INF. 14

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Schienenverkehrsforschung beim

Eisenbahn-Bundesamt

Opinion of the German Center for Rail Traffic Research (DZSF) on the risk assessment of the extra-large tank-containers of BASF

12th session of the RID Committee of Experts' standing working group, 26 November 2020

Introduction

The analysis, and the resulting opinion, are based, among other things, on the documents of the BASF risk assessment (INF.4) and the report supporting the risk assessment by TU Berlin.

Document INF.4 comprises the significance assessment; the risk assessment of TU Berlin comprises a detailed description of the identified hazards and the documentation of the performed experiments.

DZSF has carried out an independent analysis of the underlying investigations. The results, suggestions and conclusions of this analysis are briefly summarized in the following.

Introduction

BASF Class Tank Container (B-TC)

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45‘ (L4BH) 63.000 Liter, 66 t Payload

52‘ (L4BH) 73.500 Liter, 66 t Payload

45‘ (L4BH) 53.500 Liter, 66 t Payload

45‘ (L4DH) 62.500 Liter, 66 t Payload

Specification	L4BH	L4BH	L4BH	L4DH	L10BH	L10DH
	standard			specialized		
Length [ft]	45	45	52	45	45	45
Volume [l]	63.000	53.500	73.000	62.000	63.000	62.000
Heating	X	X	X	-	X	X
Insulation	X	X	X	-	X	X
Lining	-	-	-	X	-	-

Comparison of the new equipment vs. conventional & intermodal equipment

WP 1 - Risk analysis
Comments

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The BASF investigation is focused solely on the technical changes. Within the framework of the hazard identification, not all recognized interfaces are investigated in detail (e.g. maintenance, SMS).

From the point of view of DZSF, B-TCs in conjunction with iCTWs – due to possible consequences of failures, the complexity as well as the degree of novelty – definitely represent a safety-critical and significant change.

The examination of the new system meets, in principle, the requirements of CSM-RA. However, there is no information on

- sources, experts and experiences on which the hazard identification is based,
- hazards in the field of tunnel runs, accident scenarios or environmental influences.

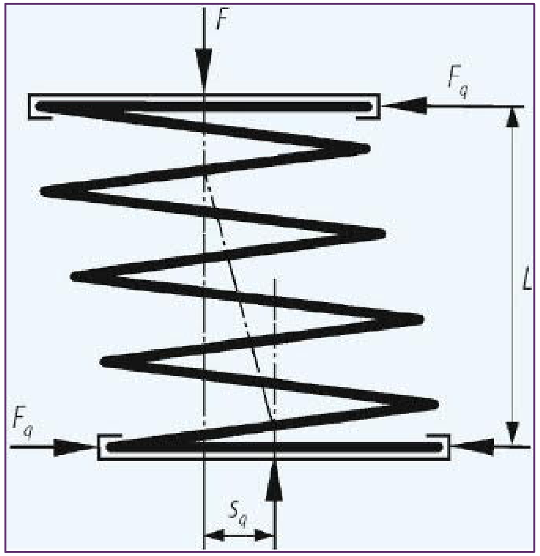
WP 2 - Investigation of sloshing movements

Overview

- Objective: Investigation of running safety taking sloshing movements into account
- Use of the simplified test procedure in accordance with DIN EN 14363
- to that end: determination of the lateral spring force F_q
- by calculating
  - the primary spring force F based on sensor readings of the deformation of the primary springs
  - the lateral movement s_q based on spring length s_q and geometrical relations
- Parameter for assessing running safety:

  Ratio of F_q to limit value of the simplified test procedure with H-force in accordance with DIN EN 14363

$$F_q = \frac{s_q}{\frac{1}{F}\left(\frac{2}{\chi}\tan\left(\frac{\chi * L}{2}\right) - L\right) + \frac{L}{S}}$$



Source: BASF RA, WP2, p. 89, Fig. 18

WP 2 - Investigation of sloshing movements

Scope of the standard

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The standard-compliant application of the simplified procedure is unclear, as

- in accordance with DIN EN 14363:2019-11, section 7.2.2, this procedure is only applicable to vehicles with conventional technology

  The authors themselves describe their systems as non-conventional.

