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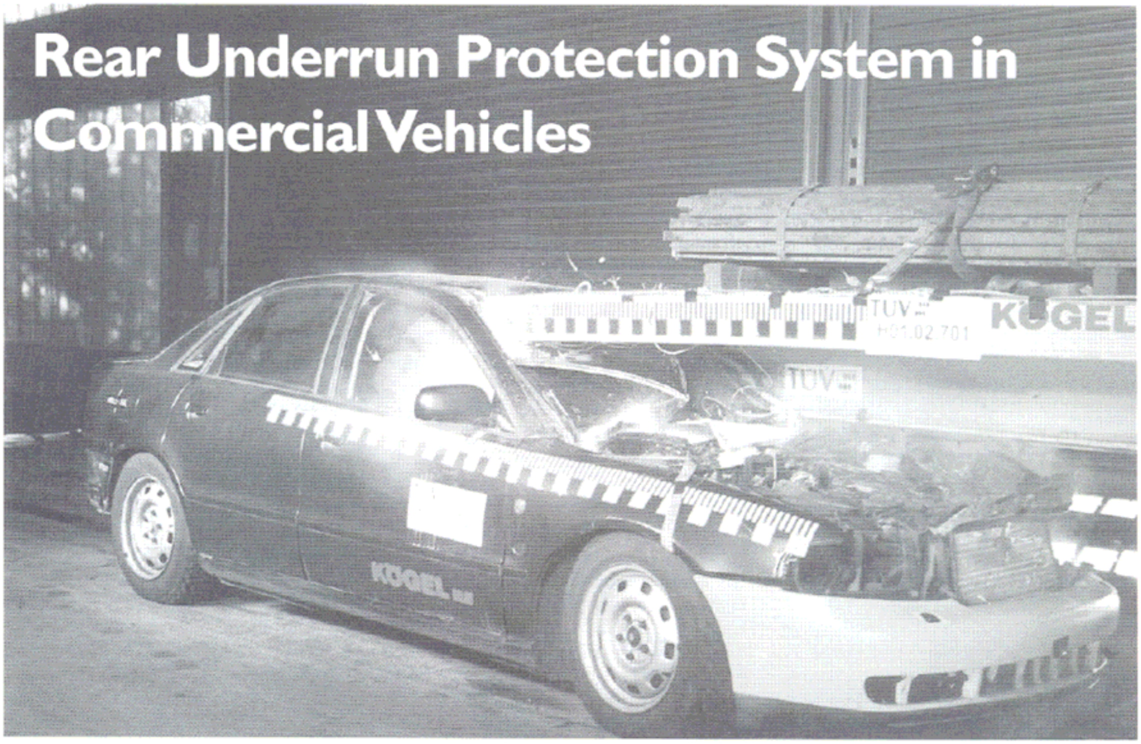
Rear Underrun Protection System in Commercial Vehicles



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By Klaus Langwieder, Johann Gwehenberger and Martin Kandler

A look at German federal statistics reveals that 395,689 traffic accidents involving injuries to persons took place in Germany alone in the year 1999. Approximately 11.5% of these involved trucks [l]. Although the number of accidents involving injuries to persons has increased only slightly (+0.3%) despite a constant increase in traffic density, collisions with trucks still have serious consequences. If one considers the total number of injuries to persons, it becomes clear that the danger of suffering fatal injuries in truck collisions is almost twice as high (3.5% of all injuries are fatal) as in all accidents involving personal injury (1.9%) [l]. An effectiveness study of accident consequences and their reduction potential by using the Rear Underrun Protection System (RUPS) has been carried out by the Institute for Vehicle Safety of the Gesamtverband der Deutschen Versicherungswirtschaft, and it findings are described in the following article.

1 Introduction

In about 60% of all cases, the other party involved in a truck accident is a car. In addition to particularly dangerous head-to head collisions, according to a recent study conducted by the Institute for Vehicle Safety in Munich (IFM), approx. 12% of all accidents resulting in serious injury are rear end collisions where cars impact the rear end of a truck [2]. In such accidents, the two colliding vehicles vary considerably as far as their geometry and design are concerned. Moreover, the considerable differences in the mass of the other vehicle causes completely different crash characteristics.

Even at low collision speeds, the car can still underrun the truck, since rear underrun protection systems in their present form offer only little resistance, **Figure 1**.

An initial evaluation within the framework of the EEVC Working Group 14, which has been carried out on the basis of 1997 data, indicated that in Europe approx. 320 car occupants are killed annually in rear underrun accidents, while 1,760 persons sustain serious injuries and 7,000 suffer slight injuries [3]. The relatively high share in Germany is remarkable, where between 110 and 160 car occupants are killed annually and approx. 4,300 sustain minor or serious injury. Although this predominance cannot be explained entirely at the moment, the main reasons are to be seen in the fact that Germany is Europe's main transit country and has the highest traffic density as well as the longest motorway network, amounting to 11,309 km [4].

You will find the figures mentioned in this article in the German issue of ATZ 5/2001 beginning on page 368.

Heckunterfahrschutz bei Nutzfahrzeugen

In the light of the high number of injuries and fatalities as well as the increase in the number of trucks and trailers for which a rear underrun protection system is prescribed by law, the Institute for Vehicle Safety commissioned a thesis [5] to be written at the College of Advanced Technology and Economics in Dresden. It contained a field study as well as an in-depth analysis of real accidents with the aim of studying the effectiveness of current rear underrun protection systems. Some of the main results of this study are introduced below. In addition, recommendations for minimum legal requirements are submitted and suggestions are made for the manufacturers of trucks and trailers. These suggestions can contribute to a sustainable improvement in the compatibility between trucks and cars in rear-end collisions.

2 A Brief Summary of Legal Regulations

The 70/221/EEC optional regulation [7], which prescribes a rear underrun protection system for trucks and trailers with a permissible total weight of more than 3.5 tonnes, was converted into national law by Section 32 b of the German Highway Code [6]. The above-mentioned EC regulation cites both mounting and testing regulations as well as permissible exceptions. Exceptions, for instance, include trucks registered prior to January 1, 1975, motor tractors for agriculture and forestry, semi-trailer tractors, two-wheel trailers for transporting long material, and vehicles such as refuse collectors which do not permit a rear underrun protection system to be mounted owing to their use. As shown in **Figure** 2, rear underrun protection systems must not be higher than 550 mm above the road surface in the unloaded state and must not be more than 400 mm from the rear of the vehicle. The profile of the cross-member must have a cross-sectional height of at least 100 mm. In addition, as part of the licensing procedure, these rear underrun protection systems must tolerate the attachment of standardised maximum testing loads of 25 kN or 100 kN. Vehicles with a permissible total weight of less than 20 tonnes, however, must tolerate testing loads amounting to only 12.5% or 50% of their permissible total weight. Further details can be obtained from regulation 70/221/EEC [7].

