

ROLLOVER ACCIDENTS OF CARS IN THE GERMAN ROAD TRAFFIC – AN IN-DEPTH-ANALYSIS OF INJURY AND DEFORMATION PATTERN BY GIDAS¹

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ABSTRACT

This paper describes the injury pattern of car occupants in rollover crashes by type, location and severity AIS. The accident cases were collected randomly within GIDAS (German In-Depth-Accident Study) at Hannover. Since 1999 in Germany a joint project between BAST (Bundesanstalt für Straßenwesen or the Federal Highway Research Institute) and FAT (Forschungsvereinigung Automobiltechnik or Automotive Industry Research Association) is being carried out in Hannover and Dresden. The paper describes the methodology of this project with statistically orientated procedure of data sampling (sampling plan, weighting factors) on one hand and describes the results of the injury pattern of car occupants after rollover and gives indication for understanding where rollovers are happened and what kind of influences are exist on the other hand. The rollover movement characteristics will be described and the resultant deformation pattern analysed by a detailed survey.

For the study 434 cases of car accidents with rollovers are used for a detail comprehensive analysis. The portion of rollovers can be established at 2.3% of all accidents with casualties in the year 2003. The accidents happened in the years 1994 to 2000 in the Hannover area. The injury distribution will report about 741 occupants with rollover accident event. These accidents are compared with the others without rollover documented in the same sample of GIDAS under a representative random spot check methodology.

The distributions of injury frequencies, injury severity AIS for the whole body and for the body regions of occupants are presented and compared to technical details like the impact speed and the deformation pattern. The speed of the car was determined at the point of rollover and on the point of accident initiency. The characteristics of the kinematics followed in a rollover movement are analyzed and the major defined types of rollover are shown in the paper.

The possibilities of In-Depth-Investigation methods for the approach of finding countermeasures against

rollover and explaining the biomechanics of injuries in rollover are shown in the paper as well.

INTRODUCTION

The participation in traffic is characterized by conflict situations that sometimes result in traffic accidents. About 20 % of all accidents occur without the participation others, mostly accidents happen at points where the road turns come to mind, however, solo-accidents also occur inside city boundaries and at other road sections. Especially noticeable within the group of solo-accidents, accident occurrences are those, where the vehicles slid sideways into the side part of the road and there sometimes rolled over. Publications show many indications relating to the corresponding severe injuries. Typically, the passengers did not use the safety belt, which is known to protect from the consequences of being ejected out of the car. Severe cervical spine and head injuries due to being ejected from the vehicle and the bodies hitting the ground outside the vehicle constituted the main injury focus points. Most serious and fatal injuries in rollovers result from ejection [Partyka 1979 - 1] and unbelted occupants have a higher risk of ejection than those belted, in cases of ejection 47% were severe or fatal injured (Hight 1972 - 2). Thus many of the publications on rollover injuries were written during the 60s and 70s, when the safety belt was not part of the standard equipment of cars.

Jones [3] reported that the fatality rates for single vehicle crashes mirror those for single vehicle crashes suggesting that the fatality rate is dominated by rollover crashes. NHTSA reported that for years 1992 to 1998 there was an average of about 227000 rollover crashes per year, following in 9063 fatalities per year. The analysis of FARS data in US shows that there are significant relationship between the risk of rollover in single-vehicle fatal crashes and engineering parameters that describe vehicle stability, i.e. track width to cg height ration was the strongest predictor for pickup trucks and utility vehicles, although for passenger cars wheelbase was a better predictor. Padmanaban [4] investigated

¹ cooperative study of FAT and BAST

about 2199 occupants involved in passenger car rollover crashes, 59% of rollovers involve one to two quarter turns, 23% involve three to four quarter turns, 15% five to eight quarter turns and 2.6% involve nine or more quarter turns. Parentau found for belted and unbelted occupants the risk to be seriously injured was higher for far than near-side occupants. For far-side occupants, the risk was highest for climb-over events and collision with other vehicles, while it was greatest for bounce-over events for near-side occupants.

In the recent years the number of persons killed in crashes reaches the highest level since 1990 driven by rollover fatalities likely due to the increase of the number of trucks and SUVs on the road and their increased likelihood to roll [Kratzke et al - 5]. Today rollovers have not so much incidence than in the past. Viano [6] reported that in the U.S. rollovers represent less than 5% of all vehicle crashes (NHTSA 1999), they account for approximately 15% of serious (AIS 3+) injuries and 20 to 25 % of fatalities. 81% of two-way rollovers were single vehicle crashes.

Even today, the majority of rollover accidents are reported from the Anglo-Saxon countries. It does turn out, though, that obviously the accident situations in the US are structured differently from the European countries. There the incidence of the accidents with resulting rollover is significantly lower frequent and also the severity of the injuries largely lower. In the traffic accidents happening in European countries a vehicle rollover does not mainly occur for solo-accidents, but also in the course of vehicle to vehicle accidents such after collision occurrences take place. Especially when 2 vehicles collide and in the course of the post-crash movement a change in friction between the tire and the road occurs, when the vehicle slide sideways either enters the unpaved verge or hits the curbstone sideways and this way a sideways overturning torque is implemented. Furthermore, there are accident situations, where vehicles climb the embankment next to the edge of the road and topple over due to the tilted plane. All these occurrences number among the group of rollover accidents. Kocherscheidt [7] reported that 2 to 5 % of all accidents in Germany are rollovers, in a special study of BMW cars 20 % rollovers were found. An influence of the driving speed could be analysed concerning the injury severity and the deformation depth. Also for German accidents it was pointed out by Miltner [8] that there is in case of not using a seatbelt a high risk for ejection with 68%. In a study published lately on accidents involving guardrails, it was pointed out that the increasing use of noise barrier walls and dams has followed in an increase of such accident occurrences [Otte - 9].

It is thus desired to determine the importance of accidents with resulting rollovers and especially

identify the resulting injuries for the current accident occurrences on European roads, in order to implement special measures on the vehicle or in the road construction, to limit the negative effects of rollovers and their pattern.

