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Proposals for amendments to annexes A and B of ADR:
construction and approval of vehicles

INF.5

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Rear Protection of vehicles – 9.7.6 ADR

Transmitted by the Government of Germany

Summary

Executive summary:	As announced at the 94th session, the German delegation presents a research report prepared by the German Federal Institute for Materials Research and Testing (BAM) on the design of the rear protection in accordance with section 9.7.6 of ADR and invites the other delegations to WP.15 to discuss conclusions of the research findings.
Action to be taken:	Acknowledgement; discussion; proposal for the future course of action
Related document:	Report ECE/TRANS/WP.15/219 on the 94th session, paragraphs 25 to 27
	Informal document INF.20 - (Germany) Section 9.7.6 Rear protection of vehicles

Federal Institute for Materials Research and Testing (BAM)

Project 0433/2012

Determination of the energy absorption capacity of metal sections on tank-vehicles carrying dangerous goods for the assessment of safety reserves by way of numerical simulation and verification of the latter by means of practical tests

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Final report - 1 June 2012 - Translation

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Nomenclature

Abbreviations	Description
ADNR	Regulations for the Carriage of Dangerous Goods on the Rhine
ADR	European Agreement concerning the International Carriage of Dangerous Goods by Road including the special arrangements signed by all states involved in the carriage
RP	Rear protection
BAB	Federal motorways
BMBF	Federal Ministry of Education, Science, Research and Technology
BMVBS	Federal Ministry of Transport, Building and Urban Development
EU	European Union
FEM	Finite element method
GGVSEB	Ordinance on the Domestic and International Transport of Dangerous Goods by Road, Rail and Inland Waterways
GGVSee	Ordinance on the transport of dangerous goods by sea
IAEA	International Atomic Energy Agency
IMDG Code	IMO regulations on the transport of dangerous goods by sea
IMO	International Maritime Organization
MKS	Multibody simulation
MN	Meganewton
RID	Regulations concerning the International Carriage of Dangerous Goods by Rail
StVO	German Road Traffic Regulations
StVZO	German Road Traffic Registration Regulations
TV	Tank-vehicle
THESEUS	Tank-vehicles with maximum attainable safety through experimental accident stimulation
TTS	Test Site Technical Safety (of the Federal Institute for Materials Research and Testing - BAM)
URP	Underrun protection
UN	United Nations
UNECE	United Nations Economic Commission for Europe
WP. 15	Working Party on the Transport of Dangerous Goods at UNECE

1. Introduction

The conditions for the transport of dangerous goods are laid down in mode-specific regulations. For road and rail, they are laid down in the annexes to RID/ADR. At the national level, they are implemented by the GGVSEB.

The technical requirements “dangerous goods vehicles” have to meet are included in Part 9 of the ADR, among others. They also govern the cross-border transport of the EU Member States as regards the transport by road. In this connection, section 9.7.6 describes requirements for the rear protection of vehicles. The main requirements are that a bumper sufficiently resistant to rear impact be fitted over the full width of the tank at the rear of the vehicle and that there be a clearance of at least 100 mm between the rear wall of the tank and the rear of the bumper. In addition, a means of protection that protects the shell in the same way as a bumper is required for vacuum-operated tanks and tilting shells with rear discharge.

The provision does not contain binding specifications for technical requirements, such as strength properties, the vertical position on the vehicle, or tests. The discussion as to whether these requirements ensure an effective protection of the rear of tank-vehicles has been going on for years. Some experts even believe that the tank could be ripped open by an angular underrun protection in the event of an accident and suggest that this particular protection measure is counterproductive. Moreover, there are frequent queries regarding the way the said 100 mm are measured that are answered based on individual points of view.

The findings of various studies led to proposals submitted by Germany (see ECE/TRANS/WP.15/2010/15, proposals for amendment]) to the WP.15 in Geneva (UNECE Working Party on the Transport of Dangerous Goods) that aim to improve the effectiveness of protective measures, such as a rear protection, and to have them laid down in ADR. These proposals are not supported by all representatives of the ADR Member States. This is due to the analysis of national accident statistics and the assumption that excessively fast driving on German motorways as a consequence of the lack of a general speed limit leads to a concentration of accidents. However, studies (see [Pötzsch et al., Machbarkeitsstudie, 2009]) show that there is a high percentage of rear-end collisions also in neighbouring countries. Accordingly, this is a transnational problem. Studies conducted within the framework of the research project THESEUS (see [BMBF, THESEUS, 1995]) concluded, with regard to the protection of the transport tank of tank-vehicles, that a rear-end collision only resulted in failure of the tank if a commercial vehicle crashed into the

rear of the tank-vehicle, with the failure criterion being the release of cargo. This lessens the significance of the speed limit argument with a view to the occurrence of a tank penetration, since these vehicles are designed in such a way that they can reach a maximum speed of approximately 90 km/h under normal driving conditions (see [Bouska/Leue, Straßenverkehrs-Ordnung, 2007]).
BAM conducted calculation-based investigations of these rear protection sections using the finite element method (FEM) in order to gain better insights into their protective effect. Upon conclusion of the model calculations, the findings were verified by way of practical tests with protective sections used in vehicle manufacturing (see [Haas, Energieaufnahme-Simulation, 2011]). To this end, quasi-static and dynamic tests were performed. The calculation-based predictions and the practical tests were performed on underrun protection sections in conformity with regulation ECE-R 58 and permitted for use as rear protection section.

