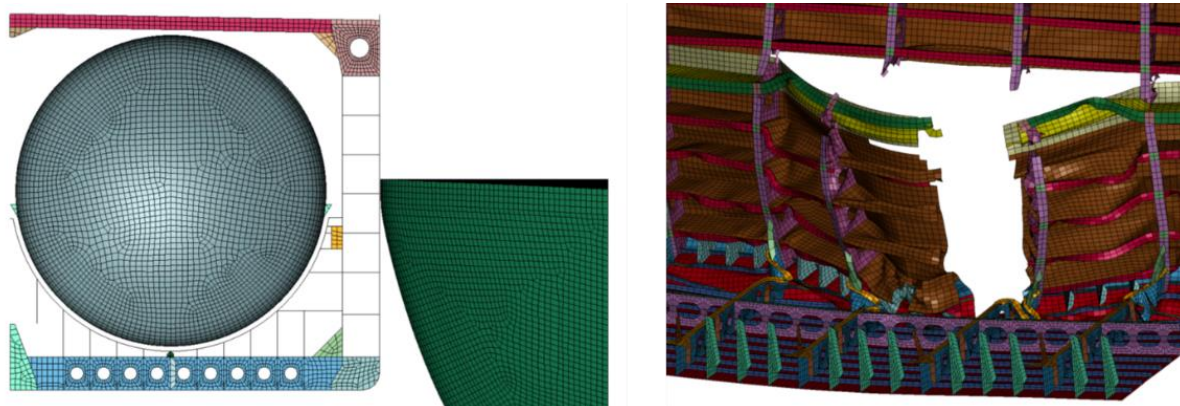


Figure 3.1 Typical collision scenario (left) and calculated damage ship structure, (right)

The calculated energy absorption versus penetration curves are shown in Figure 3.2. Four striking locations have been investigated:

1. Mid span between web frames, at stringer.
2. 50 mm forward of Mid span between web frames, at stringer.
3. Mid span between web frames, half stringer spacing below stringer.
4. 50 mm forward of mid span between web frames, half stringer spacing below stringer.

The drawn (—) vertical line indicates the penetration at which the tank fails in striking case 1, the dashed (----) vertical line refers to striking case 2, the dotted (.....) vertical line to striking case 3 and the dashed dotted line (-.-.-) to case 4. As expected, the energy absorption curve for the collision where striking at a stringer occurs lies above the curve for striking between two stringers. However, this effect is not accounted for in the current ADN regulations and could be both beneficial and detrimental depending on the layout of the ship structure with respect to the tank. The effect of a 50 mm shift of the longitudinal striking location is insignificant with respect to the energy absorption curve.

However, it is remarkable that in case of a collision at the stringer, the penetration at which tank rupture occurs shifts significantly, from 2.1 m to 1.8 m. With this shift the collision energy absorbing capacity changes as well. In case of striking between two stringers, rupture is calculated at a penetration of 1.6 m for both longitudinal positions.

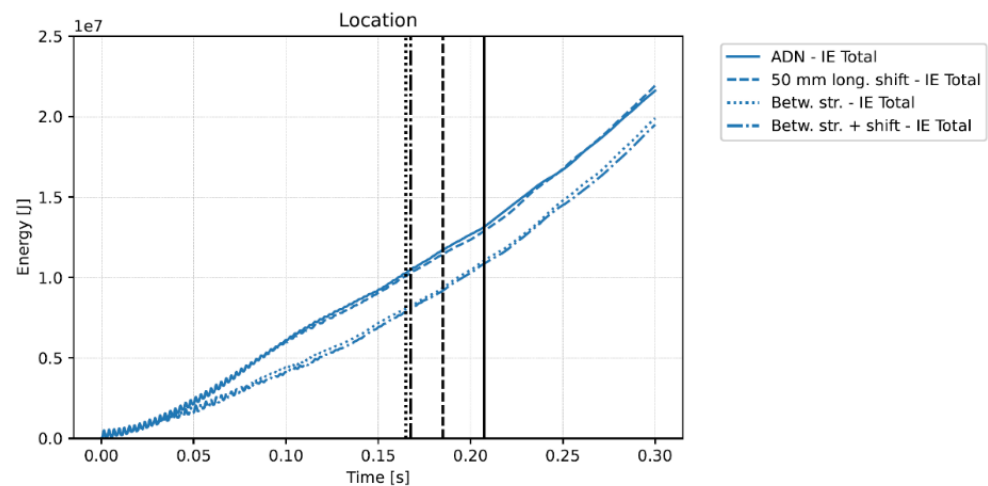


Figure 3.2 Typical collision energies absorbed and tank failure penetrations, two striking heights, effect of small longitudinal shift of striking location

