TECHNICAL BASES FOR THE DEVELOPMENT OF A TEST STANDARD FOR IMPACTS OF POWERED TWO-WHEELERS ON ROADSIDE BARRIERS

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ABSTRACT

The problem of injuries to motorcyclists caused by impacts on roadside barriers has numerously been pointed out in the literature. Nevertheless, there is a lack of agreement concerning injury criteria for these particular cases. One of the objectives of the European research project APROSYS SP4 "Motorcycle Accidents" is to propose a European crash test standard for the assessment of impact performance of roadside barriers with respect to injury risks. This paper describes the methodology of work that has been followed for the proposal of the standard.

In-depth databases have been analysed in order to evaluate the nature of motorcyclists' impacts to barriers and to gain knowledge in addition to the anecdotal cases reported in the literature. About 1000 accidents of powered two-wheelers from four different databases were analysed. In contrast to previous views, impacts in upright riding position seem to occur equally often as impacts in sliding position. A detailed analysis of the current testing procedures (e.g. the Spanish standard, the procedure developed by INRETS, France) has been performed. Full-scale crash tests in sliding position, performed by CIDAUT, and upright position, performed by DEKRA, were included in this analysis. The selection of the injury criteria, especially in head, neck and thorax, has to take into consideration the peculiarities of this kind of accidents. It was concluded that the biofidelity of available dummies (Hybrid III) needs to be further assessed for this particular application, e.g. by comparative simulations using HUMOS2 model.

The knowledge gained at the light of the results obtained from the described methodology will be used in the future development of a standard.

INTRODUCTION

Road infrastructure is of particular importance for accidents of powered two-wheelers (PTW). This is not only due to the potential involvement in the accident causation, but occupants of PTW can, unlike those of other vehicles, easily establish direct contact with the road infrastructure in the course of an accident.

Most of the previous work on this topic has focused on roadside crash barriers as an impact obstacle. It is widely acknowledged that these barriers constitute a particular hazard to motorcyclists once they have fallen, although there are controversial opinions on this topic as for example stated in [Otte et al, 1986] where the importance of injuries caused by guardrail impacts was considered to be rather low, with 1.9 % of all injuries in an analysis of 379 motorcycle accidents in the Hannover region (Germany).

A widely followed approach to reduce potential injury hazards is to prevent contact with geometries that could potentially concentrate impact forces on the human body. This idea led for instance to the development of additional lower rails and of absorbing envelopes for the metal barrier posts. Several test procedures have been developed in order to assess the efficacy of such countermeasures. Within the European research project APROSYS SP4 "Motorcycle Accidents" a crash test standard for Europe will be proposed. This paper describes the methodology followed for this work.

Representative impact conditions have to be known and biofidelic dummies with associated injury criteria for these particular impacts are needed for the development of a crash test proposal. Therefore in-depth databases have been analysed in order to evaluate the nature of motorcyclists' impacts to barriers and to gain knowledge in addition to the anecdotal cases reported in the literature. In addition, existing testing procedures were reviewed including the analysis of full-scale crash tests performed by CIDAUT and DEKRA.

ACCIDENT ANALYSIS

Accident Data Sources

For the analysis of in-depth data performed in the APROSYS SP4 project [Peldschus 2005] several in-depth databases were available within the consortium: the DEKRA database and the GIDAS data of 2002 (Germany), the data of the COST 327 project (Finland, UK, Germany), and the Dutch part of the MAIDS database.

GIDAS 2002 – GIDAS stands for "German In-Depth Accident Study" which is being carried out by two independent teams. The Hannover team is sponsored by BASt (Federal Highway Research Institute) while an industry consortium under the auspices of VDA/FAT is financing a second investigation team at the Technical University of Dresden. Both teams share a common data structure and the cases are stored in a single database. A random sampling scheme was introduced in August 1984 and is still in use. So 1985 is the first year for which this database can be considered representative of the German national statistics. Accidents are investigated at-scene using blue-light response vehicles. In most cases extensive photo documentation is also available. The data covers the accident situation, participants (including cars, motorcycles, pedestrians/cyclists, trucks, buses, trams, trains), accident cause, injury cause, human factors and vehicle technologies. The qualifying criteria are that:

- the road accident resulted in at least one person being injured.
- the accident occurred within specified regions around Hannover or Dresden.
- the accident occurred while the team was on duty (2 six-hour shifts per day, alternating on a weekly basis).

Approximately 2,000 new accident cases are investigated each year. The GIDAS 2002 dataset which was analysed for the several tasks within this work was purchased from DEKRA and relates to 230 powered two-wheelers and 248 PTW users.

COST 327 – The European Co-operation in the Field of Scientific and Technical Research (COST) 327 was formed to investigate head and neck injuries suffered by motorcyclists by carrying out a comprehensive and detailed analysis. The COST 327 accident database consists of 253 cases collected from July 1996 to June 1998 in the UK by the Southern General Hospital, Glasgow, in Germany by the Medical School of Hannover and Munich University (LMU) and in Finland by the Road Accident Investigation Team. All cases are characterised by the following criteria:

- a powered two-wheeler was involved.
- a full or open face helmet was worn.
- head/neck injuries of AIS 1 or above were suffered - or known head/helmet contact without head injuries occurred.

