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# Possibilities of In-Depth Investigation Methodology for Injury and Accident Prevention on the Example of Car Accidents with Rollover – An In-Depth Analysis by GIDAS[1]

## Abstract

This paper describes the methodology of In-Depth Investigation in Germany on the example of GIDAS (German In-Depth Accident Study). Since 1999 in Germany a joint project between FAT (Forschungs-vereinigung Automobil-technik or Automotive Industry Research Association) and BASt (Bundesanstalt für Strassenwesen or the Federal Road Research Institute) is being carried out in Hannover and Dresden. The methodology of this project is based on a statistically orientated procedure of data sampling (sampling plan, weighting factors). The paper describes the possibilities of such in-depth investigation on the results of the offered title. The accident cases were collected randomly within GIDAS at Hannover. There are more cases existing from previous investigation started in 1985 under the same methodology.

The portion of rollovers can be established at 3.7% of all accidents with casualties in the year 2000. For the study 434 cases of car accidents with rollovers are used for a detail comprehensive analysis. 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.

The presented paper will give an overview of the accident situations following in rollover movements of cars. The distributions of injury frequencies, injury severity AIS for the whole body and for the body regions of occupants will be 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 will be shown in the paper.

The paper will describe the possibilities of In-Depth Investigation methods for the approach of finding countermeasures on the example of car accidents with rollover and explaining the biomechanics of injuries in rollover movements.

## 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 of others, mostly called solo-accidents. 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. 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. VIANO [1] 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-away rollovers were single vehicle crashes. Even today, the majority of rollover accidents are reported from the Anglo-Saxon countries. 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. – 2]. 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 – 3] and unbelted occupants have a higher risk of ejection than those belted, in cases of ejection 47% were severe or fatal injured (HIGHT 1972 – 4). 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.

1 cooperative study of FAT and BASt

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 [5] 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 [6] that there is in case of not using a seatbelt an 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 – 7].

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 in-depth investigations at the site of the accident can be used. This results in accident documentations that were started by a scientific team on-site and later added to in retrospect. These accidents can be chosen randomly, which can be counted as representative cross-sections of the real accident incidence using a statistic weighting process. The injuries are classified and documented and the damages to the vehicles are measured and recorded. Driving and collision speeds are calculated from the traces found at the accident site. 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.

## Methodology of In-Depth Investigation GIDAS

In Germany as in many industrial countries, accident trends are presented annually based on the official national accident statistics. These accident statistics use the data from police accident reports. Although these statistics are useful, the limitation is that very little information about how accidents occur, the cause of the accident and the injury mechanisms is available. This limitation can be overcome by carrying out specialist in-depth accident investigations, collecting more detailed information than available in the police records. Such investigations begin immediately after the accident occurs. Specialist teams go directly to the scene of the accident to collect the necessary information to complete detailed accident reconstructions as well as the medical data about how the involved people were injured and treated. In this way, extensive information about a wide range of fields of research such as “vehicle design for passive and active safety“, “biomechanics”, “driver behavior“, “trauma medicine“, “rescue services“, “road design“ and “road conditions“ can be collected.

In Germany the first so-called “In-Depth Investigation Teams“ were initiated in the 1970s by German automakers. In 1973, the Federal Road Research Institute established an independent team at the Medical University of Hannover (in cooperation with the Technical University of Berlin). By 1984, this developed into a long term on-scene accident research study described by OTTE [8], based in a defined geographical area surrounding and including Hannover, which collected representative results. As of 1985, a target of 1000 accidents per year was set to form the basis for future evaluations. A statistical sample plan was used for selecting accidents for investigation and extensive information about the various aspects of the pre-accident, collision, and post-accident phases was collected and compiled into a database. The methodology and sample selection are described in the publication by OTTE et al. [9].

The value of in-depth accident research studies has been recognized internationally and many other countries also have such teams. Since such detailed information is essential for improving the safety of cars, a strong collaboration with automakers developed. This resulted in a joint project called GIDAS (German In-Depth Accident Study) between FAT (Forschungsvereinigung Automobiltechnik or Automotive Industry Research Association) and BASt (Bundesanstalt für Straßenwesen or the Federal Road Research Institute) in 1999. In this project, the geographical area was extended and a second team was set up in the Dresden area providing additional cases from a different part of Germany. Both teams Hannover (MUH) and Dresden (TUD) function in the same manner using the same systems, procedures and collecting data in one common database of approximately 2000 cases annually.

## Design and Methodology of the Accident Research Centers

### Geographical Area of the Research Studies

The geographical area of the Hannover team covers the city and the surrounding rural areas within a diameter of approximately 80km (Figure 1). There are 1.2 million residents in this area and the surface area is approximately 2,289km$^2$. 10% is designated as urban.

The area Dresden includes the city of Dresden as well as parts of the counties within a diameter of approximately 60km. There are approximately 925,000 residents in the area and the surface area is approximately 2,575km$^2$.

### Sample Plan – Randomly and Representative

Accidents involving personal injury are investigated according to a statistical sampling process. In both areas, the respective police, rescue services, and fire department headquarters report all accidents continuously to the research team. The team then selects accidents according to a strict selection process and investigates these cases following detailed procedures contained in a handbook and coding manual. In order to avoid any bias in the database, the data collected in the study is compared to the official accident statistics for the respective areas and weighting factors are calculated annually. This process explains why the data captured by the research teams can be seen as representative for their areas.

Statements about the national situation are only possible for those accident features that are relatively independent of regional influences. This is true for the variables which have an effect on the injuries sustained in crashes and therefore the findings from the study can be considered as representative for most aspects of passive safety.

Accident investigation takes place daily during two six-hour shifts following a two-week cycle.