- the procedure is only applicable up to a maximum nominal static wheelset contact force of 200 kN

  However, at a maximum permissible mass of 90 tonnes, the wheelset contact force is 220.725 kN, assuming an equal distribution of the wheelset load.

WP 2 - Investigation of sloshing movements
Method

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The reliability of the derived values is at least questionable due to several experimental and methodical anomalies, e.g.

- removal of an elastomer component and generalized correction of the lateral movement (here by 43 %)
- note that a displacement sensor showed values 80 % below the actual values and that a corresponding correction factor was applied.

  No description at all of a data basis for these estimations and no statement regarding statistical uncertainties

Source: BASF RA, WP2, p. 96, Fig. 23

- Further anomalies regarding force measurements (e.g. concerning the consideration of differences in spring stiffness)

WP 2 - Investigation of sloshing movements

Measurement uncertainty

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Insufficient consideration of numerical fault propagations of measurement uncertainties as well as statistical uncertainties in the calculation of forces

Source: BASF RA, WP2, p. 103, Fig. 32

WP 2 - Investigation of sloshing movements

Measurement uncertainty

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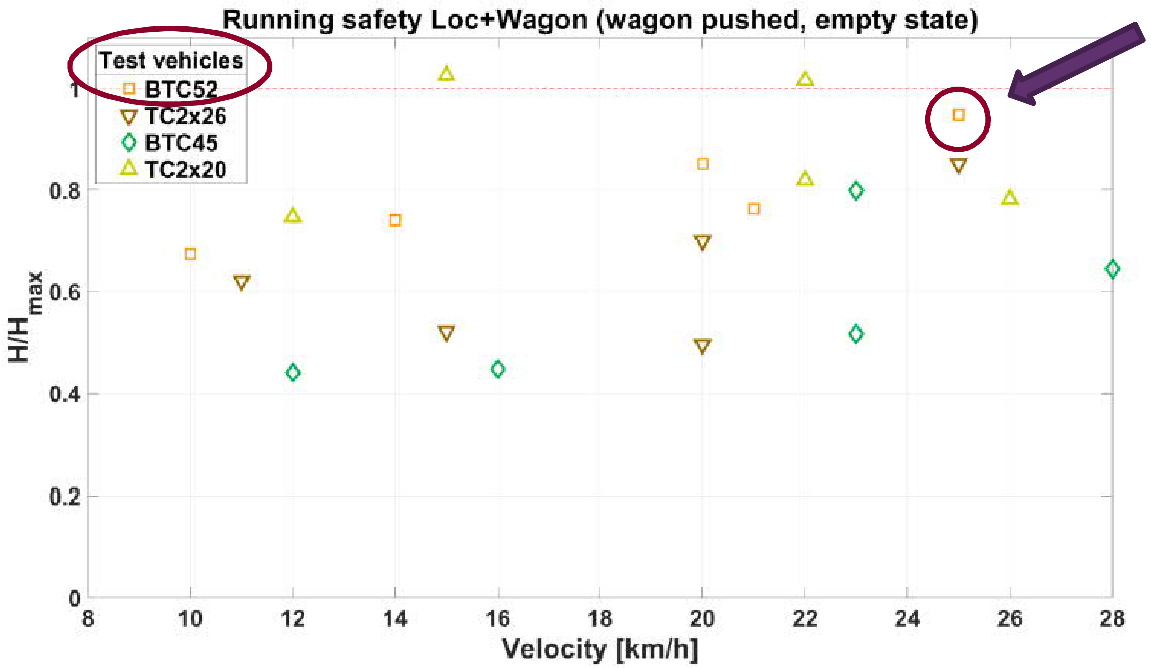
Insufficient consideration of numerical fault propagations of measurement uncertainties as well as statistical uncertainties in the calculation of forces



Source: BASF RA, WP2, p. 103, Fig. 32

maximum ratio concerning critical value: 0.93

- no consideration of the error tolerances of the measuring equipment
- no consideration of the empirical variance across several measurements
- unclear derivation of the displayed measuring points from experimental time series