3 Field Study

A field study was carried out within the framework of the above-cited dissertation and contained a total of 81 vehicles [5]. It became obvious that an enormous variety of different types of rear underrun protection systems exists despite the described standardisation, **Figure** 3. Thus, different transport objectives also require different design solutions. For instance, tiltable underrun protection systems exist for construction vehicles in particular or divided systems for vehicles with a hydraulic platform. The rear underrun protection systems of conventional platform trucks, trucks with van bodies or tank vehicles differ primarily in the way they are mounted on the chassis longitudinal beams. Besides using different geometrical shapes for support, different types of sections are used as well. Special differences between individual types of vehicles also exist in the length of the rear overhang and the height of the chassis longitudinal beams or the body above the road surface.

Particularly semi-trailers and trailers of articulated vehicles commonly known as high-volume trains have large rear overhangs, sometimes more than three metres in length, whereas the rear axles of conventional trailers are normally mounted close to the rear. If the rear underrun protection system should fail and one vehicle proceeds beneath the other, the only component to offer resistance is in many cases the rear axle. The situation in vehicles with a low frame or floor is more favourable. It is difficult, for instance, for a car to underrun commercial vehicles for cattle or car transportation or high-volume trains. The same applies to internally loadable trucks for transporting glass or finished concrete components as well as for silo vehicles, as these usually have axles located at the rear.

However, on the other hand, the incompatibility of the colliding vehicle structures plays a role in the case of trucks or trailers in which the rear underrun protection system alone could prevent a car from underrunning another vehicle. The height of the car's longitudinal member, which is 400 mm on average, is in contrast to the permissible height of a rear underrun protection system, which is 550 mm [5], **Figure 4.**

According to an earlier study with a car impacting a wall [8], however, the longitudinal members, which are attached to branched support frames, are the structures which are most essentially involved (approx. 57%) in the energy absorption by the car. The deformation absorbed by the wheel housings, mudguards, bulkhead, engine and front parts is comparatively low by contrast. The situation is also aggravated by the dynamic behaviour when braking is performed immediately prior to or during the collision. The pitching of the front sections of both vehicles favours the underrunning of the truck. According to measurements from the Federal Office of Roads and Highways [9], the front of a Volkswagen Golf III dips by about 100 mm during a full braking manoeuvre. And the frontal height of the vehicle can be reduced to an even greater extent if the car tyres burst during the course of the collision.

Rear underrun protection systems that do not comply with legal regulations can also have an added negative effect on the consequences of an accident. This might be the case if tiltable rear underrun protection systems are not correctly locked in position or if rear underrun protection systems have been improperly repaired, **Figure 5.**

4 In-Depth Analysis

The investigation of 58 serious rear-end accidents between cars and trucks or truck trains based on police accident re cords, which was performed within the framework of a total evaluation of truck accidents involving severe injuries to persons in Bavaria in 1997, made clear the following two typical accident processes:

- If the wheels of the last axle of the truck are close to the rear or if the vehicle body is very low (approx. 300 - 400 mm above the road surface), the structure of the truck itself serves to obstruct the impact. In these cases, there is no underrunning with intrusion into the car interior. The injuries sustained by car passengers are largely dependent on the restraint systems and the rigidity of the car.
- In the case of a truck and trailer with an overhang in excess of about 1 m and with a high body as well, underrunning of the truck or trailer floor is usually associated with great intrusion into the passenger compartment. The intrusion is concentrated in the roof area and the A pillar, which offer almost no resistance, so that severe injuries can occur even at relatively low speeds (30 - 40 km/h). Car restraint systems such as airbags and belt tensioners can provide little or no protection.

In addition, regarding the speed of the truck, the investigated accidents could be subdivided into three basic categories. In about one-third of all accidents, the car drove into a stationary truck; in another third, the truck had a speed of 80 km/h or higher; and in the group of remaining collisions, the speed of the truck was less than 80 km/h., **Figure 6.** The first type of accident includes accidents that occurred both on urban and rural roads, on which the truck was parked at the side of the road or had come to a stop owing to the traffic situation, as well as motorway accidents where traffic had come to a standstill due to congestion. The distribution of the relative speeds is similar in all three accident groups. Minor speed differences up to about 30 km/h predominated in almost 60% of all cases, **Figure 7.** In all three groups, however, accidents also occurred where the difference in speed amounted to 60-100 km/h (approx. 15%). These rear-end accidents resulted in considerable underrunning of the truck in all cases, combined with massive damage to the car and severe or fatal injuries to the passengers.

A closer examination of the degree of damage to the car, however, revealed that only in rare cases did an extreme deformation occur at the front of the car. This means that the crumple zone of the car was used only to a limited extent. Thus, in 45% of the cases studied, the rear end of the truck was underrun at least to the A pillar of the car. The intrusion of the truck body to the front edge of the roof or even to the B pillar of the car is particularly critical with respect to the injury risk for car passengers. The danger of severe collisions is expected to rise as the relative speed between trucks and cars rises. However, the degree of overlap with which the car impacts the rear end of the truck also has a considerable effect on the extent of underrunning. Despite a small number of cases, it became apparent that the danger of intrusion into the passenger compartment increased with a descending overlap. This is because, if there is only partial overlap, the underrun protection system can only absorb energy along a small portion of its width and transfer it to the chassis longitudinal beams, **Figure 8.**

Owing to the difference in vehicle widths (approx. 1.70 m in the case of a car and 2.50 m in the case of a truck), there can still be 100% overlap from the car's point of view even in the case of offset impact, Figure 8, top left. In this case, the force only acts on two thirds of the width of the underrun protection system. Such rear-end collisions with partial overlap are typical of evasive action attempted just prior to the collision. This is also confirmed by the distribution of impact sites. For example, predominantly left-sided impacts at the rear of the truck occurred in 42% of all cases and were thus twice as high as right-sided impacts. The car hit the underrun protection system right in the middle in only 37% of all cases, **Figure 9.**

A simplified rough calculation is intended to make it possible to estimate the tolerable collision speed as a function of the vehicle mass and the degree of overlap at the moment of impact against a stationary truck. The test loads mentioned at the outset and the maximum permissible deformation path s_{deform} = 400 mm are based on the EC regulation. It is also assumed that the kinetic energy of the car E_{kin}-car is converted completely into deformation work W max-UPS by the rear underrun protection system, and the force acts horizontally on the rear. Thus

$$W_{max-HUS} = E_{kin-Pkw} = \frac{1}{2} m_{Pkw} \cdot v^2 \quad \text{Eq (1)}$$

where m_{car} is the mass of the car and v the speed of the car at impact.

The force F_{tot} which counteracts due to the impact on the underrun protection system depends on the degree of overlap and, in a first approximation, can be considered to be the sum of the forces whose test sites have been hit by the car. In a left-sided impact still with 100% overlap from the car's point of view, these are the sites P1left, P2 left and right and P3, Figure 8, top left. Since the EC regulation prescribes that the test forces must act in succession, this assumption is made in the sense of a "best case scenario". Thus,

$$F_{ges} = \sum F_{pgetroffen} \quad \text{Eq. (2)}$$

The maximum absorbable energy W_{maxUPS} of the rear underrun protection system is then calculated as

$$W_{max-HUS} = \int_0^{s_{verform}} F_{ges} ds = \sum_0^{s_{verform}} F_{p-getroffen} \quad \text{Eq. (3)}$$

Assuming that the absorption of the force is constant over the entire deformation path s_{deform}' Eq. (3) can be simplified to read

$$W_{max-HUS} = \sum F_{pgetroffen} \cdot s_{verform} \quad \text{Eq. (4)}$$

The maximum tolerable speed v then results from Eq. (1) and (4) and is

$$v = \sqrt{\frac{2 \cdot \sum F_{p-getroffen} \cdot s_{verform}}{m_{Pkw}}} \quad \text{Eq. (5)}$$

Table 1 illustrates the calculated values of the car collision speeds that can be tolerated by the underrun protection system as a function of the degree of overlap and the mass of five common car types. It is obvious that, if the rear underrun protection system has to absorb all the energy, it will withstand a car travelling at about 40 km/h in the most favourable case. If there is only partial overlap, however, the collision speeds that the rear underrun proteetion system can tolerate drop dramatically.