This is the usual approach for the verification of results obtained by way of simulation calculations. A key objective of the work was to obtain reliable information regarding the use of a separate means of protection at the rear of tank-vehicles carrying dangerous goods with a view to an energy absorption capacity of 150 kJ, which is a target value taken from the THESEUS study (see [BMBF, THESEUS, 1995, p. 124]). Well-founded information on the resilience of protective sections was previously not, or not sufficiently, available. In conclusion, a recommendation regarding the incorporation of Germany's requests into international dangerous goods legislation (ADR) for the protection of the rear of tank-vehicles is to be presented in a more well-founded manner than before.

2. Motivation and presentation of the problem

There are various aspects to consider when carrying out studies on means of protection at the rear of tank-vehicles. First, there are the currently applicable national and international legal provisions on the safety of tank-vehicles in the event of rear-end collisions. A further aspect is the technical design of such systems against the background of previous tests and findings as well as numerical simulations on this subject. In this connection, a change of ADR regulations may be advisable. Various technical options for the effective protection of the rear of tank-vehicles against rear-end collisions are known and have been presented. This also applies to the protection of a transport tank against a loss of cargo following a rear-end collision (see [Pötzsch et al., Machbarkeitsstudie, 2009, p. 26-30]). It is to be assessed whether a combination of such measures can improve the effectiveness of this protection with reasonable effort.

The installation of an underrun protection is a stand-alone measure for the protection of vehicles crashing into the rear of commercial vehicles. A further measure relevant to tank-vehicles is the installation of a rear protection for the protection of the tank. As already mentioned, ADR governs the cross-border transport with road vehicle in Europe. It is then implemented at the national level in the individual European Member States. In Germany, the Road Traffic Registration Regulations (StVZO) fulfil this function. Both sets of rules are legally valid, but they do not always describe and regulate a specific subject matter in an identical manner in terms of the requirements they impose. Thus, Section 32b StVZO requires certain vehicles (with a speed of more than 25 km/h, a clear height of 55 cm above the road and a distance between the rear end of the vehicle and the last axle of 1000 mm) to be equipped with an underrun protection (URP). The technical requirements the URP has to fulfil are laid down in an EU directive. In addition, a mandatory test has been established for this underrun protection. Its purpose is to prevent passenger cars from sliding underneath the rear of the vehicle in front.

The rear protection (RP) in accordance with section 9.7.6 of ADR requires that "A bumper sufficiently resistant to rear impact shall be fitted over the full width of the tank at the rear of the vehicle. There shall be a clearance of at least 100 mm between the rear wall of the tank and the rear of the bumper".

According to the wording of the text, the tank must be protected over its full width. This objective is to be achieved by way of a sufficiently resistant bumper. However, no performance parameter is specified or required by ADR along with the attribute "sufficiently resistant". This results in room for interpretation regarding the strength of the section and its installation. The vertical position is not specified either. Therefore, in practice, it is often possible to "replace" the requirements for the rear protection prescribed by ADR – whose function it is to protect the tank from failing – and the underrun protection required by the German Road Traffic Registration Regulations (StVZO) by a stand-alone underrun protection. Thus, the underrun protection also functions as rear protection (see Figure 1).

Figure 1: Vehicle with underrun protection

It is also possible to meet the statutory requirements of ADR by installing a separate rear protection, as shown in Figure 2.

Figure 2: Tank-vehicle with underrun protection and rear protection

Thus, it is possible that tank-vehicles are equipped with a variety of different means of protection at their rear. The wording of ADR has yet another deficit that is due to the organizational procedures for the development of regulations. The recommendations for the development of ADR, which take the form of proposals, may only be submitted in officially recognized languages (see [UN, E/ECE/778/Rev.5, Rules, 2009, p. 13]). Subsequently, a translation into the appropriate national language is produced. Here, mistakes can be introduced which can then lead to diverging interpretations. Thus, the original reads: "There shall be a clearance of at least 100 mm between the rear wall of the tank and the rear of the bumper (this clearance being measured from the rearmost point of the tank wall or from projecting fittings or accessories in contact with the substance being carried" (see [UN, ADR 2011, p. 644]). In the English language, the term clearance refers to the unobstructed distance between two points which essentially only contains air. The German translation only uses the German word for "distance". Since the position of the back of the bumper is not clearly identified – it depends on the location of the onlooker – there are two different design options regarding the distance to the tank (see Figure 3). In the German interpretation, the unobstructed distance is reduced by the depth of the bumper which lowers the protective potential of the measure.

