# D1.1 – REPORT ON THE CHARACTERISTIC OF MOTORCYCLE ACCIDENTS

Project Acronym: **Smart RRS**

Project Full Title: **Innovative Concepts for smart road restraint systems to provide greater safety for vulnerable road users.**

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**SUMMARY:**

The objective of the "*Innovative concepts for smart road restraint systems to provide greater safety for vulnerable road users*" (Smart RRS) project is to reduce the number of injuries and deaths caused by road traffic accidents to vulnerable road users such as motorcyclists, cyclists and passengers through the development of a smart road restraint system.

Within the WP1 *"Characteristics of severe road traffic accidents concerning vulnerable road users such as motorcyclists"* the task 1.1, *"Literature Review on Motorcycle Accidents"*, aims at identifying the characteristics of motorcycle and other vulnerable road user accidents, in general, and in particular to search for the main characteristics of those accidents where motorcyclists get injured because of contact with fixed objects, on the side the road, or with the road restraint systems. To characterize the main parameters of these accidents: range of speeds at the point of impact, angles of impact, frequency of injuries by body region, etc. To know the physiological thresholds of the tolerance of the human body (or injury criteria) in the injured regions.

The analysis of the literature shows that the impact of motorcyclists against a fixed object occurred in 4% of the cases in urban areas while it varies between 10% and 20% in rural areas.

The most important obstacles with a particularly severe outcome involving accidents, are trees/poles, roadside barriers and road infrastructure in general.

According to different studies, a fatal outcome is 2 to 5 times more likely for an impact with a crash barrier than for motorcycle accidents in general.

The most dangerous aspect of guardrails with respect to motorcyclists is the exposed guardrail posts.

For sliding motorcyclist, it appears clear that discontinuous systems are worse than continuous. In this scenario, post modifications together with post envelopes shows a positive approach in decreasing risks for motorcyclists.

A much better solution seems to be the addition of a lower rail. As this provides better energy absorption than concrete solutions or wire rope safety barriers.

However, it must also be considered that the impact scenario in an upright riding position seems to be equally important, with the associated risks of being thrown on or over the barrier, and this scenario has not be investigated in depth up to now.

## INDEX

## 1. Key Words

Road safety, Vulnerable road users, Motorcyclists, Innovative road restrain systems

## 2. Introduction

The design and maintenance of road infrastructure is of particular importance for the safety of powered two-wheeler (PTWs) riders. This is due on one side, to the potential involvement in accident causation and on the other, to the possible impact of the rider with the road infrastructure in the course of an accident.
Trees, poles and sharp objects in general, represent a potential danger for PTW riders. Road Restrain Systems also called Road Safety Barriers, are supposed to avoid any direct contact of the road vehicle (and user) against these objects. Road Engineers design road safety barriers to prevent vehicles from leaving the roadway. The design of road safety barriers is generally such that a vehicle hitting the barrier is steered back onto the road. This is generally positive for cars and heavy vehicles, but very often it can increase the risk for PTW riders, as the road safety barrier can prove to be very rigid and not able to dissipate the energy of the impact, thus causing severe injuries to the rider even at low speed.

## 3. The problem of motorcycle collisions with fixed obstacles

Hurt et al (1981) investigated several aspects of 900 motorcycle accidents in the Los Angeles area. Additionally, they analyzed 3,600 motorcycle traffic accident reports in the same geographic area. They found that approximately three-fourths of these motorcycle accidents involved a collision with another vehicle, which was typically a passenger car, while approximately one-fourth were single vehicle accidents involving the motorcycle colliding with the roadway or some fixed object in the environment. Vehicle failure accounted for less than 3% of these motorcycle accidents, and most of those were single vehicle accidents where control was lost due to a tyre puncture. In the single vehicle accidents, motorcycle rider error was present as the precipitating factor of the accident in about two-thirds of the cases, with the typical error being a slideout and fall due to overbraking, or running wide on a curve due to excess speed or under-cornering. Roadway defects (pavement ridges, potholes, etc.) were the cause of the accident in 2% of the cases; animal involvement was 1% of the accidents. Weather was not a factor in 98% of motorcycle accidents.

Schuller et al **(**1982) observed that collision with an obstacle occurred in 30% of all accidents, which were referred to as 'running off the carriageway to the right or left'.

The work of Pothin & Desire (1997) is a risk study based on the French national accident records of 1993-1995. The risk for motorcycles was compared with that of light vehicles. In this comparison, motorcycles were generally involved in fewer accidents with obstacles. According to the authors, the reason was the greater ability of motorcycles to evade narrow obstacles.18% of all motorcycle fatalities due to impacts with obstacles were associated with impacts against metal barriers. That constitutes the highest total number of fatalities. In 1.7% of fatalities, concrete barriers were involved. In an interurban environment, metal barriers accounted for 30% of all fatalities with obstacles. Motorcycle accidentology seems to be particularly sensitive to certain aspects of road infrastructure. Impacts with kerbs and street refuges were observed to be frequently involved. Stationary cars and metal barriers also played a major role. Metal barriers were particularly involved in an interurban environment. The authors found evidence of an effect on the occurrence and severity of motorcycle accidents with metal barriers at curves. The roads mostly involved were 2-lane national and departmental roads.

Gibson & Benetatos (2000) reported that between 2.4% and 2.6% of fatal motorcycle crashes in Australia involved impacts on crash barriers.

Forke (2002) analysed detailed accident data from France and Austria. He estimated that 4.7% of all crashes involving injured motorcycle riders were related to impacts with a roadside protection system. To calculate the total number of accidents where motorcycle riders were killed, Forke used French and Austrian accident data as well as German data collected from the region around the city of Tübingen. He calculated that these crashes contributed to between 9.75% and 15% of all fatal crashes. This was from 92 to 114 accidents where motorcyclists were killed for the year 2003 in Germany which were related to impacts with roadside protection systems (9.75 to 15% of all 38,464 crashes with injured motorcyclists for this year).

Compagne (2004) presented the results of the MAIDS Motorcycle Accidents In Depth Study, in which 921 accidents from 1999-2000 in five sampling areas in France, Germany, Italy, Netherlands and Spain were analyzed. 60 out of 921 riders suffered from injuries due to an impact with a barrier.

The MAIDS report (ACEM, 2004) indicated that collisions with a fixed object appear to play a minor role in the urban environment (4.2%) but account for 19.7% of all accidents in rural areas, which is the second highest frequency after PTW-to-car collisions.

Ibitoye et al (2004) reported that 4% of fatal motorcycle accidents in the US involved impacts on crash barriers.

The FEMA document, “The Road to Success, improving motorcyclists’ safety by improving crash barriers” (2005) provides an overview of motorcycle-friendly guardrail pilot projects across Europe.

Berg et al (2005) analysed 57 real-world crashes involving impacts of motorcycles, and respectively the rider, with a roadside protection system.
63% of the 57 cases analysed in the study involved a steel barrier “Einfache Stahlschutzplanke” (ESP). The second most frequently struck barrier, comprising 18% of all such crashes, was another steel-manufactured system, the so called “Einfache Distanzschutzplanke” (EDSP).

EuroRAP “From Arctic to Mediterranean” first pan-European Progress Report (2005) stated that a major initiative in France was the implementation of an innovative solution for the design of crash barriers in order to protect motorcyclists. Figures show that in the mid 1990s, accidents involving motorcyclists hitting metal crash barriers, of the type typically used throughout the work, accounted for 63 deaths every year, or 8% of all fatal accidents involving a motorcyclist. This figure rose to 13% on rural roads. As a result of the recognition that different design approaches were needed for cars and motorcyclists, France introduced a Mass Action Programme involving the installation of “motorcycle-friendly crash barriers”. In the UK, the AA Trust risk analysis of fatal and serious accidents involving motorcyclists showed that not enough is being done on Britain’s roads to protect them. Whilst safety fencing is a highly effective energy absorbing restraint when struck by cars running off the road, they can be brutal to the bodies of motorcyclists. The AA Trust plans to implement a study of measures to better define crash protection for riders.

Another study conducted by Eurorap (2006), reported that hitting a crash barrier is a factor in 8 to 16 per cent of rider deaths, and riders are 15 times more likely to be killed than car occupants. Barrier support posts are particularly aggressive, they can cause a 5-fold increase in injury severity compared to the average motorcycle crash.

Gabler (2007) examined the issue of fatal motorcycle collisions with guardrails based on U.S. accident statistics. Motorcycle crashes were found to be a major reason for fatalities in guardrail crashes. In 2005, motorcycle riders suffered for the first time more fatalities (224) than the passengers of cars (171) or any other single vehicle type involved in a guardrail collision. In terms of fatalities per registered vehicle, motorcycle riders were dramatically overrepresented in number of fatalities resulting from guardrail impacts. Motorcycles comprise only 2% of the vehicle fleet, but account for 42% of all fatalities resulting from guardrail collisions.

From 2000-2005, the number of car occupants who were fatally injured in guardrail collisions declined by 31% from 251 to 171 deaths. In contrast, the number of motorcyclists fatally injured in guardrail crashes, increased by 73% from 129 to 224 fatalities during the same time period. Over two-thirds of motorcycle riders who were fatally injured in a guardrail crash were wearing a helmet. Approximately, one in eight motorcyclists who struck a guardrail were fatally injured – a risk of over 80 times higher than for car occupants involved in a collision with a guardrail.

Peldschus (2005) carried out a detailed analysis of accidents involving road infrastructure. Four different in-depth databases were used for these investigations: TNO MAIDS cases, LMU COST 327 Cases, GIDAS Cases, DEKRA Cases.
The most important obstacles with a particularly severe outcome involving accidents, are trees/poles, roadside barriers and road infrastructure in general. Analysis of the succession of collisions indicated that most of the impacts with obstacles occur as the primary impact. Accidents involving impact with a tree/pole seem to be predominantly single-vehicle accidents.
Impact speeds in accidents involving barriers as an obstacle tend to be very high, whereas impact speeds do not differ remarkably from other impact accidents involving a tree or pole. The angle with which a rider typically leaves the road seems to be very shallow and the rider thereby seems to be aligned almost parallel to the tangent of the road. In most impacts with trees/poles and barriers the rider is upright on his motorcycle. When a metal guardrail is struck, the rail seems to be hit more often than the post.
Roadside barriers seem to cause particularly severe injuries when hit. Taking into account the observed impact speeds, tree/pole impacts have to be considered at the least, equally as dangerous. Impacts with obstacles frequently involve head injuries however, lower extremity injuries occur nearly as often as the head due to impact with barriers.