APPROACH

In order to investigate the accident occurrences of vehicles with rollover consequences more closely, the evaluations of enquiries at the site of the accident are used. This results in accident documentations that were started by a scientific team on-site and later added to in retrospect. Since 1973 the enquiries at accident sites in Hannover have been conducted by the order of the Federal Highway Research Institute (BASt). Starting in 1985 these are conducted using a statistic sample plan, where annually 1.000 traffic accidents involving personal injuries are analyzed and from 1999 these have been conducted in cooperation with the Forschungsgemeinschaft Automobiltechnik (FAT) and the BASt in the areas Hannover and Dresden. All data is collected in a joint database GIDAS (**G**erman **I**n-**D**eepth **D**ata **A**ccident **S**tudy). The methodology and sample selection are described in the publication by Otte et al [10]. These accidents were chosen randomly, which can be counted as representative cross-sections of the real accident incidence using a statistic weighting process. For the enquiries, the injuries are classified and documented according to the AIS-scale (**A**bbreviated **I**njury **S**cale - 11) and the damages to the vehicles are recorded according to the CDI (**C**lassification **D**eformation **I**ndex - 12). Driving and collision speeds are calculated from the traces found at the accident site, such as brake and skid marks, the final positions of the vehicles and impact traces on the side of the road using the basics of the physical impact shock theory. Based on such an extensive analysis of the traffic accident incidence, the consequences of roll-over accidents and the detailed vehicle movements can be reproduced.

BASIC MATERIAL

For the analysis of car accidents with rollover consequence 7,744 accidents from the years 1994 – 2001 from the accident sample collected in Hannover were evaluated, altogether 9,257 cars participated with 11,361 passengers, of these 434 cars resulted in a rollover. A rollover was defined to be a movement of the car, where the vertical axis of the vehicle turned at least 90° around the longitudinal or transverse axis to its final position. Thus 430 cars and 741 occupants with rollover constitute the basis of the study. Within the analysis the amount of cases can be different as basis of the diagrams and tables concerning different related

parameters. The presented percentage-values are based on statistical weighting procedure and is given additionally as n-values based on non-weighting numbers.

For these cases, an extensive in-depth analysis of the rollover incidents in the course of an analysis of individual cases was conducted. There, special information based on the existing accident reconstruction details and of a scaled drawing of the accident location was used for the analysis, these were amongst others:

- position of the individual impact on the vehicle
- direction of load at each impact
- deformation depth at the place of each impact
- estimated energetic reduction in velocity as a consequence of each impact
- location of each impact
- direction of load in relationship to the centre of gravity for each impact
- injuries in the course of each impact and place of impact inside the vehicle

Additionally, in order to allow a comparison of the results from this paper with other scientific publications, the vehicle movement, where the Rollover is concerned, was classified; the chosen classification is according to NASS (National Accident Sampling System), where a total of 11 different types of rollovers were differentiated (Figure 1). Parentau et al [13] made a careful study of NASS data and used the rollover-type-classification of NASS, they found that currently developed trip-over and fall-over tests reflect the largest proportion of rollovers in the field.

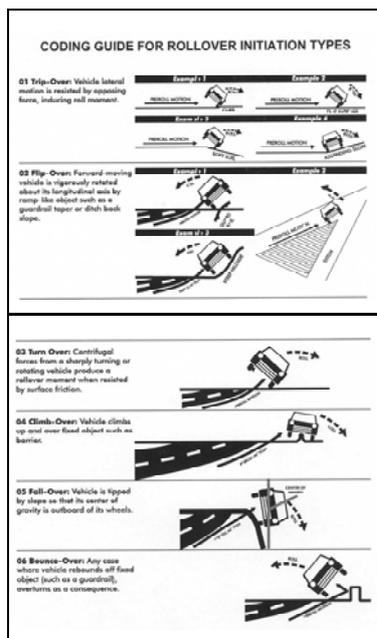


Figure 1. Classification of Rollovers (NASS-Datasampling)

All collisions of vehicles were recorded in chronological order and the driving velocity at the start of the first traces or at the point, when the vehicles left the road were calculated using standard software (PCCrash).

The frequencies of results will be presented with the percentage in weighted form and the numbers in absolute values. The injury severity is used by AIS (Association of Automotive Medicine) and used in the presented diagrams as 3 groups from minor (AIS 1), severe (AIS 2 to 4) and worst/fatal (AIS 5 and 6), with this classification a 90% correlation does exist to the definition of the national statistics based on police reports [Otte - 14].

TYOLOGY OF ROLLOVER ACCIDENTS

Frequency distribution

Accident structure of rollover situations

The percentage of rollover accidents within the framework of accident investigation GIDAS Hanover has continuously declined and constitutes currently (for the year 2003) only 2.3 % (Figure 2). It is assumed that the significant decrease of the rollover risk after 1999 can be linked to the implementation of ESP (electronic stability program), as only after 1999 vehicles with ESP have been registered in accidents as the figure pointed out. Their percentage of all cars with ESP involved in accidents (with/without rollover) has increased to 11 % in 2003. ESP prevents the pulling of a vehicle after skidding has commenced. As rollovers can also be seen by vehicle-vehicle-collisions, there are also vehicles equipped with ESP among the rollover accidents.

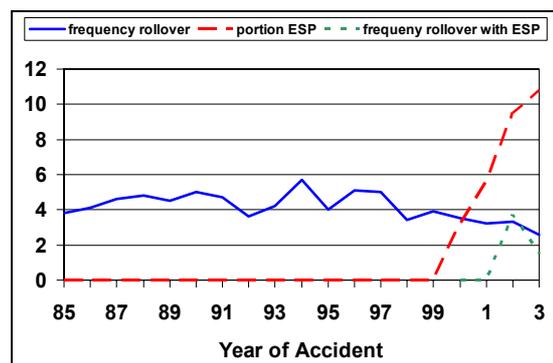


Figure 2. Portion of accidents with rollover (n=20996 Cars = 100%) on traffic accidents with injured persons

Frequently, the rollover constitutes a secondary event. The rollover seems to be an event occurring on special road segments. Nearly 90% of the cases were preceded by a collision (88% on highways, straight country roads and rural curves). A third of

these were vehicle collisions, in a quarter of the cases a tree impact took place first. On intersections, the highest frequency of secondary effect of rollover as can be seen in Figure 3 is based on prior vehicle impacts (65% on rural roads, 67% on urban roads).

	rural				urban		
	highway (n=123)	straight line (n=151)	curve (n=79)	inter- section (n=19)	straight line (n=25)	curve (n=10)	inter- section (n=26)
rollover only	13.3	12.6	22.8	7.2	12.5	12.0	-
rollover first	5.5	5.7	1.9	-	5.4	-	-
rollover follows							
- vehicle impact	15.7	11.7	2.6	65.2	21.4	20.7	67.6
- object impact	65.5	70.0	72.7	27.6	60.7	56.3	26.0
- other impact	-	-	-	-	-	11.0	6.3

Figure 3. Rollover events within Accident Chronology

The risk of suffering an accident with rollover is highest for vans at 5.2% und SUVs at 14.3%, whereas only 3.9 % of standard car types were involved in a rollover accident (Figure 4).

