INF. 10

10 November 2021

(English only)

RID: **13th Session of the RID Committee of Experts' standing working group**
(Geneva, 15 – 19 November 2021)

Subject: **Comments on the opinion of the German Center for Rail Traffic Research (DZSF) on the risk assessment of the extra-large tank-containers of BASF**

Information from BASF on behalf of CEFIC

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1. At the last session of the RID Committee of Experts' standing working group, the German Center for Rail Traffic Research (DZSF) gave a presentation on BASF's risk assessment of extra-large tank-containers. This statement is contained in informal document INF.14 of the last session of the standing working group.

2. Various extracts from this presentation are reproduced below, followed by comments in a box.

WP 1

The focus of BASF's investigation is solely on technical modifications. The risk assessment does not cover all identified interfaces in a detailed manner (e.g., maintenance, SMS).

Comment:

The risk assessment is based on an evaluation of significance carried out by BASF. Based on this, TU Berlin provides technical support for identifying and assessing risks. The use of a risk management process or the review of a safety management system (SMS) is not necessary due to the availability of the significance analysis. As such, they do not form part of TU Berlin's work packages.

The general risk assessment is based on a system comparison in terms of technical failure probabilities. The principle selected for risk acceptance was "the analysis of similarities to reference systems," with reference systems being tank cars and standard tank containers. The B-TCs do not carry any additional hazards with regard to driving through tunnels, accident scenarios or environmental impact (see comment below). For this reason, the interfaces listed were not explicitly investigated further.

TU Berlin's work was carried out in collaboration with BASF and under supervision by Bureau Veritas (contact: Marwen MEHREZ <marwen.mehrez@bureauveritas.com>, Bureau Veritas Exploitation, Immeuble le Guillaumet – 60 avenue du Général de Gaulle – 92800 Puteaux) and was based, among other things, on the feedback from the investigations performed by Bureau Veritas.

From the perspective of the German Research Centre for Rail Traffic Research (DZSF), B-TCs used in conjunction with iCTW do represent a safety-relevant and significant change, due to the possible impact of failures, the complexity and the degree of innovation.

The inspection of the new system generally corresponds to the requirements of CSM-RA. However, there is no information on:

– Sources, experts and experience that form the basis of the risk assessment

Comment:

The TU Berlin staff is headed by Prof. Dr.-Ing. Markus Hecht, who has many years of experience with risk assessments and methodologies. For example, they were involved in the international working group on the railway accident in Schönebeck in cooperation with the Federal Ministry of Transport and Digital Infrastructure (BMVI), Hazardous Goods department, Mr. Rein.

The following staff members are part of the project team:

Prof. Dr.-Ing Markus Hecht: Project manager, Chair of the Department of Rail Vehicles since 1997

Gökhan Katmer M.Sc.: His work at the department focuses on experimental investigations as well as the design and maintenance of rail vehicles. In particular, he is responsible for test design and execution.

Matthias Gülker M.Sc.: His work at the department focuses on vehicle dynamics and brake technology. Prior to this project, he conducted extensive research on simulation technology and the underlying aspects of vehicle dynamics (e.g., as part of his master's thesis on the changes to vehicle dynamics on vehicles with LL brake blocks at increasing velocities).

Qiuyong Tian M.Sc.: During his studies, he acquired knowledge on technical and material mechanics. In addition, he acquired extensive knowledge and experience with regard to finite element simulations during his work at the KIT (departments of Production Engineering, Automation Technology, Vehicle Dynamics and Vehicle Acoustics).

Ulrich Deghela, M.Sc.: He is a mechanical engineer focusing on risk and hazard analyses (FMECA or HAZOP analysis) He also has experience in the automation of technical freight car examinations, the derailment safety of freight cars, the strength and durability of components, reliability analyses (RAMS DIN EN 50126, FMEA, FTA) and especially with the CSM regulation.

Harald Jakatt (Master Craftsman) and Dirk Itzeck (Dipl.-Ing.): They are responsible for the technical test implementation, incl. the use and preparation of measurement technology.

The responsible persons of our project partners (BASF, HVLE, etc.) are not mentioned here.

– Hazards associated with driving through tunnels, accident scenarios or environmental impact

Comment: *This remark refers to the effect of a failure (environmental impact, driving through tunnels) that is comparable to a large tank car (identical tank size). The probability of occurrence is investigated and found to not be higher (WP 1, Section 4.4). This means that the risk for these scenarios was assessed.* *Accident scenarios were analyzed in WP 4 and WP 5.*

WP 2

It is not clear whether the use of the simplified method corresponds with applicable standards, as the method …

– … only applies to vehicles with conventional technology in accordance with DIN EN 14363:2019-11, Section 7.2.2. The authors themselves explicitly refer to their systems as being non-conventional.