3.3 Discussion

The example given illustrates that the effect of striking location variation may be different from expected. In case of a collision at a stringer, the calculations show a significant effect of a small (50 mm) shift of longitudinal striking location, which is not expected intuitively. This effect also affects the collision energy absorbing capacity and hence the probability of tank rupture for this collision scenario. It is unclear if this effect reflects reality or originates from the way the structural deformation is modelled numerically. This particular finding is considered unsatisfactory.

The other topics considered of the sensitivity study are addressed in the full report (ref [7]).

3.4 Recommendations

Regarding guidance for the crash calculations are the following recommendations:

1. The correct unit for exponential decay coefficient DC in the definition of the friction model in ADN 9.3.4.4.5.1 shall be provided (both 0.01 s/mm or 10 s/m are the correct coefficient with corresponding unit).
2. The plasticity model shall be described by a power law or equivalent representation discretised by at least 100 data points and up to a plastic strain of at least 1.
3. Additional locations of impact for type G tankers shall be included in the crash analysis: (i) the incoming bow first impacts the vessel at the stringer at mid tank height and (ii) the incoming bow first impacts the vessel between two stringers.
4. The maximum element size in the collision area shall be decreased to 100 mm in order to capture the deformed structure better.
5. Two initial tank pressures should be analysed for type G tankers: the minimum operating pressure of the tank and the maximum design pressure of the tank.
6. The failure model and criterion definition in article 9.3.4.4.4.1 shall be made non-ambiguous and the formula in 9.3.4.4.4.2 should be updated to match the currently accepted GL criterion.
7. It shall be clarified that failure in compression is excluded for the vessel structure.
8. As a general FEA requirement, ADN should require at least five through integration points and element deletion when at least half of the integration points have failed.
9. The crashworthiness calculations for the alternative construction should always be compared to crashworthiness calculations of a reference vessel with identical modelling approach, so that a consistent comparison can be made.
10. Element deletion based on damage accumulation shall be used in order to account for damage progression in an element.
11. Investigate a procedure where separate crash calculations are used to determine penetration at which tank rupture occurs and determine the energy absorbing capacity of the ship versus penetration. This may also be of interest for integrated tanks such as a membrane tank.

4 Issue 3: Effect analysis and exceeding 1000m³ limit

Section 9.3.4 also states a maximum allowable tank size of 1000 m³. The question was raised whether this value could be increased because of the introduction of alternative fuels in inland waterway shipping, e.g. LNG and hydrogen, requiring dedicated tankers for transporting these fuels which would benefit from tanks exceeding this limit. The feasibility of increasing the maximum tank size beyond the current 1000 m³ limit has been investigated through loss of containment effect analyses for tank sizes up to 5000 m³.

4.1 Approach

In order to investigate the consequences of increasing the maximum allowable tank size beyond 1000 m³, the effect of loss of containment has been calculated for various cargos. These analyses have been done for tank sizes ranging from 380 m³ to 5000 m³. Effect areas are compared for 1% lethality, based on toxicity, flame area, heat radiation and explosion overpressures. To be able to calculate these effect areas, modelling assumptions have to be made and these are conservative. The most important ones are:

1. Weather conditions: stable atmosphere and low wind speed, which means that the dispersion of gas clouds is slow resulting in higher concentrations. These conditions occur only during night time.
2. A large hole size of 2 m². This means that the outflow of liquids and gases from the tanks is relatively fast.
3. The position of the hole is taken at the bottom of the tank, and on the water level without ship structure. This leads to complete emptying of the tanks (with liquids) and complete outflow from the tank and the ship onto the water surface.
4. No dissolving of liquids in the water onto (or into) which it is spilled. This means that in the calculations, all of the spilled liquid evaporates from the water surface.
5. Clouds of flammable gas are ignited at the moment when their areas are at its largest (cloud fire) or the explosive mass is at its maximum (gas cloud explosions). Earlier or later moments of ignition would result in smaller effect areas.

