INF.13
(English only)

Risk Assessment BASF Class Tank Container

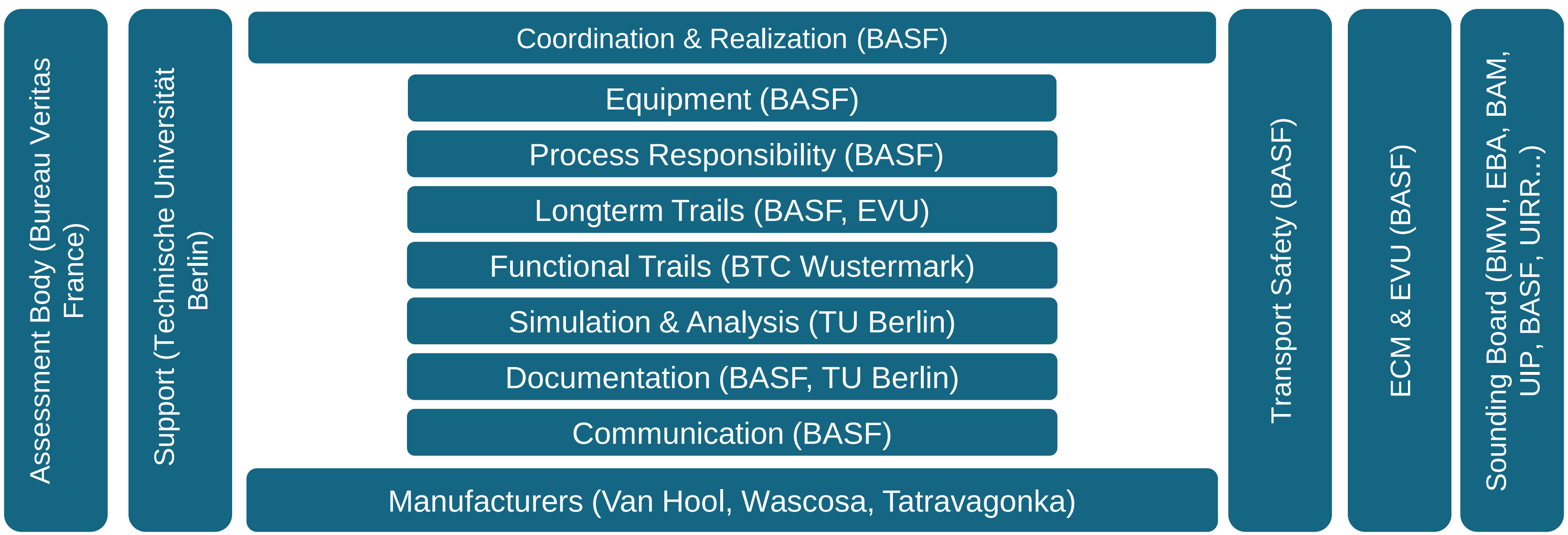
Technical University of Berlin | Department of Rail Vehicles | 15.10.2019

Prof. Dr.-Ing. Markus Hecht
Gökhan Katmer, M.Sc.
Matthias Gülker, M.Sc.
Qiuyong Tian, M.Sc.
Ulrich Deghela, M.Sc.

Motivation & Objectives of the Risk Assessment

- BASF Class Tank Containers are certified and approved since 2015 for the transport of dangerous goods and since 2017 in use without incidents
- In 2018 BASF started a voluntary Risk Assessment according to

CSM – VO (EU) 402/2013



System comparison

New System | Conventional Systems

- **B-TC on iCTW**
- Bogies TVP-NBS
- L-Buffers
- Strengthened spigots and corner-castings

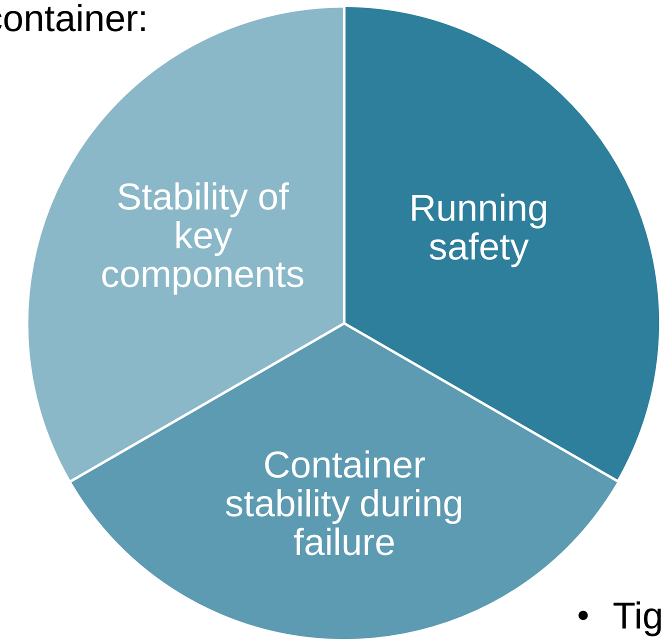
- **Rail Tank Car**
- Approved bogies Y25
- A-Buffers

- **ISO-Tank Container on intermodal car**
- Approved bogies Y25
- A-Buffers
- Tank size up to 26'

Influences of system adaption

Higher forces due to larger container:

- Strengthened spigots and corner-castings
- L-buffers
- Reinforced car-frame
- Hump yard suitability



- Sloshing movements with partially filled container
- Innovative bogie with disc brakes
- Hump yard suitability

- Tightness of container after impact
- Influence of car construction
- Movement of container during impact

Scope of Risk Assessment

Comparison of

- Technical specifications
- Driving behavior
- System limits
- Sloshing movements

Comparison by

- Driving trails
- Simulations
- Impact-tests
- Data analysis

Paper based technical comparison

- System definition
- Risk Analysis & Detection
- Risk Evaluation

Running stability with sloshing impact

- Analysis of sloshing forces on driving behavior
- Measurements and Simulation with increased velocities

Long-term trials and hump investigation

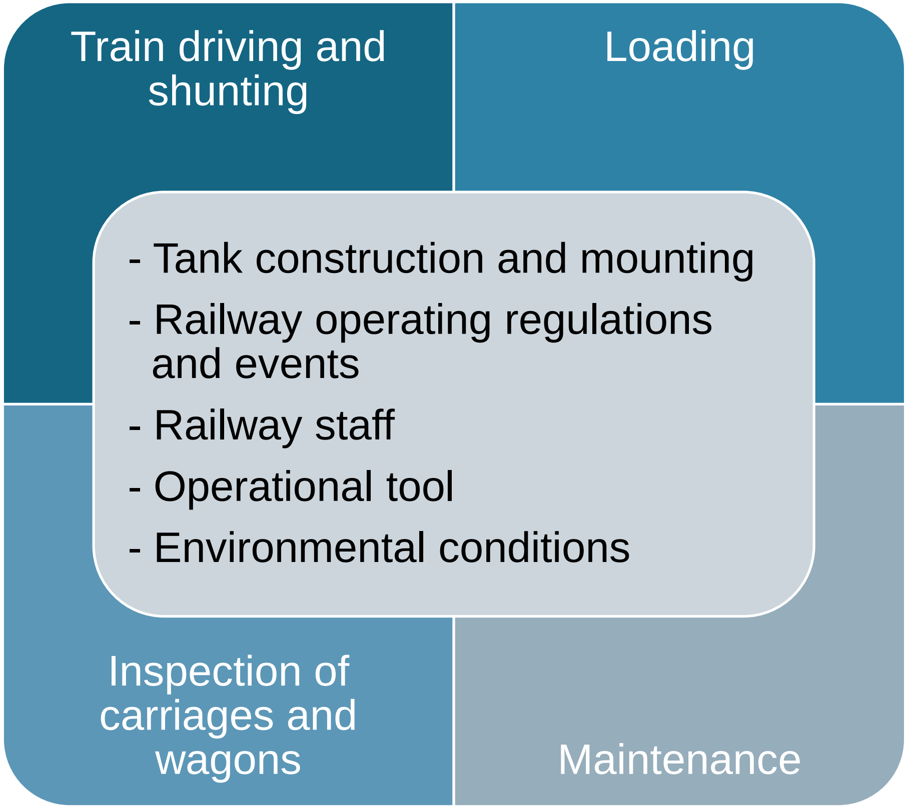
- Shock detection during operation
- Hump yard suitability
- Buffing Simulations

Impact tests

- Container stability during Overriding
- FE Simulations and Tests of occurring damage

Paper based technical comparison

- Based on technical standards / RID requirements
- Identification of critical components
- Comparison of reference values for container materials
- Exposure of identified system modifications:
  - Hazard Identification
  - Hazard Management
  - Risk Evaluation

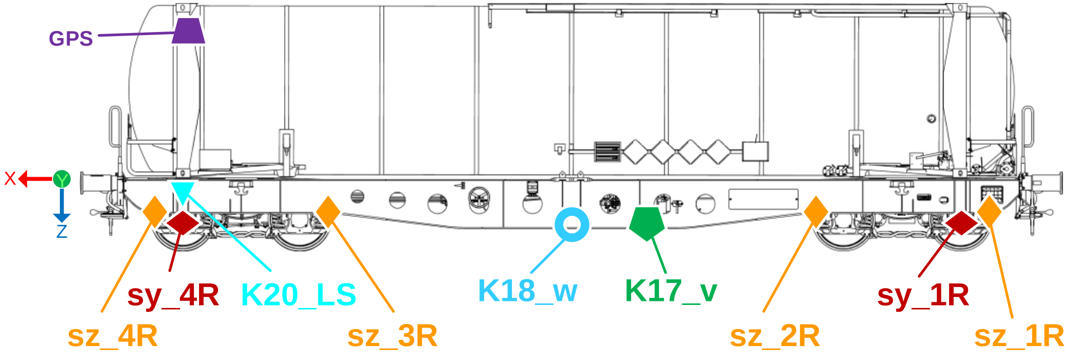


Investigation of sloshing movements („Schwall“)