McCharty et al (2008) performed a comparative analysis between the MAIDS and the On the Spot (OTS) studies. They found that impact against a fixed object occurred in 4% of the cases in urban areas in both databases, while they were 20% and 10% respectively for MAIDS and OTS in rural areas.

## 4. Severity of the Problem

Quellet (1982) found that with 9.5 fatalities per 100 motorcyclist impacts, crash barriers are relatively more dangerous than other motorcycle accidents in general with 6.6 fatalities per 100 cases. Severe injuries, i.e. AIS3+ according to the Abbreviated Injury Scale (AAAM, 2005), were observed more often (in 41%) for head/neck impacts with poles or trees than with barriers (34%) and the pavement (16%). Similar numbers were given for impacts with other body regions.

A study by Quincy et al (1988) indicated that a fatal outcome is at least 5 times more likely for an impact with a crash barrier than for motorcycle accidents in general.

The work of Hell and Lob (1993) comprised a detailed analysis of 173 motorcycle accidents in the area surrounding Munich from 1985 to 1990. Accidents with minor injuries were also considered. The authors found that single-vehicle accidents followed by contact with an object (like traffic lights, trees or barriers) were associated with high injury severities while the same type of accident followed by a slipping or sliding movement was associated with a relatively small risk of injury. The mortality rate was more than double for those accidents due to contact with an obstacle - compared to the overall average - and zero for those accidents without contact with an obstacle.

In a study conducted in Germany, Ellmers (1997) revealed that the probability of being killed rose from 2.2 % to 10.9 % when the roadside was fitted with a crash barrier. He also recommended the use of Sigma posts in place of I posts and the fitting of crash barrier protectors.

In a French study (SETRA, 1998) 157 accidents with impacts against metal guardrails followed by physical injuries were analyzed. It was found that impacts against metal guardrails present a severity which is five times higher than for motorcycle accidents on average.

The FEMA report (FEMA, 2000) describes analysis performed by the Austrian Bureau of statistics, showings that 40% of Motorcycle accidents with a crash barrier, ended with severe injuries. Moreover, 11.7% of the fatal motorcycle accidents reported between 1990 and 1996 in Austria involved crash barrier impacts.

Gibson & Benetatos (2000) stated that in the United Kingdom 0.3 % of all motorcycle accidents involved crash barriers but constituted 2.1 % of all motorcycle fatalities. Comparable numbers were found for Canada, where in 0.4 % of the motorcycle accidents, impact with barriers occurred, but the proportion on all motorcycle fatalities was 1.5 %. The probability of a motorcyclist being killed as a result of impacting against a crash barrier was therefore seen to be more than double than for motorcycle crashes in general.

Kloeckner & Ellmers (2002) found that in 1999 the severity of motorcycle accidents in Germany was a factor of 2.5 higher for impacts with guardrails compared to accidents that had not impacted with guardrails.

The MAIDS study (ACEM, 2008), states that roadside barriers presented an infrequent but substantial danger to PTW riders, causing serious lower extremity and spinal injuries as well as serious head injuries.

## 5. Details of Impacts

In 2.7% of the accidents analyzed by Quellet (1982) the rider was thrown over a barrier due to the (low) height of the barrier.

Quincy et al (1988) quantified the impact features. Of 38 fatal impacts with barriers, 42% were in a position where the rider was still upright on the motorcycle. In 34% of cases, the rider was sliding with the motorcycle, and in 24% of cases, the rider impacted with the barrier when sliding, after being separated from the motorcycle. The authors also described a typical scenario. They found that most motorcycle collisions with crash barriers occurred at shallow angles with the rider typically sliding into the barrier at a bend.

In a study by the French authority SETRA (1997), 46 fatal accidents during the period 1990-1991 were analyzed. These accidents involved 47 motorcycles and 51 fatalities. In 31 of 46 cases the location was a curve, 24 of the 31 cases occurred at the outer edge of the curve. In 19 of the accidents the road class was a motorway, in 27 accidents, the road was departmental or national and 8 of the 46 accidents occurred at or near an interchange. Only half of the riders and pillions killed were wearing a helmet when the impact occurred. In 25 of these 46 accidents the impact against the barrier occurred in an upright position, in 18 cases, in a sliding position. In 33 cases impact with the barrier-post was identified.

Gibson & Benetatos (2000) demonstrated that there is a high risk for a rider to directly hit one of the barrier posts while approaching a guardrail in a sliding position. For a distance of 2.5m between the posts, the probability is more than 35% for an angle of impact of 30 degrees, increasing to more than 70% for a 15-degree angle. An analysis of 113 motorcycle fatalities in New South Wales in 1988-1989 indicated that 5 out of 8 impacts with a barrier occurred at shallow impact angles of 45 degrees or less.

From a literature review, Duncan et al (2001) suggest that the most dangerous aspect of guardrails with respect to motorcyclists is the exposed guardrail posts. These guardrail posts present edges which concentrate the force of the impact, resulting in more severe injuries to motorcyclists. This is a potential problem for any barrier system that has exposed posts.

The MAIDS study (ACEM, 2008) reported that roadside barriers accounted for 60 PTW rider injuries out of 921 collected accidents. In 29.6% of the accidents the PTW was either in a curve or a corner.

## 6. Investigation method

Interaction between motorcyclists and roadside barriers is a topic that has been addressed in many research projects, first by experimental impact testing of barriers using both Post-Mortem Human Subjects (PMHS) (Schueler et al, 1984) and crash test dummies (Jessl, 1987; Quincy et al, 1988). As the methods increased, numerical simulation was also applied to research on motorcycle accidents as described in Nieboer et al. (1991), Yettram et al. (1994).

## 7. Testing procedures

Several testing procedures have been developed in order to give results that can be reproduced for the evaluation of roadside barriers and additional protective devices.

Quincey et al (1988) developed a testing procedure in order to analyze the risk of injuries for motorcyclists when impacting with different types of barrier. The dummy was ejected from a moving platform lying on its back and slid for 2 meters before impacting against the barrier with its head forward at a speed of 55 km/h. The angle between the longitudinal axis of the dummy and the barrier was 30 degrees. It should be noted that repetition seemed to be somewhat problematic, at least for the small number of tests performed.

In 1993, the 'Technical Regulations for Delivery of Guardrail-Post Protections' (BASt, 1993) were implemented by the German Ministry of Transport. Apart from specifying various issues of design and durability, this standard describes the requirements of energy absorption that have to be fulfilled. The deceleration of the impact body, a wooden cylinder of 35 kg weight, is not allowed to reach a maximum of more than 60g, and its time interval of over 3ms must not be greater than 40g at any time.

Ellmers (1994) reported that at the time of the implementation of this standard, no product was available that could meet its requirements at the prescribed impact velocity of 35km/h. Tests showed that the attenuators reached their limit of energy absorption at around 20km/h where contact occurred between the impact body and the post. Hence, the prescribed speed was reduced to 20km/h and only in 1998, it was set to the level which was originally intended.

In 1998 the LBSU, a laboratory of INRETS, the French National transport and safety research institute (Institut National de Recherche sur les Transports et leur Securite) elaborated a report concerning a test procedure (Bouquet et al, 1998). The objective of the study was to help the laboratory, INRETS Road Equipment Test Laboratory (Laboratoire d’essais Inrets Equipements de la Route) with the final preparation of a protection device test protocol for motorcyclists. Firstly LBSU performed accident analysis in order to choose the test configuration, as well as different biomechanical criteria needed for assessing the impact severity of a chosen dummy, taking into account the potential risk of injury.

From the accidentology analysis, two test configurations were identified. Configuration 30º: the motorcyclist is launched against the safety device (guardrail) lying down with his/her back on the surface and with the head in the direction of impact, this describes a trajectory that forms a 30º angle (tolerance 0.5º) with the barrier.

Configuration 0º: the motorcyclist is launched against the safety device which describes a 30º angle trajectory. However, in this case, the body is parallel to the barrier to be tested so that the dummy will impact with the shoulder and the head.

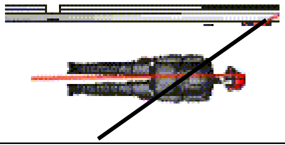
| | |
|---|---|
|  |  |
| Configuration 30º | Configuration 0º |

*Figure 1: Impact configurations of the test proposed by LIER (France)*

The impact speed in both cases is 60 km/h with a tolerance margin of 5%. The surface of the road was required to be made slippery for the dummy in order to reach the barrier, due to the significant reduction of speed caused by the motorcyclist sliding along the ground prior to impact.

The dummy selected for performing the tests was an assembly of elements from other dummies. It had no specific technical card. This dummy was comprised of:

- Hybrid II thorax, limbs and shoulders,
- a pelvis from a pedestrian kit in order to give it an articulate standing position.
- Hybrid III Head and Neck allowing measures of acceleration, force and moments,
- Motorcyclist equipment: suit, glove, boots and helmet.

Biomechanical criteria that the measured data has to comply with the values are given in table 1

| **Measurement** | **Biomechanical limit** |
|---|---|
| Resultant head acceleration | 220 g |
| HIC | 1000 |
| Neck flexional moment | 190 Nm |
| Neck extension moment | 57 Nm |
| Neck lateral flexion | - |
| Neck Fx | 330 daN |
| Neck Fz traction | 330 daN |
| Neck Fz compression | 400 daN |

*Table 1: Biomechanical criteria used in LIER test*

The HIC limit, measured in the gravity centre of a Hybrid III Head, corresponds to a probability of 40% of suffering an AIS3. No value is defined for lateral flexion (Mx) although this parameter is also measured to be used as an indicative and comparative index between the different systems tested. All the measured curves were filtered with 1000Hz.

With regards to the dummy used, it should not be forgotten that the Hybrid II was conceived for frontal impacts and so some of its body elements, such as the shoulder and the knee, might not comply properly with the strict duration requirements for lateral tests.

It was reported that parts of the dummy fractured in tests with a concrete barrier. The parts that failed were the clavicle and the knee. It was therefore suggested to improve the design of the Hybrid II by changing the fragile pieces that broke during the test or to make them from a plastic material in order to withstand lateral loading more robustly.