DEKRA Accident Database – The fundamental basis of the DEKRA accident databases is the accumulation of written expert opinions containing the accident analyses that are drawn up by skilled forensic experts at the DEKRA branches throughout Germany and totalling about 25,000 annually. The particular feature of these reports is that generally the experts are called by the police or prosecuting attorney to come to the accident scene directly after the accident happened. The DEKRA experts have to answer case specific questions in their expert opinions. Therefore they have the right to determine the accident circumstances, which includes, if necessary, a detailed technical inspection of the involved vehicles. The DEKRA experts operate all over Germany on a 24hour/7day week basis. Thus, the nearly 500 DEKRA accident experts have the opportunity to attain all the information necessary for their task. The reports provide a substantial basis for accident research work. The DEKRA Accident Research & Crash Test Center has the opportunity to select and analyse interesting cases, which normally consist of the written expert opinions, detailed accident reconstructions, sketches and photo material. Sometimes single injuries are described but by and large only the general injury severity is stated. The actual DEKRA PTW database comprises 350 cases from 1996 to 2005 with all kinds of other vehicles as well as single PTW accidents. About 300 parameters per accident are reviewed when using the DEKRA questionnaires. Since expert opinions are normally commissioned only when the accident is of a really serious nature, the main focus of the PTW database is on accidents resulting in severely or fatally injured occupants. These accidents happen mostly in rural areas and involve high speeds. Therefore, the outcome of each accident and the relevant impact velocities have to be interpreted under the circumstances mentioned above.

Dutch MAIDS Data Set – In order to better understand the nature and causes of PTW accidents, the Association of European Motorcycle Manufacturers (ACEM) with the support of the European Commission and other partners conducted an extensive in-depth study of motorcycle and moped accidents during the period 1999-2000. Sampling was carried out in five areas located in France, Germany, Netherlands, Spain and Italy, resulting in a large PTW accident database called after the MAIDS (Motorcycle Accident In Depth Study) project. The methodology developed by the Organisation for Economic Co-operation and Development (OECD) for on-scene in-depth motorcycle accident investigations was used by all five research groups in order to maintain consistency in the data collected in each sampling area. A total of 921 accidents was investigated in detail, resulting in approximately 2,000 variables being coded for each accident. The investigation included:

- a full reconstruction of the accident
- detailed inspection of vehicles
- interviews with accident witnesses
- collection of factual medical records relating to the injured riders and passengers. These were subject to the applicable privacy laws and were obtained with the full cooperation and consent of both the injured person and the local authorities.

The in-depth data gathered in the Netherlands by TNO are part of the MAIDS database. In this segment of the database 200 accidents were investigated and coded. The accidents incorporated were PTW accidents in the Haaglanden region (The Hague, Rotterdam), in which a police alert was sent to the Dutch accident research team. The coverage was over 90 % of all PTW accidents in the region.

Findings in the Database Analysis

Due to very different data and inclusion criteria of the several databases results can only be given for each database seperately. In addition, the queries for the analysis had to be adapted to each database specifically.

The impact velocities for accidents involving contact with road infrastructure were analysed. The impact speed could not be exactly determined for the actual impacts at the object of interest from some databases. Therefore the primary impact speed was analysed. Some uncertainty remains for the accidents which involved further impacts to other objects.

The median primary impact speed for accidents involving impacts to road infrastructure was above 50km/h for all the four databases. Figure 1 and 2 give the distribution of impact speeds for the DEKRA data and the GIDAS data, respectively. These figures show the quite different overall distribution of impact speeds between the two databases. The numbers of relevant cases within the COST data and the Dutch MAIDS data were small with 16 and 4, respectively.

Only the GIDAS data contained information on the road-leaving angle, i.e. the angle between the velocity vector of the powered two-wheeler and the road tangent. In case a roadside barrier was installed next to the road, this angle would be approximately the impact angle. Figure 3 shows the distribution within different angle ranges. This supports the observations found in the literature, that impacts to roadside barriers usually involve shallow angles.

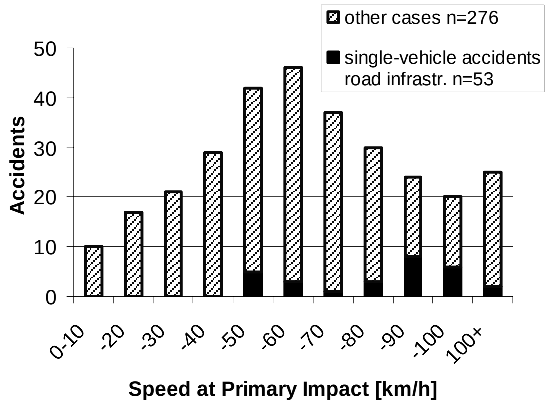

Figure 1. Impact speed for accidents involving impacts to road infrastructure compared to all other cases (DEKRA data).