Similar results were also shown in two crash simulations carried out by the TÜV Automotive [10] in which a car impacted the rear -end of the platform trailer of a 40 tonne articulated vehicle with 75% overlap. This means that, with regard to the semitrailer, there was a 50% overlap. The rear underrun protection system failed even at a collision speed of only 35 km/ho At an impact speed of 50 km/h, the Audi even slid 2 metres beneath the edge of the platform, thus causing the boot sill to intrude into the interior and impact the head of the dummy with load values that were fatal, **Figure 10.**

A more detailed observation of the types of failure exhibited by the rear underrun protection system revealed that, due to a unilateral load, the system failed in more than half of all cases investigated because it was either bent or torn off, **Figure 11 and 12.**

In particular in vehicles with a hydraulic platform and a divided rear underrun protection system, the underrun protection system was torn off outside the consoles which are intended to transfer the force to the chassis longitudinal beams of the truck, Figure 12, bottom right. In trucks with a low total permissible weight (< 20 tonnes), the reduced stability of the rear underrun protection system due to reduced testing loads also played apart.

When a car impacts the rear-end of a truck, this not only causes serious damage to the car but also frequently results in considerable damage to the truck as well. For instance, the vehicle body was also damaged in almost one of every three trucks in the cases at issue. In most cases, the hydraulic platform or components of the hydraulic platform were affected. lust less than 10% of all trucks suffered damage to the wheels or axles. In one case, the rear axle of a trailer was torn out of its mounting on one side and a secondary collision of the skidding trailer against the crash barrier could be avoided only because the motorway shoulder was very wide. Particularly, in combination of the high centre of gravity of the truck, such sudden independent steering behaviour involves the risk of the truck overturning or being involved in another serious subsequent collision.

The disadvantage for the haulage company in such cases is not only high repair costs and unmet deadlines but also the downtime caused by transferring the cargo or the time spent in a garage. Although such considerations are rarely taken into account when purchasing a commercial vehicle, reference should nonetheless be made to the enhanced image for a haulage company that only employs safe vehicles

Conclusions: As the studies have shown, rear underrun protection systems that comply with the law are currently inadequate in two respects in particular:

- they are too far from the road surface
- they do not have sufficient stability.

Since, in a huge number of real accidents, the rear underrun protection system was located above the energy-absorbing structures of the car, and dynamic factors such as braking-pitch can also negatively affect the accident situation, the car can underrun the re ar section of the truck as far as the rear axle. The body of the truck often intrudes into the passenger compartment of the car. Serious or fatal injuries to the passengers are the consequences, particularly since restraint systems such as airbags or belt tensioners are not activated at all or only to a limited extent if predefined deceleration values are not exceeded or are exceeded with delay.

5. Recommendations for Future Minimum Legal Requirements

An improvement in conventional rear underrun protection systems in these two respects could effectively prevent cars from underrunning trucks.

As the studies conducted by IFM and the crash tests carried out by the Technical Inspection Association (TÜV) clearly indicate, the lower edge of the rear underrun protection system should not be higher than 400 mm above the road surface when the truck is fully loaded.

Furthermore, evaluations of accidents also put an emphasis not only on lowering the height at which the rear underrun protection system is mounted but also on the necessity of improving its stability. The testing loads currently prescribed in the EEC regulation must be at least doubled for this reason. The simple estimate based on Equation 5 could increase the collision speed tolerated by rear underrun protection systems by a factor of $\sqrt{2}$ =1.41. However, special attention should be given to a stable support in order to prevent the console sections from buckling and the ends of the rear underrun protection system from being torn off, as occurred in more than 10% of all cases examined, Figure 12.

Finally, it has to be urgently recommended that the status of rear underrun protection systems be examined within the framework of MOT and safety tests.

6 Recommendations for Manufacturers of Trucks, Trailers and Semi- Trailers

The recommendations for minimum legal requirements should not prevent the manufacturers of trucks, trailers and semi-trailers from setting additional standards at an early date and from surpassing the minimum legal requirements of the future with respect to partner protection. This applies in particular in light of the length of time it currently takes to introduce EC regulations within the framework of European legislation. In appealing to the vehicle manufacturers and operators, therefore, a few additional aspects are mentioned below as well

The in-depth analysis revealed that 55 of 58 rear-end accidents involving severe injuries to persons occurred on rural roads, approx. 78% of these having occurred on German motorways. These roads are characterised by high speed differences between cars and trucks on the one hand and, on the other, by the fact that in many cases the driver performs a full braking manoeuvre immediately prior to the collision, thus making an underrun protection height < 400 mm necessary.

Problems with low underrun protection especially in vehicles that have large rear overhangs can occur at ramps such as those in operational yards or when loading commercial vehicles, **Figure** 13. By contrast, problems do not normally arise in normal road traffic, since in this case generous transitions from the flat surface to the incline are generally provided.

In order to prevent the rear of the truck from scraping along the ramps on the one hand and to lower the rear underrun protection system as far as possible, on the other, the height of the underrun protection h could be determined as a function of the rear overhang length l of the truck. As a minimum requirement that should be met by a truck with a double-stacked cargo load, for example, it should be possible to drive up a ramp that has a 10% incline. Furthermore, there should still be a ground clearance of x = 100 mm in this case. Based on the definition of the incline and the assumption that the truck will be driving up the ramp very slowly (quasi-stationary), the resultant equation will be as follows:

$$\tan\alpha = \frac{h_{min} - x}{l} \qquad \text{Eq. (6)}$$

or, when resolved for the minimum necessary height of the underrun protection h_{min}

$$h_{min} = l \tan\alpha + x \qquad \text{Eq. (7)}$$

Figure 14 illustrates the minimum height of a rear underrun system when the incline = 10% or tan α = 0.1 and the required ground clearance x = 100 mm.

Hence, in the case of vehicles with an underrun protection height of 400 mm and a rear overhang of up to 3000 mm, there will be at least 100 mm of ground clearance left in any case when driving up a 10% incline. To prevent the underrun protection from scraping along the road, tiltable rear underrun protection systems are conceivable for the relatively low number of vehicles that have a rear overhang greater than 3000 mm. However, it must be taken into account that such devices can be operated even when they have been tilted up. Unlike current constructions, it will be necessary to design new rear underrun protection systems whose height can be variably adapted to road conditions or which are equipped with a warning device to acoustically or optically warn the driver.