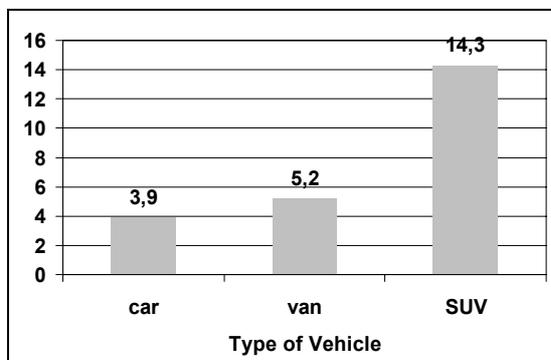


Figure 4. Portion of Rollover events on accidents with injured person related to type of vehicle

Half of all accidents with rollover occur on German streets outside urban areas (Figure 5). Rollovers while cornering are not rare at 16.9%, but in comparison to highways (26.2%) and straight highways (33%) much less frequent. Accidents resulting in a rollover occurred at rural intersections only at 4.5% - at urban ones however at 8.5%. 80.7 % of all rollover accidents occur outside city limits.

road type	rural				urban		
	highway (n=123)	straight line (n=151)	curve (n=79)	inter- section (n=19)	straight line (n=25)	curve (n=10)	inter- section (n=26)
rollover n=434 (100%)	26.2%	33.0%	16.9%	4.5%	8.1%	2.7%	8.5%
MAIS 0	5.2%	2.3%	4.9%	6.7%	5.8%	-	11.5%
MAIS 1	60.3%	66.1%	63.0%	78.1%	60.8%	53.6%	79.4%
MAIS 2-4	29.4%	28.6%	28.1%	15.2%	33.4%	46.4%	6.7%
MAIS 5/6	5.1%	3.0%	4.0%	-	-	-	2.4%
non-rollover n=8827 (100%)	8.2%	8.2%	2.5%	6.9%	23.2%	2.8%	41.1%
MAIS 0	39.2%	31.3%	15.4%	39.1%	66.0%	43.9%	61.8%
MAIS 1	49.3%	49.3%	52.6%	51.2%	30.3%	45.6%	34.3%
MAIS 2-4	10.2%	16.4%	27.5%	9.3%	3.5%	9.9%	3.8%
MAIS 5/6	1.3%	3.0%	4.5%	0.3%	0.2%	0.6%	0.1%

Figure 5. Accident Location and Injury Severity of Rollover Events

If additionally the severity of the passengers and drivers of cars involved in rollover accidents is considered, the accidents on freeways, straight

highways and in bends outside of urban areas turn out to be especially injury prone: about 29% of these accidents have a maximum injury severity of MAIS 2 to MAIS 4 and 3 to 5 % even fall under injury severity degrees MAIS 5/6. Injuries of a severity of MAIS 5/6 nearly completely missed in urban areas except at intersections (2.4%). Figure 5 shows a comparison with the situation in case of accidents without resulting rollover. A significant risk for resulting rollover consequences can be seen for rural roads and highways, thus roads where possibly a high velocity constitutes a significant influence.

For accidents resulting in rollover most of the vehicles leave the road and turn over at the roadside. Only within city limits do more than two thirds of all rollover accidents occur on the road. Rollover accidents after a tree impact on straight sections of a road do only occur on urban streets (5.4% of the rollover accidents on straight roads). Outside city limits, especially ditches next to the road constitute frequent places of impact (41% on straight roads, 36.6% in curves).

road type	rural				urban		
	highway (n=123)	straight line (n=151)	curve (n=79)	inter- section (n=19)	straight line (n=25)	curve (n=10)	inter- section (n=26)
road	48.9%	11.6%	13.4%	42.7%	60.4%	76.5%	86.2%
field, grass	20.6%	44.0%	46.7%	17.8%	14.7%	5.8%	11.6%
ditch, slope	25.6%	41.0%	36.6%	39.5%	9.3%	12.0%	2.2%
pole, tree	2.3%	2.4%	1.3%	-	5.4%	-	-
wall	-	0.6%	-	-	-	-	-
others	2.6%	0.4%	2.0%	-	10.2%	5.7%	-

Figure 6. Primary Impact Location of Rollover Events

A rollover accident can consist of several impact phases and the body of the vehicle can touch ground at different places within the course of the rollover motion (Figure 7). Only on highways and in curves did more than 3 impacts occur in the course of a rollover accident (0.2% of accidents with rollover on highways, 1.3% of accidents in curves).

number of impacts	rural				urban		
	highway (n=123)	straight line (n=151)	curve (n=79)	inter- section (n=19)	straight line (n=25)	curve (n=10)	inter- section (n=26)
1	65.9	70.4	71.0	80.9	89.3	73.0	80.4
2	26.1	22.5	23.9	19.1	10.7	27.0	14.8
3	7.7	7.1	3.9	-	-	-	4.8
4	0.2	-	1.3	-	-	-	-

Figure 7. Number of Impacts during Rollover Events

Causes of rollovers

A rollover of a vehicle is the consequence of high lateral angular speed, caused by suddenly occurring great deceleration forces between tires and road surface. They can thus be the result of different friction values (μ -split) or of a sudden hooking in the area of the wheels, i.e. when sliding against a curb. In 3.0 % of the cases with rollover a curb stone was evident as cause of the rollover (Figure 8). In 38.0 % the car was swerved under μ -constant or μ -split conditions, in 45.4 % a sliding into an embankment downwards or upwards could be established. In 13.7 % a pre impact with another vehicle implemented the rollover movement.

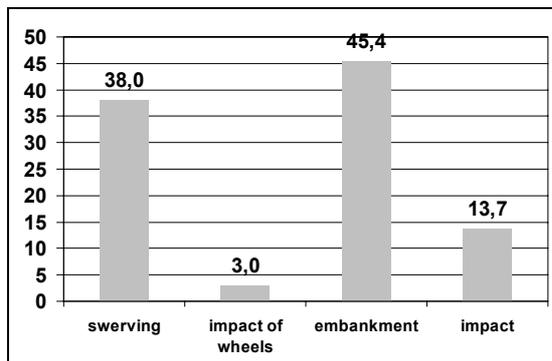


Figure 8. Cause of rollover of n=411 cars (n=23 unknown)

In 20.2 % of the cases with rollover the banquette area was even, compared to 51.2% of non-rollover accidents (Figure 9). Only for 17 % the surface was situated either higher or lower. One third of all rollover events happened on grass/field surfaces (34.3%), collision objects like trees (1.8%) and walls (0.1%) were in 1.9 % rare as location of rollover impacts. A ditch and an embankment could be seen in 29 % as impact location (Figure 10). This resulted in the greatest risks for a rollover in case of a ditch running parallel to the side of the road, into which the skidding vehicle slid (27.9 % of the accidents with rollovers happened with ditches related to 3.3 % of accidents without rollover).