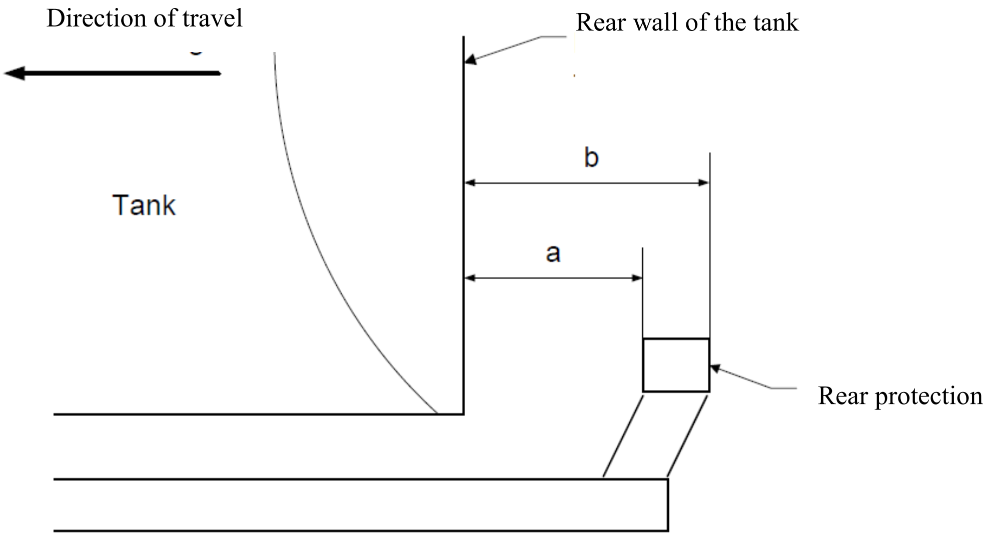

Figure 3: Interpretation of the distance to the tank wall in Anglo-Saxon countries (a) and on the continent (b)

Concrete technical specifications are provided for the requirements the underrun protection has to meet (see [EU Directive 2006/20/EC]). Tests are required in which specified performance criteria have to be fulfilled. Calculation-based proof is also admissible. After passing these tests, an EC type approval can be issued which approves the underrun protection. The technical requirements these sections have to meet are to be made substantially more stringent in the future.

3. Objective

The objective of this work is to investigate the effectiveness of a separate rear protection on tank-vehicles. To this end, below theses were to be verified or falsified (see 3.2 Theses for the test series). Aspects relevant to type approval were taken into account in the investigations. A comprehensive investigation on the installation on the vehicle and the further transmission of force into the vehicle by these protective systems was not conducted.

Beforehand, a dissertation entitled "Determination of the energy absorption by the rear protection of dangerous goods vehicles by way of numerical simulation" ("Ermittlung der Energieaufnahme des hinteren Anfahrschutzes an Gefahrgutfahrzeugen mittels numerischer Simulation“) was prepared in order to assess the energy absorption capacity in the event of a rear-end collision (see [Haas, Energieaufnahme-Simulation, 2011]). The propositions put forth by the dissertation were to be confirmed or rejected by way of quasi-static and dynamic tests. They are listed in the following:

3.1 Propositions of the dissertation

- The crash behaviour of the rear protection of tank-vehicles carrying dangerous goods in the event of a rear-end collision can be simulated realistically with the help of simulation software.
- In the event of a rear-end collision, the energy absorption capacity of an underrun protection section (U section that is almost open towards the back) is extremely low.
- Comprehensive design changes, e.g. using deformation elements, can increase the energy absorption significantly.
- The target value of E=150 kJ is almost impossible to achieve.
- It is necessary to adapt the international regulations to include more stringent requirements for the rear protection to reduce the risk of severe injuries to persons and damage to the environment in the event of a vehicle crashing into the rear of a tank-vehicle carrying dangerous goods. (see [Haas, Energieaufnahme-Simulation, 2011])

3.2 Questions to be answered

- Can the assumptions used in the model calculation for the determination of the loads a protective section is subjected to be modelled in a realistic manner and verified in the tests?
- Can an energy absorption capacity of 150 kJ be achieved by means of a suitable construction, such as the rear protection, as a stand-alone measure?
- Can the effectiveness of existing protective systems be improved by adapting the regulations to include minimum requirements so as to reduce the risk of substantial damage to the tank in the event of a rear-end collision?
- Can manufacturers of accessories perform sufficiently precise tests based on existing test setups and procedures (tests), or is it necessary to develop a suitable procedure?

4. Quasi-static tests

The model used for the calculation with the finite element method or with other comparable methods (e.g. multibody simulation MKS) as well as its framework conditions are to be verified by means of experimental investigations. In particular in the present configuration, this step is essential.

For the practical tests, underrun protection sections made from aluminium and steel were used. In order to verify the information gained in the preparatory work for the determination of the energy absorption capacity, quasi-static and dynamic tests were carried out on the test site (BAM TTS Horstwalde). The law requires that the underrun protection be subjected to quasi-static tests. Since a real accident usually involves a great number of dynamic elements, dynamic tests were carried out additionally. This provided the basis for the comparability of the test results. A total of seven sections including their mounting brackets were subjected to a quasi-static load. Four of the sections were made from aluminium (AlMgSi 0.7 / specification EN AW 6005) and three from steel (fine-grain alloy S 650 MC; in accordance with EN 10149-2).
For the test setup, two IPE 260 beams were used to represent the longitudinal beams of the HGV which were bolted to a massive IPE 400 beam (see Figure 4). The IPE 260 beams served as replacement for the real vehicle frame and as support for the rear protection that could be mounted on them. They were fitted at a distance of 980 mm from one another. This distance is realistic for tank-vehicles without dual formation. The force was applied to the weakest spot – the spot with the maximum bending moment – centrally and via an indenter. The test setup as well as the indenter were modelled after the underrun protection test, since a different, more realistic construction using a HGV frame would have required unreasonable effort.