This makes it possible to cover all periods of the day throughout the whole year for the random approach.

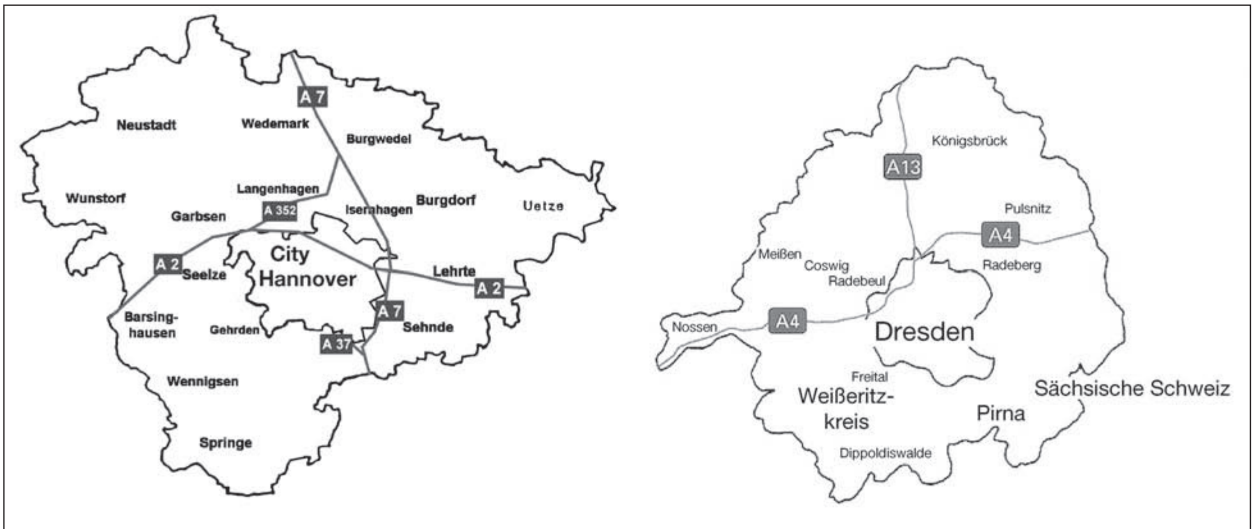


**Fig. 1:** In-depth Investigation Area Hannover and Dresden

### Accident Team Structure, Equipment and Dataset

During each shift, a team consisting of two technicians, a doctor, and a coordinator is on duty. The coordinator manages the team by using the sample plan and the defined praxis orientated criteria “last happened accident in time” on the information list of accident events by the police dispatching centers. Each team Hannover and Dresden has two specially equipped vehicles available (Figure 2). These are equipped with flashing blue lights, sirens, special signals and emergency radio equipment. Various cameras and instruments are available for measuring and recording purposes. Accurate scale sketches of the scene of the accident are created using different techniques:

- hand measurement
- 2D photogrammetry
- 3D photogrammetry
- 3D laserscans
- GPS

The data are collected with forms and include such information as:

- environmental conditions
- road design
- traffic control
- accident details and cause of the accident
- crash information, e.g. driving and collision speed, Delta-v and EES, degree of deformation
- vehicle deformation
- impact contact points for passengers or pedestrians
- technical vehicle data
- information relating to the people involved, such as weight, height etc.

The information collected “on the scene“ is complemented by more detailed measurement of the vehicles (usually on the following day), further medical information about injuries and treatment and an extensive accident reconstruction generated from evidence collected at the accident scene.

By applying established physical principles, the impact events are reconstructed (e.g. collision speeds) using proven software such as PC-Crash[2]. The output can be graphically displayed to allow a full understanding of the crash events (Figure 3). The movement in rollover can be analysed in correlation to the impacted zones on the vehicle and their time sequences.

Very important for the later analysis is the true to scale drawing produced by the measurement of the team at the scene.

Approximately 500 to 3,000 pieces of information per accident are obtained in total. Any personal data included is processed according to data protection regulations. Medical confidentiality and the rights of the individuals are guaranteed. All information is stored anonymously in database produced using SIR (Scientific Information Retrieval) software[3] and is available for evaluation.

Different classification systems are used, i.e. AIS [10], CDC [11], Polytrauma Score [12], and other scores [OTTE – 13].

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2 Steffan Datentechnik, Graz