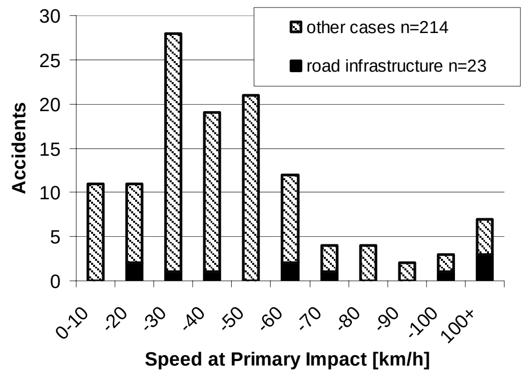

Figure 2. Impact speed for accidents involving impacts to road infrastructure compared to all other cases (GIDAS 2002 data).

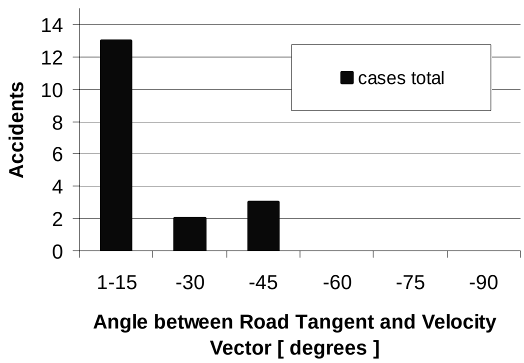

Figure 3. Road leaving angle (GIDAS 2002 data).

The GIDAS and the COST data allowed an analysis of injuries and the objects that had caused them. Figure 4 shows the severity of injuries caused by impacts to different groups of obstacles. Injuries caused by obstacles in general were predominantly of AIS1 score. However, looking at injuries caused by road infrastructure or barriers, a shift towards higher AIS scores can be observed.

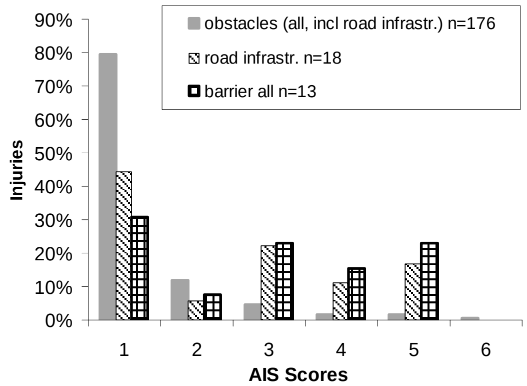

Figure 4. Severity of injuries caused by different groups of obstacles (GIDAS 2002 data).

Figure 5 gives the location of the injuries that were caused by impacts to obstacles in general, road infrastructure and roadside barriers. The most commonly injured body regions are the head and the lower extremities, followed by the thorax and the upper extremities. There was a high incidence of neck injuries caused by barrier impacts. The number of cases is small however, and this result could also be related to the inclusion criteria of the COST database.

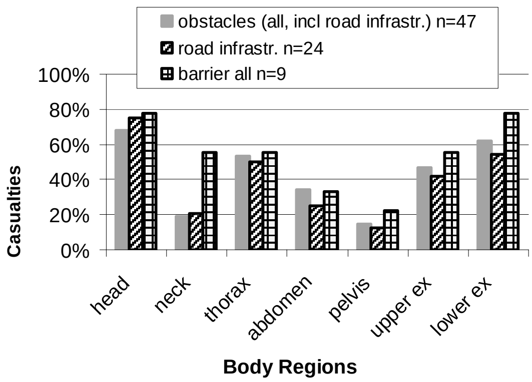

Figure 5. Location of injuries caused by different groups of obstacles (COST 327 data).

The position of the rider with respect to the powered two-wheeler at the time of impact to an obstacle was analysed in the manner of a single-case analysis for the DEKRA, COST and Dutch MAIDS data. This analysis included impacts to trees and poles as well as to roadside barriers. The results are given in table 1. In most of the cases, for which the constellation could be determined, the occupant impacted the obstacle still being on his vehicle, with the powered two-wheeler in an upright position.

In summary, high velocities (above 50km/h), shallow impact angles and upright riding position as well as sliding after separation from the PTW seem to constitute typical impact scenarios for road infrastructure and similar obstacles. Even if the incidence of such impacts is not high, the problem appears to be of importance as related injuries are severe. Head, thorax and lower extremities seem to be most commonly injured by such impacts.

Table 1.
Position of occupant with respect to PTW at time of impact (tree/pole/barrier, cases counted)

	DEKRA	COST	Dutch MAIDS
Separated	5	6	1
Not separated, upright	19	14	9
Not separated, sliding	2	0	0

CRASH TESTING

Analysed Crash Test Procedures

Three different procedures, which were seen to be suitable in order to represent the above-mentioned accident impact conditions, were analysed.

DEKRA Tests - The analysed DEKRA crash tests were carried out within a research project [Gaertner et al 2006] by order of the German Federal Highway Research Institute (BASt). This included impact tests of occupant and powered two-wheeler in two different configurations. The aim of this project in continuation of a previous one [Buerkle and Berg 2001]was to develop a new, motorcyclist-friendly safety barrier which can easily and with reasonable efforts be adopted to already existing barriers in Germany. Two main issues have been worked out to define a motorcyclist-friendly safety barrier. The contact of a motorcyclist in upright riding position with sharp edges and injurious parts of the upper safety barrier has to be prevented as well as the impact of a sliding motorcyclist against the barrier posts. Many efforts had been undertaken for the development of devices to prevent a sliding motorcyclist from severe or fatal injuries by impact to barrier posts. The risks in an upright impact have been identified but there were no practicable solutions available to adopt to existing barriers. Therefore new solutions had to be designed and tested.