With consideration to the helmet, it was concluded that reference to this should be well defined before performing any tests, as its energy absorption characteristics influence the values measured in the dummy.

It was observed that the type of barrier influenced the measured values, but the impact angle showed an even stronger influence on the results. This included wide variations of the compression forces that may result in an unacceptable neck value for any type of device.

Gibson & Benetatos (2000) suggested shallow impact angles of 15 to 45 degrees for barrier impact testing in their study. According to the authors the impact speed should be greater than 60 km/h and a helmeted dummy with appropriate biofidelity, which allows the representation of post-impact kinematics, should be used. The use of two configurations of the test set-up was suggested. One configuration, in which the dummy approaches the barrier sliding on the ground on its own, and a second one in which it is mounted on an upright motorcycle.

In the course of a research project, DEKRA developed a testing procedure for barrier impact of a motorcycle including the rider (Buerkle & Berg, 2000). The project was funded by the German Federal Highway Research Institute, which also defined the test parameters. For this procedure the impacted barriers were 35m in length. The distance between the posts of the tested metal guardrails was 2 meters. The motorcycle had a weight of 180 to 220 kg, 500 to 750 cc, no fairing and no boxer engine. The rider was represented by a Hybrid III dummy, 50th percentile male in a standing position. The modifications of the Hybrid III leading to the MATD, according to ISO 13232, were not seen to be necessary in order to get valuable results in the course of the project. Data was recorded through a miniaturized device mounted on the motorcycle.

The motorcycle and dummy were accelerated to 60 km/h on a sled for all tests. In the tests with the motorcycle and rider impacting against the barrier in upright position, there was virtually no distance between the sled release point and the impact point. The loss of velocity before the impact was about 2 km/h. For the tests with a sliding motorcycle, the sled release was at 10 m distance from the barrier with the motorcycle leaning to the side, where the actual velocity of the dummy head at the impact with the barrier was between 42 and 46 km/h.

The angle between the barrier and the direction of the initial velocity of the motorcycle was 12 degrees for the upright impact and 25 degrees for the sliding impact.

Based on the European Experimental Vehicle Committee Working Group 11, the Biomechanical limits given in table 2 were applied.

| **Measurement** | **Biomechanical limit** |
|---|---|
| Resultant head acceleration | 80 g over 3 ms |
| HIC | 1000 |
| Neck flexional/extension moment | Max. retroflexion 57 Nm |
| Neck shear load | 1.1 kN over 45 ms |
| Neck tensile/compression load | Max. tension 1.1 kN over 45 ms |
| Resultant chest acceleration | 60 g over 3 ms |
| SI | 1000 |
| Chest deflection | 50.8 mm |
| Resultant pelvis acceleration | 60 g over 3 ms |
| Femur load compression | 10.0 kN |
| Femur load compression | 10.0 kN |

*Table 2: Biomechanical criteria used by DEKRA*

The CIDAUT Centre for Automotive Research and Development has developed a standard (CIDAUT, 2005) under the requirements of the Spanish Transport Ministry (Ministerio de Fomento). The available report deals with the test procedure characteristics in order to evaluate the behaviour of all types of motorcyclists' protection systems, both punctual and continuous systems.

The requirements of this procedure are that the dummy (motorcyclist) should travel sliding on the ground by itself while separated from the motorcycle and hit the protection system to be tested, with a specific entrance angle and speed. Once the test is performed, the conclusions about the behaviour of a specific protection device are obtained. This takes into account the level of severity defined from the combination of biomechanical severity indices that are identified in the report. This report on standards attempts to give some guidelines. However in order to identify whether a motorcyclist protection system is valid or not, every motorcyclist protection device installed in a safety crash barrier and every crash barrier specially designed to improve protection for motorcyclists, have to guarantee that this does not negatively affect its performance when impacted by other road vehicles (according to EN 1317-2).

The test location shall normally be a flat area with less than the 2.5% of unevenness, the surface shall be resistant and shall have no pools of water, ice or snow while performing the test.

The test is performed launching a dummy against a lineal section of a crash safety barrier covered with a motorcyclist protection device.

Three types of approximation trajectories are defined:

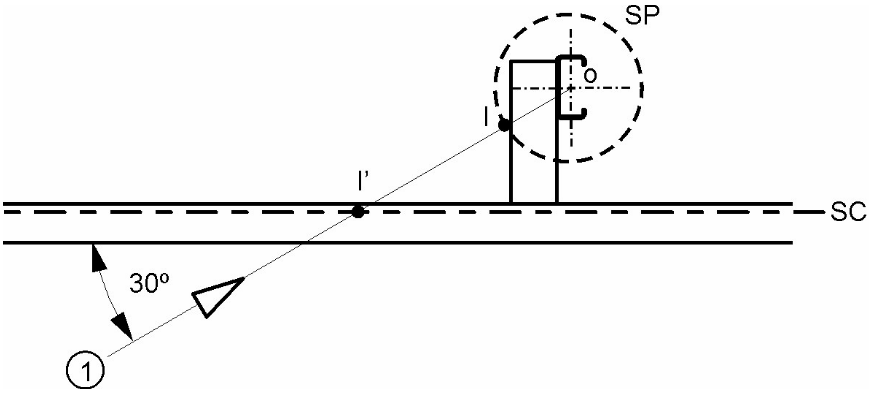


*Fig. 2: Trajectory 1: Centred Impact (Top View)*

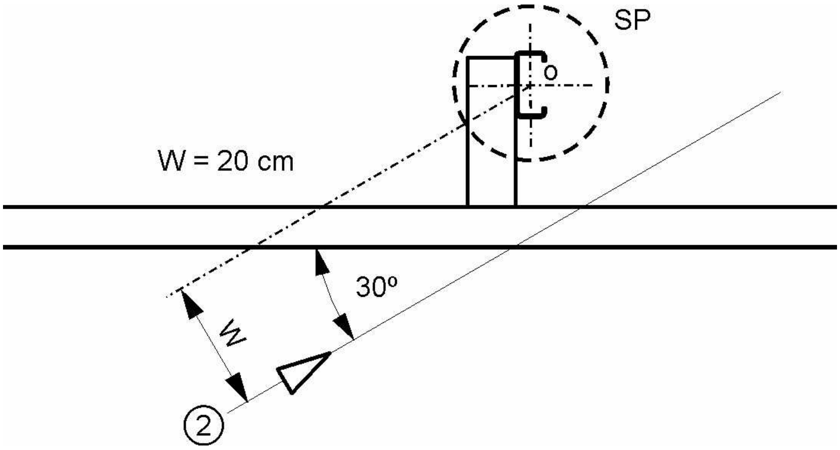


*Fig. 3: Trajectory 2: Off-Centre Impact (Top View)*

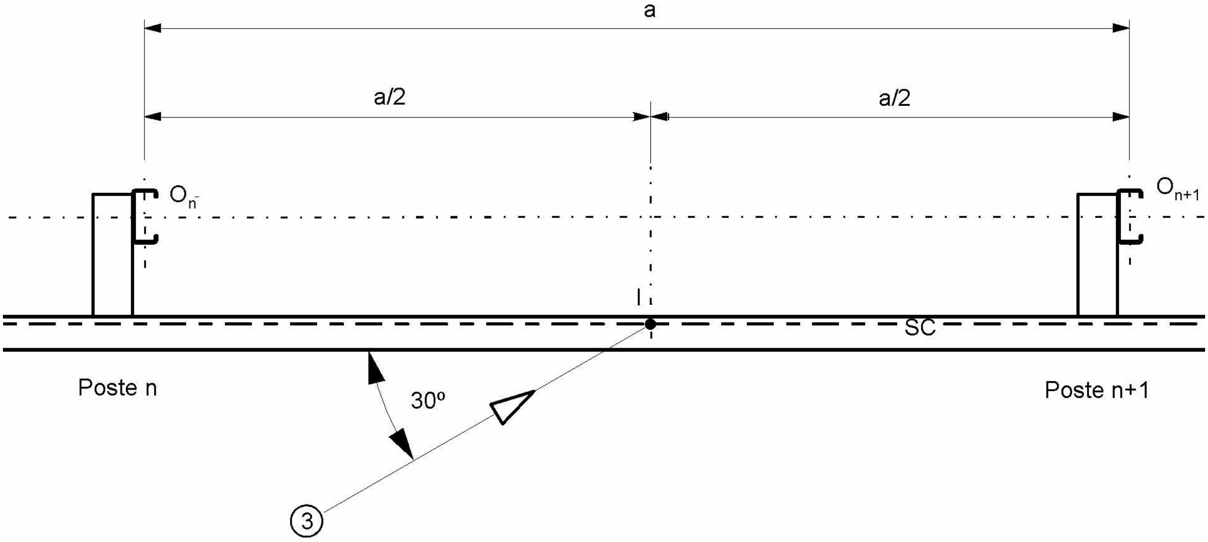


*Fig. 4: Trajectory 3 (Top View): Impact against the centre of the part between two posts (only applicable to continuous systems)*

Taking into account the previous three trajectories, the launching position is defined, as described by the following picture, where the dummy spine axe coincides with the approximation trajectory:

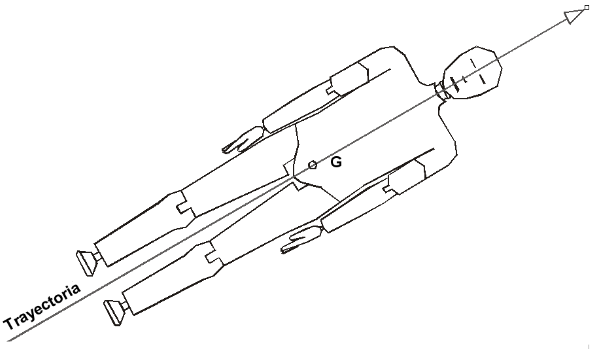


*Fig. 5: Launching position*

The impact speed is defined at 60 km/h.

For performing tests, the dummy shall be a Hybrid III 50th Percentile Male, equipped with a kit pedestrian that allows a standing position.

In order to measure the head accelerations a three-axe sensor should be installed in the Hybrid III Head centre of gravity.
In order to measure the neck forces, a load six-axe cell should be used 3 channels for measuring the forces and the other three for the moments.

The dummy will be equipped with an integral helmet that should comply with the requirements of Regulation ECE R22. The dummy will be equipped with a leather motorcyclist suit of thickness from 1mm to 1,5mm, complying with the Standard UNE-EN 1621. It will also be equipped with leather gloves and motorcyclist boots.