3 Scientific Information Retrieval, Sydney


**Fig. 2:** Vehicles for In-Depth Research and In-Depth Team on Scene

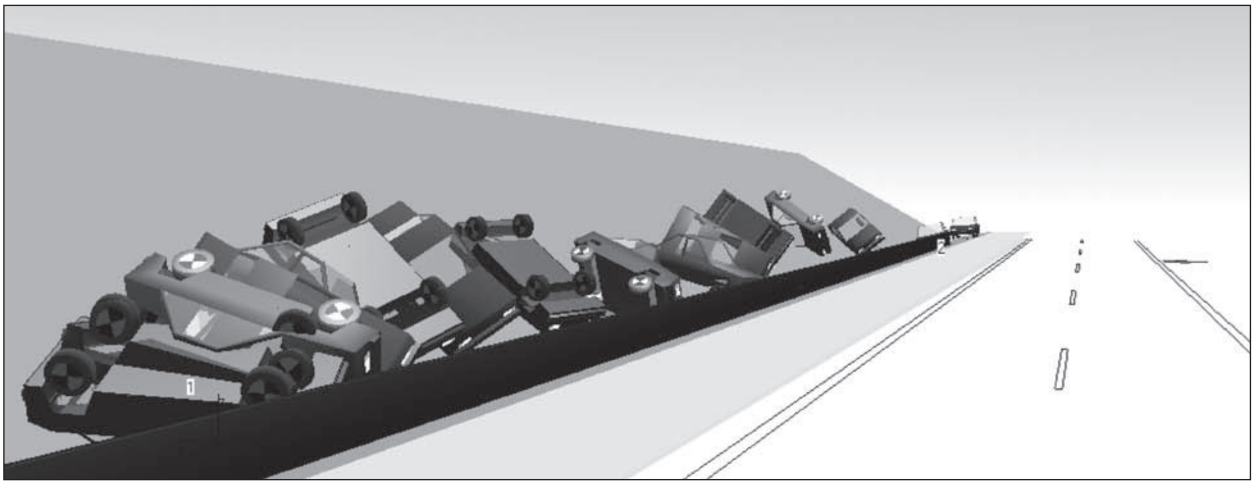


**Fig. 3:** Reconstruction by Simulation on the Basis of a True to Scale Drawing

## Basic Material for Rollover Study

For the analysis of car accidents with rollover consequence 6,713 accidents from the years 1994–2000 from the accident sample collected in Hannover were evaluated, altogether 7,846 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 434 cars and 741 occupants with rollover constitute the basis of the study.

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 of 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 according to NASS (National Accident Sampling System), where a total of 11 different types of rollovers was differentiated (Figure 4).

PARENTAU et al. [14] 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. All impacts of vehicles within a rollover were recorded in chronological order and the driving velocity at the start of the first traces and at the point, when the vehicles left the road as well as points of rollover impacts were calculated. The frequencies of results will be presented with the percentage in weighted form and the numbers in absolute existing 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 –13]. For describing the risk of a rollover event the frequencies of rollover cases are compared to those of non rollover cases documented in the whole GIDAS sample (434 cases versus 7412 cases).

## Typology of Rollover Accidents

### Frequency Distribution

The proportion of the rollovers for accidents with personal injury was 5.8% in 1994. A constant decrease is visible up to today. In the year 2000 the proportion of rollovers was 3.7%.

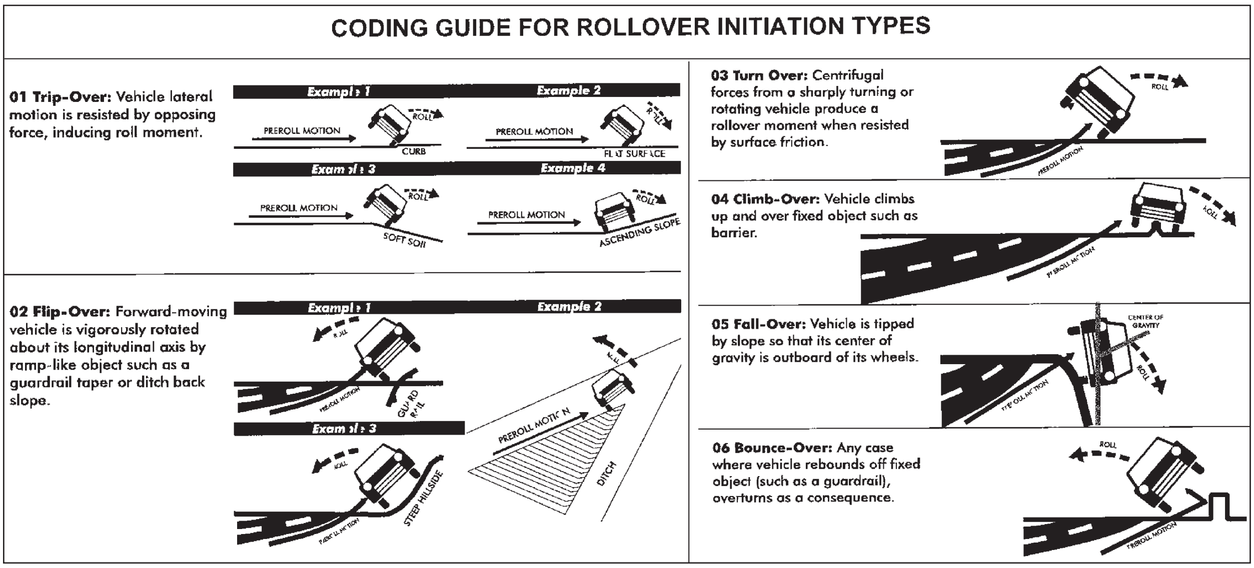


**Fig. 4:** Classification of Rollovers (NASS-Data sampling)

Rollovers mainly occur in the course of accidents outside of city limits and on freeways (Autobahn), but the portion of rollovers changed over the years with an increase on rural streets and a decrease for the urban area. Thus the proportion of accidents with rollover consequences in 1994 outside of city limits (rural) amounted to 14.9%, on freeways 21.3% and within city limits (urban) only 1.5%, whereas in 2000 12.3% of the accidents with personal injury on freeways, 9.9% of the accidents outside of city limits and a small percentage of 0.8% of the accidents within city limits resulted in a rollover. An influence of the production year of the participating cars could not be found in the study. The same year of manufacture distribution was registered for vehicles with rollover as without rollover. But a difference was obviously concerning the type of the car model, where 4.5% of the small cars, 3.4% of the mid-size and 3.5% of the luxury class cars were involved in a rollover, the percentage of rollovers for so-called vans and off-road-vehicles was at remarkable 11%. For convertibles there was also a higher risk of rollovers, of the cars involved in accidents 1,8% of those without rollover and 2.6% of those with rollover were convertibles. Most of the accidents involving rollovers occurred at night. 5.4% of the accidents happening at night resulted in a rollover, in contrast 3.8% occurred in the daytime and 4% during dawn or dusk. 13.7% of the accidents in curves, 6.7% on straight sections and 1.2% at intersections included a rollover. Thus the risk of suffering an accident with rollover consequences is significantly larger for curved road sections, but the evaluations also showed that from an absolute point of view accidents with rollovers occur mostly on straight sections (63.3%), whereas only 19.9% of the accidents with rollover consequences occurred in a curved area. 14.3% happened at intersections. The structure of the accidents with rollover consequence is thus largely determined by accidents on straight sections and at intersections (78% of all rollover accidents).