The calculations were done with the software package EFFECTS (ref [3]) and are reported in full in ref [8].

4.2 Main findings maximum tank size limit

For illustration purposes propane is selected. Results of cloud fire calculations for different tank sizes are shown in Figure 4.1. The contours represent the flame area of the burning cloud if it is ignited at the moment that the cloud has its largest flammable area. It is observed that for all tank sizes the area exceeds the river limits. Notably, for 5000 m³ tanks, the cloud can reach both sides of the river, while

for the tank sizes between 380 and 1000 m³, the majority of the affected area is over water.

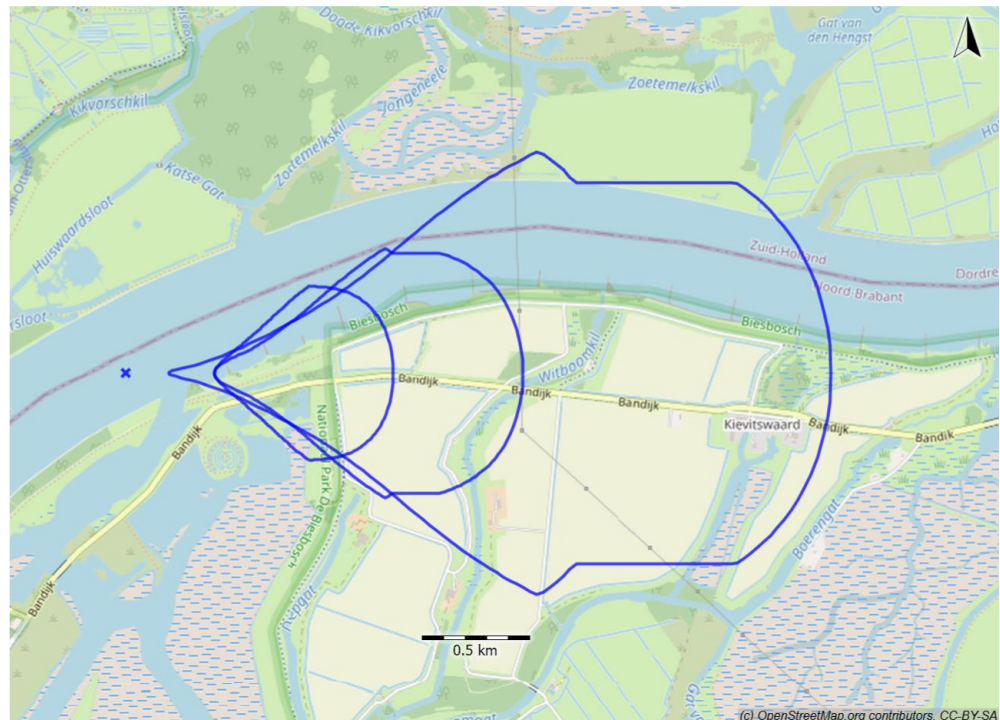


Figure 4.1 Propane – cloud fire contours for tank sizes 380, 1000 and 5000 m³.

Results for all substances are given in Figure 4.2. Effect areas vs. tank size are shown for all substances considered. The critical lethality criterium for each substance is shown in the legend. The largest effect area is the one for the propane cloud fire.