Investigation	Test vehicle	Track	Velocity
Experiment	45' B-TC on 45' iCTW (BTC45)	Double S-Curve r = 190 m	10, 15, 20 and 25 km/h
	45' B-TC on 52' iCTW (BTC52)		
	2x 20' TC on 40' CTW (TC2x20)		
	2x 26' TC on 60' CTW (TC2x26)		
Simulation	45' B-TC on 45' iCTW (BTC45)	Curve r = 500 m and S-Curve r = 150 m	Curve up to 150 km/h S-Curve up to 70 km/h
	45' B-TC on 52' iCTW (BTC52)		
	3x 20' TC on 60' CTW (TC3x20)		
	Rail Tank Car		

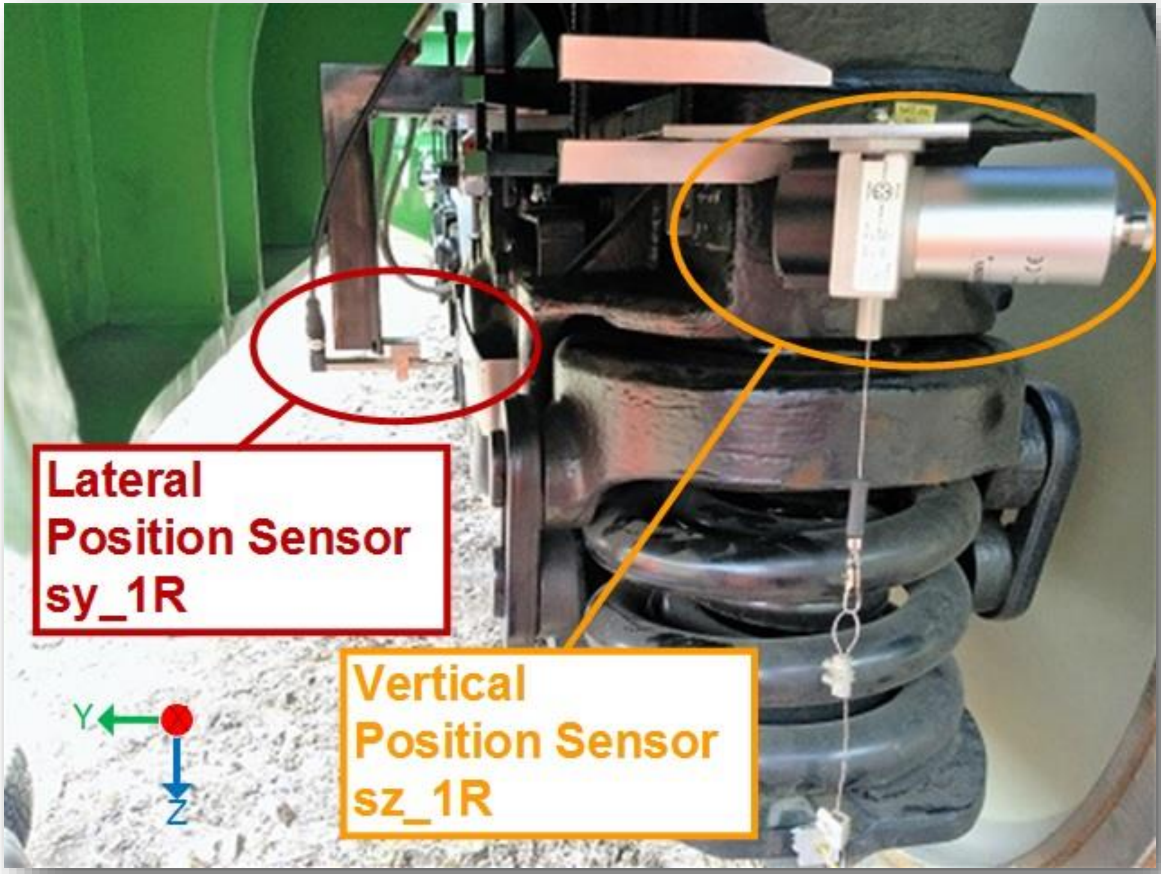
Experimental investigation

- Measurement of running stability with evaluating influence of liquid sloshing:
  - Full / partially loaded / empty
  - Different velocities
- Data acquisition for simulation models
- Comparison of different systems



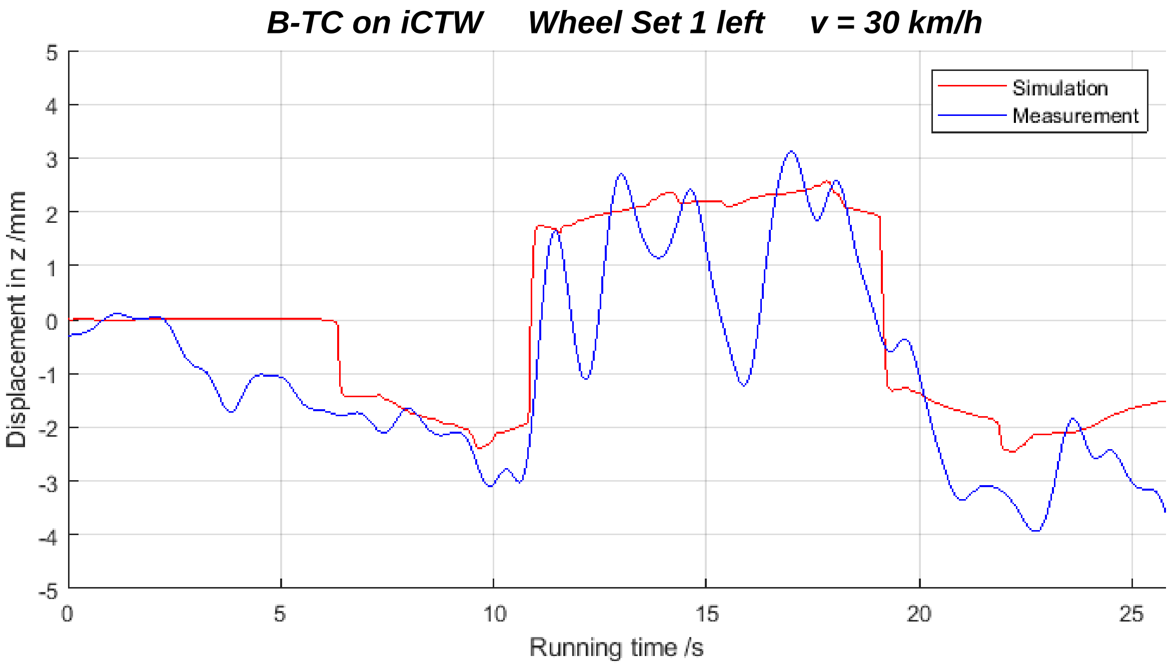
	Measurement	Location
	Vertical Position Sensor	Bogie
	Lateral Position Sensor	Bogie
	Velocity Sensor	Car Body
	GPS Sensor	Container
	Gyroscope	Car Body
	Photoelectric barrier	Car Body

Measurement equipment for lateral and vertical movement



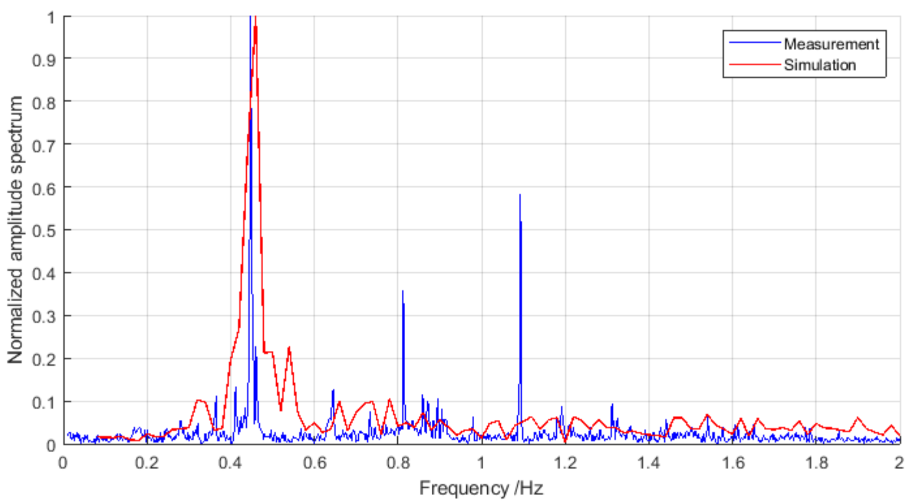
Simulation of sloshing movements

- Approximation of critical states at increasing velocities
- Evaluating different operation scenarios

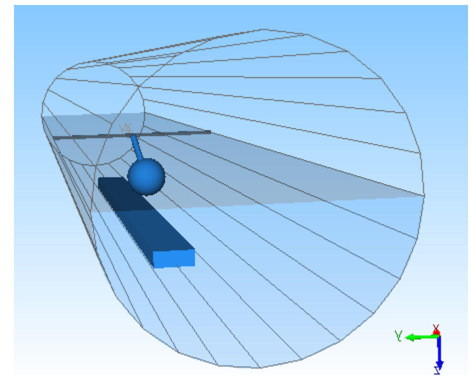


Sloshing model

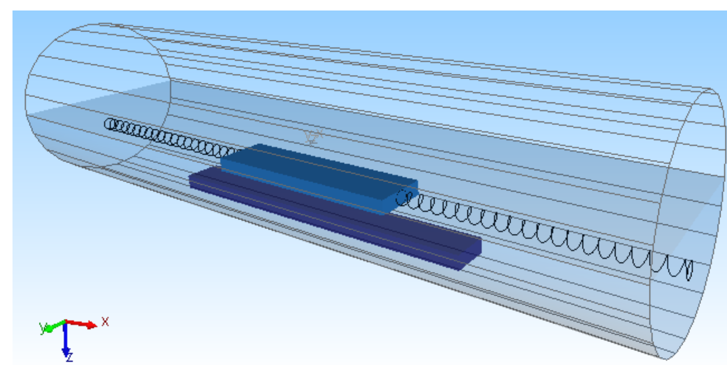
- Simplified mechanical models for lateral and longitudinal sloshing:
  Pendulum / Spring-Mass-System
- Validation with measurements from investigation of sloshing movements