### 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 ($\mu$-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 curbstone was evident as cause of the rollover (Figure 5). In 38.0% the car was swerft under $\mu$-constant or $\mu$-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.

In 69.5% grass and only in 1.4% gravel on the side of the road were registered for rollover accidents. In only 20.2% of the cases the levels of the rollover surface and the road surface were even (Figure 6).

One third of all rollover events (34.3%) happened on field surfaces, collision objects like trees (1.8%)

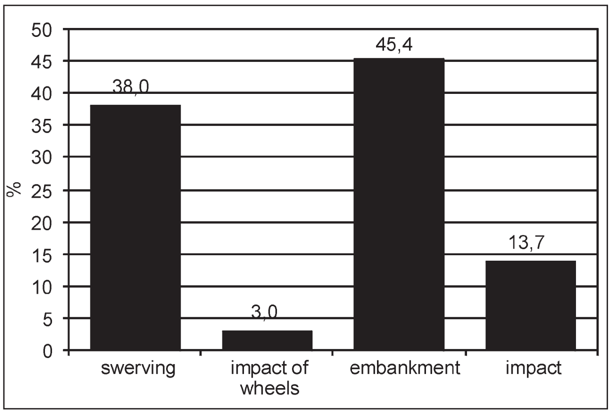


**Fig. 5:** Cause of Rollover of n=411 Cars (n=23 Unknown)

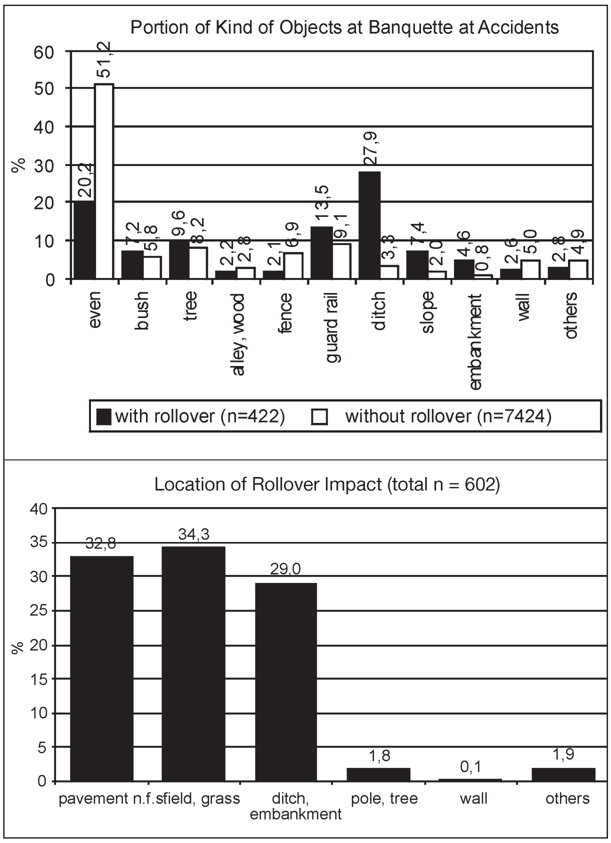


**Fig. 6:** Frequencies of Object Struck at Banquette in Car Accidents with and without Rollover

and walls (0.1%) were rare. A ditch and an embankment (29%) could be seen often as impact object.

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 (27.4% of the accidents with rollovers happened at road sections with ditches related to 3.3% of accidents without rollover). In the course of the study it was thus shown that rollover accidents of cars mainly occur outside the city on country roads, 95% of all impact objects in the course of such an accident occurrence are situated at underground of pavement, field, grass, ditch and embankment.

## 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 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% in 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 7). 1.6% of the belted drivers and 2.4% of the belted frontseat passengers ejected during the rollover movement, compared to this 31.9% of the unbelted drivers 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.

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

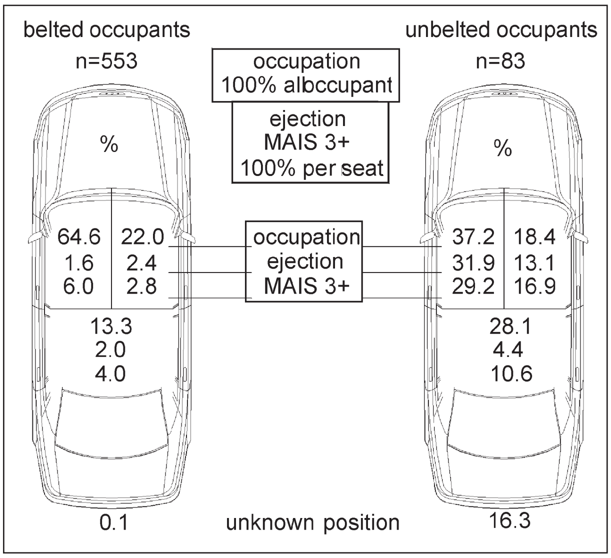


**Fig. 7:** Occupation Distribution, Proportion of Ejection and Injury Situation of Cars with Rollover

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 8a–c. It is visible that an impact zone that occurred very frequently was the front part of the car (A) 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. 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+.