Krone, a semi-trailer manufacturer, has taken a particularly courageous step forward with its concept of the Schimmelpfennig outside frame, which provides a laudable solution for semi-trailers. In a vehicle known as the Safe-Liner, all frame support elements were consistently moved to the outside. The lower frame structure is approx. 28 cm above the kerb and forms an integrated underrun protection system at the rear and along the sides. A crash test in which a car travelling at 50 km/h crashed into the rear of the semi-trailer demonstrated that the passenger compartment remained intact and that the car passengers who had been protected by seatbelts and airbags would have survived such an accident without any serious injuries [11]. Besides a marked enhancement in partner protection, even with respect to unprotected road users, the manufacturer also cites additional advantages such as lower fuel consumption due to improved aerodynamics, reduction of water spray, additional cargo space and storage space, and an enhancement of corporate image. The problems that were voiced in an opinion poll [12] by haulage companies and operators, e.g. somewhat higher kerb weight (7,080 kg), difficulties when changing tyres, more difficult maintenance and repairs when the chassis has been lowered or an inadequate slope angle, could be quite easily solved.

7. Prospects

The truck will remain the number one means of transport in European commercial traffic in the foreseeable future. The outcome is that there[5] will continue to be collisions between cars and trucks in future as well. The severity of rear -end collisions between cars and trucks can be reduced in particular by design measures on trucks.

Initial conservative estimates made by the European EEVC Working Group 14 [13] indicate that a prevention potential of about 100 fatalities and 600 serious injuries could exist, or at least their degree of injury could be reduced, by lowering the rear underrun protection system, whilst at the same time raising the testing forces. Furthermore, the working group calculated that between 69 and 78 million euros could be saved based on the average cost of fatalities and serious injuries. Based on approx. 200,000 new heavy truck registrations per annum in Europe, this would me an that about 345 to 390 euros would be available to equip each vehicle with an improved rear underrun protection system.

In summary, the above discussion leads to the following urgent recommendations:

2. Rapid implementation of the given suggestions for minimum legal regulations
3. Adoption of these by manufacturers on a voluntary basis
4. No impairment of the specific use of the vehicles.

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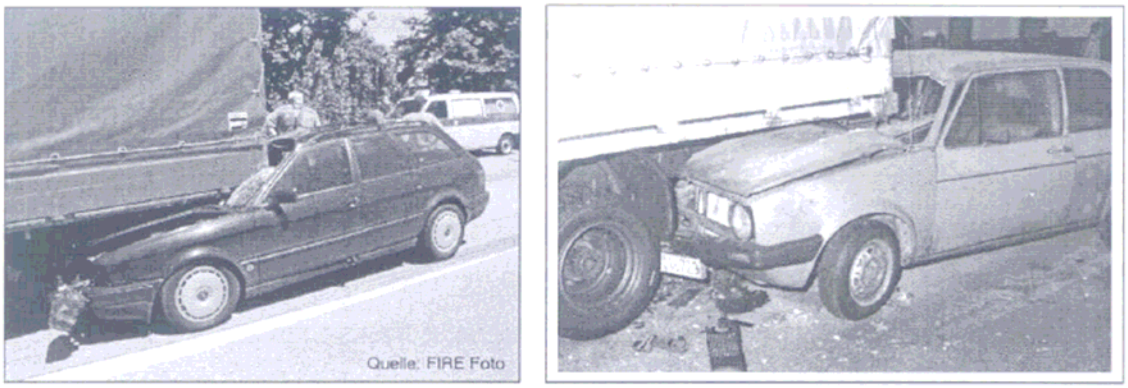


Fig. 1: Typical underrun accidents of cars under the rear of a truck with intrusion of the truck bed into the passenger compartment

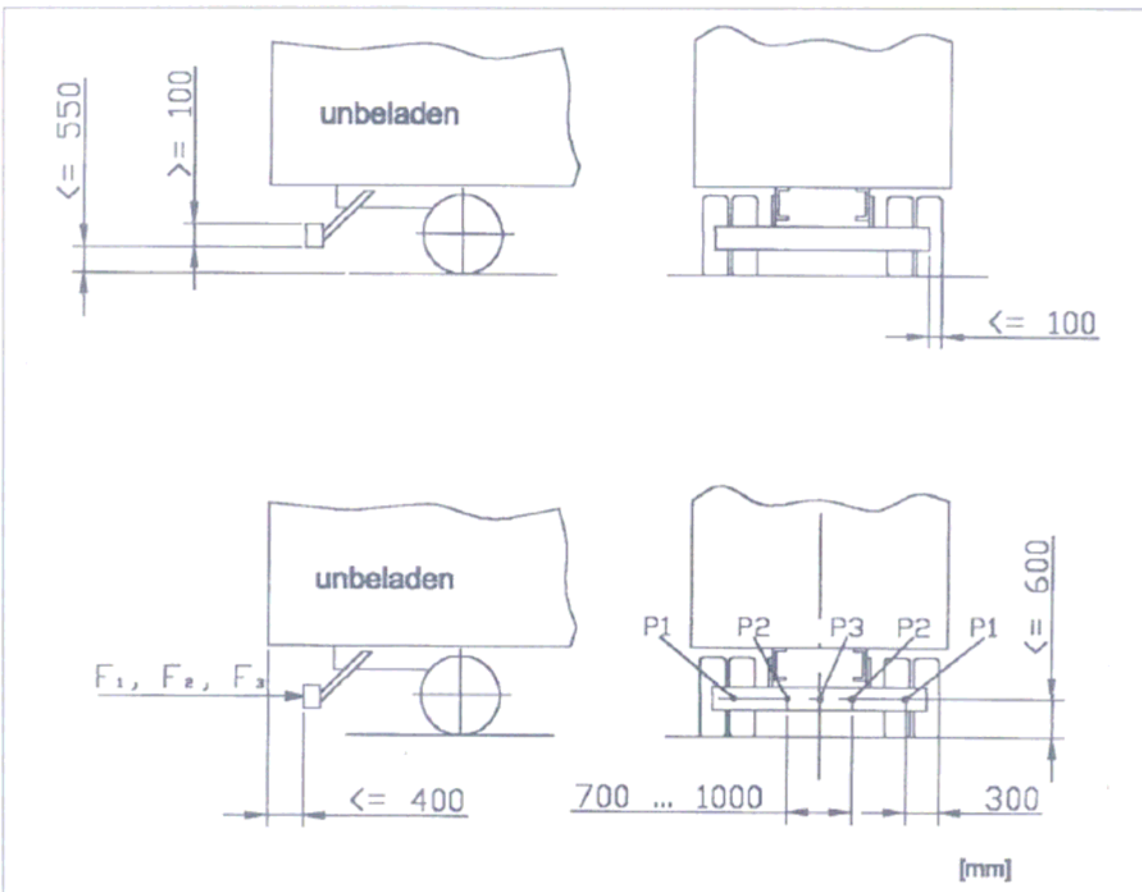
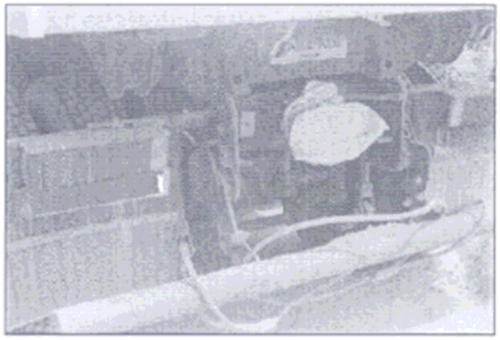
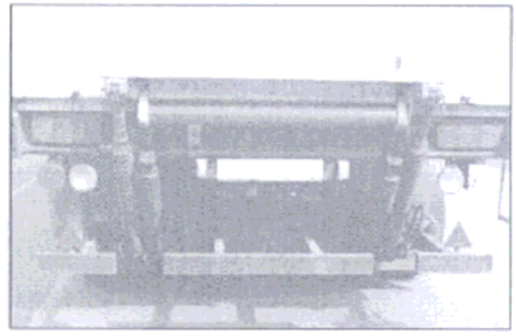