– …only applies up to a maximum nominal rail-wheel contact force of 200 kN. However, assuming an even rail-wheel load distribution, the rail-wheel contact force for a *permissible total weight of 90 t is 220.725 kN.*

Comment: *WP 2 merely serves to estimate the stability values and to compare configurations. It is not intended to produce a complete assessment. The simplified method was selected for this reason, due to the fact that it produces good comparative values. Given that the main focus was on empty rail cars (which is critical for driving safety) and partially loaded cars (sloshing movement, influence of sloshing), the rail-wheel contact force was not considered as an exclusion criterion for fully loaded railway cars. The tests were additionally carried out, as they are important for gathering data for the model validation in WP 3.*

The reliability of the derived values is at least questionable, due to several experimental and methodological issues, e.g., with regard to:

– Removal of an elastomer component and generalized correction of transverse movements (in this case by 43%)

– Note on a displacement sensor displaying values reduced by 80% and a corresponding correction factor being applied Missing description of the data basis for these estimates and no statement on statistical uncertainties

– Other issues regarding force measurements (e.g., consideration of deviations in spring stiffness)

– Inadequate consideration of numerical fault propagation of measurement uncertainties as well as statistical uncertainties in force measurements

– Lack of consideration of fault tolerances of measuring devices

– Lack of consideration of the empirical variance of several measurements

– No clear description of how the measuring points described were derived from experimental time scales

Comment: *The elastomer components were introduced to stiffen the transverse bearing, in order to enable a better inference between displacement (small amplitude) and force. The stated factor was given by the manufacturer.* *All in all, the individual measurements only have low significance with regard to the limit value, given that only a small number of measurements were conducted at low velocities. In addition, there may be large fluctuations in terms of component sizes. However, the measurement confirmed that the magnitude of the parameters measured for the new system is comparable to that of the conventional system and partially loaded railway cars. As such, the measurement forms the basis of the simulations.* *Measurement uncertainties can be found for all types of railway cars and are reflected in all measurements. In the course of the investigation, it was found that the simulation made it possible to make more comprehensive and more reliable statements. For this reason, the less efficient investigation based on conducting S-curve tests had lost its relevance.*

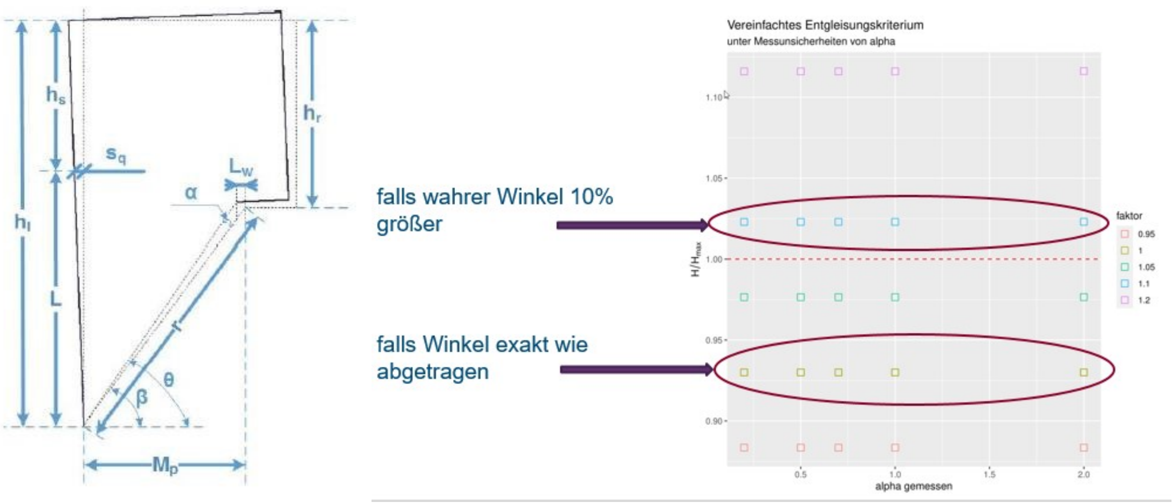
Example:

– Measurement uncertainty of the tilting angle ***α***

– Transverse deflection sq = L tan α

– Calculation of α not verifiable due to lack of original data

– Own analysis: criterion of driving safety depends on uncertainties with regard to ***α***