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 8b). Mostly there were places of secondary impact on BL, BM, BR zones, 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 8c) 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 in front 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 9). Side glasses

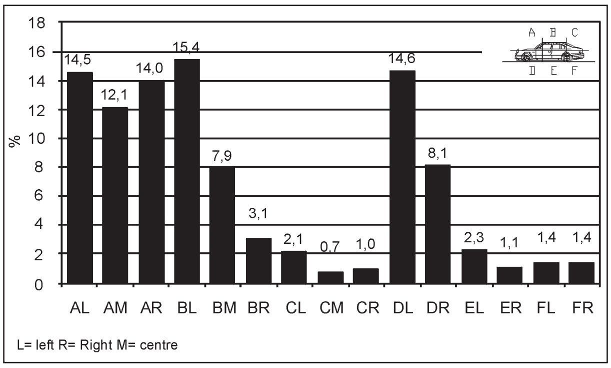


**Fig. 8a:** Impact Zones at Car (First Impact within Rollover Movement – n=599)

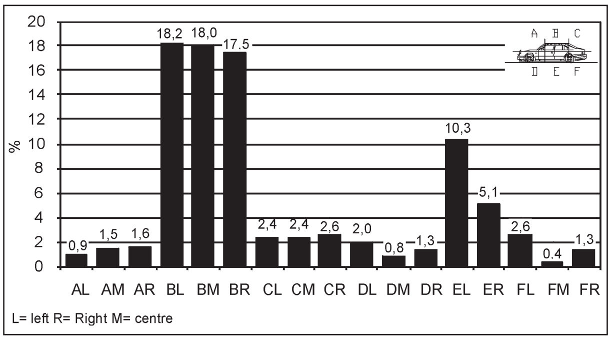


**Fig. 8b:** Impact Zones at Car (Second Impact within Rollover Movement – n=534)

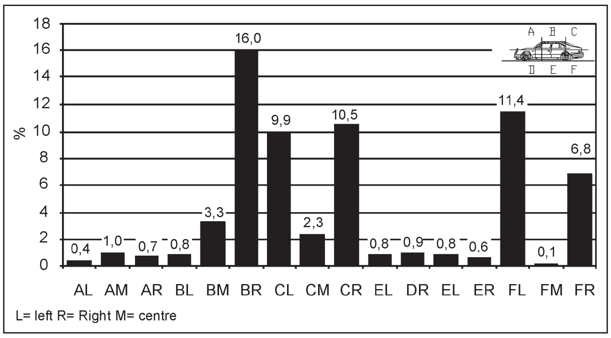


**Fig. 8c:** Impact Zones at Car (Third Impact within Rollover Movement – n==391)

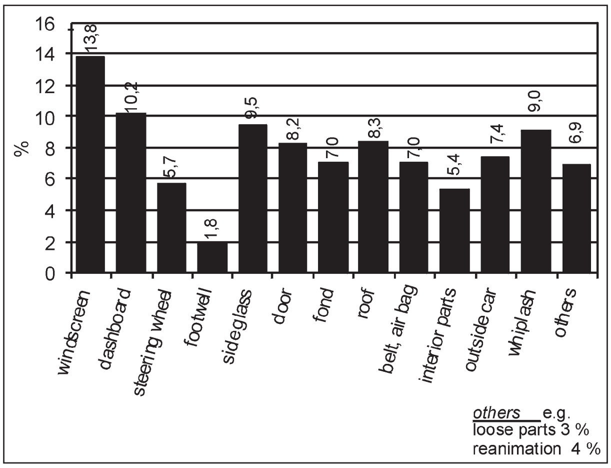


**Fig. 9:** Injury Causing Parts of Car Occupants in Rollovers (n=408 Injuries Caused by Rollover)

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”.

## 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 10). 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 too 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.

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 11). Approximately 30 to 50% of these resulted in injured 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 suffers high

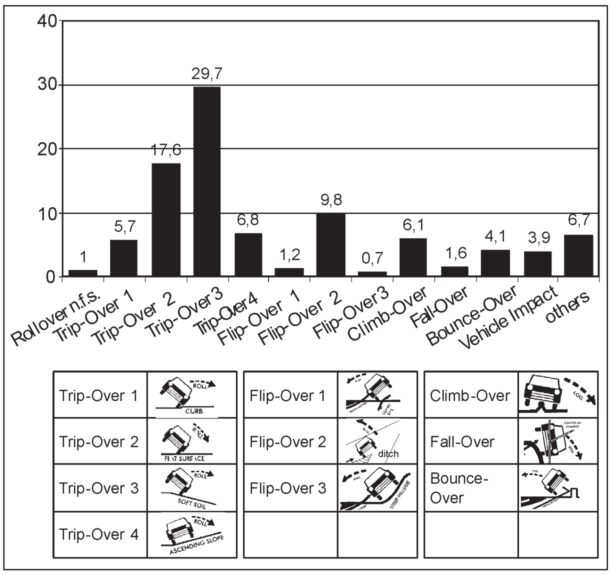


**Fig. 10:** Frequencies of Different Rollover- Types (NASS Classification), n=422

deceleration loads. Regarding the resulting severity of injury, out of the accident types with increased frequency, the Trip-Over 2 – which is very frequent too – seems to cause the worst injuries (36% MAIS 2+). Especially remarkable in its complete distribution concerning the severity of injuries is the Flip-Over 3, where a vehicle falls sideways off the road onto a significantly lower terrain. The type Fall-Over is also remarkable, it has the lowest percentage of soft part injuries. 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.