Fig. 2: Fitting and points of application of the test forces of an underrun protection device according to Directive 70/221/EEC (test forces at the test points P1 to P3; F1, F3 = 25 kN, resp. 12,5% of GVM; F2 = 100 kN resp. 50% of GVM (vehicle unladen)

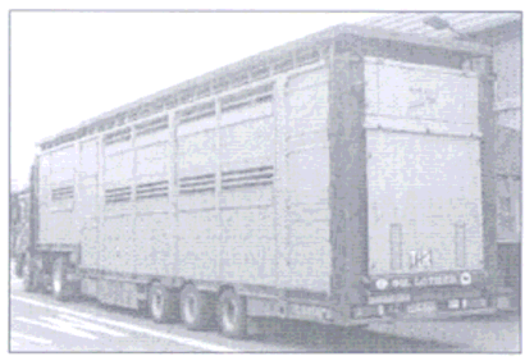


tiltable



interrupted

large overhang



large overhang with low frame

Fig. 3: Examples of different rear underrun protection devices

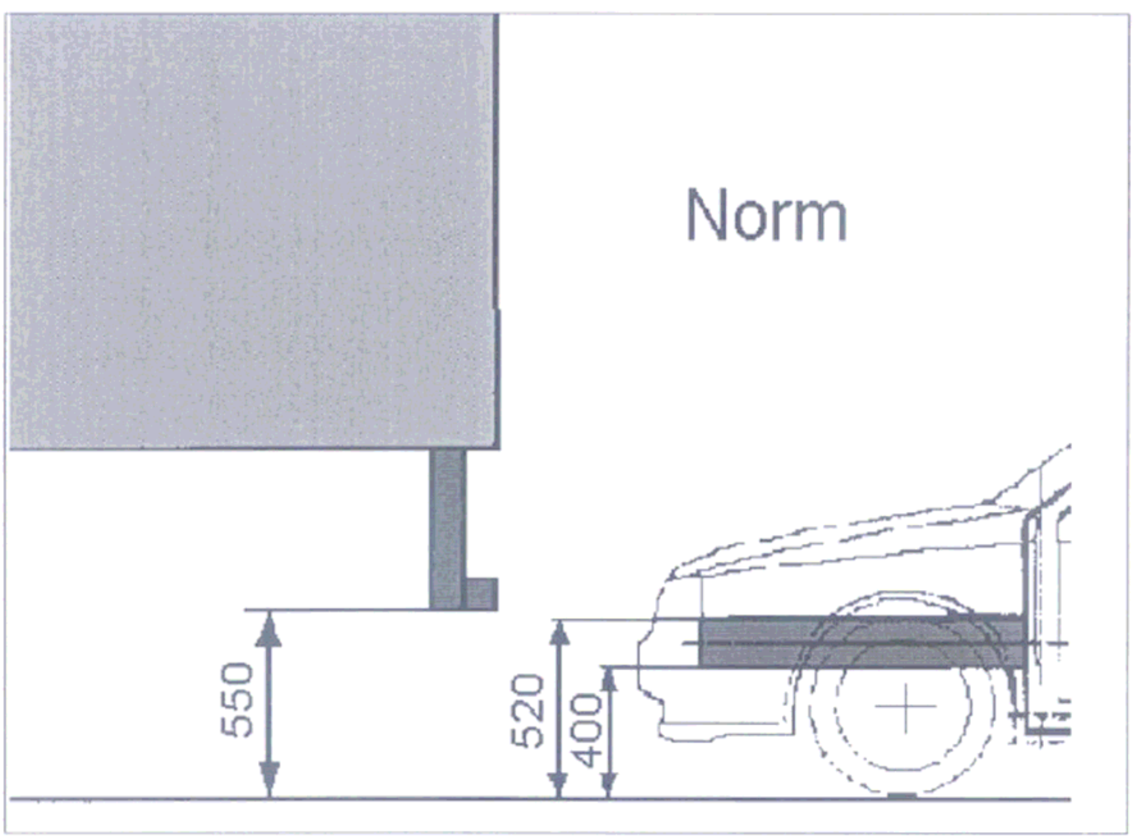


Fig. 4: Comparison of the heights of the rear of a truck and the front of a passenger car