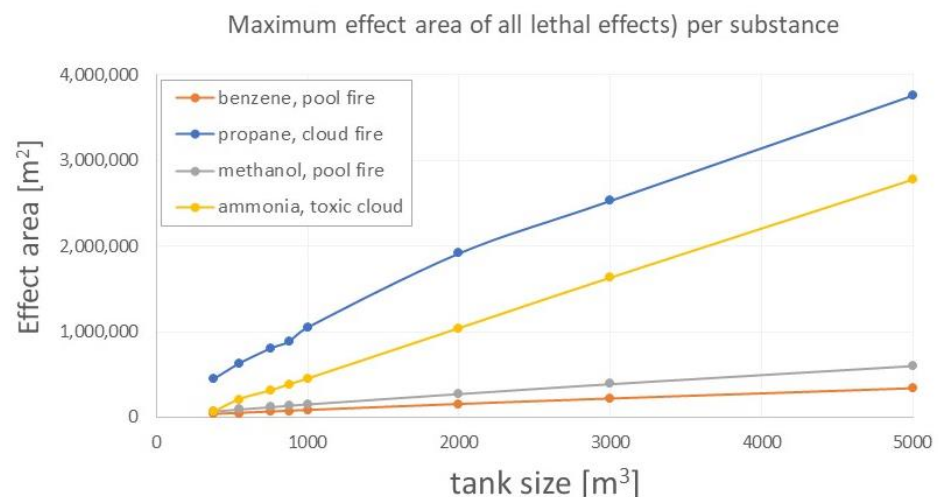


Figure 4.2 Largest effect area for all scenarios vs. tank size.

4.3 Discussion maximum tank size

For tank sizes up to 1000 m³, the rules as currently written in ADN 9.3.4 still hold. Doubling the tank volume results in almost doubling the effect area, and in most cases the affected area is over water.

For tanks larger than 1000 m³, the linear relation between tank volume and effect area remains more or less valid; the effect area sizes are slightly less than proportional to the tank size. The largest effect area occurs for the propane cloud fire and has a size of almost 4 km².

The effect area will reach the riverbanks in most cases and people on land will be affected as well. This is exacerbated by the fact that effect areas are not circular and not always centered around the release point and can cause hazards relatively far downwind from the release. This is especially the case for the toxic cloud of ammonia.

This study has looked at benzene, propane, methanol and ammonia. In the domain of transportation of fuels over inland waterways, there is also an increasing interest in LNG and in hydrogen. Some scenarios concerning accidents with LNG have already been investigated and published on the Scenarioboek EV (ref [4]). Using those scenarios and the assumptions of this study, similar calculations can be done to calculate effect areas for LNG. (Compressed) hydrogen is a very light gas and is therefore hard to model with current models implemented in EFFECTS that are aimed at neutral and dense gases. However, recent developments in EFFECTS' dispersion models will probably make it possible in the near future to model hydrogen accidents as well. Liquified hydrogen would involve also the outflow and evaporation analysis.

It is recommended for future work to incorporate LNG and liquid and compressed hydrogen as cargo.

4.4 Recommendation maximum tank size limit

In this effect study, it has been shown that areas beyond the riverbanks will also be affected when tanks larger than 1000 m³ would be used. Therefore, the risks associated with the use of larger tanks to transport hazardous chemicals is not acceptable without a more thorough risk evaluation that also involves the frequencies (probabilities) of accidents, the possible number of casualties (presence of population in the effect areas) and the specific substance being transported. Complete risk assessments are recommended in case tanks larger than 1000 m³ are proposed, addressing, among other aspects:

- Sailing routes
- Number of ship passages
- Tank size
- Hole sizes and positions with resulting outflow
- Substances to be transported
- Hazardous scenarios and mitigation measures
- Population densities along the waterways

5 Discussion, conclusions

5.1 Risk analysis framework

To be able to regulate the use of larger tanks with alternative fuels as cargo and other chemicals, a full-fledged risk analysis is recommended. Different countries have different frameworks for regulations of risks from transportation of hazardous goods. An example of such a framework is the Basisnet (ref [5]) which is applied in The Netherlands, and uses risk ceiling values for the 10^{-6} per year PR (*Plaatsgebonden Risico*: risk at specified location) value at the shore line. It is recommended that the ADN safety committee discusses what risk assessment framework is most suitable for ADN 9.3.4.

5.2 LNG and Hydrogen

As said in general it is recommended not to increase the general maximum limit of 1000 m³ tanks. However it still may be acceptable to allow increased upper limits in case of specific cargos, especially LNG and hydrogen. In order to decide to develop an opinion on these specific cargos they should be analysed with respect to effect distances in case of a loss of containment in a similar fashion as referred to in this document. The framework of alternative designs as used in IGF may be a good starting point for a specific section in ADN. Such an approach requires the designers to address operational and incident scenarios, cargo characteristics and allowable consequences in a comprehensive manner for the specific ship and tank design.