An MATD (Motorcyclist Anthropometric Test Device) Dummy was used. This dummy has been especially designed for the multiple movements and loads at motorcyclists' impacts. The MATD is equipped with 9 uni-axial instead of one tri-axial acceleration sensor in a Hybrid III. Therefore the MATD-Dummy would also allow measurement of the rotational accelerations of an impacting head. In the neck the moments and forces in all 3 directions are measured. Four tackle-potentiometer in the chest measure the intrusion for the upper and lower chest area in x and y-direction as well as the upper and lower intrusion velocity. The sensors of the femur measure forces and torque. The femur itself is made out of fiber-reinforced plastics and can break if a certain force level is exceeded. Shear pins and elastic plastic elements in the knee reproduce the twisting of the knee. The tibias are also breakable and are equipped with sensors that measure the forces and moments in all 3 dimensions. In total, the MATD dummy was equipped with 66 measurement channels in the head, neck, chest, pelvis, femurs and tibias. The motorcycle recorded acceleration data with two tri-axial acceleration sensors in the front and rear frame – a total of 6 channels.

The first of the two impact configurations is depicted in figure 6. The initial velocity of the motorcycle leaving the sledge was 60 km/h and the impact angle was 25°.

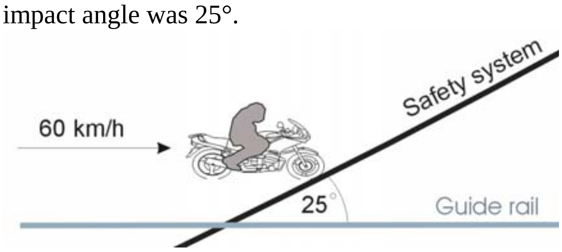

Figure 6. Parameters inclined impact.

Figure 7 shows the sled that was used for this impact configuration. It is in principle the same as used in the second configuration but with an additional device which is mounted. This device enables an inclination of 45° which initiates the tumble of the dummy and the motorcycle.

Some loads of the test are displayed in Table 2. To distinguish the data between actual contact with the system and loads that are due to the fall on the ground, the data was divided into primary and secondary data. This separation into primary and secondary data is necessary because the impact of the head against the ground results in a very high peak in the acceleration data. This would otherwise modify the evaluation of the protection potential of the barrier system. At the test displayed in Table 2 head contact with the ground occured during secondary data recording – resulting in a very high peak of 101 g's. But the significant values that show the performance of the safety system appear during primary data recording.

The second of the two impact configurations was in purely upright position of the occupant and the motorcycle. Like in the first impact tests the initial velocity of the sledge was 60 km/h. The angle between the velocity vector of the impacting motorcycle and the safety system was elaborated to 12° – Figure 8.

Figure 7. Test sled inclined impact with dummy and motorcycle.

Table 2.
MATD data of the inclined test

	limit	primary	%**	secondary	%**
Head					
$a_{res\ 3ms}$	80 g	33,2	**42**	101	**127**
$HIC_{36\ ms}$	1000	69,0	**7**	584	**58**
Neck					
$M_{b\ y}$	57 Nm	11,5	**20**	18	**31**
$F_{x\ max}$	3100 N	175,8	**6**	243	**8**
$F_{z\ max}$	4000 N	31,6	**1**	1283	**32**
Chest					
$a_{res\ 3ms}$	60 g	11	**19**	9	**16**
Pelvis					
$a_{res\ 3ms}$	60 g	12	**20**	14	**24**
Femur					
$F_{z\ right\ max}{}^{*}$	9070 N	-2764	**30**	776	**9**
$F_{z\ left\ max}{}^{*}$	9070 N	401	**4**	-774	**9**

*: neg. values = compression, pos. values = tension

**: % of the limit

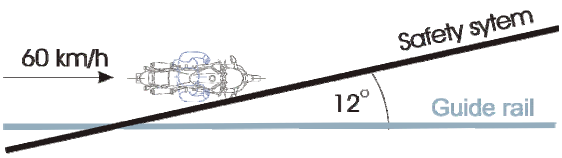

Figure 8. Parameters upright impact.

Figure 9 shows the sled with the mounted motorcycle and the dummy. A motion sequence of both impact configurations is depicted in figure 10.

Some loads of the upright test are displayed in Table 3. The separation into primary and secondary data can roughly be seen in Figure 10 right column. Secondary data begins at the last picture sequence just when the dummy has left the guard rail. The data collected until this point is primary data. Data after this point – including head impact on the ground – is secondary data.

Figure 9. Test sled upright impact with dummy and motorcycle.

Figure 10. Motion sequence of inclined and upright crash test.