Figure 4: Tension-compression testing machine with aluminium underrun protection and end support

In the tests, the force applied by the testing machine was recorded along the distance. A maximum distance of 120 mm was selected so as to ensure that the required 100 mm distance between tank wall and rear protection was captured. A force transducer from Hottinger Baldwin Messtechnik (HBM) – model C6A – with a maximum nominal force of 5 MN (see [HBM, Montageanleitung, 2012]) was used to record the force. It is capable of recording within a realistic measuring range.

4.1 Results of the quasi-static tests

The results of the recordings are visualized in Tables 1 and 2 by determining the integral

$$W = \int F \, ds \qquad (1)$$

for the steel section and the aluminium section. For further illustration, Figure 6 and Figure 8 show the load-displacement curves for the steel sections and the aluminium sections, respectively.

	Point 1	Point 2	Point 3	
Distance s	x=92 mm	x=100 mm	x=120 mm	
Absorbed energy	W in kJ	W in kJ	W in kJ	
Specimen nos.				
11059	6.58	7.23	8.89	
11065	8.00	8.69	10.51	
11066	7.75	8.43	10.13	
Average	7.44	8.12	9.85	
Standard deviation	0.62	0.64	0.69	Average of the standard deviation in %
Standard deviation in %	8.34	7.83	7.03	7.74

Table 1: Energy absorbed by steel section with mounting brackets

From Table 1, it is evident that a rear protection made from steel can absorb a maximum of 8.69 kJ of energy over a distance of 100 mm. In this test series, an average of 8.12 kJ was determined. Thus, this value exceeds the value determined in the computer-based preliminary investigation (see [Haas, Energieaufnahme-Simulation, 2011]).

4.2 Discussion of the test results

For comparable steel products (fine grain steels S355MC, S420MC and S550MC), an energy absorption of between 2.33 kJ and a maximum of 5.12 kJ was determined. Based on the tests, it was possible to demonstrate that the calculation-based assessment indicates a lower energy absorption capacity and accordingly makes an earlier component failure seem likely.

	Point 1	Point 2	Point 3
Distance s	x=90 mm	x=100 mm	x=120 mm
Absorbed energy	W in kJ	W in kJ	W in kJ
Specimen nos.			
11061	5.38	5.90	7.05
11062	5.43	5.97	6.96
11063	5.20	5.73	6.69
11064	5.42	5.97	7.06
Average	5.35	5.89	6.94
Standard deviation	0.09	0.10	0.15
Standard deviation in %	1.74	1.72	2.15
Quotient (mm/kJ)	16.81	16.97	17.29
Average quotient	17.00		

Table 2: Energy absorbed by aluminium section with mounting brackets

As Table 2 shows, the aluminium section can absorb a maximum of 5.97 kJ of energy over a deformation path of 100 mm. An average of 5.89 kJ was determined. With regard to these values, it should be noted that a considerable amount of energy was transmitted into the mounting brackets. When comparing the sections without mounting brackets, a higher energy input into the aluminium than into the steel underrun protection was recorded (see Figure 5, Note: different cross sections!). The influence of the brackets on the energy input is by no means negligible.

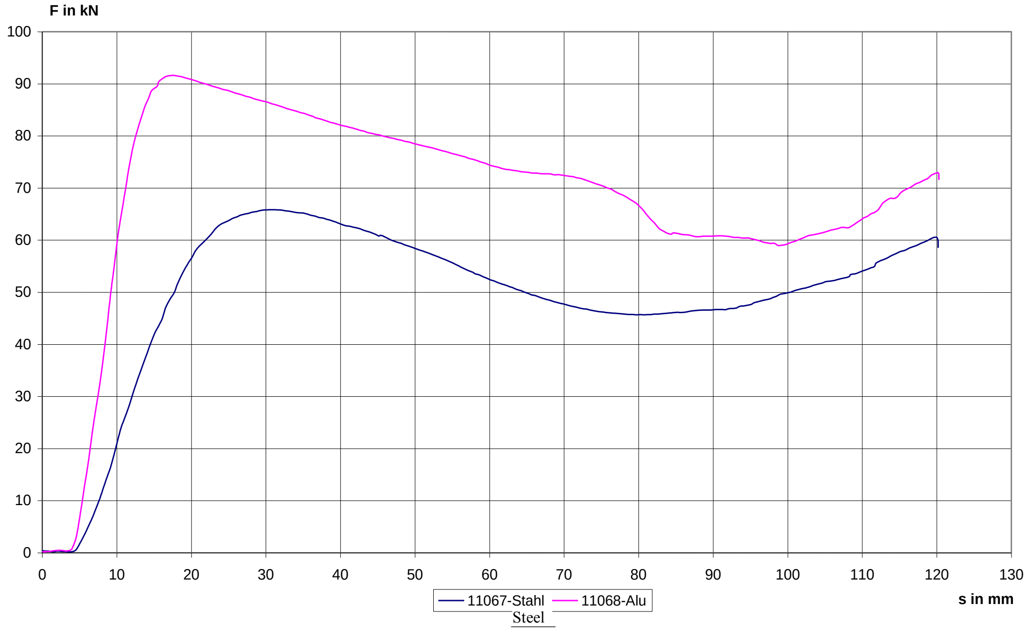

Figure 5: Load-displacement diagram without mounting brackets

Since, in the finite element based calculation, the material was varied by using different steel products, a further discussion taking into account the results of this practical work is necessary.