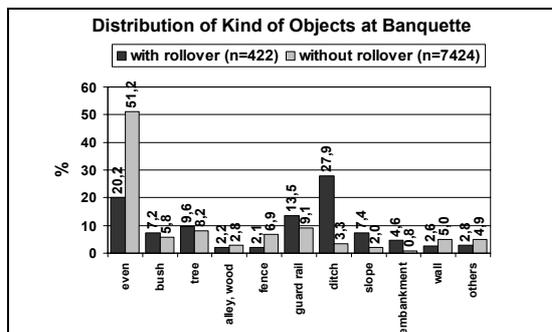


Figure 9. Kind of Objects along the Road in Accidents with and without Rollover

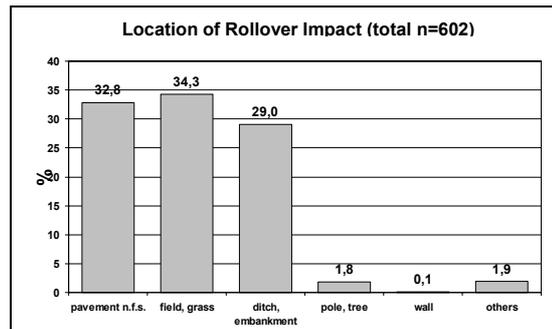


Figure 10. Frequencies of objects struck at banquette in car accidents with and without rollover

PLACE AND SEVERITY OF INJURIES

Accidents with rollover consequences result in injuries more frequently than those without rollover. For accidents with rollover (maximum injury severity per car) only 5.0 % of the passengers in the car remained uninjured. In contrast, for all accidents with personal injuries 55.6 % of the passengers in the car remained uninjured. 37.4 % of the passengers in the car without rollover suffered injuries of the degree of severity MAIS 1 (with rollover 66.8%) and were thus classified as slightly injured (outpatient), 6.4 % suffered MAIS 2 to 4 (with rollover 25.8%) and 0.6 % suffered degrees of severity MAIS 5/6 (with rollover 2.4%). In case of rollovers 68.7 % of the vehicles were involved in just one impact, 23.5 % in two impacts, 7.5 % in three impacts and 0.4 % more than three impacts. The severity of the injuries shows clearly that an increase of the number of impacts results in an increase of the severity of the injuries. For one impact only 28 % showed injuries of severity MAIS 2 and higher (MAIS 2+), for three impacts this number had increased to 43 %. It also turned out that a rollover on the road surface results with a probability of 30 % in injuries of the type MAIS 2+, a rollover at the side of the road however does not necessarily increase the severity of the injuries. Frequently in such cases even lower degrees of injury severity occurred. Thus only 28 % of the rollovers in the paved embankment and merely 18 % in the unpaved embankment were related to injuries of severity MAIS 2+.

Belted occupants have a lower risk for ejection (Figure 11). 1.6 % of the belted drivers and 2.4 % of the belted frontseat passengers and 2% of the rear seated occupants ejected during the rollover movement, compared to this 31.9 % of the unbelted drivers and 13% of the unbelted frontseat passengers were thrown out of their vehicles. The presented occupation distribution gives a 79.5% reduction for the driver of severe injuries MAIS 3+ by wearing a seatbelt.

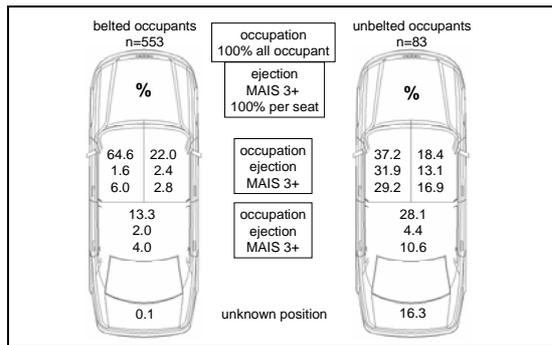


Figure 11. Occupation distribution, proportion of ejection and injury situation of cars with rollover

The type of the collision object and the place of impact on the vehicle seem to be of importance for the severity of the injuries. Concerning the place of impact on the vehicle, the vehicles were subdivided into different zones for the purpose of this study. The sides of the vehicles were subdivided into 6 different zones A – F and the vehicle as seen from above was divided into left - centre - right. This resulted in the frequency distribution of the places of impact on the vehicles depicted in Figure 12a-c.

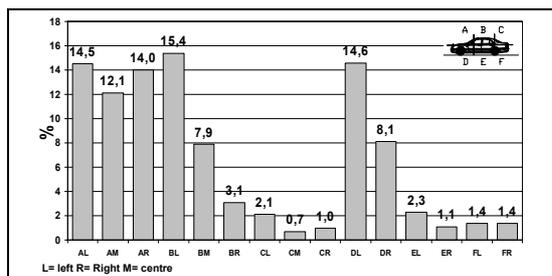


Figure 12a. Impact zones at car (first impact within rollover movement - n=599)

It is visible that an impact zone that occurred very frequently was the front part of the car (AL,AM,AR: total 40.6%) and at still 15.4 % also the position of the driver (BL) as impact zone of the first impact in the course of the rollovers. But also the underbody structure DL can be seen with 14.6% very often as first impact zone within an rollover. Especially the position of the driver is also that with the most severe injuries. 42 % of the passengers suffered injuries of a degree of severity MAIS 2+ when an impact zone BL occurred.