WP 2 - Investigation of sloshing movements

Measurement uncertainty

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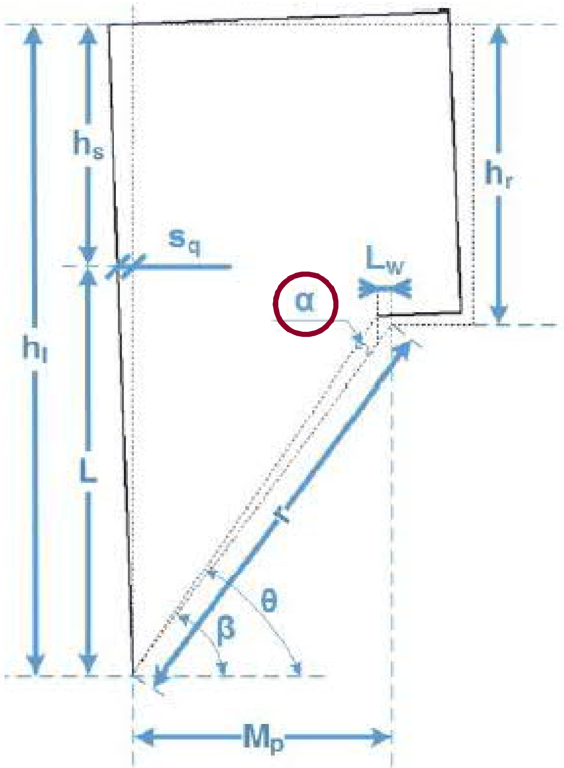


Source: BASF RA, WP2, p. 89, Fig. 19

Example: Measurement uncertainty regarding angle of inclination α

- lateral spring movement $s_q = L \tan \alpha$
- calculation of α not comprehensible due to lack of original data

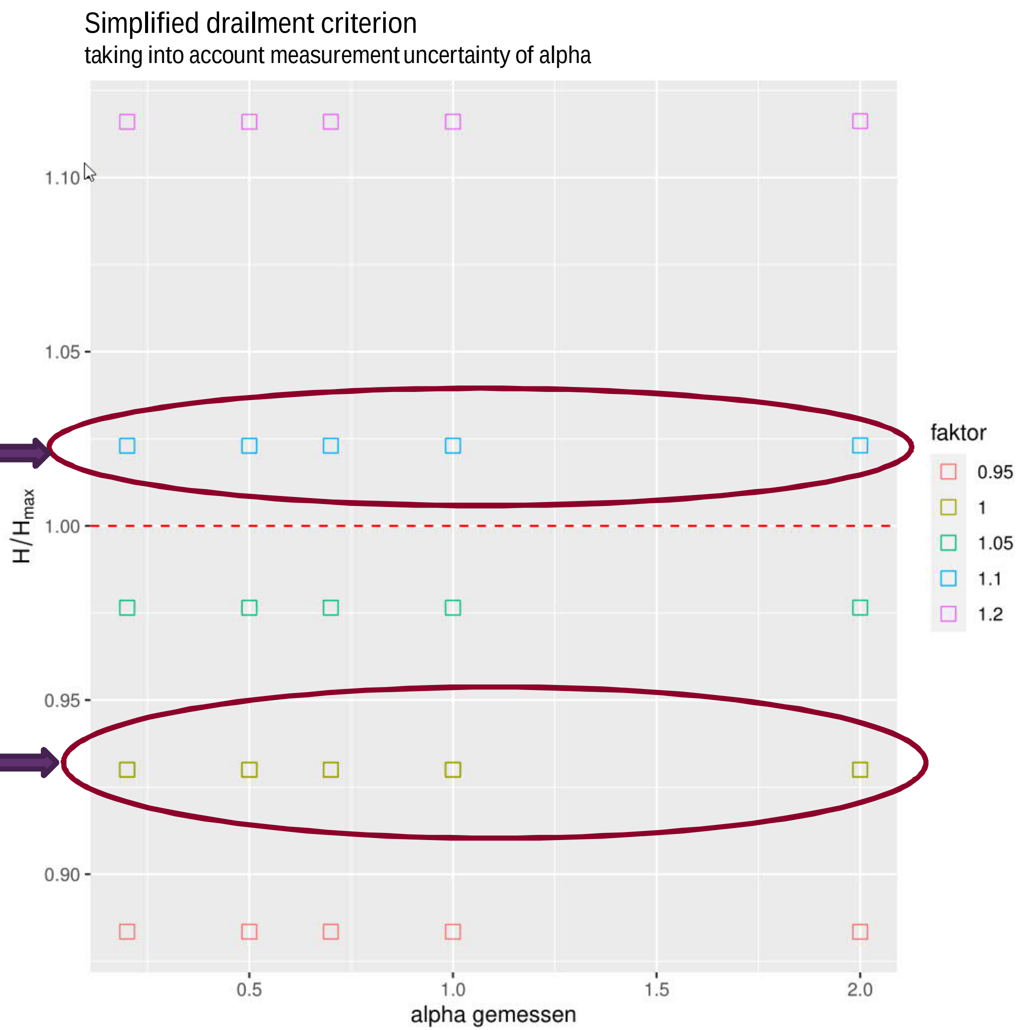
- own analysis: running safety criterion dependent on uncertainties regarding α