The following measurements are to be taken for the evaluation of the impact severity:
HEAD: HIC36
NECK: Fx, Fy, Fz, Mx, My

The maximum accepted values, according to two different types of severity levels, are those included in the following table:

| Level | **Head** | **Neck** | | | | | |
|---|---|---|---|---|---|---|---|
| | HIC36 | Fx (N) | Fz traction (N) | Fz compression (N) | Mcox (N.m) | Mcoy extension (N.m) | Mcoy flexion (N.m) |
| I | 650 | Following the corridors specified in the protocol (based on Mertz). | | | 134 | 42 | 190 |
| II | 1 000 | | | | 134 | 57 | 190 |

*Table 3: Biomechanical criteria proposed by CIDAUT*

The first part of the acceptance criteria of the impact test is the behaviour of the safety device. No element from the crash safety barrier weighting 2kg or more should result separated from the device unless that is necessary for its correct performance. The working width and dynamic deflection of the device with the dummy impact should not be in any case equal or higher than those defined by the Standard UNE EN 1317-2 for a vehicle impact. The device specially designed for the motorcyclist protection, should ensure no negative repercussion on its performance with regard to the vehicles impact.

The behaviour of the dummy is the second part of the acceptance criteria. The dummy used for the test should not have intrusions, body breaking, result beheaded or suffer any dismemberment. On the other hand, the dummy clothing (general equipment) should not result cut. Finally, the dummy should not get hooked by any part of the safety device.

## 8. Numerical simulation

In the feasibility study by Duncan et al (2000) research methods for a numerical simulation of motorcyclist impacts on barriers were suggested. The authors recommended using the numerical model of an anthropomorphic test device after validation against experimental crash tests. Multi-body models of the barriers were described as the most appropriate representation. Including the motorcycle in the simulations was seen as not advisable, at least not in the early stages of such research.

Apart from applying biomechanical limits used in previous studies in order to obtain absolute measures, performing comparative analysis of the performance of roadside barriers was suggested. The identification of injury mechanisms and evaluation of future barrier designs were mentioned as promising applications of such simulations.

Sala & Astori (1998) developed a new lower rail for metal barriers by means of numerical impact simulation using the multi-body code VEDYAC. After validating their numerical models by means of experimental tests, they performed the simulations applying the Biomechanical limits listed in table 4. The simulations comprised multi-body models of different barriers and of a human sliding into the barrier.

ERAB applied the Finite-Element code LS-Dyna to impact simulation with wire-rope safety barriers (Duncan et al, 2000). The barrier impact was simulated for a motorcycle including the rider, for a car and for a heavy goods vehicle.

Ibitoye et al (2004) applied the multi-body code MADYMO to the simulation of a motorcycle impact against a guardrail including a 50th percentile Hybrid III dummy model to represent the rider.

Berg et al (2005) compared concrete and wire-rope barriers by simulating impacts with the multi-body code MADYMO. The system of the concrete barrier model, the motorcycle model and the model of a non-helmeted 50th percentile Hybrid III dummy was validated against previously performed crash tests.

Apart from the work of Sala & Astori, none of the studies previously mentioned included modelling of a helmet.

| **Measurement** | **Biomechanical limit** |
|---|---|
| Resultant head acceleration | - |
| HIC | 1000 |
| Neck extension moment | 57 Nm |
| Neck flexional momen | 190 Nm |
| Neck shear load | 1.1 kN with duration > 45 ms |
| Neck tensile load | 1.1 kN with duration > 45 ms |
| Neck compressive load | 5.7 kN |
| Resultant chest acceleration | '60 g criterion' |
| Abdomen injury by acceleration | 130 g |
| Lumbar spine compression | 6.67 kN |

*Table 4: Biomechanical criteria used by Sala & Astori*

## 9. Injury Mechanisms

The risk of injury due to hitting a fixed object appears to be related to the impact area and the rigidity of the object. Hence small rigid objects such as posts are most likely to cause injury as they concentrate the forces of impact on a small area of the human body. The configuration of the impact determines the portion of the body that is struck, and thus influences the severity of the injuries sustained by the motorcyclist.

Quellet (1982) saw injury-causing objects generally in rigid surfaces perpendicular to the motion of the rider. For those riders remaining upright when impacting the crash barriers, most injuries occur when after shallow impact, the rider slides and tumbles into the top of the supporting posts. Riders sliding into the barrier strike the base of the posts, and motorcyclists impacting a wire mesh barrier are likely to suffer injuries by deceleration of the torso or fracture of the extremities from contact with the mounting posts.

Schueler et al (1984) conducted an in-depth analysis and reconstruction of 12 single accidents involving 14 casualties. In these cases 7 fatalities occurred, out of which 5 were only due to the impacts on the sharp edges of IPE-100 posts. Although the authors considered the accident scenarios not to be extremely dangerous in general (e.g. in terms of impact velocity), the observed injuries were seen as disproportionally severe, particularly if posts were involved. It was found that helmets can reduce the severity of head injuries well in impacts against posts. Nevertheless, in some cases the impact velocity was above the helmet's limit of effectiveness, leading to cerebral trauma. Another injury mechanism observed in conjunction with head impacts is a mechanical overloading of the cervical spine due to bending moments, axial and shear forces, leading to spinal-cord injury with fatal consequences. Associated with impacts of the shoulder/arm region on both rails and posts, rupture of the subclavian blood vessels occurred. It was concluded from the study that an impact on a post can, depending on the part of the body involved, cause fatal injuries at impact velocities as low as 20km/h.

In 1985 PMHS tests were performed by Schueler et al (1985) in order to investigate the potential benefit to passive safety of impact attenuators for barrier posts. In these tests cadavers were projected onto barrier posts, simulating an impact with a motorcyclist sliding on his back, feet forward, under a trajectory angle of 15 degrees against the barrier. The body was fixed to a sled and aligned with the trajectory. The right arm was bounded in order to let the post hit against the medial side of the proximal upper arm (near the armpit). The four cadavers weighed between 65 and 85 kg and hit the post with an impact speed of 32 to 33 km/h.

The impact on an uncovered IPE-100 post led to a subtotal amputation of the arm. The injuries were caused by the sharp edges of the post: the cross-section may be described as a double 'T' or as an 'I'. According to the Abbreviated Injury Scale this represents an MAIS = 3. The authors noted however that these injuries were very close to be considered as an MAIS = 4. Impact on an uncovered sigma post led to MAIS = 2, causing several non-complex fractures of the humerus and radius. The sigma post, whose cross-section is similar to the letter sigma, has considerably less sharp edges compared to the IPE-100 post, at least on one side. The cadavers were hit by this slightly rounded side. In two cases the presence of the tested impact attenuator by SPIG, made of polyurethane-coated polyethylene, reduced the injuries to MAIS = 1. The detected injuries after these tests were mainly contusions. It was concluded by the authors that the tested impact attenuator has a significant protective effect for motorcyclists and is suitable as an element of passive safety measures. Also the injury potential of the sigma post was seen to be considerably lower compared to the IPE-100 post due to the less aggressive shape.

For impacts on barrier posts, Quincey et al (1988) stated that the most numerous and most severe injuries were to the head.

The region of the body that is struck in the impact greatly influences the overall outcome. Hell and Lob (1993) found that injuries to the head, thorax and spine were particularly frequent in single-vehicle accidents involving impacts with obstacles. Collisions with a fixed object were associated with a risk of head and thorax injuries, which is at least 50% higher than for motorcycle accidents in general.

Ellmers (1997) pointed out that posts are a very dangerous feature of the guardrail system. He described the scenario of motorcycle accidents with a fall of the motorcyclist and a first impact on the road surface not causing major injuries. But if, in the course of the accident, the rider is then sliding into the barrier, a secondary, more severe impact with one of the posts may occur. As the distance between the posts is usually between 2 and 4 metres, there is a high probability of hitting a post at small impact angles.

Duncan et al (2000) reported that barrier posts were seen by stakeholders as the most dangerous feature of guardrail systems. Another particular hazard was seen in the sharp edges of the rails. In contrast, concrete barriers with their smooth surface were regarded to be less dangerous when impacted at shallow angles. Protrusion, as for instance for reflectors, were mentioned as unnecessary complications of an existing problem. The height of guardrail systems was also criticized. When a rider is impacting the barrier in upright position on the motorcycle, if the height of the barrier is too low, this may cause the motorcyclist to be thrown over. This way the rider might impact against obstacles from which road users are supposed to be protected by the barrier.

According to the MAIDS (ACEM, 2008) some areas of the body seem to be injured more often when impact with a barrier occurs. This is the case for the spine with 26.7% of these cases compared to 5.6% for all accidents, and the abdomen with 13.3% compared to 4.8%, whereas the upper and lower extremities as well as the thorax are less frequently injured than on average.

Ibitoye et al (2004) concluded from numerical impact simulations that impacting against barrier on the motorcycle at steep angles causes the rider to be catapulted over the barrier and this is then associated with a high risk of head and neck injuries when impacting the ground surface with the head first and the neck being bent thereafter.

Another conclusion from numerical simulations was drawn by Berg et al (2005). The authors found that upon impact with a wire-rope barrier, the rider is very likely to be caught between the wires regardless of angle or speed, which led to the supposition that this may constitute a relatively higher risk of injury.

## 10. Performance of Roadside Barriers and Counter-Measures

Roadside barriers are supposed to protect road users, in case they leave the carriage way, e.g. from the critical interaction with obstacles. Schueler et al (1984) commented that in such a case the kinetic energy of the human body has to be absorbed or dissipated to plastic-type deformation in order to reach a risk of injury as close as possible to a barrier-free roadside (figure 6).

Upon impacting a barrier the trajectory of a road user should not return into the traffic. This is particularly important for motorcyclists. Ellmers (2002) therefore defined the desirable performance of a barrier if involved in a motorcycle accident. The rider or pillion should slide closely to the barrier without getting caught in it. As in other accident scenarios, it is desirable that the rider separates from the bike, the primary impact should be as moderate as possible, and the velocity should be reduced as much as possible. The author claimed that the motorcycle should, in the case of an upright impact, fall quickly in order not to cover a long distance in an uncontrolled state. According to Ellmers, crossing the barrier can only be tolerated when there are no potentially dangerous structures behind. But this will often not be the case, as barriers are usually meant to protect from impact with these structures.