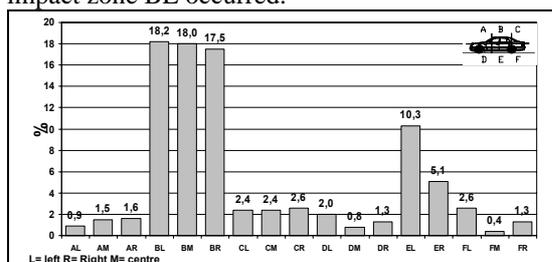


Figure 12b. Impact zones at car (second impact within rollover movement - n=534)

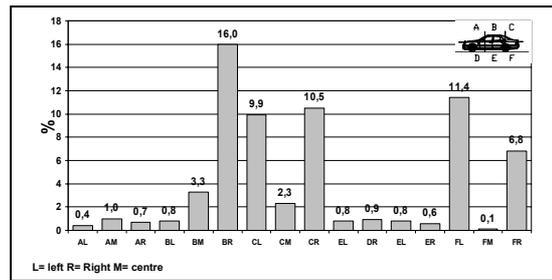


Figure 12c. Impact zones at car (third impact within rollover movement - n=391)

A rollover is mostly characterized by several different places of impact on the vehicle. A second impact in the course of the rollover was determined on very few parts of the vehicles (Figure 12b).

Mostly there were places of secondary impact on BL, BM, BR – zones (in total 53.7%), thus in the area of the front passenger seat – with approximately 18 % each. Here, the severity of the injuries was usually significantly higher for the area of the passenger cell than outside the compartment. Only the third impact in the course of the rollover phase (Figure 12c) occurred mainly in the rear area of the passenger compartment (CL, CM, CR) but still also in the area of the front passenger seat at 16 % (BR). The most severe injuries were mostly registered in the course of the third impact, if this impact occurred in the front part of the roof of the passenger cell (AL, AM, AR).

13.8% of the injuries of car occupants were caused by the windscreen, 10.2% by the dashboard and 5.7% by the steering wheel (Figure 13). Side glasses of the vehicle caused 9.5% of the injuries within rollovers and 8.3% were registered as the roof parts. Remarkable is the fact that 7.4% of the injuries were caused outside the vehicle and 9 % were non contact injuries called “whiplash injuries”.

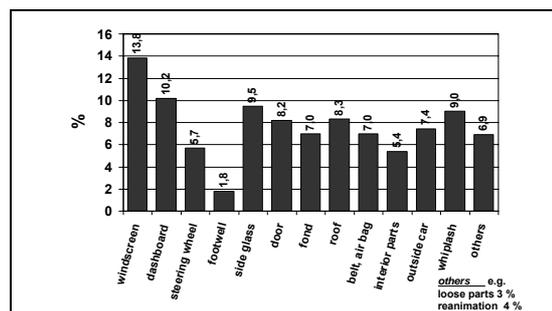


Figure 13. Injury causing parts of car occupants in rollovers (n=408 injuries caused by rollover)

KINEMATICS AND CHARACTERISTICS OF THE ROLLOVERS

Concerning the typing of the Rollover according to NASS classification it turns out that the most common accident type at 29.7 % is the Trip-Over

type 3 (Figure 14). This is a type of accident where the rollover occurs on a gradient with soft surface and a sideways tilting vehicle. This type is followed by the type Trip-Over 2 at 17.6 %, where the vehicle skids sideways on a flat surface and topples over. All others of a total of 11 different types according to NASS occur at low frequencies. The type Flip-Over 2 occurs relatively frequently at 9.8 %, where a vehicle moves mainly along the longitudinal axis of the vehicle, reaches a ditch by rotating around its longitudinal axis and topples over. These three dominant rollover types build 57.1% of all rollover events.

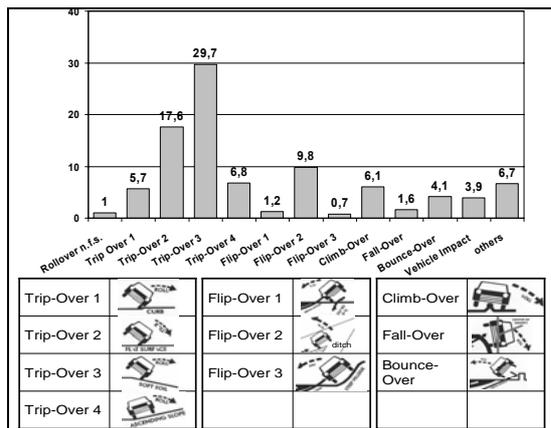


Figure 14. Frequencies of different rollover-types (NASS classification), n=422

Accidents in the shape of a rollover characteristic with a sideways knock are not very frequent (Trip-Over 1 - 5.7 %, Flip-Over 1 - 1.2 %, Bounce-Over - 4.1 %), and they seemed especially minor (Figure 15). Approximately 30 to 50 % of these resulted in uninjured occupants (MAIS 0). The lower severity of injuries can be explained by the more rotational speed the tilting car undergoes. In other types of rollover the impact to the car body suffer high deceleration loads. Regarding the resulting severity of injury, out of the accident types with increased frequency, the Trip-Over 2 seems to cause the worst injuries (26 % MAIS 2+), whereas especially remarkably in its complete distribution concerning the severity of injuries is the Flip-Over 3 with nearly 50% MAIS 2+, where a vehicle falls sideways off the road onto a significantly lower terrain. The type Fall-Over also remarkable, it has the lowest percentage of soft injuries, but very few in occurrence. The subsequent roof impact is correspondingly usually massive. In 56 % of the cases rollover occurs over the left side of the vehicle. No significant change of the resulting severity of the injuries in relation to the side of the rollover was found.

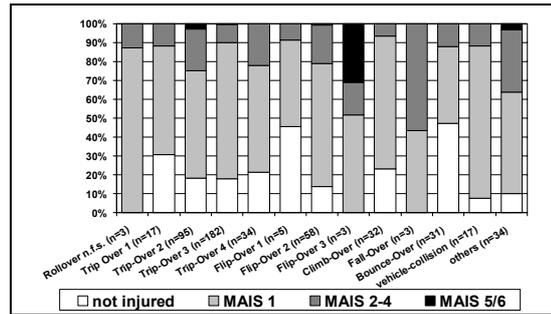


Figure 15. Injury severity grades of belted not ejected occupants for different kinds of rollover

INJURY SITUATION TO BODY

The main emphasis where injuries on the body after a rollover had taken place were concerned was placed mainly on head, thorax and arms. 42.5 % of the belted not ejected occupants in car accidents resulting in a rollover were injured on the head, 26.2 % on the thorax and 44.6 % at the upper extremities. In comparison with the injury image of belted occupants in car accidents without a rollover, there 34.5 % of head, 30.9 % of thorax and 18.4 % of arm injuries occurred. It was thus shown that under rollover conditions the risk for head and especially for arms is much more higher than without rollover. That is the same for neck injuries, which could be seen in 25.1% of rollover cases.