WP 2 - Investigation of sloshing movements

Measurement uncertainty

if actual angle of inclination 10% greater

if angle of inclination exactly as plotted



WP 3 - MBS for sloshing movements

Overview

- Objective: Investigation of the effects of sloshing movements on
  - loss of cargo (loss of the container)
  - damage to vehicles and containers
  - safety against derailment
- to that end: creation of multibody simulation (MBS) models for various configurations of carrier wagons, conventional tank-containers, B-TCs as well as tank-wagons
- Simulations of runs of these vehicles on different track layouts

WP 3 – MBS for sloshing movements
Model validation

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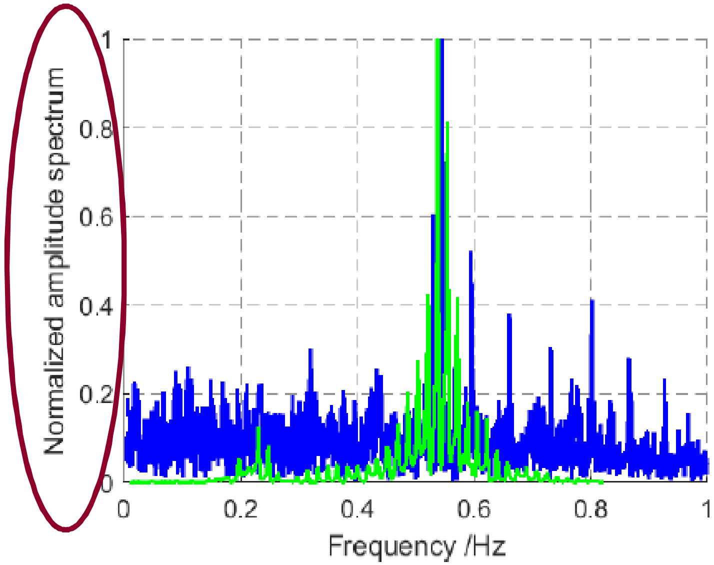
It is stated that the model, for both longitudinal and lateral movements, maps the natural frequencies measured in WP 2, but

- no discussion of whether also amplitude and phase position of the sloshing movement are reproduced (no illustration, just normalized amplitude spectrum after Fourier transformation).



Source: BASF RA, WP3, p. 278, Fig. 17

A validation with non-normalized measurement and simulation data would be desirable, as in particular the force amplitude of the forces caused by the sloshing is of importance.

WP 3 – MBS for sloshing movements

Model representativeness

With regard to basic design and the parameters, the simulations do not model a representative use of the tank-containers, as

- only water is mapped as cargo

In practice, dangerous goods are carried which may deviate regarding density and viscosity. There is no parameter study on the dependence of derailment safety on these properties.

and

- the filling level is not fully investigated (only 0%, 50%, 100%).

A parameter study with granular variations of the filling level would be helpful, in particular given the conclusion that the tank-containers may be operated at any filling level.