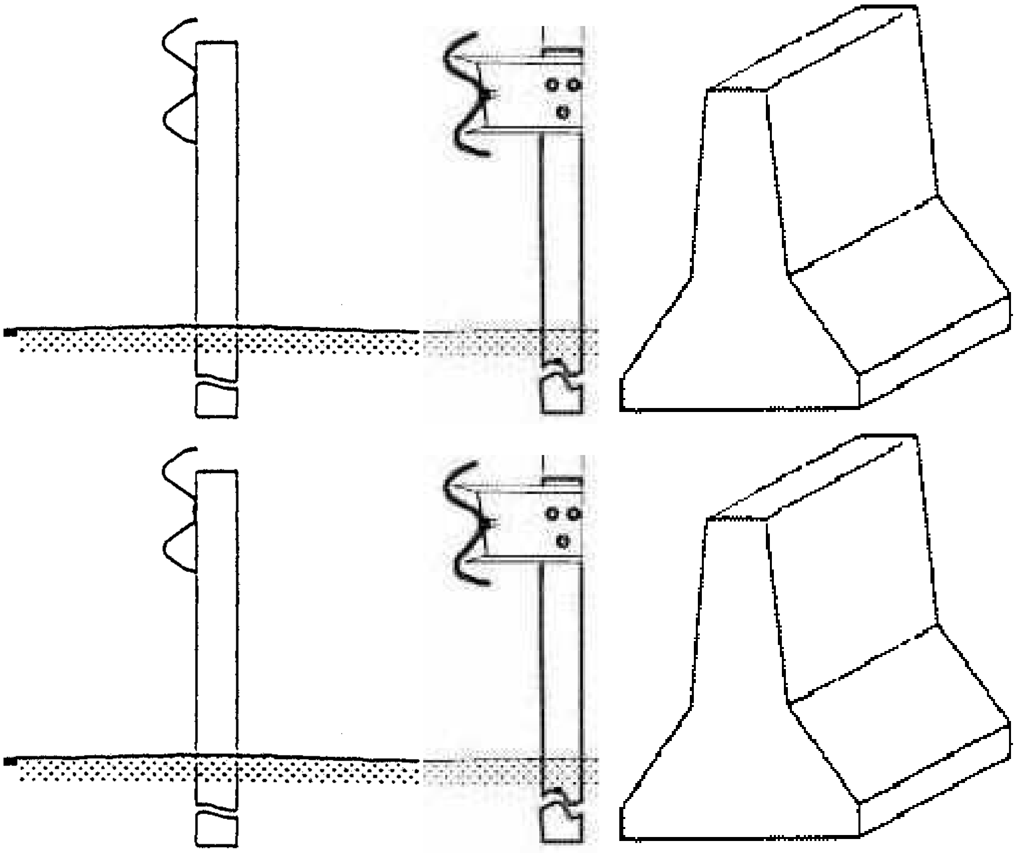
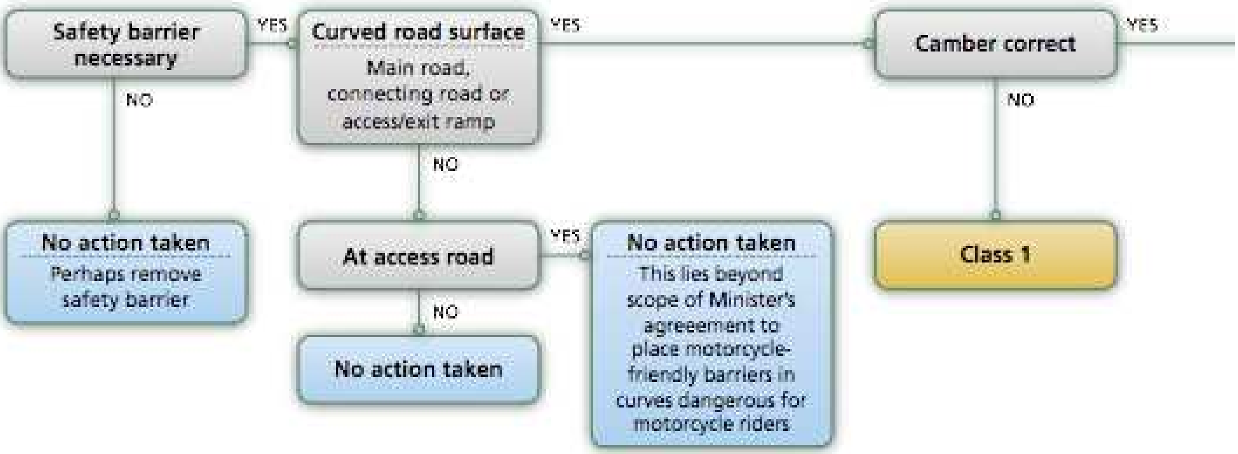
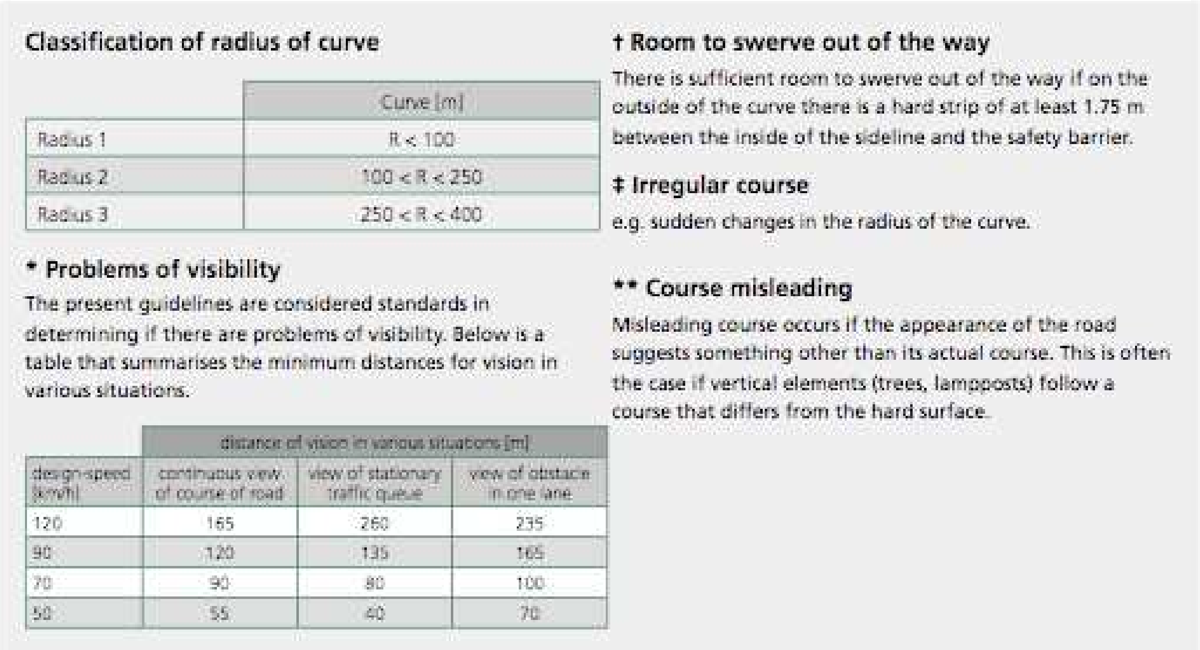


*Figure 6: Cross sections of simple guardrail, guardrail spacer-type, concrete barrier*

According to Eurorap (2008) Road engineers in the Netherlands use a decision tree approach to guide them through the selection process. The tree is reported in figure 7:

## Annex 1: Dutch decision tree





### Classification of radius of curve

| | Curve [m] |
|---|---|
| Radius 1 | R < 100 |
| Radius 2 | 100 < R < 250 |
| Radius 3 | 250 < R < 400 |

### * Problems of visibility

The present guidelines are considered standards in determining if there are problems of visibility. Below is a table that summarises the minimum distances for vision in various situations.

| | distance of vision in various situations [m] | | |
|---|---|---|---|
| design-speed [km/h] | continuous view of course of road | view of stationary traffic queue | view of obstacle in one lane |
| 120 | 165 | 260 | 235 |
| 90 | 120 | 135 | 165 |
| 70 | 90 | 80 | 100 |
| 50 | 55 | 40 | 70 |

### † Room to swerve out of the way

There is sufficient room to swerve out of the way if on the outside of the curve there is a hard strip of at least 1.75 m between the inside of the sideline and the safety barrier.