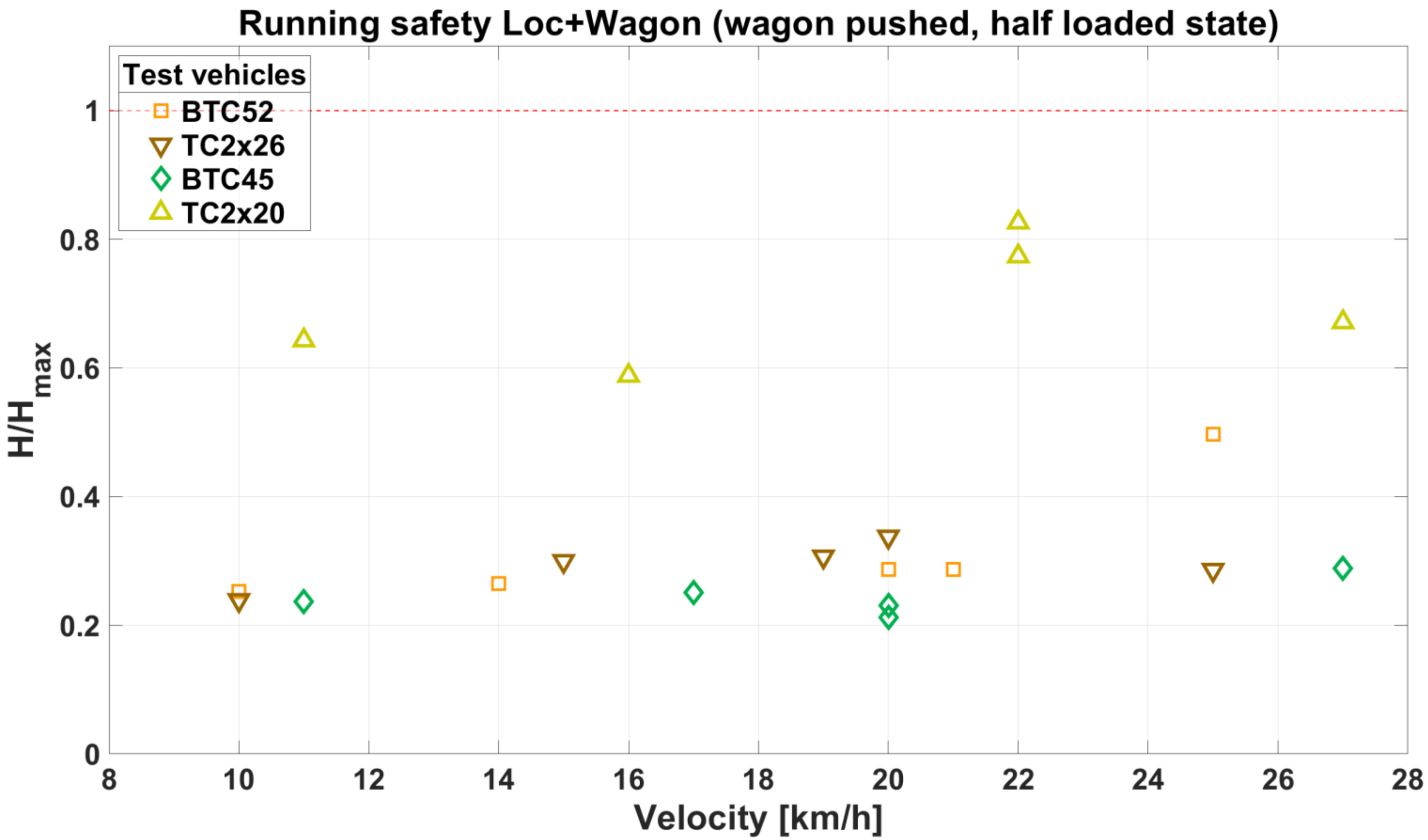
Lateral



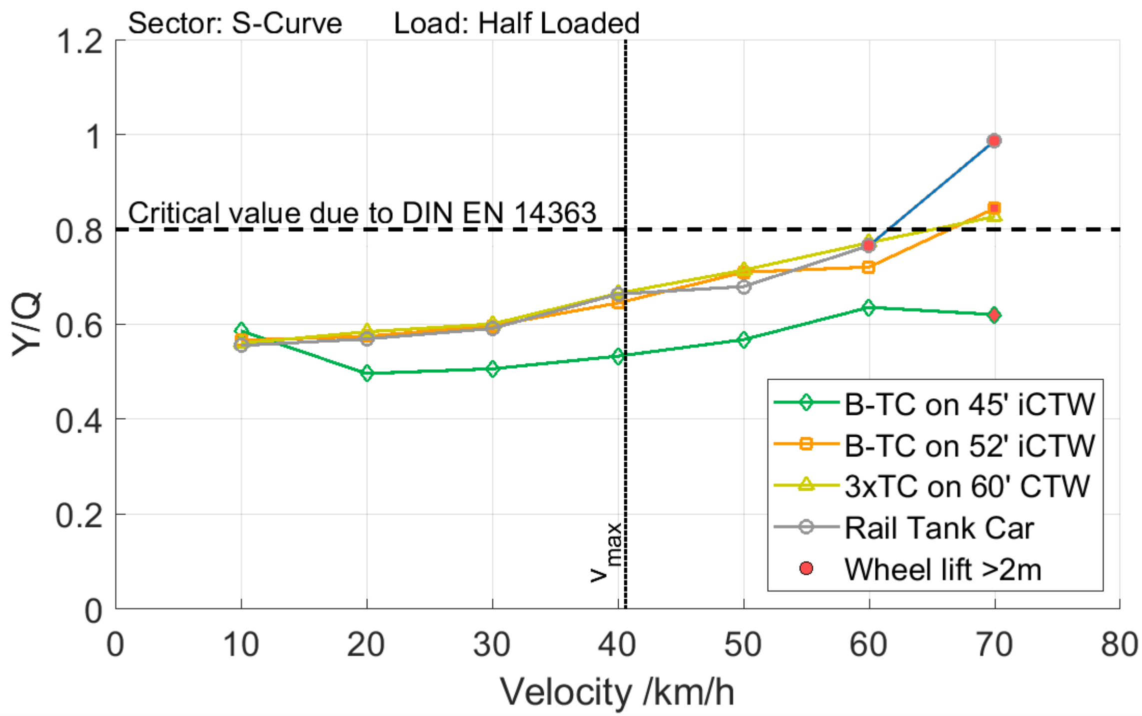
Longitudinal



Experimental results of the investigation



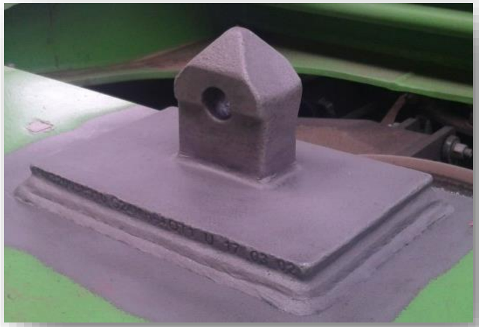
Simulation results of investigation



No critical sloshing movements are detected during the measurements and simulations

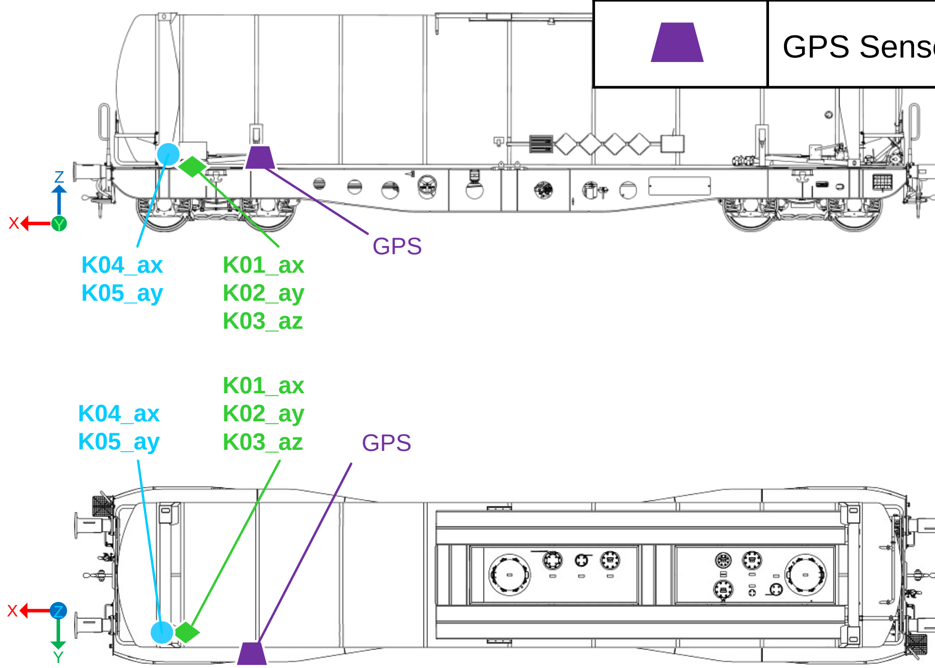
Long-term trials

- Evaluation of accelerations and forces on critical components (spigots, buffers)
- Comparison of fully and partially loaded B-TC on 45' iCTW with conventional intermodal car
- Testing areas:
  - Shuttle operation Ludwigshafen ↔ Schwarzheide (∑ 15,000 km)
  - Hump yard (∑ 250 runs / load status)
- Execution of non-destructive testing on spigots and corner-casting to detect failures
- Data processing: LPF 16 Hz (EN 12663-2)



Instrumentation

Sensor	Measurement
●	1-axis Accelerometer at container
◆	1-axis Accelerometer at car
⏢	GPS Sensor