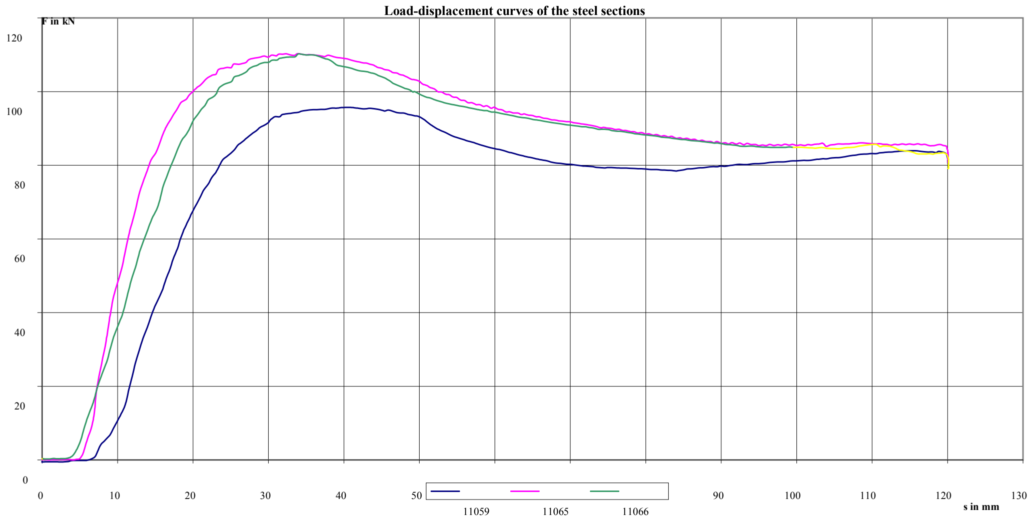

Figure 6: Load-displacement diagram of the steel sections

Above curves show the deformation path of the steel sections (see Figure 6). The initial part of the curve is linear reflecting the deformation path up to where the section buckles. The buckling occurs when forces of 95 and 110 kN are applied. Up to this point, a significant change in the gradient of the curves is visible. This is probably due to the simple forming process used in the manufacturing.

The webs of the sections are not parallel to one another which promotes their bending up during the application of the load. The webs have a semicircular form where the indenter touches them; this also promotes the bending up of the section. The damage patterns show that all steel sections were bent outwards (see Figure 7).