5.3 Updates/ corrections ADN 9.3.4

Notwithstanding the above discussions, some updates are recommended to include on short notice. These recommendations are detailed in appendix A and include corrections, updates of data and solving ambiguities.

5.4 Alternative calculation method crashworthiness

In case independent tanks are applied, the energy absorbing capacity of ship structure and tank calculated in one model is challenging and may arouse many discussions. It is recommended to investigate a procedure where crash calculations are separated for tank and ship structure. Calculations performed on the tank are used to determine penetration at which tank rupture occurs and the ship structural analysis is used to determine the energy absorbing capacity of the ship versus penetration. This method may be useful for independent tanks, as well as integrated tanks such as membrane tanks.

6 Signature

TNO, May 2023

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Appendix A

Recommendation for updating section 9.3.4

	Section	Proposed text amendment or modification
9.3.4	Alternative constructions	
9.3.4.1	General	
9.3.4.1.1		AMEND However, in case of tanks intended for only one substance, of which it can be demonstrated that effect distances remain within a radius of 135 m from the outflow location in case of a loss of containment, larger tank capacities may be acceptable. The effect distance calculation method and assumptions made for the calculations are to be agreed upon with the recognised classification society.
9.3.4.2	Approach	
9.3.4.3	Calculation procedure	
9.3.4.3.1.2.2.2	Tank vessel type G	REPLACE For a tank ... be assumed. WITH For a tank vessel type G, three vertical collision locations shall be assumed; 1) at half tank height, 2) half stringer spacing below half tankheight and 3) half stringer spacing mm above half tankheight.
9.3.4.3.1.2.4.2	Tank vessel type G	REPLACE 1. 3 = 3 WITH 3 x 3 = 9
9.3.4.3.1.3.2.2	Tank vessel type G	REPLACE The weighting factor location is assumed WITH The weighting factor for the each of the three vertical collision locations has the value of 0.333.
9.3.4.3.1.5.1		REPLACE Entire article. WITH For each collision energy absorbing capacity $E_{loc(i)}$, the associated probability of exceedance is to be determined. For this purpose the values for the cumulative probability density functions (CPDF) from the tables in 9.3.4.3.1.5.6 shall be used.
9.3.4.3.1.5.6		REPLACE Existing tables WITH Tables and text given in Appendix B.

	Section	Proposed text amendment or modification
9.3.4.4	Determination absorbing capacity	
9.3.4.4.1.1		AMEND The code shall also be capable of calculating and outputting (plastic) strain energy (energy by material deformation), friction energy and, in case of type G tankers, energy dissipated by tank deformation and fluid compression.
9.3.4.4.2.4		REPLACE 200 mm WITH 100 mm
9.3.4.4.2.5		AMEND Shell elements shall have at least 5 integration points through-thickness.
9.3.4.4.2.6		REPLACE In the FE option. WITH In the finite element calculation a suitable contact algorithm that includes self-contact shall be used. DELETE For this ... FE-programs.
9.3.4.4.2.7		NEW ARTICLE <i>Tank vessel type G</i> For a tank vessel type G, the internal tank pressure shall be modelled by means of a compressible fluid volume. The initial pressure shall be set at max. design pressure of the tank.
9.3.4.4.3.1		REPLACE Ag = theand WITH Rm = ultimate tensile stress [N/m ²] Ag = the uniform strain [-] at Rm AMEND The stress-strain relation shall be described by a power law directly or equivalent representation discretised by at least a 100 data points up to a plastic strain of 1.
9.3.4.4.3.2		AMEND Tensile test results are to be done in accordance with regulations from a recognised classification society.
9.3.4.4.3.3		REPLACE If only ...value: WITH If only the ultimate tensile stress Rm is available, for shipbuilding steel with a yield stress not exceeding 355 [N/mm ²], the following approximation may be used in order to obtain the Ag value for a known ultimate tensile stress Rm with Rm in [N/mm ²]:

	Section	Proposed text amendment or modification
9.3.4.4.4	<i>Rupture criteria</i>	
9.3.4.4.4.1		REPLACE The first ... calculation steps. WITH The rupture of an element in a FEA is defined by the failure strain value. If the calculated strain, i.e. plastic effective strain, principal strain or the strain in the thickness direction, of this element exceeds its defined failure strain value at at least half of the through-thickness integration points, the element shall be deleted from the FE model. The deformation energy in deleted elements shall no longer change in subsequent calculation steps.
9.3.4.4.4.2		AMEND In order to avoid element deletion of elements in compression, rupture shall be ignored for all stress states with a triaxiality below -0.33, i.e. all stress states between equibiaxial compression and uniaxial compression.
9.3.4.4.4.6	Tank vessel type G	REPLACE Equivalent plastic ... ignored. WITH In order to avoid element deletion of elements in compression, rupture shall be ignored for all stress states with a triaxiality below -0.33, i.e. all stress states between equibiaxial compression and uniaxial compression.
9.3.4.4.4.7		NEW ARTICLE <i>Tank vessel type G</i> Other rupture criteria for the pressure tank may be accepted by the recognised classification society if proof from adequate tests is provided.
9.3.4.4.5.1		REPLACE DC = 0.01 WITH DC = 10 [s/m] REPLACE friction velocity WITH friction velocity [m/s].
9.3.4.4.5.2		REPLACE force penetration curves WITH energy-penetration curves
9.3.4.4.5.3.2		REPLACE V_0 = volume WITH V_0 = vapour volume REPLACE V_1 = volume WITH V_1 = vapour volume
9.3.4.4.6.2		REPLACE extremely strong side structure WITH exceptionally stiff side structure

Appendix B

CPDF tables to be used in section 9.3.4.3.1.5

The probability for collision energies between the listed energy values shall be obtained through linear interpolation or by selecting the probability for the next higher energy listed.

The probability for collision energies between the listed effective mass values shall be obtained through linear interpolation or by selecting the probability density function for the next higher effective mass listed.

Table B.1: Cumulative probability density functions for collision energy.

Energy_MJ	Effective mass of struck vessel											
	1500 tonne				2000 tonne				2500 tonne			
	30% v max	50% v max	66% v max	100% v max	30% v max	50% v max	66% v max	100% v max	30% v max	50% v max	66% v max	100% v max
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0.792	0.999	1.000	1.000	0.944	0.999	1.000	1.000	0.962	0.999	1.000	1.000
4	0.000	0.630	0.988	0.999	0.000	0.893	0.993	0.999	0.000	0.948	0.995	1.000
6		0.000	0.712	0.999		0.060	0.928	0.999		0.292	0.957	0.999
8			0.170	0.988		0.000	0.417	0.991		0.000	0.637	0.995
10			0.000	0.972			0.044	0.983			0.253	0.986
12				0.809			0.000	0.946			0.000	0.968
14				0.481				0.805				0.910
16				0.276				0.530				0.795
18				0.042				0.352				0.552
20				0.000				0.205				0.373
22								0.000				0.236
24												0.060
26												0.000

The probability for collision energies between the listed energy values shall be obtained through linear interpolation or by selecting the probability for the next higher energy listed.

The probability for collision energies between the listed effective mass values shall be obtained through linear interpolation or by selecting the probability density function for the next higher effective mass listed.

Energy_MJ	Effective mass of struck vessel											
	3000 tonne				3500 tonne				4000 tonne			
	30% v max	50% v max	66% v max	100% v max	30% v max	50% v max	66% v max	100% v max	30% v max	50% v max	66% v max	100% v max
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0.979	0.999	1.000	1.000	0.981	0.999	1.000	1.000	0.982	0.999	1.000	1.000
4	0.000	0.961	0.996	1.000	0.000	0.969	0.997	1.000	0.000	0.976	0.998	1.000
6		0.447	0.969	0.999		0.574	0.980	0.999		0.652	0.981	0.999
8		0.000	0.812	0.995		0.058	0.851	0.996		0.189	0.887	0.997
10			0.412	0.986		0.000	0.514	0.988		0.000	0.610	0.988
12			0.063	0.979			0.238	0.981			0.316	0.982
14			0.000	0.942			0.000	0.954			0.058	0.958
16				0.850				0.910			0.000	0.920
18				0.683				0.824				0.842
20				0.530				0.643				0.701
22				0.355				0.500				0.590
24				0.249				0.338				0.466
26				0.070				0.240				0.330
28				0.041				0.070				0.232
30				0.000				0.044				0.065
32								0.000				0.044
34												0.000

The probability for collision energies between the listed energy values shall be obtained through linear interpolation or by selecting the probability for the next higher energy listed.