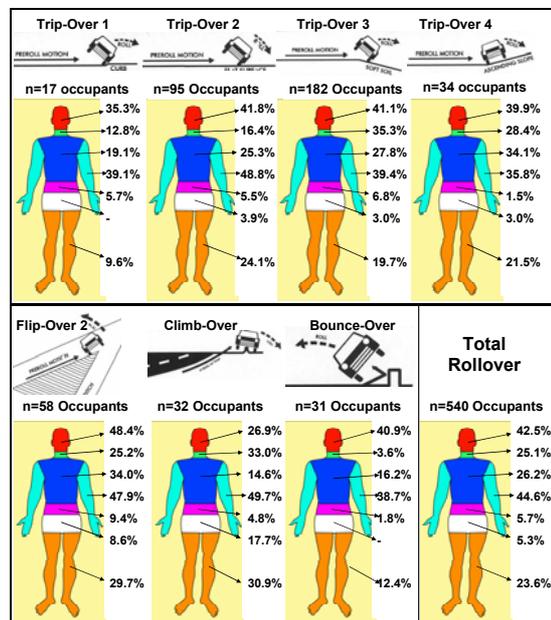


Figure 16. Frequencies of injured body regions of belted not ejected occupants for different kinds of rollover (100% all occupants each group)

The analysis of the injury pattern found this high risk for head impacts in rollover accidents especially when the car collided with additional impacts on

other vehicles and objects before or after the rollover event (Table 1). 47 % of occupants of vehicles with additional impacts suffered soft tissue lesions on the head, 3.5 % fractures to the face and 11.4 % brain injuries compared to occupants of vehicles with isolated rollover, 37 % suffered soft tissue lesions, 0.8 % facial fractures and 9.5 % brain injuries. Table 1 explains that an isolated rollover is not a severe accident event, the severity is increasing if a pre- or post-impact to other vehicles or objects occurs.

Kind of Injuries	Rollover cases	
	isolated	additional impact
total (n)	91	650
soft tissue head	37.0%	47.0%
fracture face	0.8%	3.5%
fracture skull	-	0.8%
fracture base of skull	-	1.3%
SHT	9.5%	11.4%
soft tissue neck	-	1.9%
whiplash injury	23.1%	18.3%
fracture cervical spine	2.0%	2.8%
others neck	2.8%	1.5%
soft tissue thorax	25.9%	26.8%
fracture ribs	1.4%	2.6%
fracture sternum	-	1.1%
fracture shoulder	1.4%	2.9%
thoracic spine	0.9%	2.5%
thorax organic	3.3%	2.0%
soft tissue upper extr.	48.1%	39.7%
fracture upper arm	-	1.6%
fracture elbow	-	0.3%
fracture lower arm	0.8%	1.9%
fracture hand	2.7%	2.5%

Table 1
Frequencies of injured body regions of belted not ejected occupants for different kinds of rollover (100% all occupants each group)

63 % of the vehicles with rollover skidded at the time the accident started, 90 % of the vehicles were driven at velocities exceeding 60 km/h at the moment the accident started (Figure 17). Thus a high driving speed is a typical feature of accidents with rollover consequences. Whereas for accidents without rollover consequences 90 % of the vehicles were driven at speeds exceeding 10 km/h and 70 % were doing less than 60 km/h the moment the accident started. On the other hand, the analysis of collision speeds of the vehicles with and without rollover did not show any significantly deviating

velocity distribution. 80 % of the vehicles with rollover primarily collided in the course of the accident primarily at speeds of up to 52 km/h, without rollover it was 60 km/h. This means that obviously a large amount of speed can be dissipated after the accident has started, up to the point of collision in the course of the skid movement.

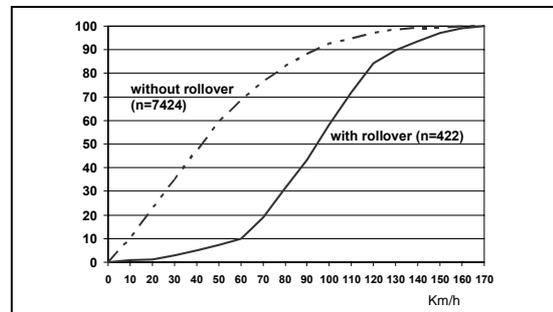


Figure 17. Cumulative frequencies of driving speeds of cars before reaction

DEFORMATION PATTERN ON THE VEHICLE AND INFLUENCE ON THE SEVERITY OF THE INJURIES

Very rarely more than one complete turn occurred in the course of rollovers. 16.7 % were classified as 1/4-rotation, 52.1 % as 1/2 rotation, 6.5 % as 3/4 - rotation. Only in 4 % of the cases more than a complete rotation of the vehicle was found. 88 % of the rollovers were consequences of previously occurred primary collisions.

The deformation depth of each impact was measured in the direction of the impact load. Deformations of up to 40 cm occurred by rollovers. Looking to the depth of deformation for cases with minor injury outcome compared to those with severely injured occupants, only small different accumulated frequency distribution of the deformation depth on the resulting severity of the injuries MAIS for the belted occupants was apparent (Figure 18). 80 % of the severely injured belted occupants MAIS 5/6 as well as 80 % of the MAIS 1 minor injured belted occupants suffered within the rollover, deformation depths of up to 15 cm.

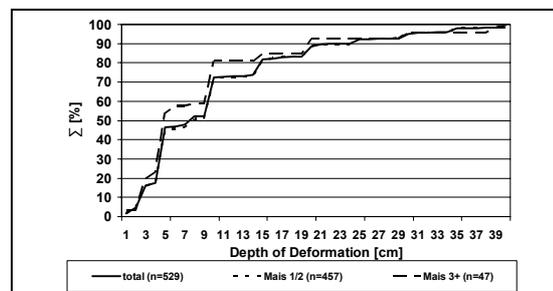


Figure 18. Cumulative frequencies of depth of deformation related to different injury severity grades for belted not ejected occupants

Each deformation on the car was related to the number of impacts during the rollover movement as primary, secondary or third contact. The deformation was measured with the deformation depth and assessed concerning the suffered speed change during this impact; this was done by an EAS-value (Energy Assessed Speed) even this could not be done exactly and in a physical allowed manner. This EAS value should be given an assessment for the severity of rollover impact to the car body shape. In these cases EAS is represent an assessment of the deformation-impact-configuration of the rollover movement. 80% of the values for impacts by the rollover can be found up to EAS 15 km/h (Figure 19). Similar distributions in the cumulative frequency curves of this value can be seen for primary, secondary or third contact. In contrast to this 80% of the EAS-values for cars with no rollover were estimated above EAS 10km/h.