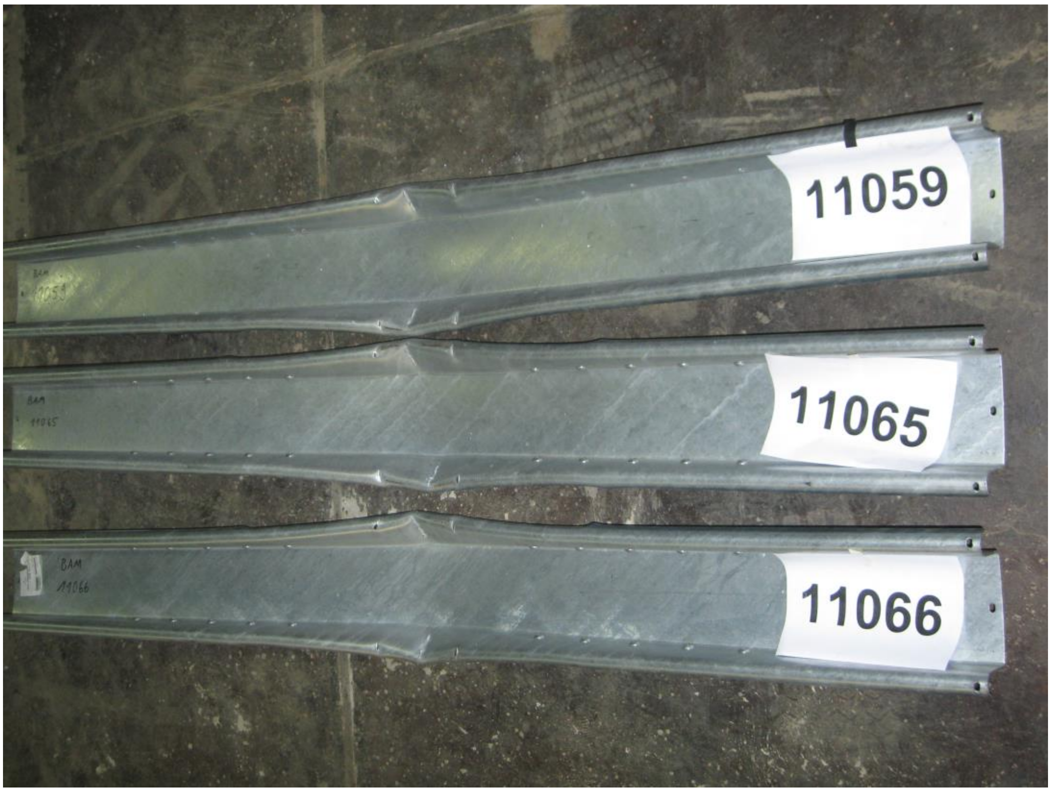

Figure 7: Damage patterns of the steel sections

In their later part, two of the three load-displacement curves run relatively level while one curve rises (test no. 11059). Initially, the test piece is deformed elastically within the linear part. As the load increases, plastic deformation occurs. Once the maximum load is exceeded (1st and 2nd order theory), the section buckles. This is linked to an increase in deformation under smaller loads.

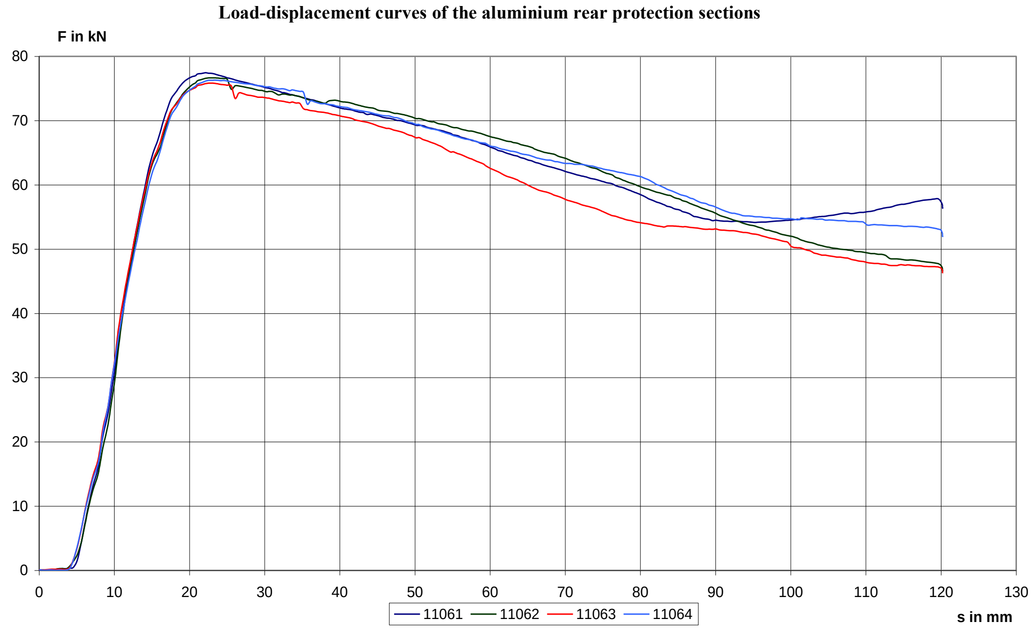

Figure 8: Load-displacement diagram of the aluminium sections

As can be seen in the curves above, the deformation behaviour of the aluminium sections (see Figure 8) is almost identical up to where the buckling occurs at around 25 mm. Although aluminium is a material that is naturally well suited for deforming due to its face-centred cubic lattice structure (FCC lattice), the section is, as a result of its more complex manufacturing process, nevertheless capable of withstanding forces of up to almost 80 kN before buckling begins. Figure 9 shows the damage pattern after application of the load.

Figure 9: Aluminium section after application of quasi-static load

5. Dynamic tests

Dynamic tests were carried out on the TTS in Horstwalde to investigate the energy absorption of underrun protection (URP) systems. Compared to the quasi-static tests, they simulate an accident more realistically. In practice, rear-end collisions always occur dynamically, i.e. with a difference in speed (Δv) between the vehicles involved in the accident. According to the THESEUS study, the average difference in speed is 5.75 m/s (see [BMBF, THESEUS, 1995, p. 123]). Moreover, comparing the results of quasi-static and dynamic tests provides insights into the magnitude of the dynamic component. This quotient is the ratio of bend and work (see chapter 6 “The comparative test factor”) and is listed in Table 2.

5.1 Test setup and performance

The dynamic tests were carried out using a guided drop test stand on the BAM Test Site Technical Safety (TTS) in Horstwalde. Unlike with the quasi-static tests, the IPE 260 used to mount the URP sections were used further, with a steel fundament embedded in concrete on which the test pieces could be mounted assuming the function of the IPE 400 (see Figure 10).