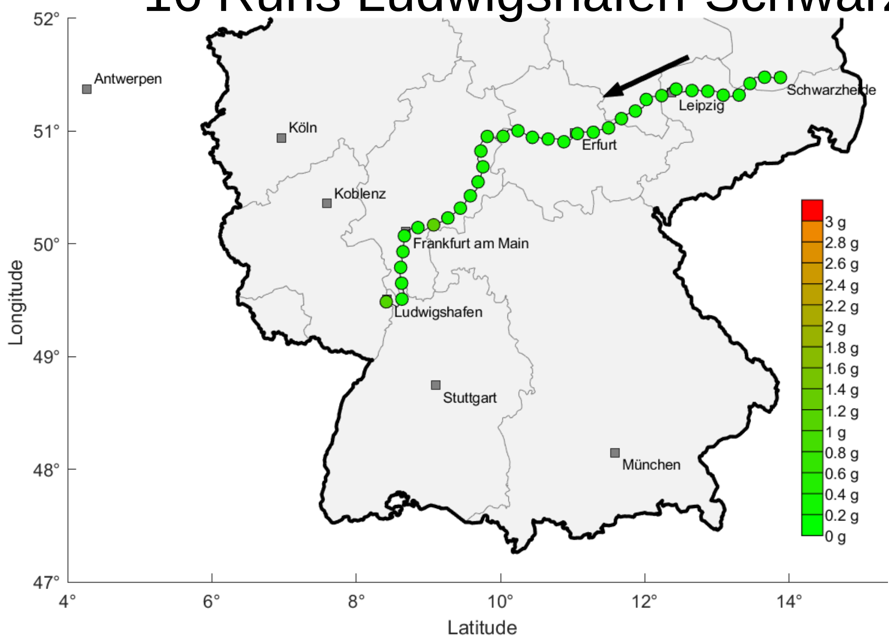


Equipment

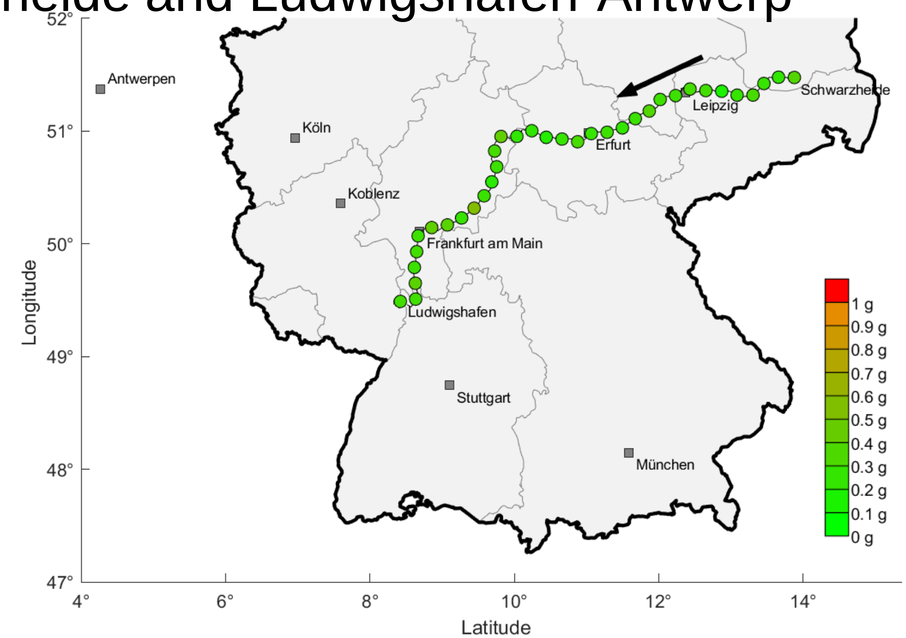
	Set 3	Set 4	Set 5	Set 11
Wagon type	45' iCTW	45' iCTW	45' iCTW	60' CTW
Container type	45' B-TC	45' B-TC	45' B-TC	2x 26' TC
Load	Full	Full	Half	Full
Operation	Shuttle (LU-SH)	Hump yard	Hump yard	Hump yard
Goods	MEG	MEG	Water	MEG

Shuttle measurements

- No excess of longitudinal (left) and lateral (right) acceleration limits between the destinations
- 16 Runs Ludwigshafen-Schwarzheide and Ludwigshafen-Antwerp

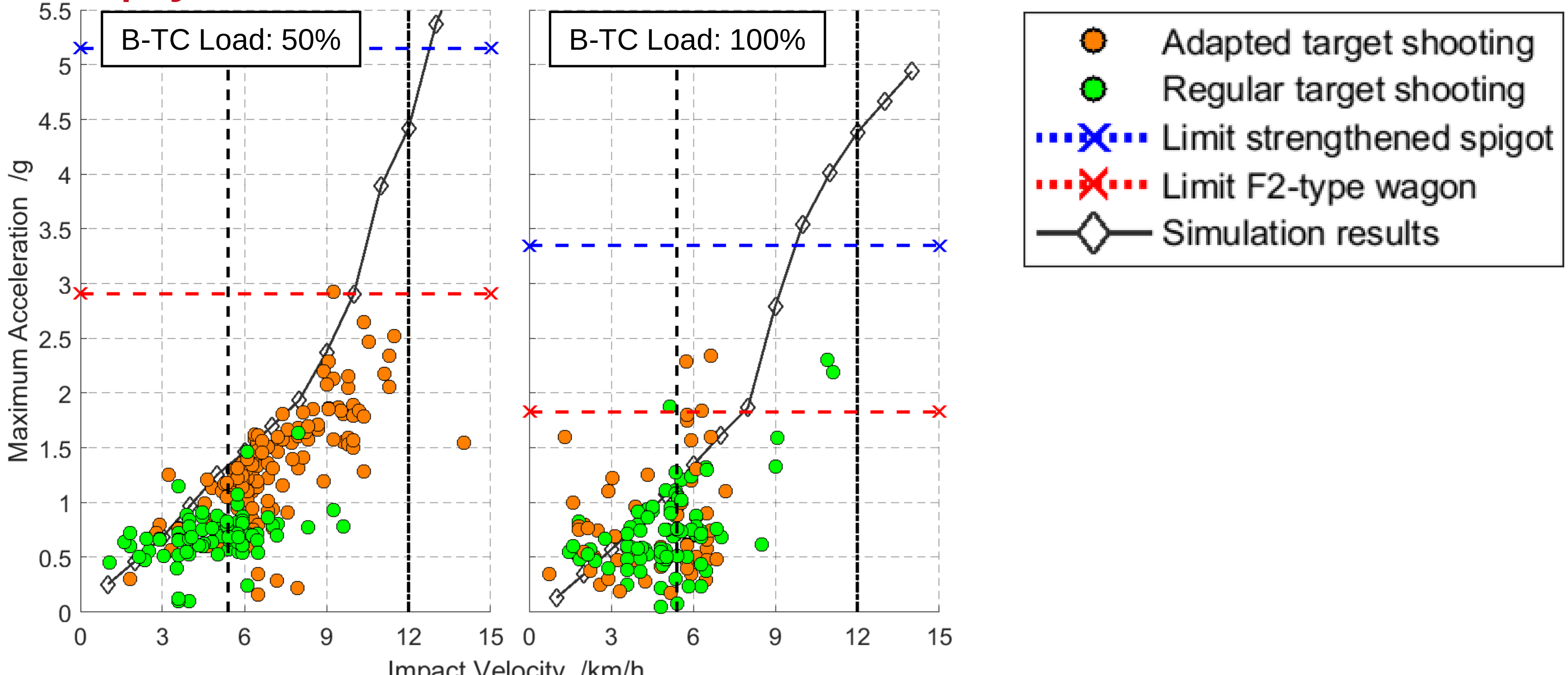


Longitudinal limit 3g



Lateral limit 1g

Hump yard measurements and simulations



No critical states during measurements and simulations detected

No damage at examined components detected

Impact tests

Evaluation of damage on overriding cars and derailment collision

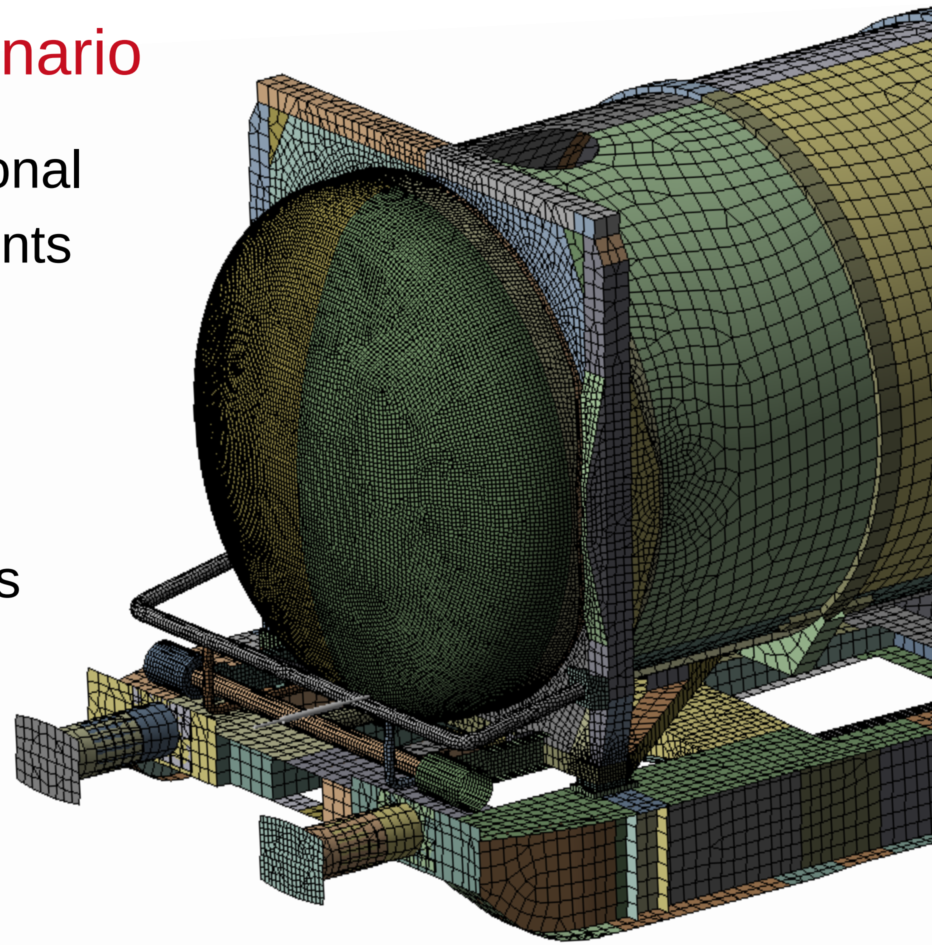
Equipment

<table>
<tr><th rowspan="2">Investigation</th><th rowspan="2">Test vehicle</th><th colspan="2">Velocity [km/h]</th></tr>
<tr><th>Simulation</th><th>Experiment</th></tr>
<tr><td rowspan="4">Side-on and frontal impact simulation
and
Frontal impact experiment</td><td>45' B-TC (Van Hool) on 45' iCTW (BTC45 VH)</td><td rowspan="4">Side on: 25