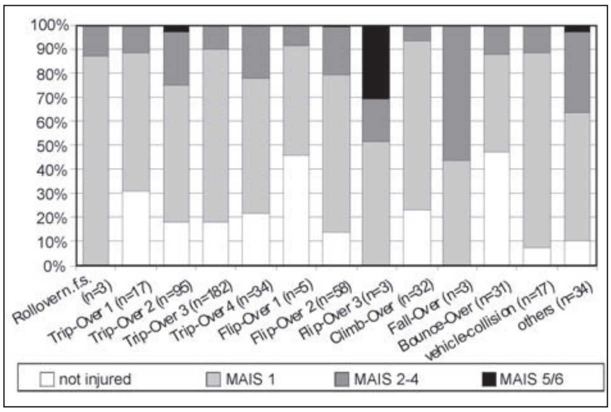


**Fig. 11:** Injury Severity Grades of Belted not Ejected Occupants for Different Kinds of Rollover

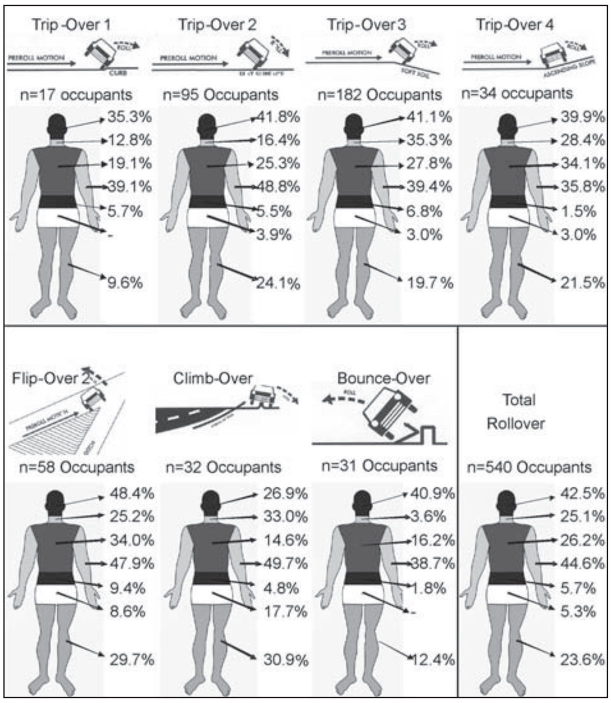


**Fig. 12:** Frequencies of Injured Body Regions of Belted not Ejected Occupants for Different Kinds of Rollover (100% all Occupants Each Group)

Injuries on the body after a rollover had taken place 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 higher.

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. Thus a high driving speed is a typical feature of accidents with rollover consequences (figure 13). 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. 90% of the speed values of cars with rollover were calculated above 60 km/h. 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.

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.

## Deformation Pattern on the Vehicle and Influence on the Severity of the Injuries

The deformation depth of each impact was measured in the direction of the impact load. Deformations of up to 60cm occurred by rollovers. Only a small influence of the deformation depth on the resulting severity of the injuries MAIS for the belted occupants was apparent (figure 14). 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.

Each deformation on the car was related to the number of impact 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 EES-value (energy equivalent speed), even this could not be done exactly and in a physical allowed manner for rollover impacts. In rollover cases EES represents an assessment of the deformation volume of the impact during the rollover movement. 80% of the values for impacts by the rollover can be found up to rollover-EES 15km/h (figure 15). 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 EES-values for cars with no rollover were calculated above EES 10 km/h.

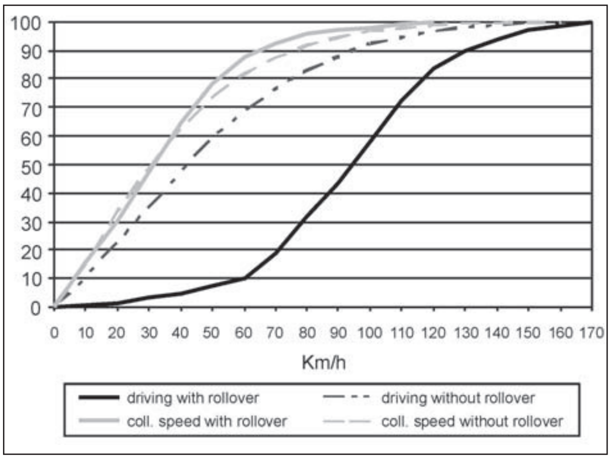


**Fig. 13:** Cumulative Frequencies of Driving Speeds of Cars Before Reaction and Collision Speeds

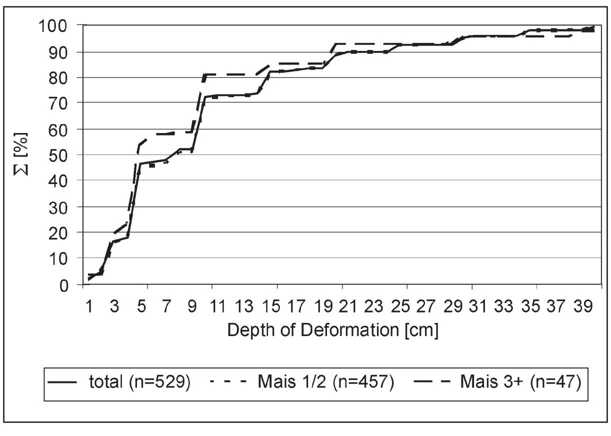


**Fig. 14:** Cumulative Frequencies of Depth of Deformation over Different Injury Severity Grades for Belted not Ejected Occupants