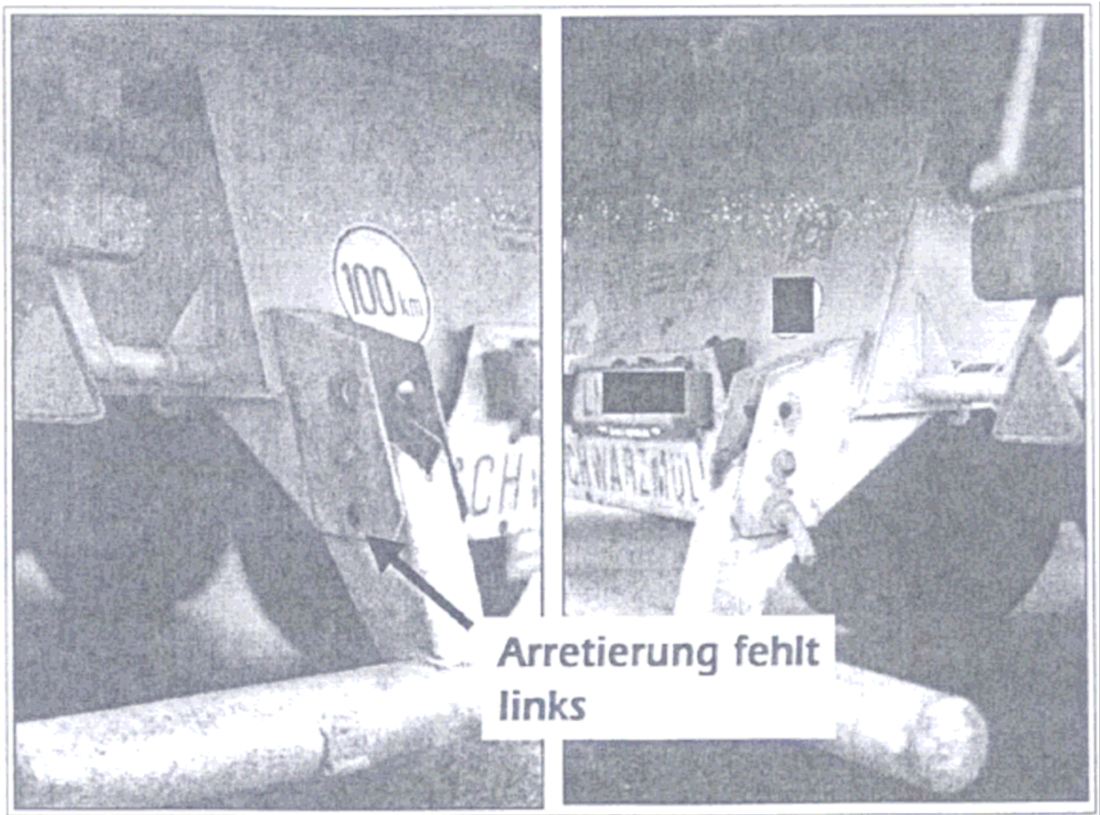


Fig. 5: Example of an incorrect use of a tiltable rear underrun protection (locking is missing on the left)

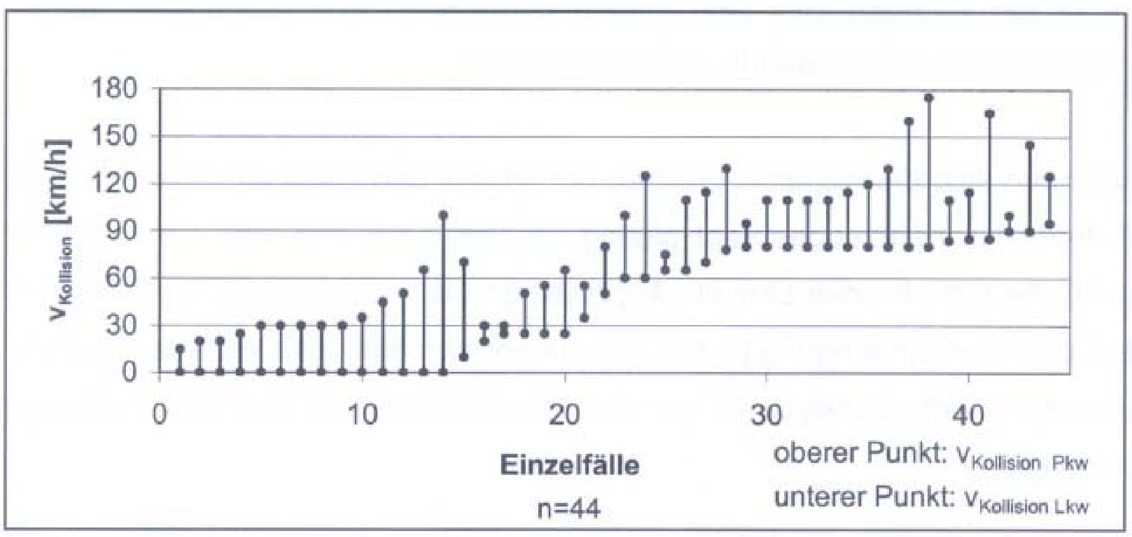


Fig. 6: Comparison of the collision speeds in the 44 individual cases in which the speeds of both accident participants were known (upper dot: $v_{coll,\ car}$, lower dot: $v_{coll,\ truck}$)

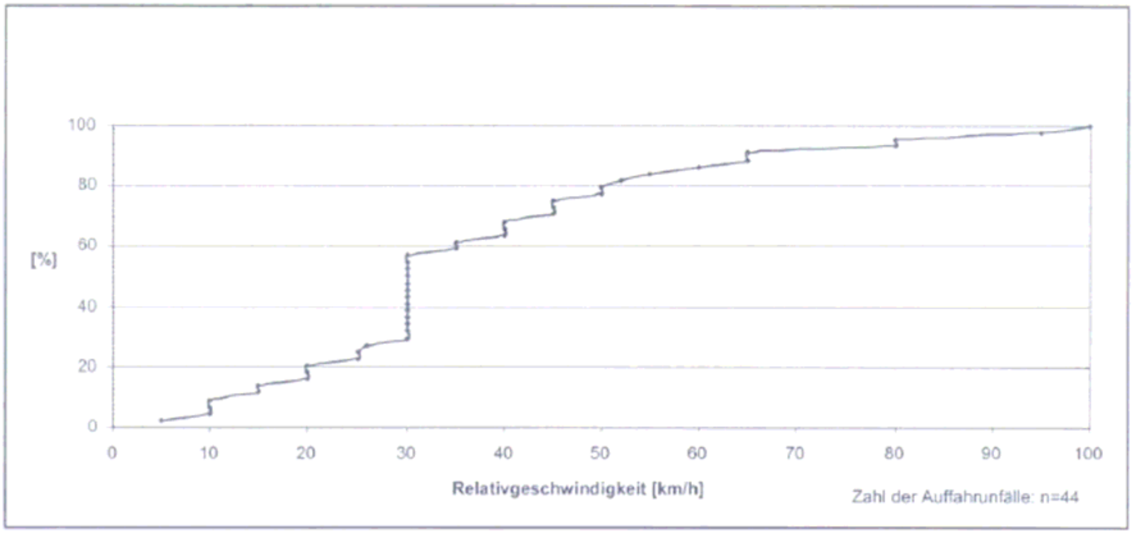
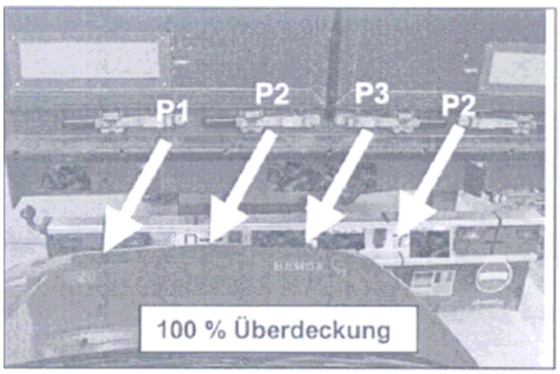
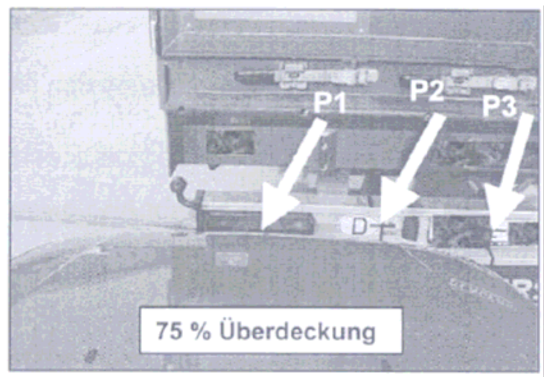