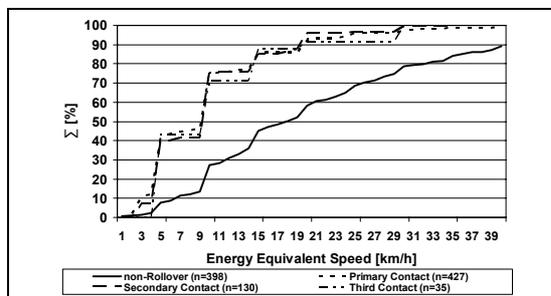


Figure 19. Cumulative frequencies of deformation energy assessed by EAS for cars with rollover for different impact situations

For the analysis of the injury severity related to the rollover movement, a special MAIS was built for all rollover related injuries. The so called “MAIS rollover” was plotted in a diagram related to the depths of deformation by rollovers (Figure 20). The injury severities by rollovers are for belted occupants mostly not above MAIS 2 and there are many uninjured occupants within a rollover movement. The Spearman correlation coefficient was calculated with 0.212, that means a small positive relationship between deformation depth and injury severity was found.

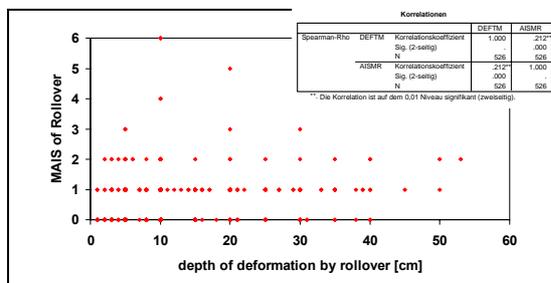


Figure 20. injury severity MAIS of rollover related injuries and the depth of deformation of those contact points on the cars with rollover (n=529)

A similarity can be established for non-rollover cases (correlation 0.051), but compared to the injury severity of rollover related deformations the injury severities of non rollover related deformations following in more significant correlation of these two parameters (Figure 21). Larger deformations are mostly linked with higher injury severities for deformations not related to rollovers. The Chi² test shows that the higher injury severity grades are more linked to non-rollover situations ($p < 0.001$).

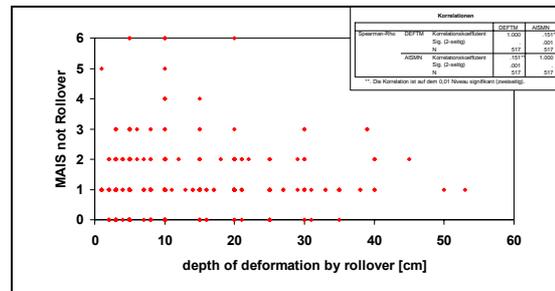


Figure 21. injury severity MAIS of non-rollover related injuries and the depth of deformation of those contact points on the cars with rollover (n=517)

From this analysis it can be seen that the injury severity MAIS of occupants after rollover resulted mainly from the injury severity of the head (Figure 22), because the head is exposed as flexible extremity part for the injury risk. It can be pointed out from the diagrams that the risk for severe head injuries is statistically starting for belted occupants with roof deformation depths of above 30 cm.

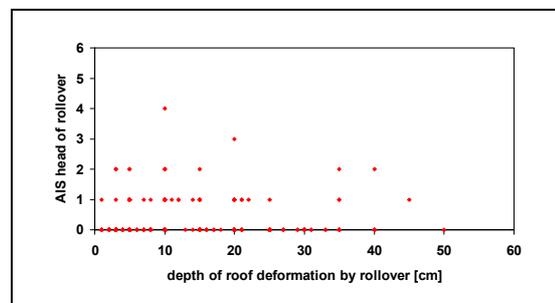


Figure 22. injury severity of the head of occupants with rollover related injuries and the depth of deformation of those contact points on the cars with rollover (n=438)

CHARACTERISTICS OF THE ACCIDENT SET-OFFS

From the detailed documents of the accident reconstructions, especially the in-scale drawing of the traces found on the accident site, such as brake and skid traces, the take-off angle of the road surface, the skid, brake/skid distance could be determined and the period of time from hitting the brake to the point of the primary impact could be calculated. Mainly very small angle deviations from

the longitudinal axis of the road occurred, when the vehicle left the road towards the side. 65 % of the vehicles left the road at an angle of less than 5 degrees (Figure 23).

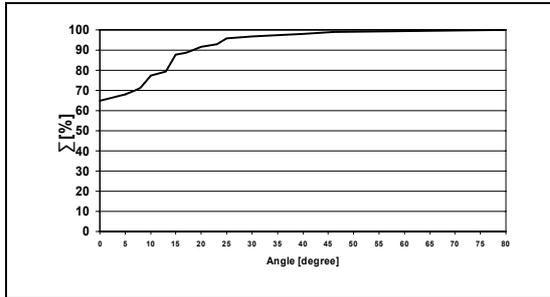


Figure 23. Angle of running off the roadway (n=334). This angle exists between the direction of car's centre of gravity and the direction of the road when leaving the roadway

Angles of more than 25 degrees occurred only in 5 % of the cases. This means that the take-off angle for accidents with rollover consequences does not exceed 25 degrees. An attitude angle for the vehicle to the left of up to 80 % between 0 and 120 degrees as well as to the right as to the left side can be determined (Figure 24).

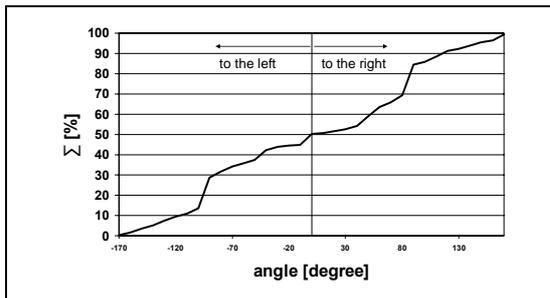


Figure 24. Cumulative frequencies of attitude angle at rollover (n=409)

For 80 % of the accidents with rollover consequences a time of up to 4.3 seconds elapsed from the start of the accident to the first impact during rollover. In only approx. 10 % of the cases periods of more than 5 seconds elapsed and 5% registered with more than 6 seconds (Figure 25).