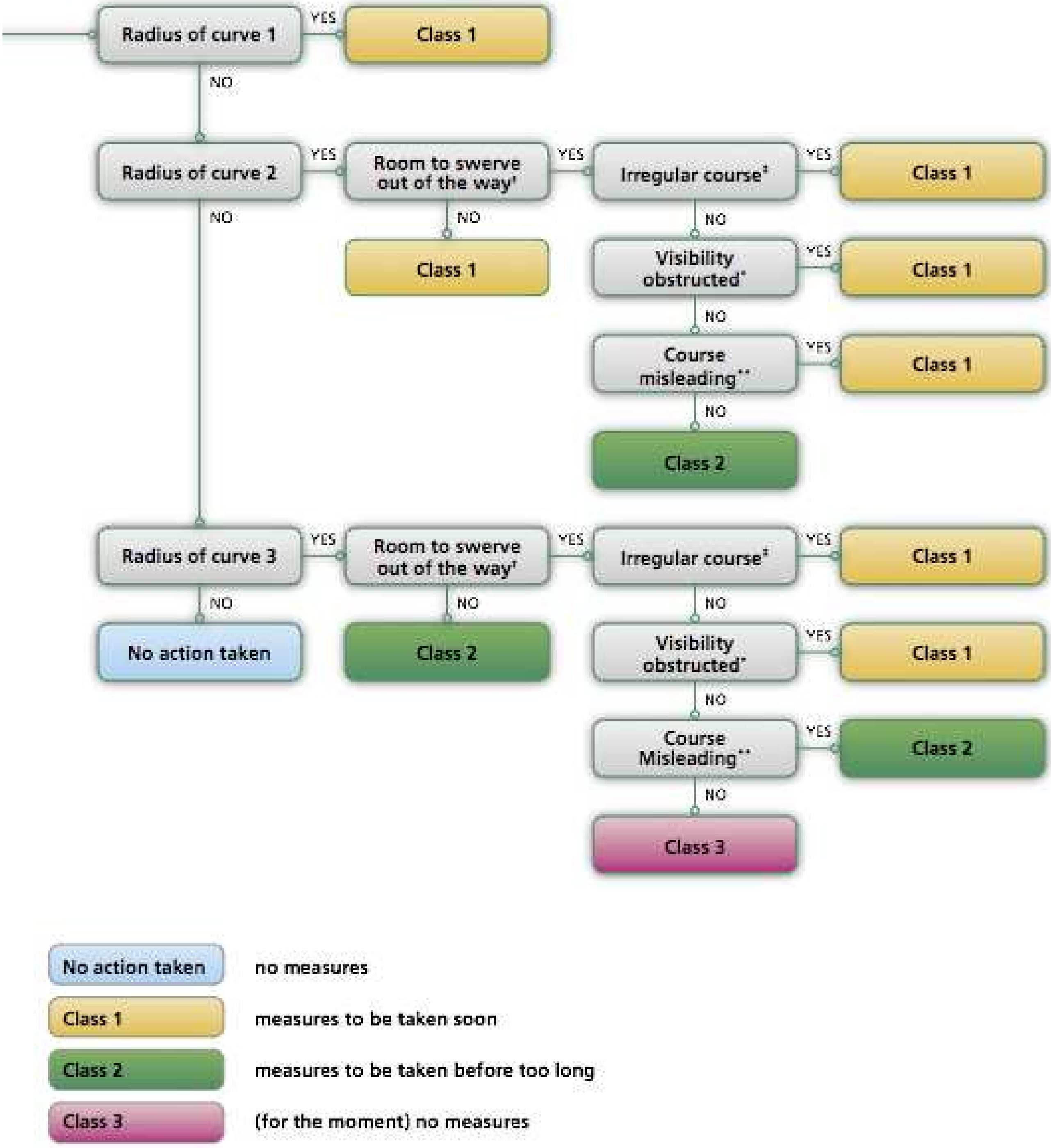
### ‡ Irregular course

e.g. sudden changes in the radius of the curve.

### ** Course misleading

Misleading course occurs if the appearance of the road suggests something other than its actual course. This is often the case if vertical elements (trees, lampposts) follow a course that differs from the hard surface.

*Figure 7: The Dutch decision tree for the design guidelines for road engineers (part A)*



Compiled by the Dutch Ministry of Transport (AVV), Motorcycle Action Group (MAG) Netherlands, & Royal Dutch Motorcycle Club (KNMV)

*Figure 7: The Dutch decision tree the design guidelines for road engineers (part B)*

## 10.1 Concrete Barriers

Schueler et al (1984) claimed that barriers which constitute a vertical sliding surface for motorcyclists should be developed. This could be concrete walls or metal guardrails with a lower part that is similar in shape to concrete barriers like the New Jersey Profile (see figure 6).

The tests performed by Quincy et al (1988) according to their procedure showed that measured head accelerations stayed well below the biomechanical limits for concrete barriers as well as for two different models of protective devices for metal guardrails. The results however differed for the acceleration over a 3ms duration and for the HIC. The latter values were considerably lower for the concrete barrier (HIC=110) than for the additional lower rails (HIC from 175 to 365). The concrete barrier gave a higher value (110g) for the 3ms acceleration than the protective devices (40g to 80g).
It has to be noted that the values given in the paper justify questioning the repeatability of the tests results.

Bouquet et al (1998) also compared the performance of concrete barriers to metal guardrails equipped with a protective device. Although the established biomechanical limits were not exceeded, the HIC values were remarkably higher for the concrete barriers. For the impact configuration of 30º the compression value measured in the head-neck joint was 457daN for the concrete wall. Thus the value exceeded the biomechanical limit of 400daN.
In general, the metal guardrail was seen to be less aggressive than the concrete wall, although it was difficult to draw final conclusions on the performance of the concrete barrier due to unsuitable design of the Hybrid II dummy used.

Sala & Astori (1998) investigated the performance of concrete barriers and metal guardrail systems in sliding impact scenario. The study was performed by means of numerical simulation. The concrete barrier was seen to be superior to the standard metal guardrail. Its continuous surface was given as a reason for this result.

Buerkle & Berg (2000) compared conventional metal guardrails with concrete barriers in impacts including the motorcycle in an upright and sliding position. Although the dummy did not separate from the motorcycle during the sliding impact with the concrete barrier, this configuration was seen to constitute a lower risk of injury for the rider than an impact with an uncovered guardrail post.

Comparing the two systems in an upright impact, the dummy showed a strong tendency to pass over the barriers due to their relatively low height. The dummy was caught in the spacers of the metal guardrail while passing over the concrete barrier without further loading, which again was seen to be advantageous for the concrete barrier.

Duncan et al (2001) compared concrete barriers, wire-rope safety barriers and metal guardrails in experimental car impact tests and drew conclusions from their behaviour on motorcyclist impacts. The high peak accelerations associated with concrete barriers were seen to be likely to cause more severe injury outcomes for motorcyclists than W-beam or wire-rope barriers. Also, the worst performance of concrete barriers in impacts at greater angles due to the small capacity of energy dissipation was considered to be crucial.

Berg et al (2005) compared the performance of concrete barriers with that of wire-rope safety barriers. The authors found that the risk of injuries is high for both impact with concrete barriers and wire-rope safety barriers. But the impact with a motorcycle in an upright position into a concrete barrier is likely to cause survivable injuries only. The greatest risk in this case was seen in being catapulted over the barrier. Compared to the possibility of the rider being caught in the wires of the other barrier, the authors supposed that the concrete barrier may constitute a relatively lower risk of injury.

The above-mentioned studies by Bouquet et al and Quincy et al were aimed at finding out whether the concrete barrier constitutes a better or worse alternative to a conventional metal guardrail than a metal guardrail equipped with an additional lower rail. In order to be able to classify the concrete barrier as such an alternative, it should first be evaluated in comparison to a standard guardrail. This has partly been done in the above-mentioned study by Buerkle & Berg. The study clarified this issue for impacts involving the motorcycle by means of experimental testing. Accordingly, the concrete barrier was compared to a wire-rope barrier by Berg et al using numerical simulation as described above. But a similar comparison for impacts in a sliding position without the motorcycle has only been reported by Sala & Astori, who used numerical simulation and suggested validation by full-scale experimental testing. Such a comparison would be likely to involve high costs due to fractures of dummy parts.

Gabler (2007) in a study conducted in the USA, shown that motorcyclists suffer the third highest number of fatalities and motorcyclists are overrepresented in the risk of fatalities. Motorcycles accounted for only 3% of registered vehicles in the U.S. in 2005, but incurred 22% of all fatalities with concrete barrier collisions. However, comparing motorcycle-guardrail and motorcycle-concrete barrier fatalities per registered vehicle, guardrail collisions pose a greater risk for motorcyclists than concrete barriers.

## 10.2 Guardrail, Posts and Post Envelopes

Schueler et al (1985) investigated injuries caused by impacts with different barrier posts and protective devices in PHMS tests. The impact of the upper arm on an uncovered IPE-100 post (figure 8) with an impact speed of 32 to 33 km/h led to a subtotal amputation of the arm. According to the Abbreviated Injury Scale this represents an MAIS = 3. Impact to a sigma post lead to MAIS = 2, causing several non-complex fractures of the humerus and radius. In two cases the injuries were reduced to MAIS = 1 by the use of the tested impact attenuator by SPIG, made of polyethylene foam with a density of 30 kg/m3 , with a diameter of around 300 mm and coated by 1mm-thick polyurethane. In these cases the detected injuries were mainly contusions. Conclusions were drawn that the tested impact attenuator has a significant protective effect for motorcyclists and is suitable as an element of passive safety measures, and that the potential for injury of the sigma post is considerably lower than that of IPE-100 posts due to the less aggressive shape.

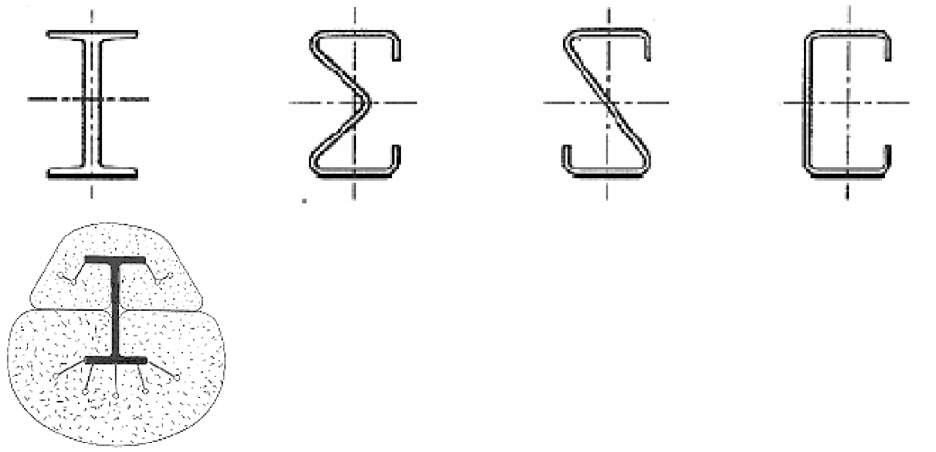


*Figure 8: Cross sections of guardrail posts IPE100, Sigma, Z, C and attenuator*

Using a Sierra Hybrid II part 572 dummy, Jessl (1987) investigated, the potential for impact-related injury reduction of an attenuator consisting of polystyrene foam with a density of 22 g/l. For some of the tests a polyurethane-based coating of 1 mm thickness was applied to the foam. He used three different drop-test set-ups with an impact speed of 32 km/h, the first one being an arm impact similar to that used in the PMHS tests by Schueler et al, (1985). The second configuration involved a primary impact of the head against the post, followed by impacts of the shoulder and the arm. In the third set-up only the dummy head was used to impact the post. The author concluded that the arm impact was the configuration representing the smallest loads to the attenuator. For the head-only impact, the attenuator reduced the maximum resultant head accelerations by 50 % while nearly doubling the impact time. In the other two set-ups the application of the protective device also reduced the maximum head and chest accelerations by roughly 40 - 60 %, although the impact speeds of the tests without the attenuator were reduced to 22 km/h, in order to avoid damage of the dummy. Jessl stated however, that the only biomechanical tolerance limit exceeded in the tests was the chest acceleration in test configuration 2 when not using the protective device.