Table 3.
MATD data of the upright test

	limit	primary	%	secondary	%
Head					
a res 3ms	80 g	10	**13**	84	**106**
HIC 36 ms	1000	5	**1**	383	**38**
Neck					
M b y	57 Nm	26	**45**	56	**98**
$F_{x\ max}$	3100 N	144	**5**	317	**10**
$F_{z\ max}$	4000 N	391	**10**	3406	**85**
Chest					
a res 3ms	60 g	13	**21**	51	**85**
Pelvis					
a res 3ms	60 g	18	**30**	12	**20**
Femur					
$F_{z\ right\ max}$	9070 N	-6744	**74**	-590	**7**
$F_{z\ left\ max}$	9070 N	-2960	**33**	-815	**9**

*: neg. values = compression, pos. values = tension
**: % of the limit

INRETS/LIER Procedure – The procedure has been defined based on an accidentology study performed by the LIER laboratory of INRETS [Bouquet et al 1998, Quincy 1998] in 1995 through the medical investigation of 230 motorcyclists involved in accidents in the region of Lyon. Although the quantity of cases is high, the disadvantage of this study is that the information contained in this study concerns all type of motorcyclist accidents, not only collisions against barriers.

The consideration that LIER has taken for the test definition is that when a motorcyclist has an accident in a curve, the vehicle skids and the motorcyclist falls. After that, the motorcyclist slips on the roadway following a nearly rectilinear trajectory, runs off the roadway and impacts against a post of the barrier. The variables 'impact angle' and 'impact speed' are complementary, in the sense that, a greater impact angle can compensate for a reduction of impact speed. Also, the definition of LIER test is based on 'impact angle' detailed in the study by Cayet and Godge [Cayet and Godge 1978]. LIER took into account the two mentioned studies and technical aspects such as the impossibility of throwing a dummy with a small impact angle, because it is pursued that head be the only part of the body impacting the barrier. Considering these limitations, the final LIER test consists on throwing a dummy against the metal barrier with an impact angle of 30º as shown in figure 11) with the dummy lying on its back and with the head towards the barrier.

From the accidentology analysis, two test configurations were identified:

• Configuration 30º: the motorcyclist is launched against the safety device (guardrail) lying down with the back on the floor and the head in the impact direction, describing a trajectory that forms a 30º angle (tolerance 0.5°) with the barrier.

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

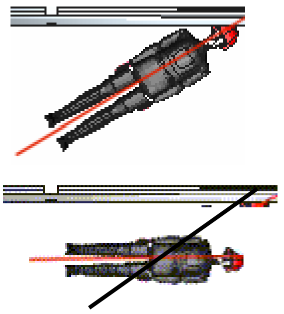

Figure 11. Impact configuration LIER tests.

In the LIER test, the 'motorcyclist's impact speed' used is 60 km/h, which could be associated with a travelling speed equal to 80 km/h. The main problem in the dummy selection to perform the test is that there is not a specifically designed dummy for this type of test and it is necessary to make modifications from a standard dummy. The dummy selected by LIER for performing the tests was an assembly of elements coming from other dummies. This dummy comprised:

• Hybrid II thorax, limbs and shoulders,
• a pelvis of pedestrian kit in order to give it an articulate standing position,
• Hybrid III Head and Neck allowing measures of accelerations, forces and moments,
• motorcyclist equipment: suit, glove, boots and helmet.

The biomechanical criteria that are applied as limits to pass the test are given in table 4. These focus on head and neck. No value is defined for the 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.

Table 4.
Biomechanical criteria used in LIER tests

Measurement	Biomechanical limit	Filter class
Resultant head acceleration	220 g	CFC 1000
HIC	1000	CFC 1000
Neck flexional moment	190 Nm	CFC 1000
Neck extension moment	57 Nm	CFC 1000

It was reported that parts of the dummy fractured in the impact tests. The failed part was usually the clavicle. It was therefore suggested to improve the design of the Hybrid II in order to better withstand lateral loading.

Spanish Standard – In 2005, the Spanish standard (UNE 135900) 'The assessment of motorcyclists' protection systems performance situated in safety roadside barriers and pretils was defined by CIDAUT under requirements of the Spanish Transport Ministry (Ministerio de Fomento) [CIDAUT 2005]. The purpose of this standard is to define the methods that allow evaluating the behaviour of the motorcyclist protection systems (MPS), punctual as well as continuous ones.

Depending on the kind of system to be tested, a different trajectory is chosen:

• Trajectory 1 – Centred post impact: Applicable to punctual and continuous MPS with an approaching angle equal to 30º, as the Figure 12 shows.

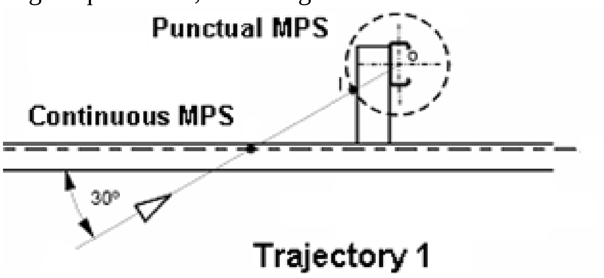

Figure 12. Trajectory 1.