Frontal:
15 and 19</td><td>15.0 and 18.6</td></tr>
<tr><td>45' B-TC (Magyar) on 45' iCTW (BTC45 GM)</td><td>15.0</td></tr>
<tr><td>Tank wagon (TW) Zacens</td><td>14.6</td></tr>
<tr><td>2x 26' TC on 52' iCTW (Conventional)</td><td>15.1</td></tr>
<tr><td>Frontal impact</td><td>45' B-TC (Van Hool) on 52' iCTW (BTC52 VH)</td><td>15</td><td>14.0</td></tr>
</table>

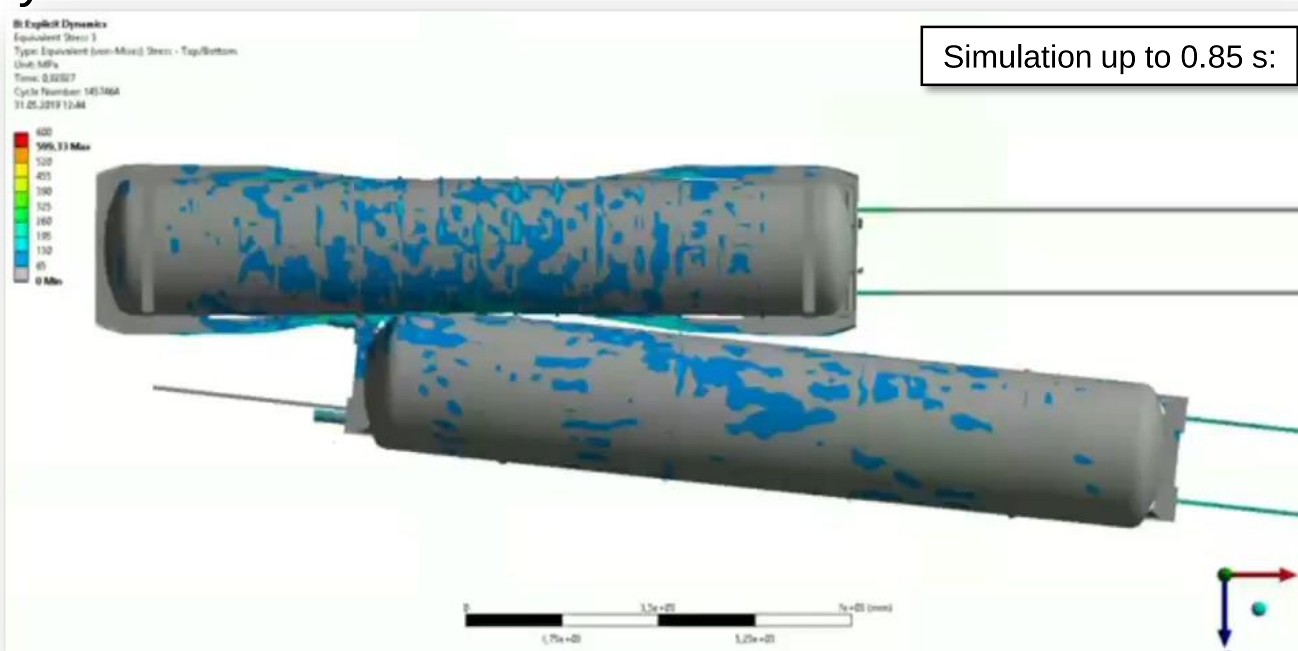
FEM simulation of impact scenario

- Execution with ANSYS Professional
- Models with up to $2.5x10^6$ elements
- Analysis of material failure
  - Maximal tension
  - Maximal strain
- Execution with different velocities



Side-on impact simulation

- Additional modelling of bogies
- Simplified rail-wheel contact
- Impact velocity: 25 km/h



Material properties of the tank shell

Tank	Van Hool	Magyar	Tank wagon	Conventional
A_1 [%]	50	48	35	43
Number of vaccum rings	deleted	deleted	deleted	deleted
Thickness of vaccum rings [mm]	deleted	deleted	deleted	deleted
Head Wall Thickness [mm]	7.9	5.65	8.0	5.2
Shell thickness [mm]	3.4	4.5	6.3	4.2

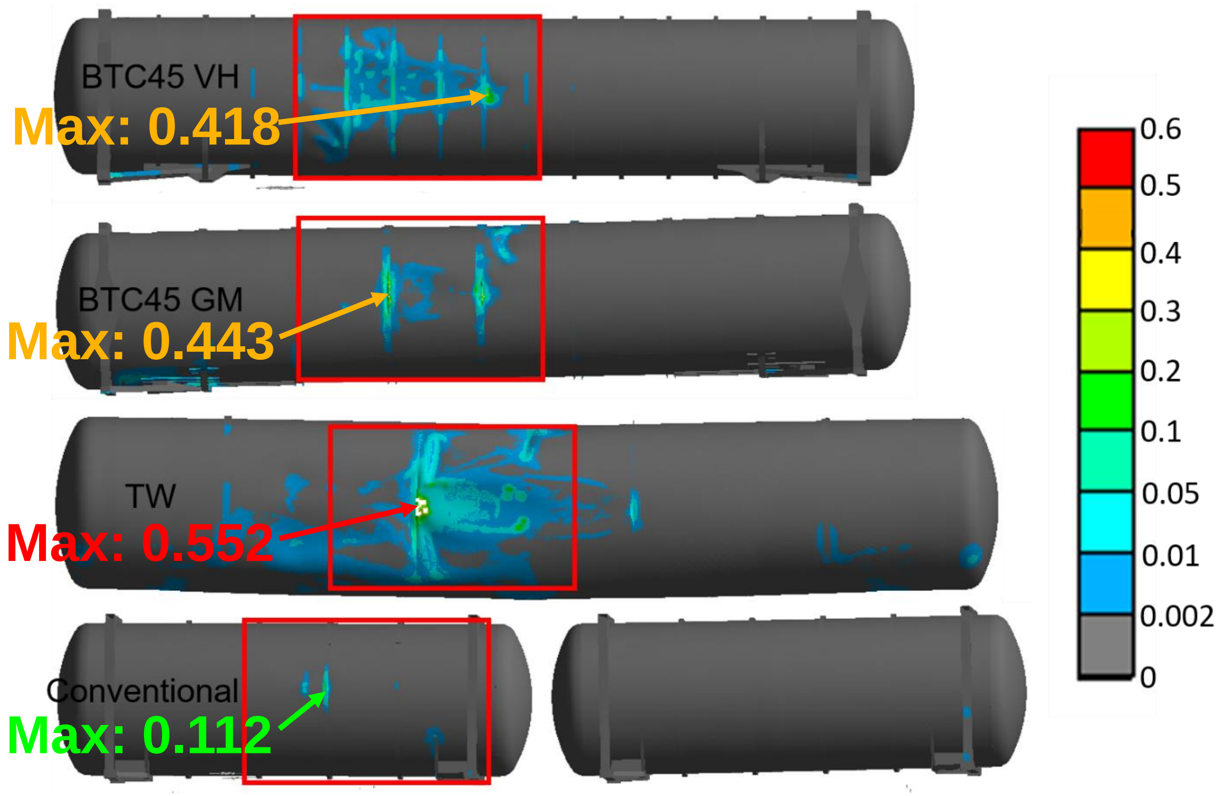
Plastic strain distribution on the impacted tank

45' B-TC VH/45' iCTW

45' B-TC GM/45' iCTW

TW

2x26' TC/52' iCTW



Plastic strain distribution on the impacted tank

Max plactic strain:

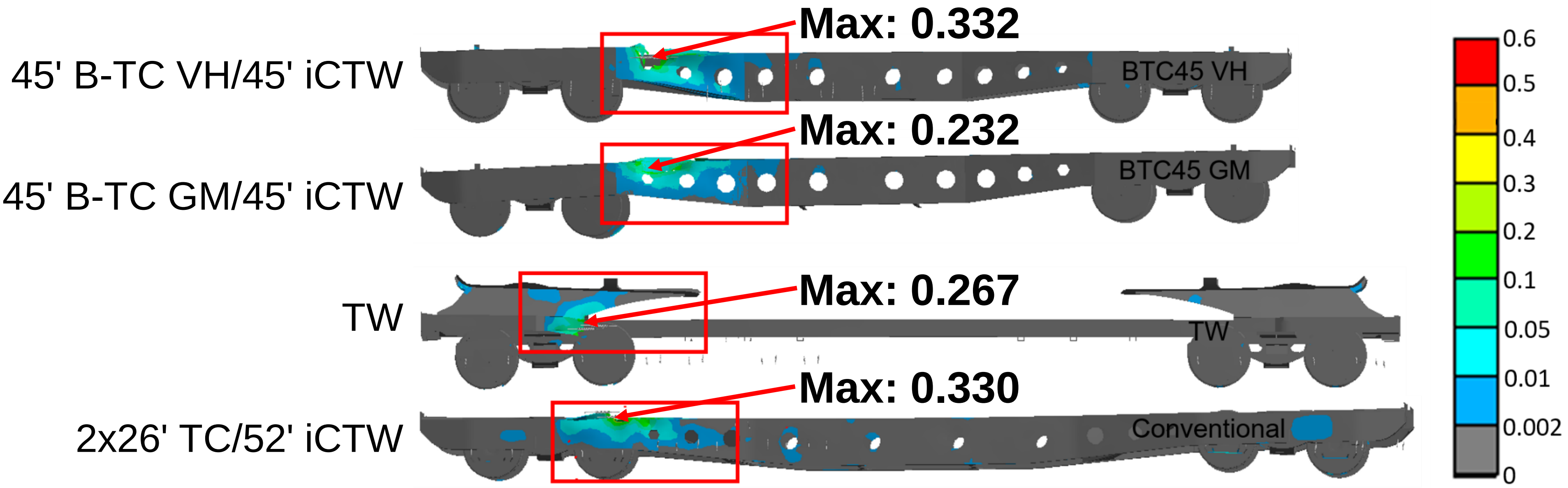
45' B-TC VH/45' iCTW – Max 0.418

45' B-TC GM/45' iCTW – Max 0.443

TW – Max 0.552

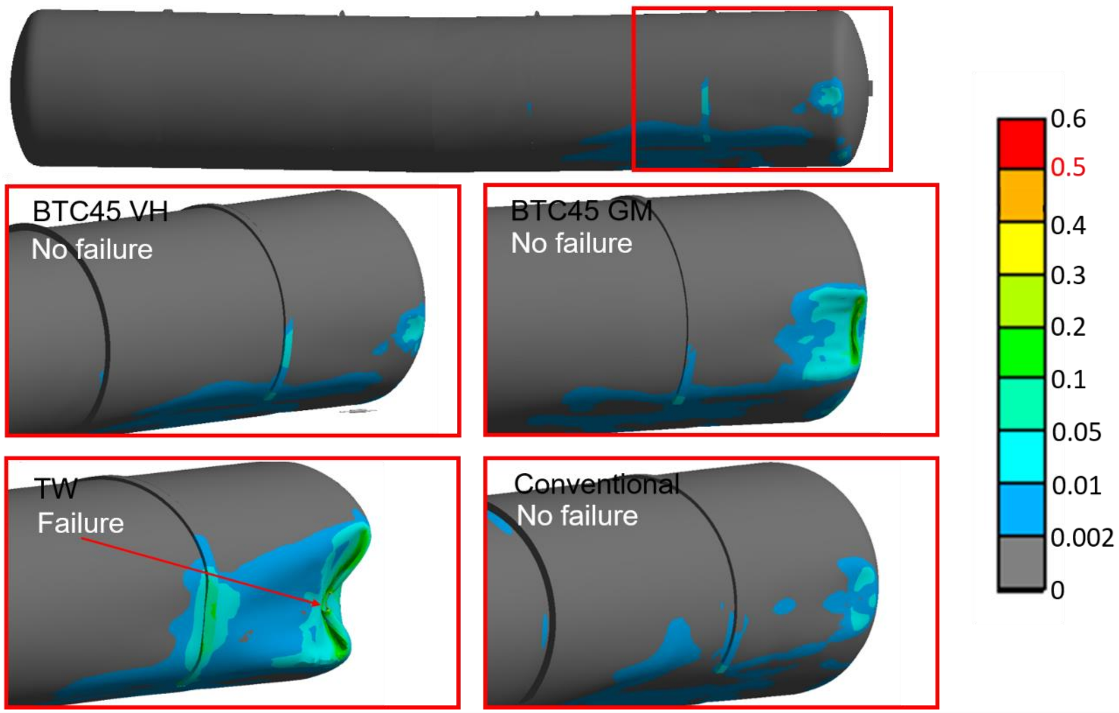
2x26' TC/52' iCTW – Max 0.112

Plastic strain distribution on the impacted wagon



Advantage of the longitudinal beams of the iCTW against tank wagon
Reasonable impact force ratio of the tank to the wagon

Plastic strain distribution on impacting tank



Most deformation in case of side-on impact between tank wagons

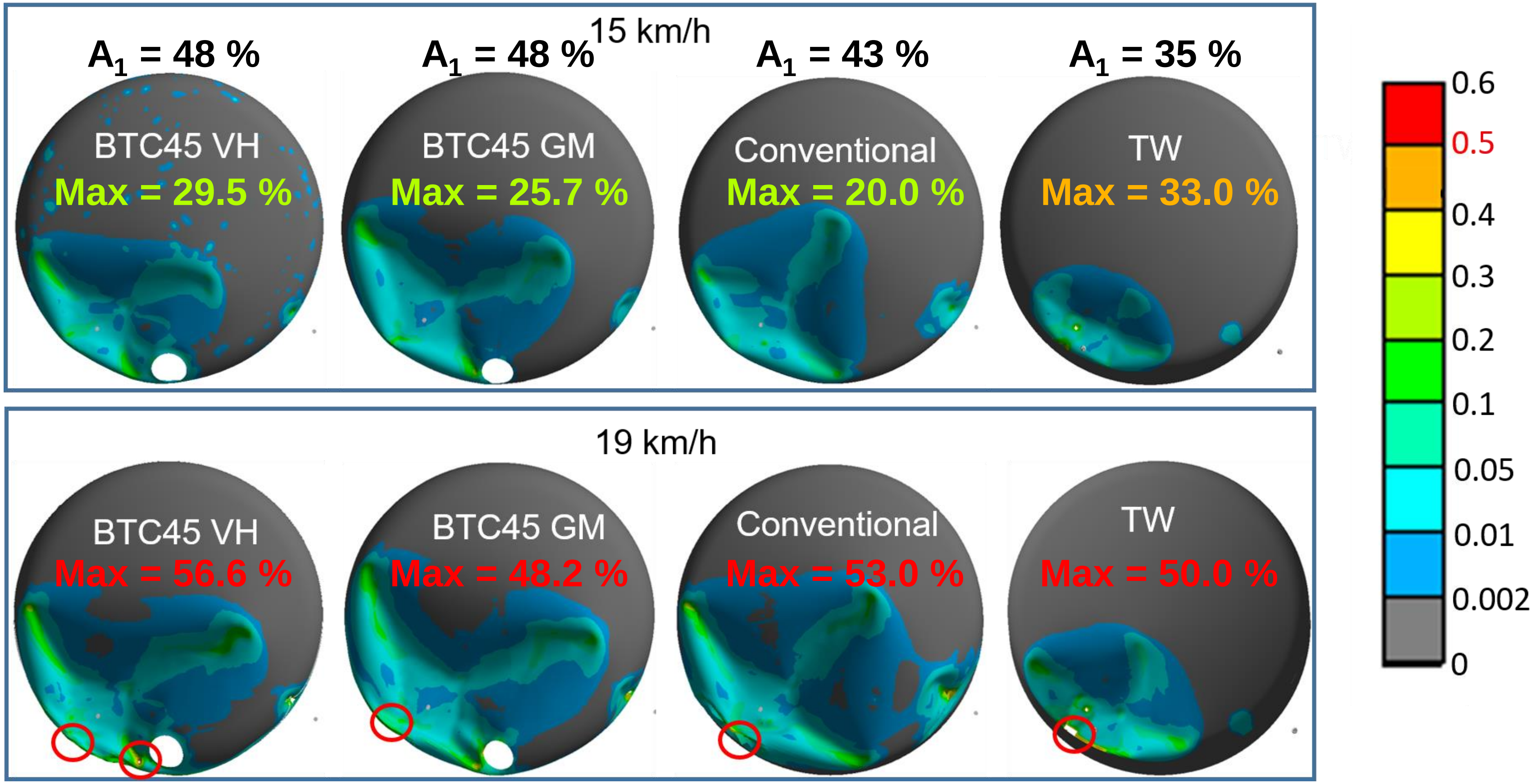
Both tanks failed!

Simulation results of side-on impact

Safety reserve = 1- Max. plastic Strain / A1

		TW-BTC45 VH	TW-BTC45 GM	TW-TW	TW-Conventional
A_1/Max. Strain	**Investigated tank**	50/**41.8**	48/**44.3**	35/**55.2**	43/**12.2**
	Safety reserve of investigated tank	**16.4 %**	**7.8 %**	**-57.7 %**	**71.6 %**
	Stationary car body	20/**33.2**	20/**23.2**	20/**26.7**	20/**33.0**
	Impacting tank	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**

Plastic strain distribution on tank bottom



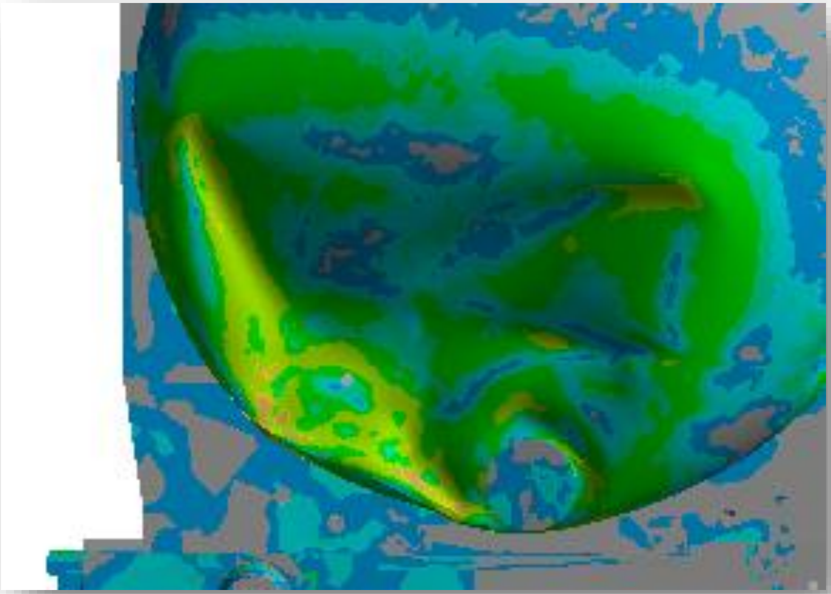
Technische Universität Berlin

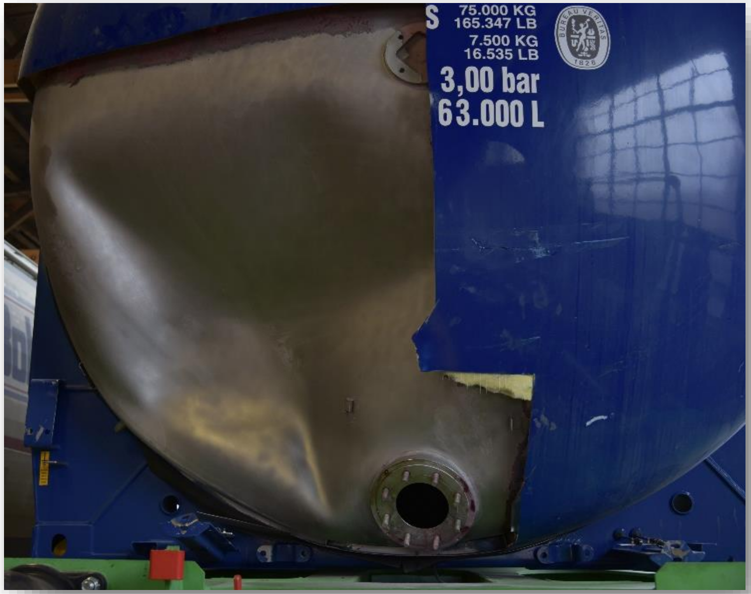
Simulation results of frontal impact

Safety reserve = 1- Max. plastic Strain / A1

	Tank Material Norm	Thickness Head / Shell [mm]	Equiv. Head Thickness [mm]	Equiv. Shell Thickness [mm]	Safety reserve (V_{imp}= 15km/h)	Safety reserve (V_{imp}= 19km/h)
TW	1.4571 DIN 17440	6.3 / 6.3	9.15	9.15	**5.71 %**	**-42.86 %**
Conventional	1.4404 SANS 50028-7	5.2 / 4.2	9.23	7.46	**53.49 %**	**-23.26 %**
BTC45 VH	1.4402 SANS 50028-7	7.9 / 3.4	15.82	7.07	**38.54 %**	**-17.92 %**
BTC45 GM		5.65 / 4.5	11.31	9.01	**46.46 %**	**-0.42 %**
BTC52 VH		7.9 / 3.4	15.82	7.07	**100 %**	n.a.