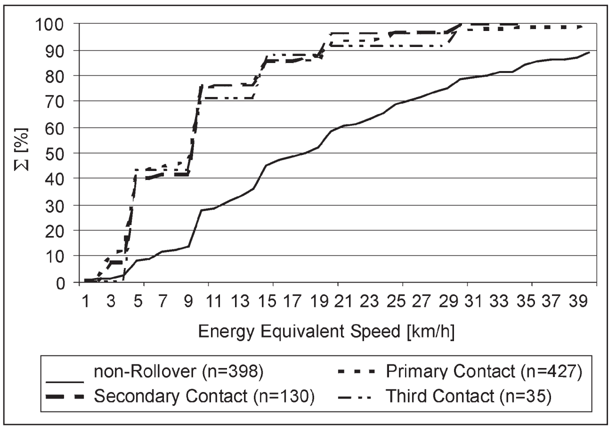


**Fig. 15:** Cumulative Frequencies of Deformation Energy Assessed by EES for Cars with Rollover for Different Impact Situations

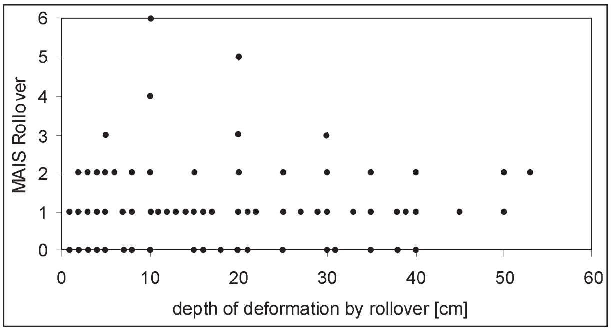


**Fig. 16:** Injury Severity MAIS of Rollover Related Injuries and the Depth of Deformation of those Contact Points on the Cars with Rollover (n=529)

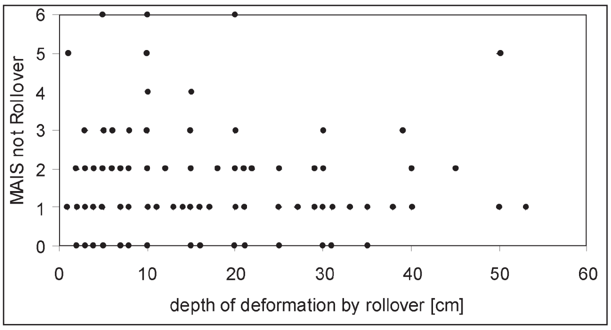


**Fig. 17:** Injury Severity MAIS of Non-Rollover Related Injuries and the Depth of Deformation of those Contact Points on the Cars with Rollover (n=517)

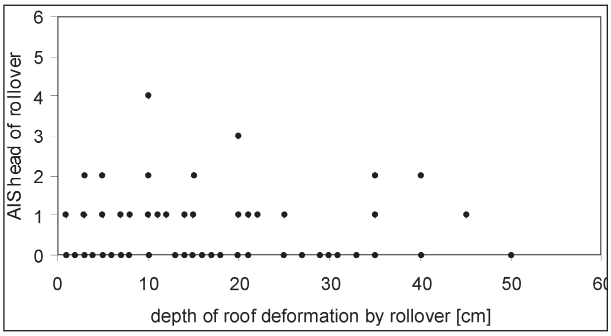


**Fig. 18:** Injury Severity of the Head of Occupants with Rollover Related Injuries and the Depth of Deformation of those Contact Points on the Cars with Rollover (n=438)

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 16). The injury severities by rollovers are for belted occupants mostly not above MAIS 2 and there are many uninjured occupants within a rollover movement.

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 17). Larger deformations are mostly linked with higher injury severities for deformations not related to rollovers.

From this analysis it can be seen that the MAIS is mainly presenting the injury severity of the head (figure 18), because the head is exposed as flexible extremity part for the injury risk. The distribution shown in figures 13 and 15 are nearly the same. It can be pointed out from the diagrams that the risk for severe head injuries AIS 3+ is starting for belted occupants with roof deformation depths of above 30cm.

## 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 19).

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 130 degrees as well as to the right between 0 and 110 degrees can be determined (figure 20).

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 (figure 21).

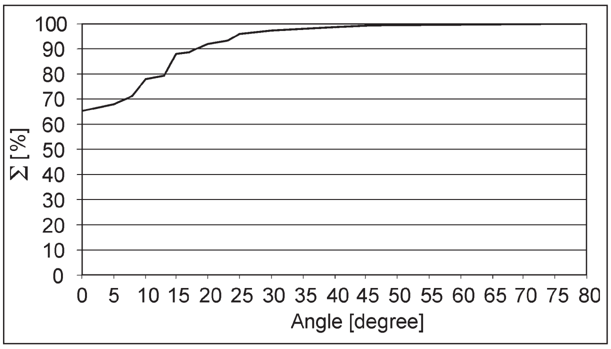


**Fig. 19:** Angle of Running off the Roadway (n=334). This angle exists between the direction of car's centre of gravity and the direction of the road when leaving the roadway