• Trajectory 2: Excentric post impact: Applicable only to punctual MPS. It is the horizontal line that goes at a distance 'W' of the center of masses of the post, with an approaching angle equal to 30º, as the Figure 13 shows.

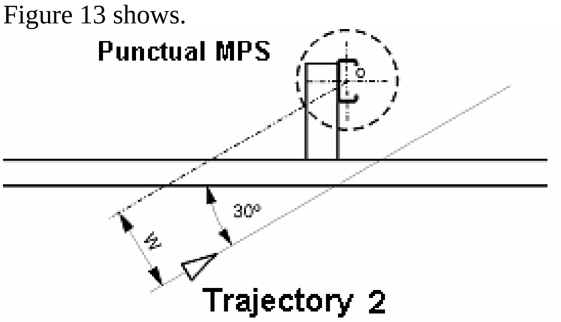

Figure 13. Trajectory 2.

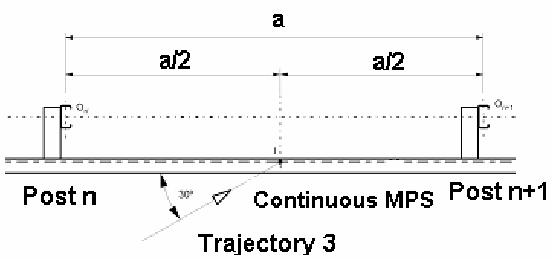

Figure 14. Trajectory 3

• Trajectory 3: Centred rail impact: Applicable only to continuous MPS (figure 14).

The main objective of the roadside barriers is to redirect the motorcyclist into de road but very close to the barrier. The roadside barriers should have the appropriate stiffness to achieve this objective. A very high stiffness barrier can cause serious injuries of an impacting motorcyclist. On the other hand, a very compliant barrier could absorb a lot of energy but also allow the rider to underride the upper rail of the system. To assess this issue, a rail-centred impact has to be performed (figure 14). A very compliant lower rail can also lead to a severe contact of the motorcyclist with the post in trajectory 1 (figure 12), which is actually to be prevented by the MPS.

The Spanish standard defines the impact speed of 60 km/h as the impact speed for the all three possible trajectories detailed in the standard for punctual (PS) and continuous (CS) motorcycle protective systems (MPS). Taking into account the three trajectories, the launching position is defined as depicted in figure 15, where the dummy spine axe coincides with the approximation trajectory.

Figure 15. Trajectory and dummy position.

As LIER specified, the variables 'impact angle' and 'impact speed' are complementary, and this Spanish standard tries to cover the worst situation.

The requirements of this procedure are that the dummy (motorcyclist) should travel sliding on the floor by itself, separated from the motorcycle, and hit the protection system to be tested, with a specific entrance angle and speed. Once a test is performed, the conclusions about the behavior of a specific protection device are obtained taking into account the severity level defined from the combination of biomechanical severity indexes that appear determined in the report. Though this report of standard tries to give some guidelines in order to identify whether a motorcyclist protection system is valid or not, every motorcyclist protection device installed in a safety crash barrier or pretil and every crash barrier or pretil especially designed to improve motorcyclists protection, have to guarantee that it does not affect in a negative way in the performance when impacted by road vehicles (according to EN 1317-2).

The dummy is to 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. For performing tests, the dummy shall be a Hybrid III 50th Percentile Male, equipped with a kit pedestrian that allows a standing position. The following measurements are to be taken for the evaluation of the impact severity:

• HEAD: HIC36
• NECK: Fx, Fy, Fz, Mx, My

In order to measure the head accelerations a three-axe sensor should be installed in the Hybrid III head centre of gravity and 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 twist moment is measured but it is not used in the acceptance criteria.

The first part of the acceptance criteria of the impact test is the behavior of the safety device. No element from the crash safety barrier or pretil 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 behavior of the dummy is the second part of the acceptance criteria. The dummy used for the test should not have intrusions, dummy breakage except the clavicle, 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.

By courtesy of HIASA, an example of an impact test passed with level I result (best level) according to the Spanish standard is shown in figures 16 and 17.

Table 5 gives the according measurement results for this test together with the maximum accepted values, according to the better of two different types of protection levels.


Figure 16. Test side view.