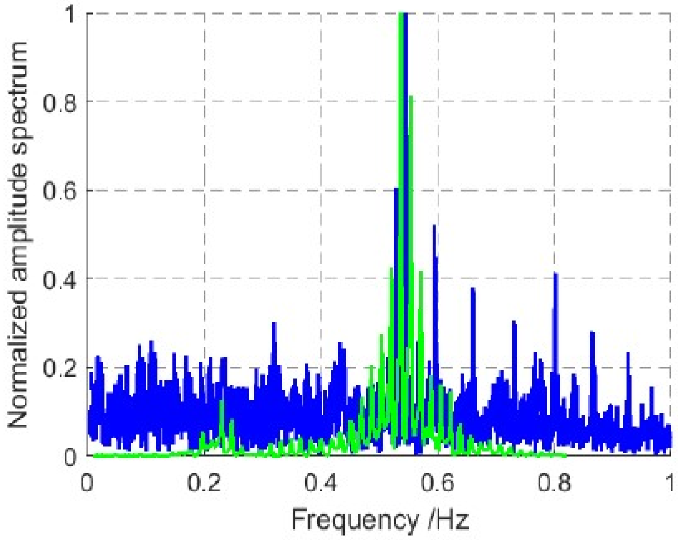


falls wahrer Winkel 10% größer	If the actual angle is 10% larger
falls Winkel exakt wie abgetragen	If the angle is as specified

WP 3

It is described that the model simulates the natural frequencies measured as part of WP 2, both in the direction of travel and in transverse direction. However, it is not discussed whether the amplitude and the phase position of the sloshing movement are reproduced as well (no explanation, only normalized amplitudes in accordance with the Fourier transformation).

Validation with non-normalized measurement and simulation data would be desirable, since the amplitude of the forces caused by the sloshing is of particular importance here.



Comment:

In this case, the sloshing movement of water (measured) is compared to the movement of water bodies (simulated in the model). Since the models merely represent a behavioral model of force build-up and given that they can only be compared to the sloshing movement measured within the tank (it was not possible to measure the force of the water against the tank), a mere comparison of force amplitudes or movement amplitudes is neither possible nor sensible.

The models were taken from various sources, in which their plausibility was also checked.

From an empirical perspective, the phase position for the simulations was selected such that the least favorable sloshing movements would occur at the most critical track sections.

The simulations do not reflect a representative use case of the tank containers in terms of the general structure and the parameters used, because…

- …only water is considered as load. In practice, however, hazardous goods are being transported, which can deviate in terms of density and viscosity. It was not investigated whether these parameters influence the derailment safety.

- …the investigation of the liquid level does not cover all scenarios (only 0%, 50%, 100%).

Comment: *An advanced investigation on this aspect was subsequently carried out in November 2020. Simulations were performed with a higher-density liquid (1.8 kg/l) and a load of 50%, as well as with a load of 75% of water. The following results were obtained:* *“In the S-curve, it was found that a load of 50% is the most critical case of partial loading at regular speeds, regardless of the configuration. At excessive velocities, rail cars with conventional Y25 bogies showed slightly increased values for a B-TC with 75% load, albeit without reaching more critical values.* *– The curve results show that no rail car with partial loading reaches a critical value.* *– As a general rule, rail cars with empty or fully loaded containers require more scrutiny than cars with partial loading."* *The viscosity was not considered here. The models only refer to the viscosity of water. In this case, the critical state would be: high density, low viscosity. The following table (provided by BASF) lists potential/probable goods to be transported. It shows that higher-density liquids tend to have a high viscosity, while those with low viscosity tend to have a low density. Based on this information, it was decided not to investigate this matter any further.*

Load	*Density [g/cm³]*	*Viscosity [mPaS]*
Water	*0.98*	*1.0087*
Isopropylamine	*0.6871*	*0.47*
Oleum	*1.8*	*24*
Glues	*1.3*	*750–1000*

– The lifting of the container was ruled out as a questionable result, whereby the limit of permissible vertical movement being set at the height of the spigot. No sources were given to substantiate this provision. It is also questionable whether a free container movement of approx. 10 cm above the carrying wagon can be defined as a permissible scenario. In this case, there are no lateral forces acting between the wagon and the container. Further acceleration would inevitably result in a loss of the container.