Impact test execution





Impacting wagon

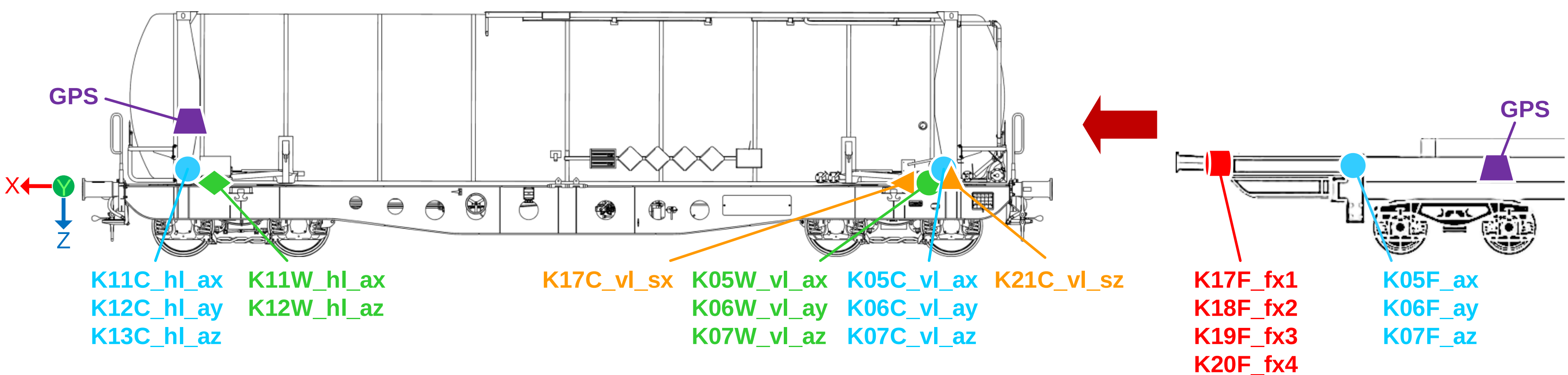
Flat wagon Rs 671 as an impacting wagon

Appropriately prepared Rs 671 for the impact tests

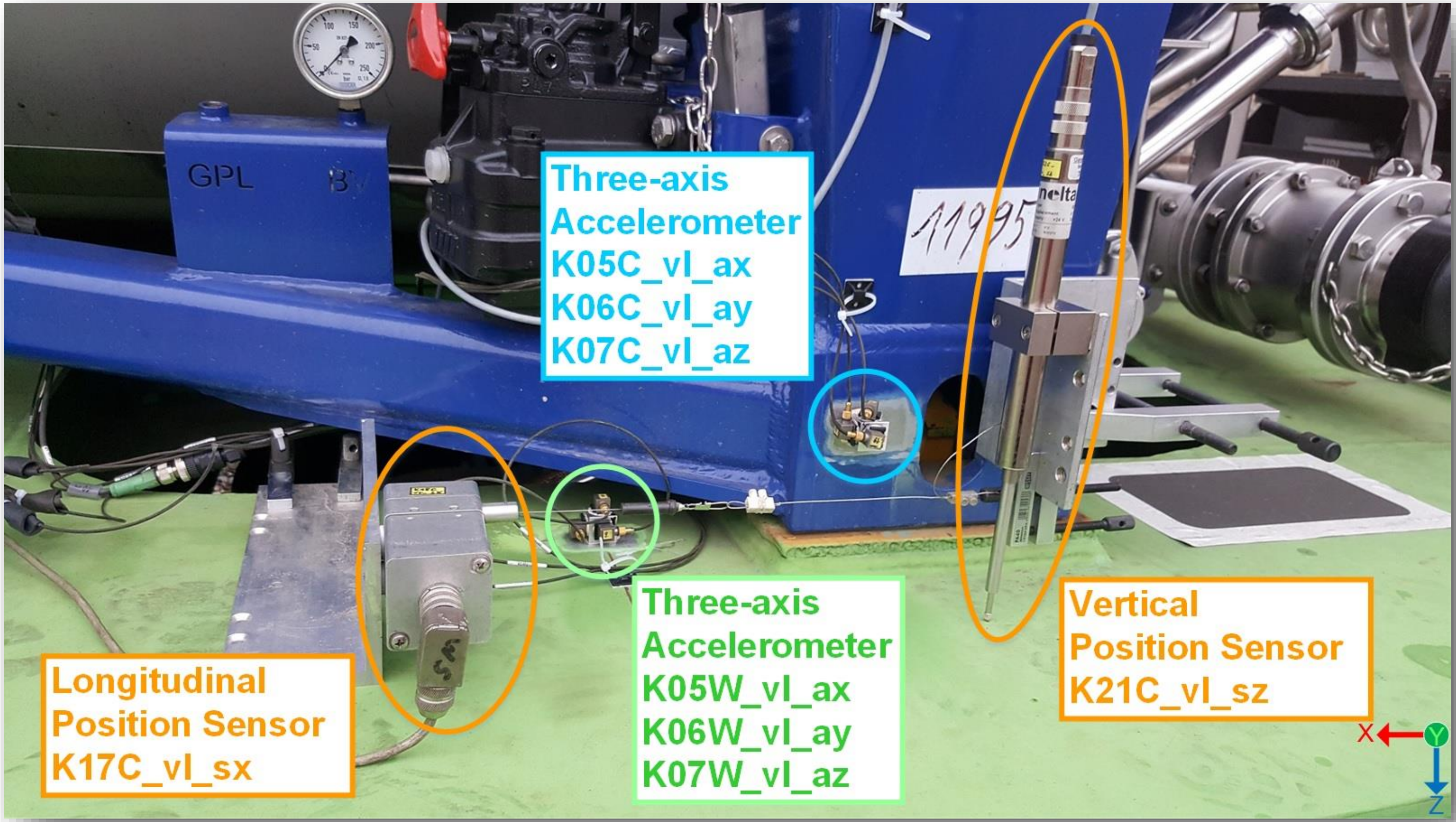
Instrumentation

- Measuring:
  - Accelerations & velocities
  - Container movement
  - Impact forces

	Measurement	Location
● (green)	3-axis Accelerometer	Car Body
◆ (green)	2-axis Accelerometer	Car Body
● (blue)	3-axis Accelerometer	Container
▲ (purple)	GPS Sensor	Container
◀ (orange)	Longitudinal Position Sensor	Car Body
▲ (orange)	Vertical Position Sensor	Car Body
■ (red)	Force transducer	Impacting Buffer

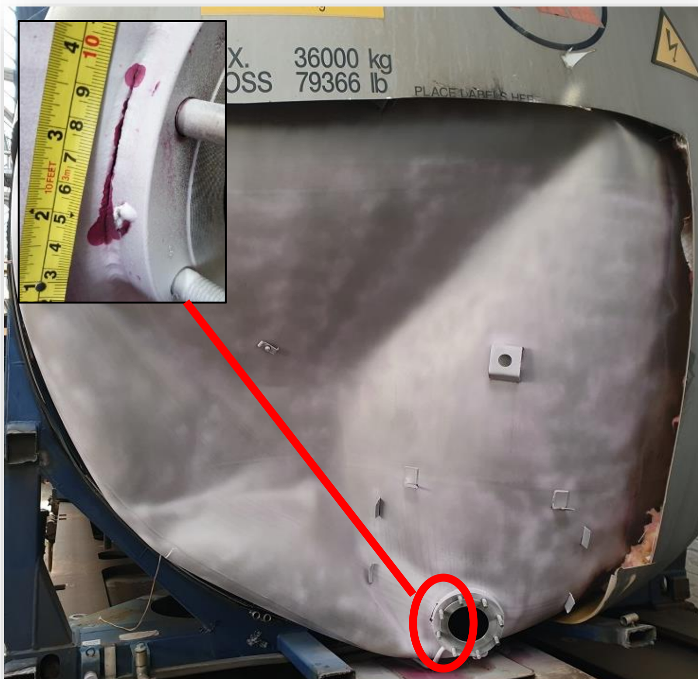


Measurement equipment on B-TC/iCTW System (front left)