The probability for collision energies between the listed effective mass values shall be obtained through linear interpolation or by selecting the probability density function for the next higher effective mass listed.

Energy_MJ	Effective mass of struck vessel											
	5000 tonne				8000 tonne				10000 tonne			
	30% v max	50% v max	66% v max	100% v max	30% v max	50% v max	66% v max	100% v max	30% v max	50% v max	66% v max	100% v max
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0.983	0.999	1.000	1.000	0.984	0.999	1.000	1.000	0.985	0.999	1.000	1.000
4	0.068	0.981	0.998	1.000	0.325	0.983	0.999	1.000	0.400	0.983	0.999	1.000
6	0.000	0.723	0.982	0.999	0.000	0.859	0.983	0.999	0.000	0.874	0.984	0.999
8		0.317	0.919	0.998		0.532	0.947	0.999		0.589	0.949	0.999
10		0.000	0.703	0.989		0.241	0.853	0.991		0.324	0.861	0.991
12			0.471	0.983		0.041	0.640	0.985		0.081	0.691	0.985
14			0.247	0.964		0.000	0.440	0.980		0.000	0.532	0.981
16			0.044	0.944			0.301	0.958			0.361	0.959
18			0.000	0.889			0.095	0.926			0.245	0.930
20				0.818			0.043	0.875			0.089	0.897
22				0.683			0.000	0.828			0.040	0.858
24				0.575				0.721			0.000	0.738
26				0.489				0.652				0.692
28				0.356				0.576				0.612
30				0.276				0.496				0.563
32				0.212				0.402				0.464
34				0.069				0.329				0.407
36				0.042				0.281				0.346
38				0.000				0.219				0.290
40								0.095				0.245
42								0.080				0.112
44								0.043				0.091
46								0.017				0.077
48								0.000				0.042
50												0.039
52												0.014
54												0.000

The probability for collision energies between the listed energy values shall be obtained through linear interpolation or by selecting the probability for the next higher energy listed.

The probability for collision energies between the listed effective mass values shall be obtained through linear interpolation or by selecting the probability density function for the next higher effective mass listed.

Energy_MJ	Effective mass of struck vessel							
	12000 tonne				14000 tonne			
	30% v max	50% v max	66% v max	100% v max	30% v max	50% v max	66% v max	100% v max
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0.985	0.999	1.000	1.000	0.986	0.999	1.000	1.000
4	0.436	0.983	0.999	1.000	0.458	0.983	0.999	1.000
6	0.035	0.876	0.984	0.999	0.037	0.880	0.984	0.999
8	0.000	0.611	0.956	0.999	0.000	0.650	0.956	0.999
10		0.363	0.874	0.993		0.393	0.875	0.993
12		0.107	0.706	0.986		0.134	0.726	0.986
14		0.039	0.571	0.981		0.042	0.592	0.981
16		0.000	0.409	0.962		0.034	0.440	0.963
18			0.291	0.947		0.000	0.330	0.948
20			0.109	0.921			0.138	0.923
22			0.076	0.865			0.089	0.874
24			0.038	0.821			0.041	0.835
26			0.000	0.711			0.035	0.732
28				0.660			0.000	0.676
30				0.591				0.609
32				0.535				0.553
34				0.444				0.474
36				0.388				0.423
38				0.341				0.376
40				0.291				0.330
42				0.244				0.267
44				0.123				0.242
46				0.103				0.126
48				0.080				0.102
50				0.043				0.079
52				0.040				0.044
54				0.037				0.041
56				0.035				0.039
58				0.000				0.036
60								0.034
62								0.000

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