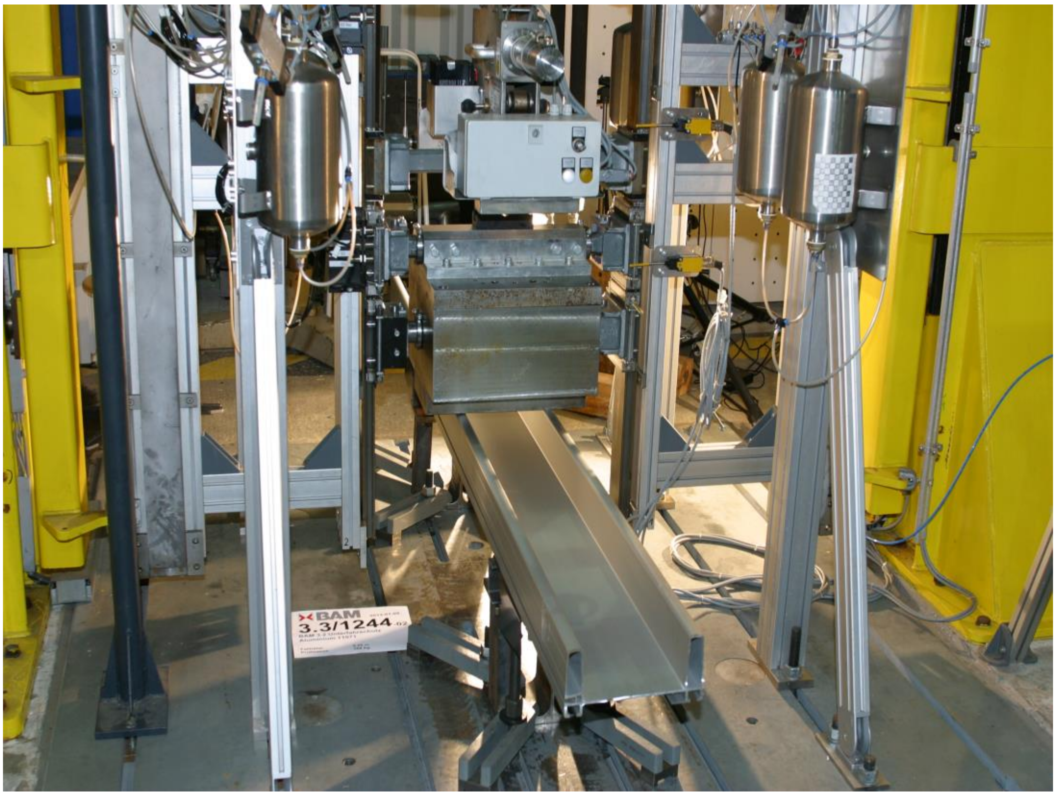

Figure 10:Test setup for dynamic tests at the guided drop test stand

5.2 Measurement

To allow for the determination of dynamic test components, the stand generally offers the possibility to work with potential energy or kinetic energy. In both cases, a mass is dropped on a test piece. The energy input resulting from the potential energy is determined as follows:

$$E_{pot} = m*g*h \qquad (2)$$

m= mass, g = gravitational acceleration, h= height above ground

The energy input resulting from the kinetic energy is determined as follows:

$$E_{kin} = \frac{1}{2} m*v^2 \qquad (3)$$

m= mass; v= velocity

Both options allow for the input of energy into the component to be tested. As is known from previous tests, the weather conditions in December result in an increased resistance value in the roller bearings of the guideway for the masses. This has a detrimental effect on the results of the measurements, since the acceleration component decreases to an undefined value below 9.81 m/s^2. To exclude this negative side effect, the kinetic option was chosen instead of determining the energy input in this way. Here, the stand permits the use of different drop weights on which the indenter is mounted. Thus, it is possible to influence the energy input by varying mass or velocity. The indenter was mounted on the drop weight with the lowest mass (388 kg) to achieve, at the same energy input level, the highest possible velocity and thus a large dynamic component.

The rate of fall was determined between two measuring points just above the point of impact. Based on the formula (3), the required height of fall was determined by varying the height of fall and thus influencing the velocity. When testing the steel section, the height of fall was 2.74 m, and when testing the aluminium sections it was 2.20 m. Thus, it was possible to achieve an energy input into the test piece that was similar to the input in the quasi-static tests. In the dynamic tests, the energy input was determined before the indenter penetrated the test piece. By contrast, the energy input in the quasi-static tests was determined after applying the load in accordance with (1). This results in an imprecision leading to an estimated error of 5 per cent. Accordingly, the loads were slightly higher in the dynamic test. Two aluminium and two steel sections including their mounting brackets were tested. For the aluminium, an average energy input of 5.94 kJ was determined while the value was 7.68 kJ for steel. In the dynamic tests, too, the energy input for the URP was greater for the steel sections. The results of these guided dynamic drop tests are shown in Table 3.

No.	Material	Ekin	xmax.bend	Quotient
		in kJ	Mm	xmax/Ekin
11071	AlMgSi 0.7	5.89	158.44	26.88
11072	AlMgSi 0.7	5.99	169.43	28.30
11073	S 650 MC	7.51	160.28	21.34
11074	S 650 MC	7.86	158.58	20.18

Average

AlMgSi 0.7	5.94	163.93	27.59
S 650 MC	7.68	159.43	20.76

Table 3: Results of the dynamic drop tests for steel and aluminium

6. The comparative test factor

The test findings described above show different results for static and dynamic loads at a similar energy input level. The deformation of the sections is greater in the case of dynamic loads than it is in the case of the application of static loads. In order to describe this influence and to make it calculable, an attempt was made to determine a load factor that expresses this difference. To this end, quotients were derived for both materials from the average bend and the energy input for both types of loads (static or dynamic). These values depend, among other things, on the thickness of the material to be tested. For the 3-mm-thick steel section, the value was 12.2 for static loads and 20.76 for dynamic loads. The values for an aluminium profile with a thickness of 4.7 mm were 17.23 (static) and 27.59 (dynamic).