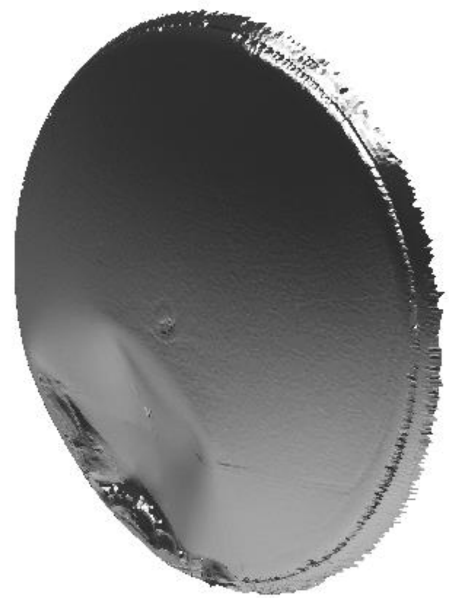


Impact test evaluation

Crack testing per liquid penetrant inspections

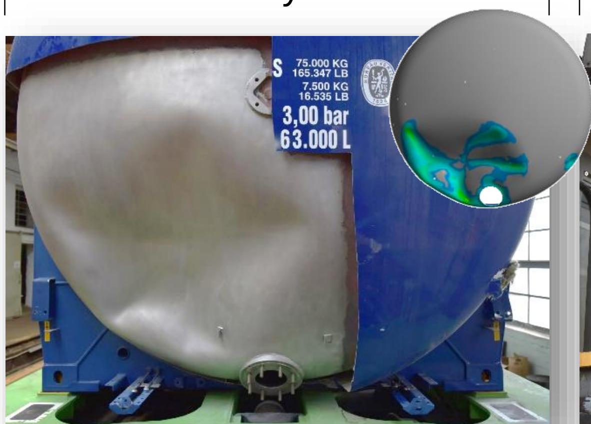


Deformation of tank per 3D-Scan



1: Different Systems

New System | Conventional System



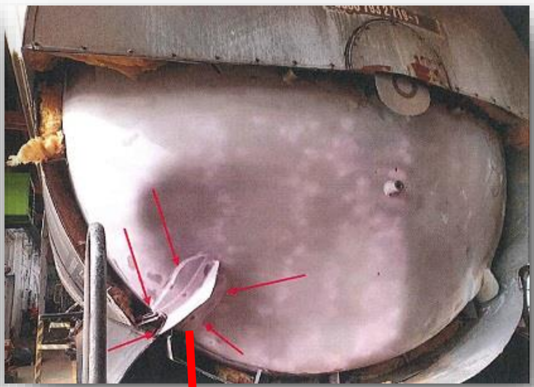
- **B-TC Van Hool on iCTW**
- Equiv. thickness in mild steel: (calculated acc. RID §6.8)
  Shell 7.1 mm, Head 15.8 mm
- No leakage
- Deformation: 90 l

- **Tank wagon**
- Equiv. thickness in mild steel:
  Shell 9.2 mm, Head 9.2 mm
- No leakage
- Deformation: 100 l

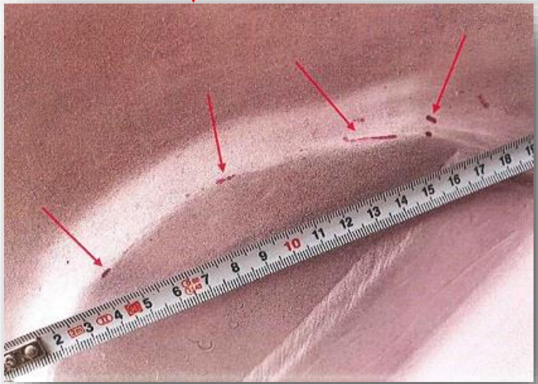
- **ISO-TC on intermodal wagon**
- Equiv. thickness in mild steel:
  Shell 7.5 mm, Head 9.2 mm
- No leakage
- Deformation: 390 l

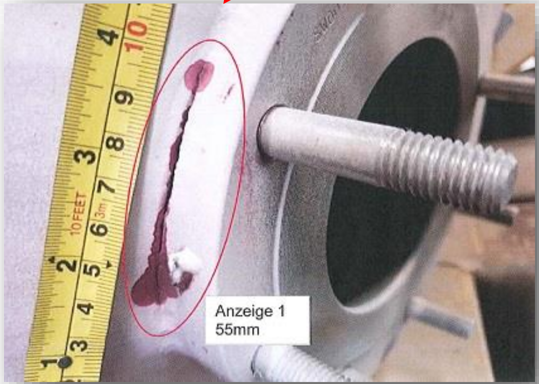
1: Different Systems – PT Results

New System | Conventional System



- **v = 15 km/h**
- No crack on BTC VH
- Cracks on conventional systems

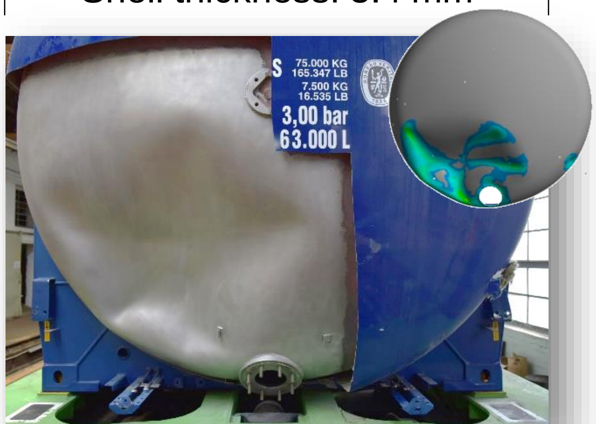




Technische Universität Berlin

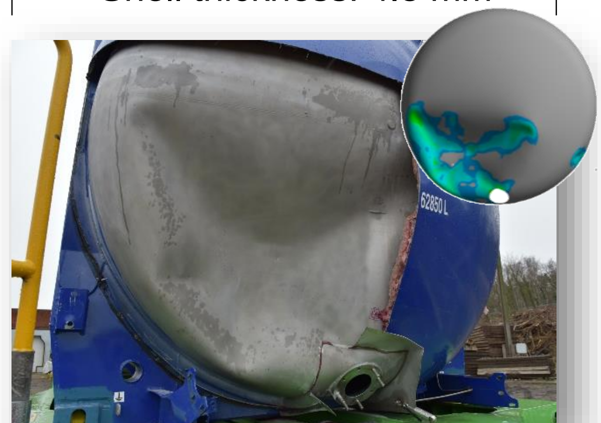
2: Shell thickness

Shell thickness: 3.4 mm



- Equiv. shell thickness: 7.1 mm
- Equiv. head thickness: 15.8 mm
- Deformation: 90 l

Shell thickness: 4.5 mm



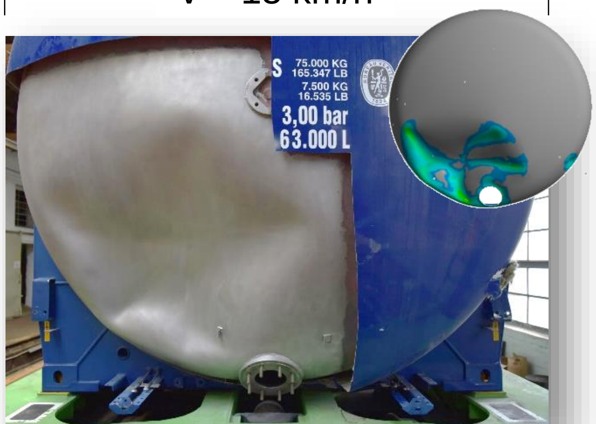
- Equiv. shell thickness: 9 mm
- Equiv. head thickness: 11.3 mm
- Deformation: 190 l

No deformation at frame and cylinder surface on either containers

Comparable deformation at container bottom

3: Increased velocity

v = 15 km/h	v = 19 km/h



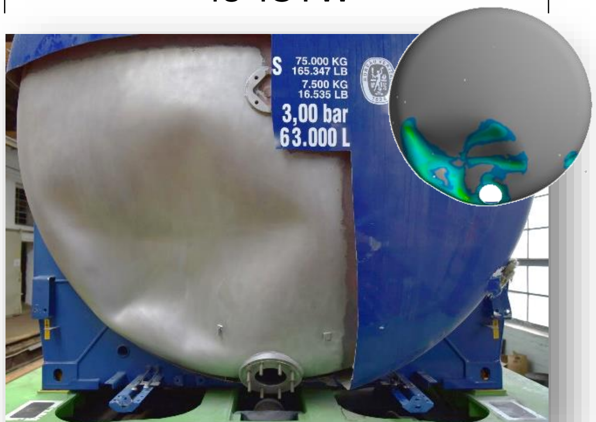
- Shell thickness: 3.4 mm
- Head thickness: 7.9 mm
- Deformation: 90 l

- Shell thickness: 3.4 mm
- Head thickness: 7.9 mm
- Deformation: 210 l

Increasing deformation with increasing velocity - no leakage

4: Increased car length

45' iCTW



52' iCTW

- Shell thickness: 3.4 mm
- Head thickness: 7.9 mm
- Deformation: 90 l

- Shell thickness: 3.4 mm
- Head thickness: 7.9 mm
- Deformation: 0 l

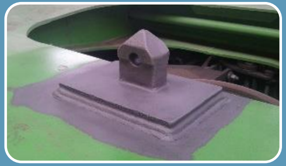
Impact car stopped by bogie before reaching container with 52' iCTW

Conclusions for running safety

New System with comparable running stability on straight tracks, curves and at hump yard

Detected sloshing movements with no effect to driving safety

- Specific filling degree for containers in rail transport not recommended → adjust to Rail Tank Cars
  (RID -chapter 1.6.4.33)



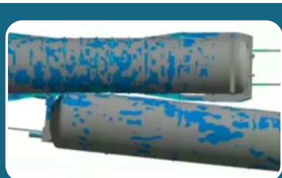
No damage on new, high-strength spigots

- New components suitable for all intermodal transport units
  (EN 12663-2, RID -chapter 6.8.2.1.2)

No damage on any component after hump yard tests

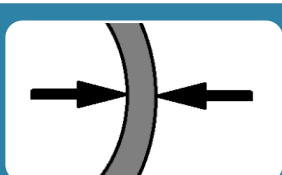
- All loaded iCTW suitable for hump yard
  (EN 12663-2)

Conclusions for failure status / Impact



RTC only vessel with leakage for side impact

- Safety level of conventional system exceeded
- Longitudinal beams of iCTW improve safety for side impacts



Minimum shell thickness with no effect on frontal impact safety

- Amendment of regulations for minimum shell thickness not necessary
  (RID -chapter 6.8.2.1.17; 6.8.2.1.18; 6.8.2.1.19 and 6.8.2.1.20)
- No leakages for all systems – equivalent safety level.

The larger distance between tank-head and buffer of the Rail Tank Car has no positive safety effect compared to the B-TC

- Minimum distance not recommended for TC / B-TC
  (RID -chapter 6.8.2.1.29)

A positive safety effect for both systems can only be reached by a significant distance increase

- Safe replacement for Crash-buffers and overbuffering protection
  (RID TE25)

Contact Person

Technical University of Berlin

Gökhan Katmer, M.Sc.

Matthias Gülker, M.Sc.

Qiuyong Tian, M.Sc.

Ulrich Deghela, M.Sc.

Department of Rail Vehicles

Office SG 14

Salzufer 17-19, D-10587 Berlin, Germany

Phone: +49 (0)30 314 - 25195 (Secretariat)

Fax: +49 (0)30 314 - 22529

www.schienenfzg.tu-berlin.de