WP 3 – MBS for sloshing movements

Lifting of the container

As a questionable result, it is stated that no container lift occurs, with the limit of a permissible vertical movement being set at the height of the spigot.

- This determination is not substantiated by sources.
- questionable: a free flight movement of the container approx. 10 cm above the carrier wagon considered permissible
  - in this case, no longer lateral forces between carrier wagon and container
  - additional accelerations result in an inevitable loss of the container
- helpful: comparison of the contact forces of the container with the maximum guiding forces (comparable to the derailment criterion (Y/Q) or the slip resistance in general mechanical engineering).

WP 4 – FEM Simulations

Overview

- Investigation of the crashworthiness of carrier wagons with B-TCs in comparison with conventional tank-containers or tank-wagons
- Instrument: FEM simulations
- Models are based on the experimental tests of WP 5 and map the side-on impact and overriding of buffers accident scenarios.

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Source: BASF RA, WP4, p. 362

WP 4 – FEM Simulations

Strength criterion

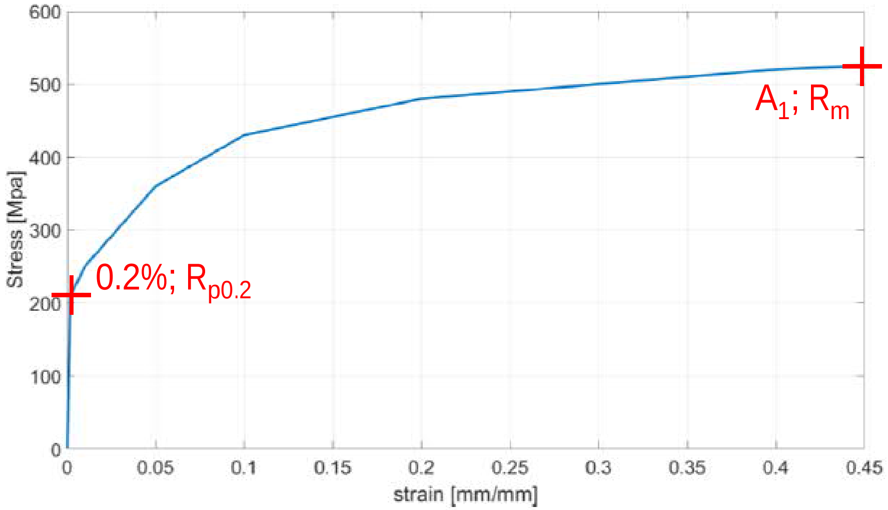

Table 9 Summary of side-on simulations,

		TW-BTC45 VH	TW-BTC45 GM	TW-TW	TW-Conventional
A_1/Maximum Strain	Investigated container	50/41.8	48/44.3	35/55.2	43/12.2
	safety reserve of investigated container	16.4%	7.8%	-57.7%	71.6%
	Stationary car body	20/33.2	20/23.2	20/26.7	20/33.0
	Impacting container	35/7.0	35/23.1	35/35.1	35/4.3
	Impacting car body	20/25.6	20/26.3	20/12.7	20/30.1
Derailment [mm]	In lateral direction	90	530	125	540
	In driving direction	1,740	1,730	880	2,275
		4,560	4,610	5,520	3,950

Here, a minimum safety value considerably higher than 1.2 should be chosen:

- due to the unusual verification method (comparison of strains instead of stresses)
- due to the non-linear stress-strain diagram (safety reserve stress-related ≠ strain-related)
- due to uncertain material properties (statistical survival probability $P_ü$ of A_1)

Reaching the plastic elongation at break A_1 was chosen as the strength criterion.

- Verifications on the basis of stresses are customary (not applicable here due to extensive plastic deformations).
- Minimum safety values of ≥ 1.2 (~20% reserve) are customary.