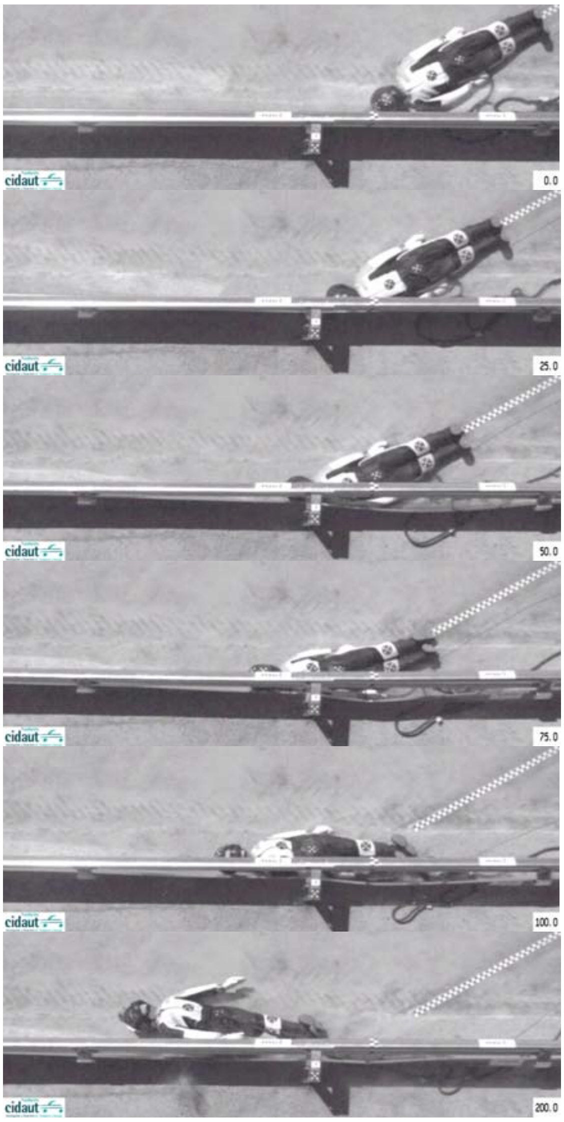
Figure 17. Test top view.

Table 5.
Test results and acceptance limits for sliding barrier impact

	Test results	Limit Level I	
HIC 36	107.16	650	
Fx	Appendix A	Appendix A	
Fz traction	Appendix B	Appendix B	
Fz compression	Appendix C	Appendix C	
Mxc	75.63	134	Nm
Myc flexion	42.75	190	Nm
Myc extension	37.26	42	Nm
Working width	0.41	EN1317	m

Injury Criteria and Biofidelity

Different injury criteria have been encountered in existing crash test procedures. Those have mostly been transfered from other kinds of crash tests, which leads to the question of the suitability of the used dummies and the validity of the injury criteria. Accident reconstruction and PMHS testing would be necessary in order to properly investigate relevant injury mechanisms and to establish valid injury criteria. The in-depth accident data analysis desribed in this paper did not provide single cases suitable for reconstruction of both the course of the accident and the injury causation. On the other hand, only one report [Schueler et al. 1984] on PMHS testing in this field - focusing on upper extremities - can be found in the literature.

The analysis of the full-scale crash testing may however serve to identify some potential for further improvements in biofidelity and injury criteria. The results of the tests performed by DEKRA suggest to consider the extremities in more detail. Particularly the second impact configuration, in purely upright position, potentially involves high injury risks for the upper and lower extremities. The upper extremities can be caught in the parts at the top of the barrier (like spacers), while the lower extremities can be clamped between the motorcycle and the barrier. Even if impacts and injuries to the extremities are not as threatening as those to other parts of the body, they may greatly influence the kinematics of the rider and this in turn influences the overall injury outcome and the protection potential of a barrier system.

The tests in sliding impact position performed by CIDAUT demonstrate that the shoulder and the arm establish contact to the barrier post through the lower rail. This leads to the question whether the thorax is remarkably loaded in such an impact. In the light of the lack of suitable data and investigation methods, a preliminary numerical crash simulation with a human model was applied to gain insight into this problem.

Simulation with Human Model – The PAMCrash HUMOS2 model has been validated for lateral thorax loading [Merten 2006] and it has been demonstrated to depict injury mechanisms in motorcyclists' impacts to roadside barriers [Peldschus & Schuller 2006]. The sequence of the simulation given in figure 18 shows an impact as in the test of figure 17 with a similar barrier model provided by HIASA. In this simulation the deflections of the impacted half of the thorax were measured according to the methodology presented in [Kuppa et al. 2003]. The maximum deflections at 50% of the half circumference of the thorax at the height of rib 4 and rib 8 were 51mm and 48mm, respectively. These results indicate a risk for severe thoracical injuries caused by lateral loading in such an impact. It is therefore suggested to include injury criteria for lateral thorax loading in a test procedure of sliding barrier impact.