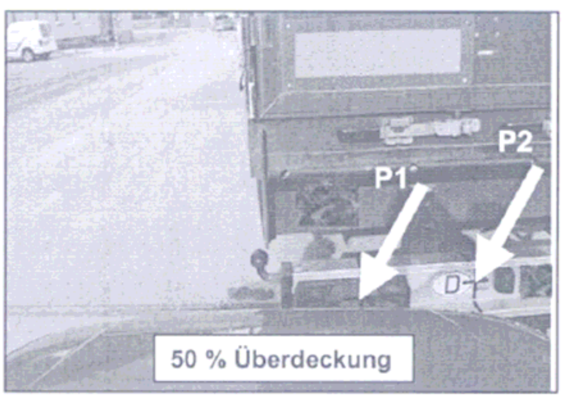
Fig. 7: Distribution of the relative speeds of severe rear impact accidents (44 accidents)



100 % overlap



75 % overlap



50 % overlap

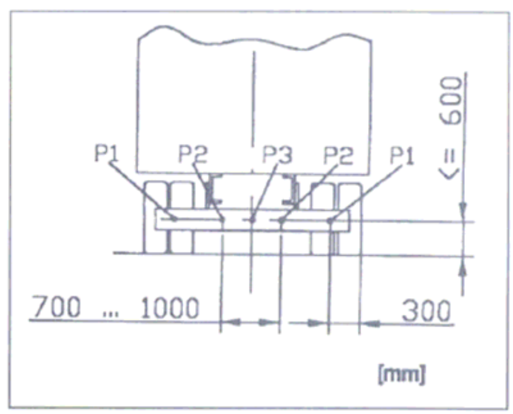


Fig. 8: Different overlaps referring to the passenger car with marking of the hit test points according to Directive 70/221/EEC

Fig. 9: Distributions of the impact areas of rear impact accidents (43 cases)

car type — degree of overlap (referred to the car) tolerable collision speeds (km/h)

		ertragbare Geschwindigkeiten [km/h] bei Grad der Überdeckung (aus Sicht des Pkw)			
Pkw-Typ	Pkw-Masse besetzt mit 2 Personen	100% außerm. Anstoß	75%	50%	25%
VW Polo	ca. 1.180 kg	46,9	36,3	33,1	14,8
VW Golf	ca. 1.450 kg	42,3	32,7	29,9	13,4
VW Passat	ca. 1.580 kg	40,5	31,4	28,6	12,8
Mercedes E-Klasse	ca. 1.700 kg	39,0	30,2	27,6	12,3
Mercedes S-Klasse	ca. 2.000 kg	36,0	27,9	25,5	11,4

Tab. 1: Car to truck collision speeds tolerable by the rear underrun protection device as a function of the degree of overlap referred to the car and to the mass of typical cars

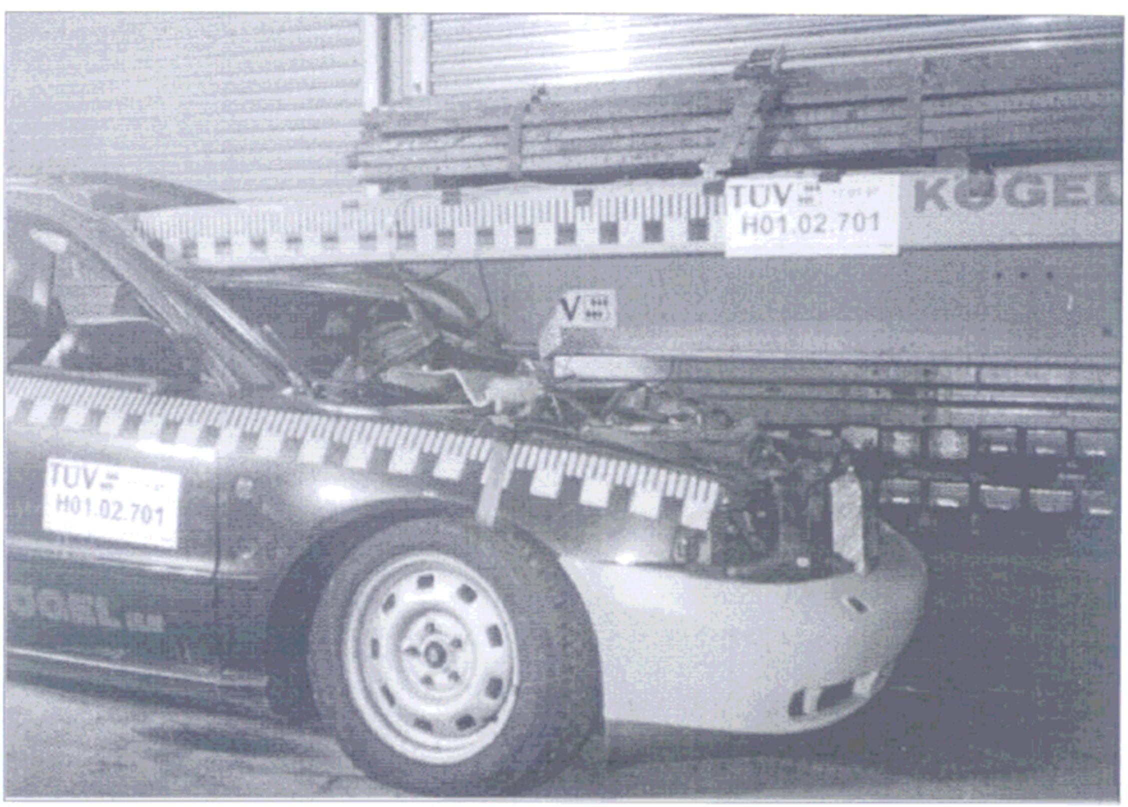


Fig. 10: Crash test: Audi A4 with 75% overlap and v_c = 50 km/h against a semi-trailer with underrun protection device (height above ground: 400 mm)