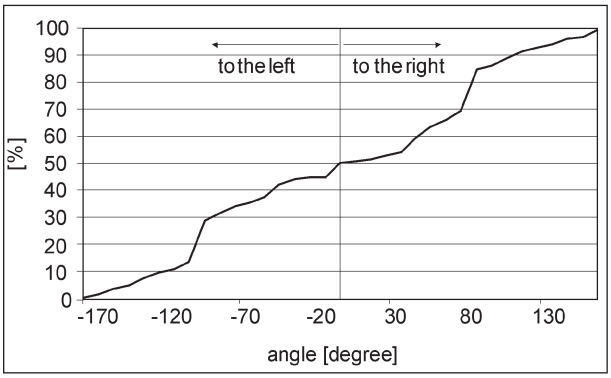


**Fig. 20:** Cumulative Frequencies of Attitude Angle at Rollover (n=409)

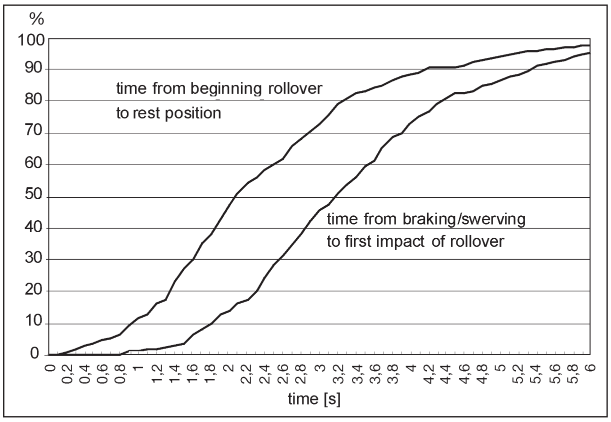


**Fig. 21:** Cumulative Frequencies over time from the Beginning of the Breaking/Swerving Movement to the First Impact in the Course of the Rollover (n=308) and the Whole Time Duration until the Rest Position of the Car (n=295)

For the whole movement of a rollover a time duration of 1 to 4 seconds (90%) can be seen as useful in real accidents.

## Conclusion

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. 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). In the accident sample there was no ESP-equipped car with a rollover registered. The portion of rollover events are at 11% remarkable high for vans and off-road-vehicles and the portion is increasing. Rollovers mainly occur in connection with accidents on straight road sections and at intersections (78% of all rollover accidents), 20% occurred in a curved section. 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 95% of all impacts within a rollover occur on flat surfaces. Comparing accident situations with and without rollover the highest risk for rollovers can be established for ditches. 88% of the rollovers were consequences of previously occurred primary collisions with other vehicles.

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" at 30%, this is also the one with the highest injury risk for head injuries. The study came to the same results as PARENTAU et al. [14] pointed out for the US situation, that trip-over reflect the largest proportion of rollover in the field. But in contrast to PARENTAU who 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 under forward movement are also frequent and 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 sufferd within the rollover, deformation depths of up to 15 cm. The risk for severe head injuries AIS 3+ is starting at roof deformation above 30cm.

The study has shown that for belted occupants in the current accident situation, there is with 3% of accidents with casualties a low risk to be injured in a rollover movement on German roads, a probability of 90% to suffer an injury severity of up to MAIS 2 does exist. In case of belt usage the risk of ejection is very low too, only 1.6% of belted drivers were known out of their vehicles.

The conclusions from the study can be formulated as follows:

1. Accident 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 $\mu$- and $\mu$-split)
   - recommendation for the implementation of a paved flat strip beside the road on the same height-level
2. Injury prevention
   - 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 presented study gives the frame conditions of rollover kinematics and injury mechanisms on the one hand and describes the time window for developing optimized sensor systems for the avoidance of a rollover and the reduction of the injury severity within a rollover movement. 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 avoindance in the main focal point of interest, there could be enough time for activating intelligent sensor technique. Herewith the paper describes the possibilities of in-depth investigation by an interdisciplinary team of researchers, starting the investigation directly after the event. From the detailed analysis of existing traces and the documentation of deformation and injuries the movement of a vehicle within the event can be reconstructed and the injury pattern can be explained. Important parameter for the further development of safety measures and the practise of crash tests can be collected by such in-depth investigation tool.

In-depth investigations are always necessary for assessing detailed information of traffic accidents. Such detailed documentations are not available from the usual statistics of traffic accidents which are based on police protocols. Therefore special teams trained in medicine and technical sciences can document the accident at the site immediately after the event and are able with this information to reconstruct the accident very well.

The working method of in-depth investigation can differ between on scene, on scene in time and retrospective depending on the fact, when the team arrives on the scene of the accident. There are advantages and disadvantages of an investigation on scene in time, but such teams are able to collect traces parallel and independently of the police work. Only those teams are able to prepare true to scale drawings with all details by their own for the basis of a technical reconstruction and determination of collision speed. With such basis a reconstruction of vehicle movement can be started and the determination of collision and driving speed can be carried out in quality.

A second priority of the in-depth investigation approach is the assessment of motion trajectories of bodies inside and outside the vehicles. The known kinematics from dummy studies can be compared to the finding of impact points of the human body in real accidents pointing out the primary and secondary impact conditions. In-depth investigation should register the causes of injury related to different parts of the body. Injuries are the result of a mechanical load to the human body that exceeds the load to the biological system. That biological system is divided into soft tissue, bony and ligamentory structures registered together with the injury severity based on AIS scaling. With the data of the technical survey, i.e. EES and Delta-v the border of injury load level can be pointed out. There are many other points describing the benefit of in-depth investigation approach.

Regarding the small radius of action of such in-depth investigation teams a very limited number of cases can be collected in a limited area of a country. Therefore a statistical sampling plan has to be defined for the approach of representative on one hand and a wide implementation of teams nationwide has to be implemented on the other hand. GIDAS (German In-Depth Accident Study) is one tool for describing in-depth investigation, there are others in the international in-depth investigation scenery. Meanwhile many teams were implemented round the world, i.e. NASS (National Accident Sampling System) and CIREN (Crash Injury Research and Engineering Network) in US, OTS (On the Spot Investigation) in UK working for the same task of detailed accident analysis, but working with different approaches and different methodologies. The demands for an exchange of data and experiences does exist, methods of data sampling and reconstruction procedures have to be concentrated internationally and a network of in-depth investigation centres has to be implemented in many countries worldwide.

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