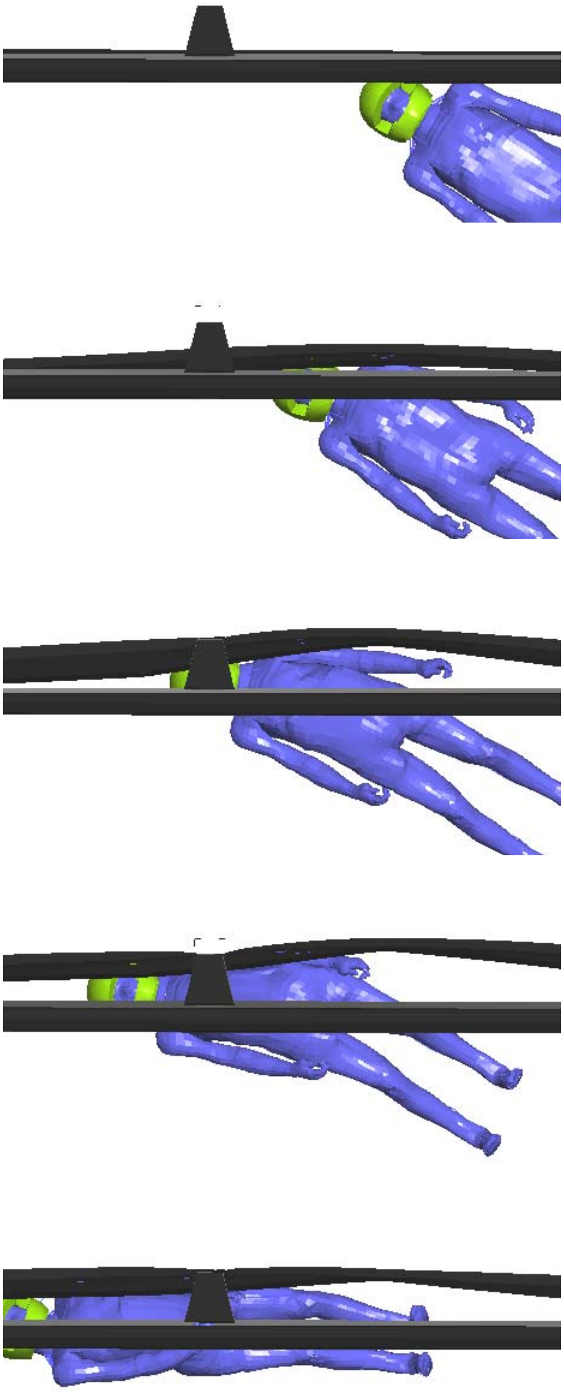

Figure 18. Impact simulation with human model (steps of 25ms).

Implications for Dummy Modification – The Hybrid III dummy was designed for frontal impact testing. The only measurement, that can be taken to assess lateral loading with a reasonable effort, is equipping the dummy with a sensor to measure lateral acceleration at Th4. However, as the dummy is not biofidelic in lateral loading, the measurement results may be misleading. As a first step to improve the biofidelity for a sliding impact of a motorcyclist into a barrier it is proposed to use a frangible shoulder as depicted in figure 19. Apart from the possible improvement of the biofidelity, some of the components of a Hybrid III dummy may not fully comply with the strong load requirements in lateral tests. An irreparable and costly fracture of the dummy shoulder has not only been reported for the LIER tests as stated above. Also Buerkle and Berg [Buerkle and Berg 2001] reported such a shoulder fracture. The Spanish impact standard desribed above considers such a modified shoulder for the Hybrid III. Inertial moments and weight are not changed significantly from the original dummy and its failure is aiming at reproducing that of a clavicle in the human body.

Figure 19. Frangible shoulder/clavicle.

CONCLUSIONS AND RECOMMENDATIONS

The results of the in-depth data analysis suggest that impacts of motorcyclists into roadside barriers typically occur at speeds above 50 km/h under shallow angles. At the time of impact the rider seems to be more often on its PTW in upright position than sliding on the ground after separation from the motorcycle. Injury mechanisms and the establishment of related injury criteria remain an issue to be investigated in more detail. For this purpose, more in-depth accident data would be needed. First studies on full-scale crash testing including the motorcycle have been performed, but future efforts should concentrate more on this issue than the work performed so far in the field of PTW and roadside barriers. Concerning the impact in sliding position an additional measurement for lateral loading of the thorax is suggested. This should however be introduced in combination with a modification of the dummy shoulder, which is also proposed in terms of durability. The results of this study will be used for the development of a standard for sliding impact within the APROSYS SP4 project. Similar efforts on upright impact, including the PTW, should be undertaken in the future.

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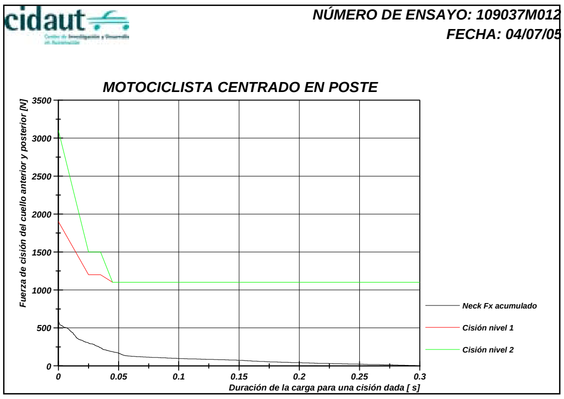
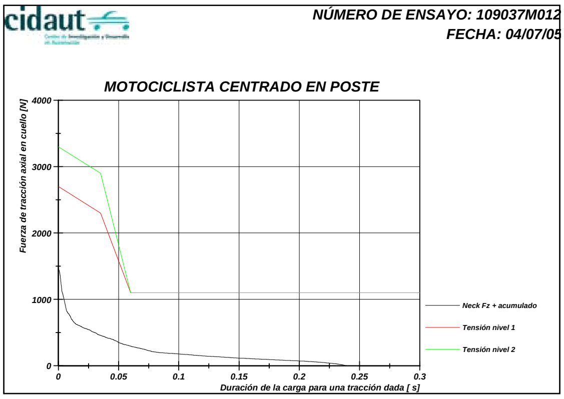
Appendix A
Fx measured on neck



Appendix B
Fz traction measured on neck



Appendix C
Fz compression measured on neck