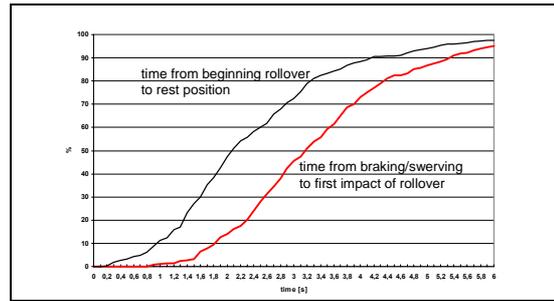


Figure 25. Cumulative frequencies over time from the beginning of the braking/swerving movement to the first impact in the course of the rollover (n=308) and the whole time duration until the rest position of the car (n=295)

For the whole movement of a rollover to rest position a time duration of 1 to 4 seconds (80%) can be seen as useful in real accidents.

CONCLUSIONS

Rollovers are found in the traffic scenery in different situations, some are the result of a high rotation of the car and an increase of friction between tires and the road surface, others are the effect of a sudden hooking in the area of the wheels. For the German accident situation the study pointed out that a rollover could be observed in 3.7% of the accidents with casualties and that the percentage has been reduced over the years to the current state of 2.3% for the year 2003. It can be awaited in the future the number of rollovers accidents will further decrease regarding the fact that many vehicles will be equipped with ESP (electronic sliding protection). But the prospective should be not too optimistically because the study found cases of ESP equipped cars in rollover accidents as well. The portion of rollover events are at 11 % remarkable high for vans and off-road-vehicles. Rollovers mainly occur in connection with accidents on straight road sections and at intersections, especially on rural roads, 20% occurred in a curved section only. It could be seen that speed influence is a major parameter for accident causation following in rollover events. Ditches and Embankments are at 29% beside the unpaved surfaces of fields or pastures the most frequent collision object within a rollover movement, an impact against trees or walls can be seen only in less than 2 %. Nearly 70% of all impacts within a rollover occur on flat surfaces (paved, field, grass). Comparing accident situations with and without rollover the highest risk for rollovers can be established, if the road side is equipped with a ditch. 80 % of the rollovers were consequences of previously occurred primary collisions. In 3% only the rollover was initiated by a wheel movement against a curb stone, in all others the increasing friction value during the sliding motion was responsible for rollover momentum.

The type of the collision object and the place of impact on the vehicle as well as the number of impacts within a rollover movement influence the injury outcome. The position of the driver is often hit first, the second impact zone being the roof of the vehicle, while the rear of the roof is more often hit third. The position of the driver is with the one, where the most severe injuries occur.

The study shows that 3 different types of rollover make up nearly two thirds of all rollover cases: firstly the so-called "Trip-over, describing a lateral movement of the vehicle on a downward sloping ramp" and secondly the "Flip-over, these are also the ones with the highest injury risk for head injuries. The study came to the same results as Parentau et al [13] pointed out, that trip-over reflect the largest proportion of rollover in the field. But in contrast to Parentau which confirmed also the Fall-over test conditions as one major accident type, the presented study pointed out that rollovers in the characteristic of a lateral sideway movement and rotation via the longitudinal axis are seldom and not very severe. For the replication of frequent and severe real life rollover accidents a screwed movement of the car on a ramp via the longitudinal forward movement should be proposed as test procedure. This corresponds to examinations of Berg et al [15]. Only a small influence of the deformation depth on the resulting severity of the injuries MAIS was apparent. 80 % of the severely injured occupants MAIS 5/6 as well as 80 % of the MAIS 1 minor injured occupants suffered within the rollover, deformation depths of up to 15 cm. This is in agreement with other authors, i.e. an investigation by Piziali et al [16] came to the conclusion, that there is only association between roof crush and injury since the occupant is not in the vehicle. Putting the occupant in the vehicle does not change association to casualty. The here presented study found a correlation of Injury risk and roof deformation for severe head injuries AIS 3+, starting at roof deformation above 30 cm. Also Cooper and Mofatt [17] found a causal relationship between roof crush and injury risk. A recent article from Australia by Rechnitzer [18] that reviews previous literature and several case studies concludes that roof crush causes injuries in rollover accidents. Also Friedman [19] includes a NASS analysis to support their contribution that roof crush causes injuries. The NASS study finds that the occupant closest to the most significant roof crush is at highest risk of injury. Parentau [20] explained this effect on the situation of the crash, that near-side occupant's head crossed the window plane more frequently than the head of the far-side occupant. This effect cannot be confirmed by the presented study, here the farside occupant suffered in 6.4% of the rollover cases an injury severity MAIS 3+ and 16 % were uninjured comparing to 5 % of the nearside occupants suffered

MAIS 3+ and 20% were uninjured. The most severe injuries were mostly registered in the course of the third impact, if this impact occurred in the front part of the roof of the passenger cell.

The here presented study describes details of the initial part of the accident phase following in rollovers. 65% of the vehicles left the road at an angle of less than 5 degrees, angles of more than 25 degrees are very rare at 5%. An attitude angle for the vehicle movement from leaving the road, or after the primary impact, respectively to the first impact during the rollover was measured in 80% between 0 and 120 degrees to the left as well as to the right side of the road. For 80 % of the accidents with rollover consequences a time of up to 4.3 seconds elapsed from the start of the accident to the first impact during rollover. In only approx. 10 % of the cases periods of more than 5 seconds elapsed. This brings strategies of accidents avoidance in the main focal point of interest, there could be enough time for activating intelligent sensor technique for the development of different airbag systems.

The conclusions from the study can be formulated as follows:

1. rollover prevention

- avoidance of vehicle sliding (63 % of cars with a rollover slipped before the rollover)
- reduction of driving speed (80 % of cars with a rollover were driven >70km/h)
- reduction of high friction values in the areas of the wheels (38 % of accidents with rollovers were initiated by lateral sliding effect μ - and μ -split)
- recommendation for the implementation of a paved flat strip beside the road on the same height-level, avoiding ditches, trees and other fixed objects

2. Injury prevention within rollover event

- development of stiffer interior structures of the vehicle cell especially avoidance of the roof deformations > 30 cm
- use of seatbelts, implemented with pre powered pull tight devices
- positioning of padding together with additional implemented airbags in lateral head and roof position

The study shown that for belted occupants in the current accident situation, there is with approximately 2 % of accidents with casualties a low risk to be injured in a rollover movement on German roads. Comparing to vehicle to vehicle impacts an isolated rollover event can be established in principle with minor injury outcome for the current car fleet and their safety equipment. In contrast to earlier studies from the 70ies [Mackay 21] the injury outcome in current vehicles can be positive reduced by wearing seatbelts.

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