Comment: *It was a sensible decision to set the limit at 10 cm. However, all simulations showed that there was NO lifting or tilting (i.e., lifting of individual corner castings) of the container in any direction. This means that it was not really necessary to define a limit value. The report states:* *“The maximum vertical displacement between spigot and corner casting of any set is less than 0.3 mm, which is caused by the non-infinite stiffness of the container fixing force element.” (source: BASF RA, WP 3, Section 3.3)*

WP 4

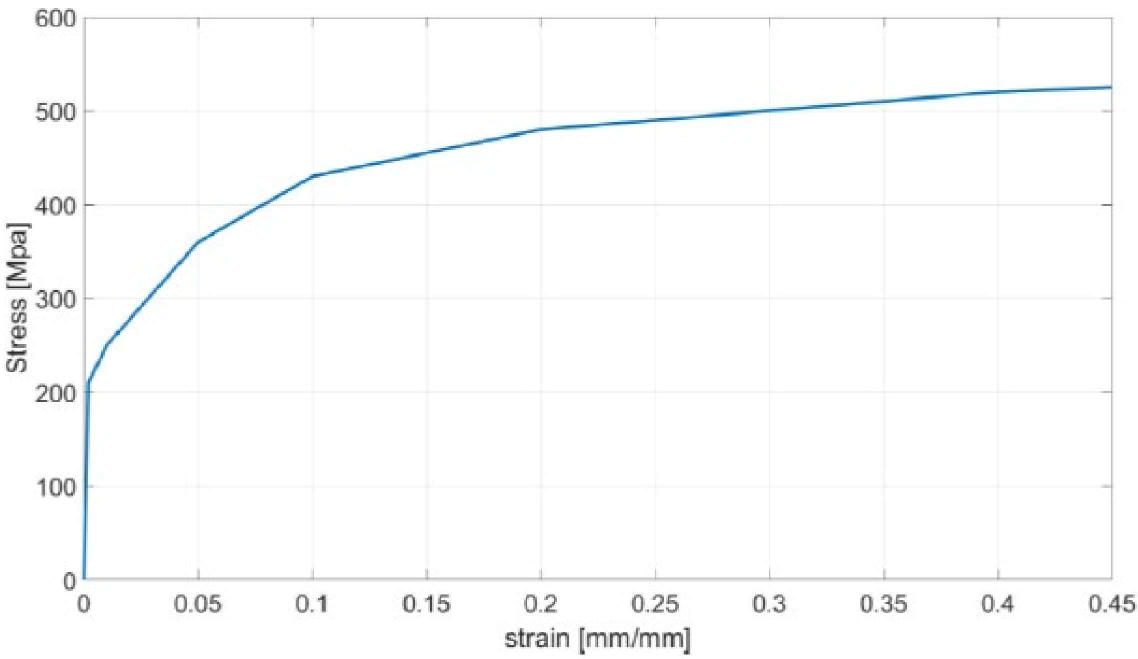


Table 9 Summary of side-on simulations,

		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

The ultimate elongation A_1 (strain = 0.45) was selected as the strength criterion.

– Verifications are usually based on stress values (not applicable in this case due to large plastic deformations).

– It is common practice to define a minimum safety reserve of ≥ 1.2 (~ 20% reserve). In this case, the minimum safety reserve should be considerably higher than 1.2, due to:
  - the unusual verification process (comparison of strain instead of stress values)
  - the non-linear stress-strain curve (stress-related safety reserve ≠ strain-related safety reserve)
  - uncertain material characteristics (statistical survival rate $P_{\text{Ü}}$ of A_1).

> *Comment:*
>
> *The results of the simulations refer to the comparison of the new vs. the conventional system. They do not reflect absolute certainties. For this reason, no minimum safety reserve was used here.*

Have local stresses on structures been adequately investigated (notch effects, meshing analysis)?

> *Comment:*
>
> *All welds have been modeled as rigid joints that are stiffer than the base material. In the crash zone, the element size was defined at 2 mm, which is smaller than usual in crash simulation.*

The modeling of welding seams was not described, even though they are subject to particularly high stresses (notch effects, failure limits?).

> *Comment:*
>
> *According to the FEM software support, welding seams can be simplified as face-to-face and rigid joints. This approach was used here.*

The area force of accelerated tank loads is considered to be the decisive factor in the investigation of whether stresses caused by sloshing movements are capable of causing damage. This reference area is not clearly defined. The approach is comparable to medium surface pressure.

However, damage caused by accelerated tank loads are not assumed to be due to surface pressure, but rather the resulting additional structural stresses, e.g., bending stresses in the tank shell or concentrated stresses at suspensions points (not considered).