Domhan (1987) reported that the limit of effectiveness of crash absorbers on barrier posts was seen to be around 50 to 60 km/h.

The above-mentioned findings of a better performance of sigma posts compared to IPE-100 posts led, according to Koch & Schueler (1987), to sigma posts being used for all new installations of guardrails reported in 1987 in Germany. The authors also found some statistical proof of the effect that additional W-beams reduced the number and the severity of crashes reported at two accident black spots.

The German guidelines for roadside barrier installation (BASt, 1993) included the description of the possibility to equip guardrails with impact attenuators. This is at least a first example of consideration for motorcyclist protection as a general goal of barrier use, as has been suggested in the study by FEMA (2000).

Although using sigma posts was seen as a protective measure, the Federal Highway Research Institute BASt, also recommended extra protection on sigma posts because there is still the risk of fractures upon impacts at relatively low speeds (Ellmers, 1997).

According to Ellmers (1997) the advantages of impact attenuators are that they can be mounted at any type of guardrail, i.e. spacer type or without spacers, and they are comparatively inexpensive. Furthermore there are no restrictions for attenuators depending on the barrier location, i.e. they can be used in any type of curve, which is not necessarily the case for lower rails for example.
The author stated that as guardrails are widely used in Germany, replacement of IPE-100 posts by sigma posts would only be done for repair purposes. Sigma posts would also be used for new installations, but generally it would take a long time until the IPE-100 posts are out of use.

The downside of impact attenuators are, according to Sala & Astori (1998), that polystyrene-coated polyurethane dampers are not effective at impact speeds of more than 50 to 60 km/h and that they do not endure environmental agents. Also, they do not withstand rodents attack. Their cost was seen to be very high.

In the study by FEMA (2000) impact attenuators were seen to be useful at low-speed impacts which would typically occur in urban areas or very tight bends.

A suggestion for making posts more frangible was mentioned by Duncan et al (2000). The thickness of the posts of the standard Australian wire-rope safety barrier should therefore be reduced to 6 mm.

Gabler (2007) showed that motorcycle riders accounted for 42% of all fatalities resulting from guardrail collisions in 2005. Following motorcycle riders, were car occupants with 32% of all fatalities in this crash mode. This was a particularly surprising finding as cars make up over half of the vehicle fleet (55%) while motorcycles are only 3% of registered vehicles.
The risk of fatality in motorcycle-guardrail collisions is 12%. The risk of fatality in motorcycle-concrete barrier collisions is 8%. The risk of fatality for motorcycle-car collisions is 4.8% - approximately one-third of the risk of a motorcycle-guardrail collision.

## 10.3 Wire Rope Safety Barrier

In a study performed by the Australian Transport Safety Bureau (ATSB, 2000), safety implications of wire-rope safety barriers were analysed. The main roadside objects involved in fatal motorcycle crashes are trees, poles or signposts (70%). The study concluded that an increasing use of wire and exposed poles by the roadside will continue to cause the rise of serious casualties as more riders hit this fence system with potentially deadly results. However, it also stated that available information suggests that Wire Rope Safety Barriers have had negligible involvement in motorcycle casualties, both in Australia and abroad. There appears to be almost no record of such incidents, either in official accident statistics or in the form of anecdotal reports.

Pieglowski (2005) in a study performed in Sweden on the effect of Wire Rope Safety Barrier on motorcyclists stated that wire rope barriers could be perceived as a safety issue for motorcyclists. However, this has to be set against the fact that there is not sufficient statistical information available on motorcyclists in any of the areas analysed. Furthermore, there has been no in-depth study of wire rope barrier safety with respect to motorcyclists. Motorcycles are also not included in approval tests of wire rope barriers (or any other crash barriers). Growing motorcycle traffic and barrier implementation and the feeling of insecurity of riders are all factors that significantly justify more research to be carried out in this area.

According to the Motorcycle Action Group in the UK (MAG UK, 2005), due to the open nature of the design, the wire rope barrier system is viewed by motorcyclists as the most aggressive form of Vehicle Restraint Systems causing the most injuries to riders. This is due to the exposed upright permanent steel posts and wire cables. This view is supported by computer simulations and tests which clearly indicate that injuries will be severe if a rider hits the cables or the exposed supporting posts of Vehicle Restraint Systems.

Carlsson A., (2009), analysed the casualty data and the fatality rate of of 2+1 roads with cable median guardrail in Sweden. These roads are also known as Collision-free Roads since the objective is to design and build roads that prevent head-on collisions. The conclusion is that there is no evidence that the fatality risks for motorcyclists have increased on collision-free roads. On the contrary, it can be stated that the fatality risks for motorcyclists have been reduced by 40-50% on 2+1 roads with cable median guardrail.

## 10.4 Additional Rails

In a study by Schueler et al (1984) analyzing motorcycle accidents with barrier impact, new design features were suggested in order to reduce the injury potential of roadside barriers for PTW riders. A first suggestion consisted of mounting a lower rail to guardrails, which include a spacer between the rail and the post. Another very simple spacer should then be used for the lower rail. It should consist of two plates between post and rail, which are slightly cambered in order to allow deformation. A second suggestion was to fix the support of the lower rail to the spacer of the upper rail, which would make it more flexible.

For guardrails without spacers the only possibility was seen by directly mounting the lower rail on the post. In this case there would be no space for deformation. The authors claimed that a new design of the lower rail should be developed in order to allow for deformation space. In this configuration the lower rail might also function as a ramp for cars in high-velocity impacts.

The aim of the study by Quincy et al (1988) was to develop a device to reduce the aggressiveness of the metal beam standard guardrail. There were 2 devices introduced, both with a lower beam for preventing post impact and one with an upper beam. It can be installed very easily.

For guardrails with spacers, Ellmers (1997) saw the possibility of installing a second beam underneath which is not connected to the posts, thus allowing the deflection of this beam without contacting the posts. The degree of possible deformation would then be the length of the spacer. According to the author, installation of such a beam would not cause negative effects on the performance for car impacts, e.g. not building a ramp. Difficulties were however seen for installing them in curves.

Bouquet et al (1998) tested a metal guardrail with an additional lower rail and compared its performance to that of a concrete barrier. For this purpose four different tests were performed. A dummy slid against both barrier types with two different orientations (30º and 0º). Although the established biomechanical limits are not exceeded, the HIC values are significantly higher for the concrete barriers. To summarise, the resulting head accelerations are almost doubled compared to the metal guardrail and the HIC is four times greater. For the neck, the forces and flexion moments are also smaller in the case of the metal guardrail. For the configuration with a rider orientation angle of 0º, both devices are acceptable. In any case, the biomechanical limits are not reached or exceeded. For the configuration of 30º the compression value measured in the head-neck joint was 392daN in the case of the metal guardrail and 457daN for the concrete wall. Thus the value for the concrete barrier exceeded the biomechanical limit of 400daN.

In general, the metal guardrail was seen to be less aggressive than the concrete wall. However, the Hybrid II was conceived for frontal impact and so some of its body elements, such as the shoulder and the knee, may not properly comply with the more demanding requirements for lateral tests.

Sala & Astori (1998) introduced a protective device for motorcycle accidents after evaluating it by means of numerical simulation. The device is a closed profile and additional lower rail and is made of pultruded continuous glass fibre and polyester resin. The protective device is a rail more or less U shaped, which is bolted to the post through a deformable steel spacer that absorbs the impact energy. The additional lower rail was found to be ideally located at 150 mm over the road surface in order to allow the front wheel of a sliding motorcycle to slip beneath it and to be caught that way.

Different types of barriers are impacted: steel, steel with rubbing rail, concrete, steel / composite. The model of the dummy was considered to slide along the pavement at a velocity of 15 ms and to impact the barriers with a trajectory angle of 15º. It is clear that an impact against posts results in concentrated loads, acting on the body of the motorcyclist. Results obtained from continuous protective device tests are beneficial. Although the study is interesting, it is incomplete for a final conclusion because it is necessary to be validated by means of full-scale crash tests. The behaviour of a device only, is real in a real crash tests. The installation of this device needs a hole added in the standard post and the material used is experimental in the Road Safety Devices.

A potential disadvantage of this model may be that it is only applicable for spacer-type guardrails. Mounted on simple guardrails, which do not include a spacer, it would protrude considerably from the original surface.

Several models of continuous protective devices for reducing risks to motorcyclists are described by Duncan et al (2000). All these devices were tested and approved to use the LIER French protocol, which consists of a dummy which is thrown head first, sliding on its back, against a fitted barrier with an impact speed of 60km/h at a 30° angle. The criteria for homologation is HIC<1000 (note: the surface of the road was required to be made slippery for the dummy to effectively reach the barrier due to the significant reduction of speed caused by the motorcyclist sliding along the surface prior to impact).
The models are:

Ecran Motard: a metal shield or plate that can be fixed under existing guardrails to cover the barrier posts. It differs from the addition of extra W-beams described above as it has a flat surface with a high degree of flexibility enabling it to absorb energy on impact. It is sold by SEC-Envel in France. The metal shield is fixed between the spacer and the W-beam. It can only be applied at this type of spacer and allocation post for the French allocation.

Plastrail: Sodilor is the manufacturer. The device consists of a soft plastic fence covering barrier posts that can be fitted to existing barrier systems. It aims to combine both energy absorption properties and impact spreading properties, the same as the previous kind alone, is applicable for the allocation of the French post.

Motorail: An integrated solution with a built in secondary rail, and minimal aggressive shapes, turned in edges, etc. It appears to be all in one.

Mototub: The "Mototub" made by Sodirel, which is similar to the Plastrail except that it is made from 70% recycled material. Apparently it is also able to be adapted to cover WRSB types.

A device that covers the upper and lower wire rope systems of standard WRSBs was not tested. The device consists of aluminium profiles that can be fitted to existing systems.

The four protective devices described above, along with the model Motoprotec by the company EUPARC, were approved by the French authority SETRA (Pieribattesti & Lescure, 1999) for use at roadside barriers installations. These devices were made compulsory for all new installations at the following locations: at the exterior of curves with a radius below 400 meters on motorways and roads with separated carriageways, at the exterior of curves with a radius below 250 meters on all other roads, and at the exterior of any junction which is not even.