WP 4 – FEM Simulations

Other modelling boundaries

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- Are the local stresses on the structures mapped in sufficient detail (notch effects, mesh convergence study)?
- The modelling of the welds is not described, even though stresses are particularly great there (notch effects, failure limit?)
- In the investigation of whether stresses resulting from sloshing movements are capable of causing damage, the force of the accelerated tank load onto a surface is considered decisive. This reference surface is unclear.

$$\sigma = \frac{m * a}{A}$$

Table 14 L d status an celeration

	Load status	Mass of fluid [t]	Max. Acceleration/g	Area [mm²]	Stress on bottom [MPa]	Yield strength [MPa]
WP2						
B-TC	50%	31.50	3.00	3,122,465	0.30	290
B-TC	95%	59.80	2.50	6,244,930	0.23	290

– Comparable to medium surface pressure

– However, damage as a result of the accelerated tank loads is not expected to be caused by the surface pressure but by resulting additional loads within the structure, such as bending stresses in the tank shell or stress concentrations at the suspension points (not considered).

WP 4 – FEM Simulations
Collision scenarios

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For the investigated collision scenarios as well as the chosen collision velocities, it was not set forth why these conditions in particular are considered relevant.

- For the side-on scenario, it remains unclear whether the relative position of the wagons to each other really represents the maximum damage to be expected.
- Chosen running velocities are based on WP 5 and allow for direct comparison
- No derivation of the vehicle collision velocities to be withstood

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Source: BASF RA, WP4, p. 388, Fig. 17

WP 5 - Impact tests
Collision velocity

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The impact tests are carried out in accordance with EN 15227, however:

- the scope of the standard only comprises locomotives, passenger and control cars, but not expressly freight wagons,
- the collision velocity indicated in the standard is 36 km/h (vehicle category C-1, head-on collision of identical trains, EN 15227, 5.4.2 a)).

Table 6: The executed tests

Date	Wagon number	Container number	System	Total mass [t]	Impact velocity [km/h]
02/15/2019	33 80 793 2 719-7	-	TW Zacens	87.8	14.6
02/19/2019	33 85 459 4 034-2	BASD 450355-4	BTC45 GM	84.3	15.0
02/22/2019	33 85 450 5 049-8	KUBU 135 383-4 KUBU 135 384-0	Conventional	91.5	15.1
03/01/2019	33 85 459 4 055-7	BASD 450170-0	BTC45 VH	84.0	15.0
03/04/2019	33 85 450 5 049-8	BASD 450109-0	BTC52 VH	84.0	14.0
03/07/2019	33 85 459 4 034-2	BASD 450214-1	BTC45 VH	84.0	18.6

→ The documented velocities range between 14.6 km/h and 18.6 km/h.

WP 6 - Long-term tests

Data basis

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The test setup is described in a plausible way. However, it is not completely comprehensible if the selected sample size is adequate:

- Number of wagon sets:
  - 3 B-TCs + iCTWs (filling level: 2x 100%, 1x 50%)
  - 1 conventional TC /carrier wagon system (filling level: 100%)

  Another set, e.g. with a filling level of 50%, could increase the comparability of the values with the B-TC system.

- Number of test runs:
  - 18 mainline runs within approx. 3 months
  - During 2 of 18 runs, excessive lateral forces occur that considerably exceed the limit values (excessive values during 11% of the test runs).
  - Stating shunting as a reason for high values is unclear, as there is no reference to mainline investigation.

WP 6 - Long-term tests

Deformation of wagon underframe

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The long-term tests found that the wagon underframes of the iCTW are vulnerable to deformations,

- in particular caused by buffing impacts during shunting.
- BASF proposes to reduce the hazard by regularly checking the loaded iCTWs after every hump run.

It remains unclear

- how these deformations can be detected
- what the detection probability of those deformations is
- in what form the requested more frequent inspections by the wagon master can be carried out and are included in internal regulations

Conclusions

- The risk assessment is, on principle, sound with regard to technical changes but contains some ambiguities and methodical gaps
- Analyses on error propagations and statistical uncertainties would be desirable
- More granular variations of the filling level and material properties in the MBS could provide a clear indication on whether operation at any filling level is possible
- Design of the FEM model not comprehensible with regard to model depth and safety validation
- Choice and limit values of collision velocities unclear
- Scope of the long-term tests in part very limited
- Questionable if statements from the BASF risk analysis are sufficient to substantiate amendments to the codes with regard to filling levels and sloshing movements with an adequate degree of safety

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