When entering the values into the formula

$$\frac{x_{\max_{kinetic}}}{x_{\max_{static}}} = \quad \text{comparative test factor} \qquad (4)$$

we get a factor of 1.70 and one of 1.60 for aluminium.

The determined values are within the same order of magnitude and show a difference of around 5 per cent. This difference is probably due to the small number of conducted tests - in particular the small number of dynamic tests. For the positioning of the rear protection, this means that, assuming a dynamic accident event, the distance to the rear tank wall should not only be 100 mm but 160 mm (for aluminium sections) and 170 mm (for steel sections). Such a requirement would now have to be included in the regulations. Moreover, this suggests that dynamic loads cannot be adequately simulated in static tests of means of protection, such as in the case of the URP.

7. Conclusion

The quasi-static and dynamic investigations on rear protection led to the following findings:
The investigation on conventional aluminium- and steel-based means of protection for tank-vehicles shows that the sections are, in terms of their energy absorption capacity, not suitable to ensure an effective protection of the tank for the absorption capacity of 150 kJ required for the tests.
The findings refer to the investigations conducted within the framework of a model calculation with the help of the finite element method and the verification of the resulting findings by way of a quasi-static test series consisting of seven profiles and a dynamic test series consisting of four profiles. In the investigations, underrun protection sections of a leading manufacturer in the field of dangerous goods tanks that are commonly found in practice were used as rear protection. The transferability of the findings as regards the use under real-life conditions is realistic. The values for the energy absorption capacity determined with the help of the finite element method (FEM) are lower than those determined in the tests. The following conclusions can be derived:

- The investigation on the sections confirmed that the statutory requirements regarding the underrun protection (UFS) were fulfilled in all of the cases investigated. Test criteria and performance requirements for the rear protection (RP) required by ADR for the protection of the tank do not exist so that, in the best case, a second protective element might be used as rear protection; however, in many cases, this function is performed solely by the underrun protection.
- Under the described framework conditions (e.g. 100 mm deformation path, see chapter 4. „Quasi-static tests“), the energy absorption capacity of individual measures is 8 kJ for steel materials and 6 kJ for aluminium materials when using an underrun protection. The values determined for a comparable section in preliminary investigations using FEM are lower (e.g. 2.33 kJ for steel, see [Haas, Energieaufnahme-Simulation, 2011, p. 31]). The degree of overlap (offset) of affected vehicles in the event of a real accident was not taken into consideration. A greater overlap could increase the energy absorption capacity of the rear protection (RP), since the energy would be applied over a larger surface area. However, there is no way of achieving the desired 150 kJ by a stand-alone measure such as the conventional rear protection in the form of a bumper section.
- Quasi-static tests can be used to model a dynamic accident in terms of magnitude if a comparative factor of 1.5 - 2 (rounded) is applied to them. This way, the greater stresses

resulting from the application of dynamic loads are taken into account (see chapter 6: “The comparative test factor”).

- Improving the energy absorption capacity by way of design modifications, e.g. by increasing the thickness of the material or by varying the material, is only possible to a very limited extent. As a general rule, the shape of the rear protection is important. The use of open sections is detrimental; closed sections are much more suitable (see [Haas, Energieaufnahme-Simulation, 2011, p. 58]).
- An increase in the energy absorption capacity of means of protection can be achieved by way of energy absorption elements referred to as crash boxes (see [Haas, Energieaufnahme-Simulation, 2011, p. 58]).
- There was no investigation as to the way the means of protection are installed. In general, it is possible, due to the very rigid and strong designs of the means of protection, that the vehicle frame or the subframe, in the case of self-supporting tanks, is pushed under the tank as a result of inertia. In that case, there is the danger of the tank being ripped open at the joints. This should be prevented by the design.
- An angular device that is located at the level of the tank can increase the risk of the tank being ripped open in the event of an accident. In many cases, the rear protection is used to hold hazard plates that can potentially contribute, in addition to the rear protection (RP) itself, to damaging the tank due to their angular shape. The energy absorption capacity is probably lower than that of an underrun protection (URP).
- With the design that is commonly used today, the distance between the tank wall and the means of protection is of minor relevance to safety, since the rear protection is severely underdimensioned, given the greater stresses that occur in a dynamic accident situation.
- Today, semi-trailers are no longer designed as rack wagons but as subframe constructions with tanks that are usually self-supporting. In the event of a rear-end collision, significant portions of the collision energy are transmitted into the tank, irrespective of the rear protection. Here, design measures at the tank itself (e.g. double tank end wall), at the intersection of tank and subframe or designing the tank itself as an energy absorption element would be effective (see [Pötzsch et al., Machbarkeitsstudie, 2009, p. 27]).

Recommendations for future work on this subject

[To be discussed in WP.15]

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