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

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

> *Comment:*
>
> *A (area [mm²]) refers to the tank bottom on which the water column acts on impact. In a partial load case, this means the lower half of the tank bottom. This area is subject to greater pressure in the tank, which is was implemented using an additional surface pressure.*
>
> *A preliminary analysis was conducted to assess the impact of sloshing movements on container structures. The impacting car was not investigated further during the crash simulation because no effects were found and given that the acting forces are small compared to the impact force during a crash. In the partial load case, the forces are distributed over a longer time scale and thus smaller than in the full load case.*

It was not described why both these conditions – the impact scenarios investigated and the impact velocities selected – were considered relevant.

– It remains unclear whether the position of the cars relative to one another actually reflects the maximum damage to be expected for the side-on collision scenario.

Comment:

Due to the unpredictability of occurrence, a probable scenario (switch with a 190 m radius) was selected. For the scenario definition, the impact scenario that produces the most damaging results (large impact area on the container, low energy absorption of the car body) was determined empirically using CAD. All systems were investigated under the same conditions.

– The selected velocities are based on WP 5 and enable a direct comparison.

– There was no explanation given for the impact velocity the rail cars were supposed to be able to withstand.

Comment:

See WP 5 below.

WP 5

The impact tests are conducted in accordance with EN 15227. However, the scope of this standard only covers locomotives, passenger and control cars. Freight cars are not explicitly included. The impact velocity given in the standard is 36 km/h (vehicle category C-1, frontal impact of identical rail cars, 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 are between 14.6 km/h and 18.6 km/h.

Comment:

This velocity does not represent the initial velocity prior to impact, rather it is the velocity after impact of the buffers incl. overriding. The velocity corresponds to the vehicle velocity prior to impact of about 27 km/h according to the principle of conservation of energy. The energy absorbed by the deforming car body is not taken into account. For this reason, the impact velocity was specified as ~ 15 km/h.

WP 6

The experimental design is described in a plausible manner, but it is not fully clear whether the selected number of samples if sufficient.

Number of car body sets:

– 3 B-TC + iCTW (filling level: 2 x 100%, 1 x 50%)

– 1 conventional TC + carrier wagon (filling level: 100%)

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

Comment:

To ensure comparability, one set each was used for a B-TC on iCTW45 (sets 3 and 4):

– *Filling level of 50% (set 5)*

– *Conventional containers (set 11)*

Two sets were used here given that the fully filled (100%) B-TC on iCTW45 was tested as the main system. Simulations show that the measurement values remain around or below the reference values. About 200 measurements have been conducted for both filling levels to ensure comparability.

However, the amount of data available for set 11 is rather small. But since this is not the system to be evaluated, this is not considered crucial.

Number of test runs:

– 18 “mainline” runs within about 3 months

– In 2 out of 18 runs, excessive lateral forces were recorded, considerably exceeding the limits (excessive measurement values in 11% of all test runs).

– It was unclear why shunting was cited as a reason for the high values, since there is no connection to the “mainline” investigation.

Comment:

– *Runs 3 and 4 were not representative due to a defective sensor (see “Data exclusion” in Section 2.3.2). For this reason, no excessive values were recorded on the mainline (0/11, 0%).*

– *The reference to shunting was intended for differentiation purposes. The wording of the sentence “The only exceedances are recorded at the destinations during shunting.” may have been ambiguous and should be deleted.*

The long-term tests show that the iCTW railcar body frames are susceptible to deformation, chiefly triggered by buffer impacts during shunting processes. BASF recommends mitigating this risk by regularly checking the loaded iCTW every time it exits the hump yard.

However, it is not explained

– how these deformations can be detected

– with what probability deformations can be detected

– whether and in what form the required increased inspections can be carried out by the technician and whether they were included in internal regulations

Comment:

This section includes a reference to the "Complementary Information on the BASF Class Tank Containers and Innovative Container-Carrying Wagons" report.

Conclusion

– The risk assessment is generally well-founded and covers technical changes, but there are some ambiguities and methodological gaps.

– Analyses of fault propagation and statistical uncertainties would be advantageous.

– Varying the filling level and material properties in smaller steps in the MBS simulation would have possibly yielded better results as to whether operation with any filling level is generally possible.

– The setup of the FEM model is unclear in terms of model depth and proof of safety.

– The selection and limit values for the impact velocities unclear.

– In some cases, the scope of the long-term tests was rather small.

– It is doubtful whether the statements from the BASF risk assessment are sufficient to warrant changes to technical rules with regard to filling degrees and sloshing movements with sufficient certainty.