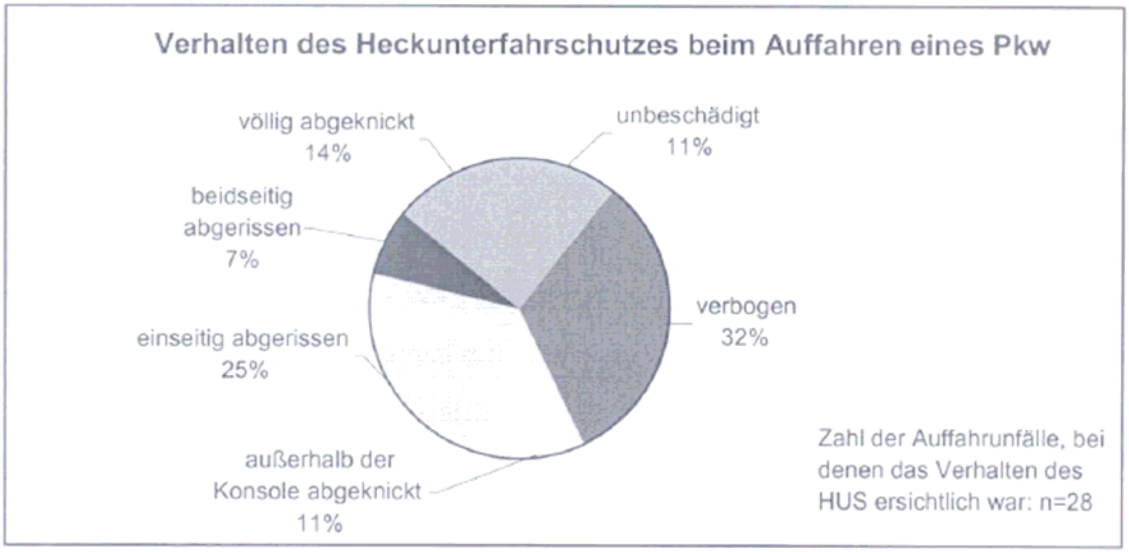
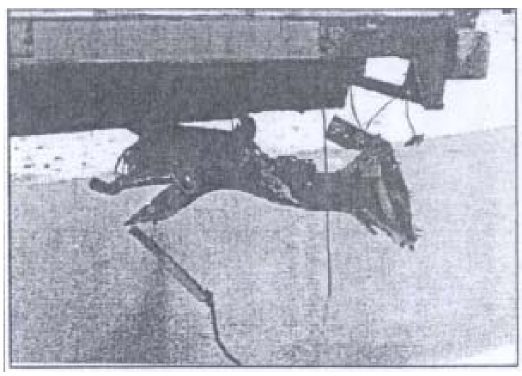
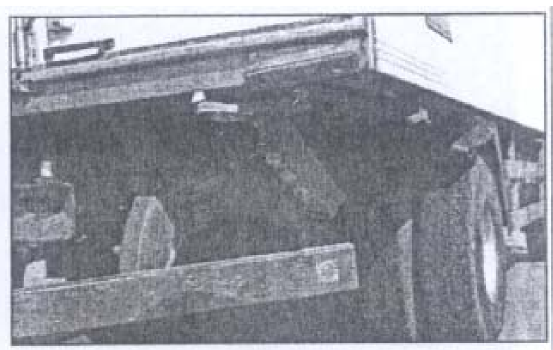


Fig. 11: Kinds of failure of the underrun protection device after an impact of a car

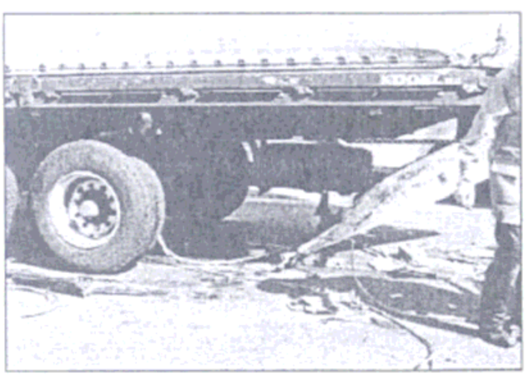
Number of accidents:	28		
entirely snapped off;	14 %	undamaged:	11 %
torn off on both sides:	7 %	bent:	32 %
torn off on one side:	25 %	snapped off outside the bracket:	11 %



torn off on both sides



bent on one side



torn off on one side

interrupted underrun protection – torn off

Fig.12: Examples of damaged rear underrun protection devices

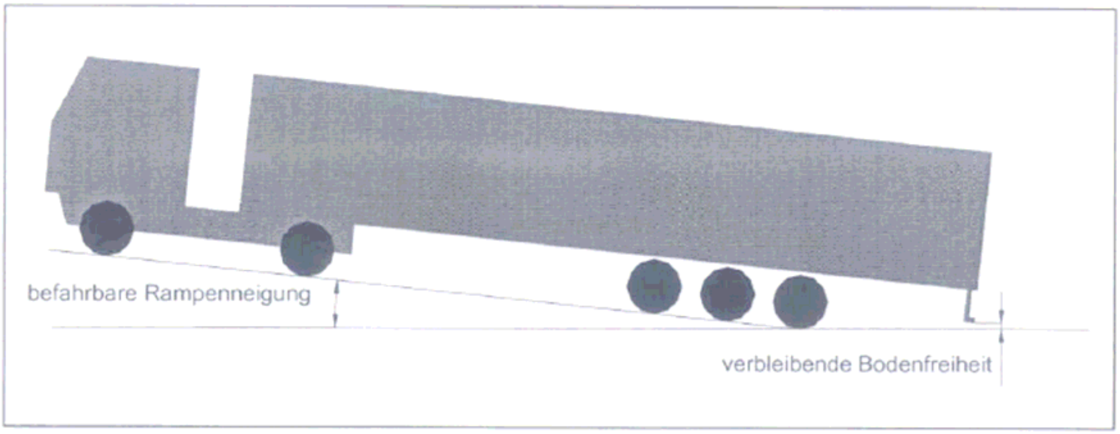


Fig. 13: Problem of the ground clearance on ramps

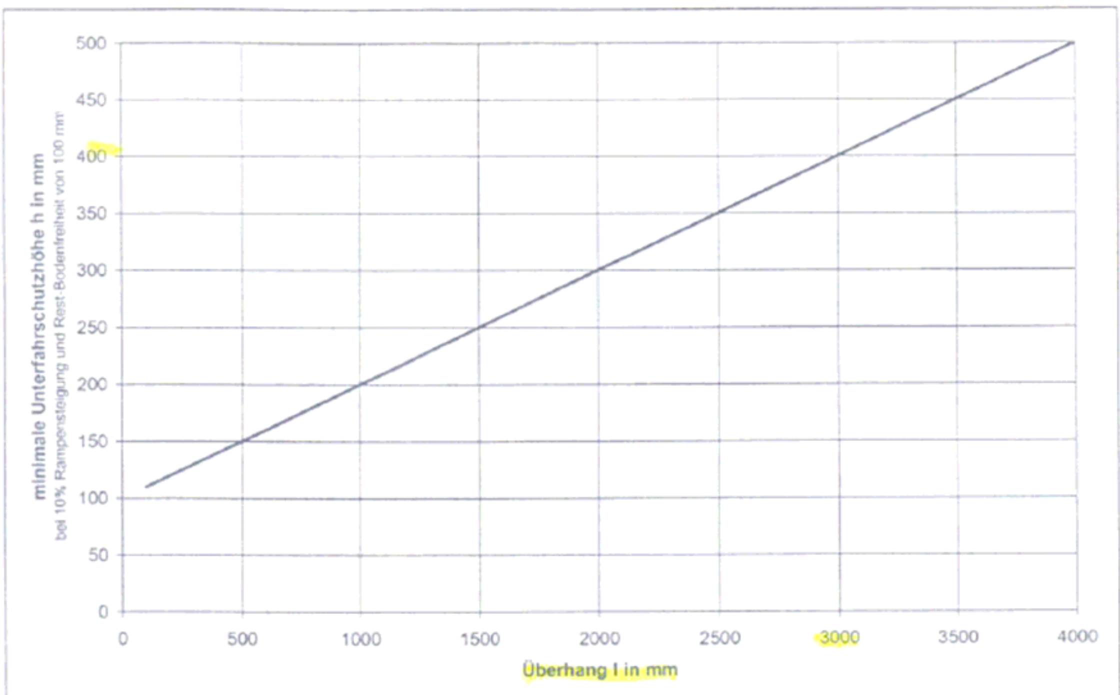


Fig. 14: Minimum height h_{min} of the underrun protection device on a ramp with 10% slope and 100 mm remaining ground clearance as a function of the rear overhang

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