Among the devices described by Duncan et al, the Ecran Motard model will probably be the least expensive. A potential problem which may be encountered with the installation of the model Motorail in tight bends, is the opening of the joint between the upper and lower rail. The design of the model Plastrail indicates that production costs are higher for this device than for the others. The metal beams connecting the segments at the location of the posts might have a negative influence on the performance for car impacts. Compared to this model, the mounting of Mototub should be less costly, as long as the upper rail does not need to be dismounted. But the greater thickness of the Mototub would create a protrusion from the original surface for guardrails without spacers and would possibly build a ramp in the case of car impacts.

The report by Fattorini et al (2000) gives an overview of guardrail hazards in relation to motorcyclists. The scope of this report is to present a motorcyclist protective continuous device named Containment Urban System for Motorcyclists – CUSTOM.

The report also includes the review of a previously existing system, the Basycco System. This consists of a high resistance net stretched between the posts and under the main rail. It avoids the sliding of motorcycle riders under the barrier, reduces the effect of lateral wind and offers better road visibility with its colour. It has not yet been tested.

The central point of this report shows the CUSTOM which is a completely closed steel device without edges exposed, which potentially can become very dangerous for the motorcyclist. It was tested in LIER and met the French protocol, additionally it can be painted in different colours allowing for good visibility in the case of insufficient lighting and or/ adverse weather conditions. Its installation is not clearly defined. It seems that it can be assembled on any W-beam but it would need a lot of holes along the barrier which are not present in the current W-beam installed on roads.

In the study by Buerkle & Berg (2000) a metal guardrail with a closed profile (called Swiss box profile) and additional lower rail was introduced. The system was compared to concrete and metal barriers in upright and sliding impacts including the motorcycle. The performance of the new system was seemed to be remarkably better in all impact configurations than for the two conventional systems. The additional lower rail was found to be ideally located at 150 mm over the road surface in order to allow the front wheel of a sliding motorcycle to slip beneath and to be caught that way. It was reported by Kloecker and Ellmers (2002) that this system was installed in a testing section in the Hesse region in Germany.

Such a closed box profile might be unsuitable for installation at curves with a small radius, as the geometry might not allow sufficient bending.

Nikolaus & Ziegler (2001) described the model Euskirchen, which is an additional lower rail with the support mounted directly on the upper rail. It has been approved, with some restrictions for the installation, by the German road authorities. Examples for the application of this model are given by MEHRSI (2005). The suspension of the model Euskirchen on the upper rail may potentially downgrade the performance of the barrier in the case of car impacts.

Kloeckner & Ellmers (2002) described the potential disadvantages of a second lower rail on a conventional W-beam guardrail. According to the authors, a motorcyclist is not protected in an upright impact when falling on top of the barrier. Also, possibilities for the application of this kind of protective device were only seen with spacer-type guardrails, not on simple guardrails, where the W-beam is directly mounted onto the posts. However, this latter type is found more frequently at relevant sites in Germany.

## 10.5 Potential Effects of Counter-Measures

Domham (1987) reported that back in 1979, the performance of an additional lower rail was evaluated by INRETS in France by conducting crash tests using dummies. In these and later tests in 1983, the protective effect of a lower beam could already be proven. In the author's opinion, it was then necessary to investigate the costs associated with this kind of counter-measure as well as the potential benefits.

It was reported that the cost per meter of an impact attenuator were less than half of that for an additional W-beam mounted as a lower rail. Equipping all guardrails in Germany with any of the proposed elements would not be efficient in terms of their costs and saved injury costs. However, if accidents were not equally distributed, some guardrail sections would have a higher cost-benefit ratio and others would have a lower one. It was estimated by the author that if 30 % of all accidents occurred on 10 % of the guardrail sections, the protective elements would reach their pay-off for certain types of roads. It was therefore recommended to equip guardrails with protective devices on selected sections of state roads and interstate roads and to install the devices on hot spots only, i.e. considerably less than 10 %, on motorways and county roads.

The author found that choosing these sections for the installation of protective measures was the critical task. This cannot be performed in advance, but only after a certain number of accidents had occurred.

Also Koch & Schueler (1987) found that it has proven to be difficult to choose appropriate locations for protective devices on roadside barriers. In the analysis of accident statistics, the figures and values used to determine where such devices are to be installed vary considerably between different local governments inside Germany. The authors noted the importance of motorcycle associations in some cases to raise attention for hot spots.

The findings of Schnuell et al (1993) indicate that a reduction of 25 % in motorcycle fatalities could be achieved by equipping crash barriers with protection at all locations where accidents had been reported. Accordingly, accident severities could be decreased by 50 %.

The French authority SETRA (1997) conducted a study to define cases in which an additional lower rail on a roadside barrier could have reduced the consequences of impact to the human body. This comprised an analysis of 46 fatal accidents involving at least one motorcycle and a metal-barrier impact between March 1990 and February 1991. Only half of the killed riders and pillions were wearing a helmet when the impact occurred. In 61% of the accidents, the presence of a lower rail would have reduced the consequences of impact to the human body, in 6 % it may have done so, in 9% it would not have, and in 24% the potential effect could not be determined.

In another study (SETRA, 1998) 157 accidents due to impacts with metal guardrails followed by physical injuries were analyzed. In 31% of the cases an additional lower rail would have definitely reduced the physical consequences to the motorcyclist. In 31% the lower rail may have been advantageous. The authors gave the following recommendations for the prioritisation of locations of barriers with improved motorcycle safety features. Junctions and interchanges in general as well as the median side of right-hand curves on motorways and urban fast-lanes were suggested. For interurban roads lower rails on barriers at the exterior of curves with a radius smaller than 250 meters was suggested, on national and main departmental roads this mainly applies to left-hand curves. Furthermore, in agreement with the study by FEMA (2000) the authors recommended the consideration of the creation of safety zones free of obstacles at curves, most importantly at the exterior of the curve.

## 11. Conclusions

The review of accidentology studies offers the opportunity to draw some conclusions despite the fact that the majority of studies are based on small data sets.

The analysis shows that the impact of motorcyclists against a fixed object occurred in 4% of the cases in urban areas while it varies between 10% and 20% in rural areas.

The most important obstacles with a particularly severe outcome involving accidents, are trees/poles, roadside barriers and road infrastructure in general.

In approximately 50% of impacts with trees/poles and barriers the rider is upright on his motorcycle.

Impact speeds in accidents involving roadside barriers as an obstacle tend to be very high.

According to different studies, a fatal outcome is 2 to 5 times more likely for an impact with a crash barrier than for motorcycle accidents in general.

The most dangerous aspect of guardrails with respect to motorcyclists is the exposed guardrail posts.

Most motorcycle collisions with crash barriers occurred at shallow angles (typically between 45 and 10°) with the rider typically sliding into the barrier at a bend.

There is a high risk for a rider to directly hit one of the barrier posts while approaching a guardrail in a sliding position. For a distance of 2.5m between the posts, the probability is more than 35% for an angle of impact of 30 degrees, increasing to more than 70% for a 15-degree angle.

Several testing procedures have been developed in order to evaluate the injury risk of a PTW rider sliding on his own into a roadside barrier. They all have an impact angle of 30 degrees and two different orientations of the rider's longitudinal axis in common. Impact speed is between 55 and 60km/h.

Another procedure includes the motorcycle. In this case the impact angles are between 12 and 25 degrees, and the speed is 60km/h.

All these procedures require a Hybrid II/III dummy, in some case with replacement parts. The biomechanical limits applied in the tests are mostly a HIC value of 1000 and a neck extension moment of 57Nm.

The risk of injury due to hitting a fixed object appears to be related to the impact area and the rigidity of the object. Hence small rigid objects such as posts are most likely to cause injury as they concentrate the forces of impact on a small area of the human body.

The sigma post has considerably less sharp edges compared to the IPE-100 post.

For riders remaining upright when impacting the crash barriers, most injuries occur when after shallow impact, the rider slides and tumbles into the top of the supporting posts.

When a rider is impacting the barrier in upright position on the motorcycle, if the height of the barrier is too low, this may cause the motorcyclist to be thrown over.

An impact on a post can, depending on the part of the body involved, cause fatal injuries at an impact velocity of as low as 20km/h.

Impact attenuators have a significant protective effect for motorcyclists and are suitable as an element of passive safety measures.

Collisions with a fixed object were associated with the risk of head and thorax injuries, which is at least 50% higher than for motorcycle accidents in general.

Roadside barriers presented a substantial danger to riders, causing serious lower extremity and spinal injuries as well as serious head injuries.

The performance of concrete barriers seems to be superior compared to that of conventional metal guardrail systems in a sliding impact scenario, at least for shallow angles, despite their higher stiffness. Some authors see the biggest risk for severe injuries in the sharp edges of guardrail posts, others in the edges of the metal rail.

According to a study the limit of the effectiveness of crash absorbers on barrier posts was seen to be around 50 to 60 km/h.

Due to the open nature of the design, the Wire Rope Safety Barrier system is viewed by motorcyclists as the most aggressive form of Vehicle Restraint Systems causing the most injuries to riders. This view is supported by computer simulations and tests which clearly indicate that injuries will be severe if a rider hits the cables or the exposed supporting posts of Vehicle Restraint Systems. However, due to the limited available information about real accidents, there is no evidence that the fatality risks for motorcyclists increase when impacting the wire rope barrier system.

In a comparison between metal guardrails with an additional lower rail and concrete barriers, the performance of the metal guardrail was seen to be less aggressive than the concrete wall.

Some studies state that an additional lower rail on a roadside barrier could reduce the consequences of impact to the human body by a percentage varying between 30 and 60% of the cases.

Future research should focus on the risks associated with impacts with trees and poles and on the question: what type of roadside barrier can effectively protect PTW riders from impacts with such obstacles.

For sliding motorcyclist, it seems apparent that discontinuous systems are worse than continuous. In this scenario, post modifications together with post envelopes shows a positive approach in decreasing risks for motorcyclists.

A much better solution seems to be the addition of a lower rail. As this one provides better energy absorption than concrete solutions or wire rope safety barriers. The solution can be observed in different materials (steel, plastic, rubber, etc).

However, it must also be considered that the impact scenario in an upright riding position seems to be equally important, with the associated risks of being thrown on or over the barrier, and this scenario has not be  investigated in depth up to now.

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