D.2.1 – Report on revision of regulation EQUS9910208C and UNE135900

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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Internal Quality Reviewer: UNIFI

SUMMARY:
Following the General Objective of the project “Innovative concepts for smart road restraint systems to provide greater safety for vulnerable road users” (Smart RRS) (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), the WP 2 will evaluate the current Standards relating to motorist protection systems.

A considerable dilemma exists when confronting and tackling injuries and fatalities relating with Powered Two Wheeler-road restraint systems. Over 4000 motorcycle related deaths every year have been revealed in past years by European Union statistics, of which nearly a third resulted from collisions with rigid roadside obstacles. From roadside restraint systems, metallic barriers are responsible for the largest death toll, 30%; due to their aggressive shape and holding posts.

In response to this information and attempts to decrease the severity of these collisions, protecting devices have been launched by various manufacturers. Numerous of these systems are being used at statistically documented, potentially dangerous curves. However, its extensive use has been limited for economical reasons.

EN 1317 is the official regulation in use across Europe covering road restraint systems. Its protocols address issues regarding safety barriers, crash cushions and terminal and transition of barriers, amongst other things. Specific to the safety barrier, EN 1317 defines criteria and process for impact testing for vehicle barriers.

Motorcyclist safety during roadside obstacle collisions is not precedence for all European countries and so due to the minority they represent; specific regulations are not always deemed a requirement. However, some countries have discovered this field problematic and have consequentially introduced additional protocols: the UNE-135900 (regulation implemented in Spain as an assessment of effectiveness for protective roadside devices for motorcyclists), and the French LIER test protocol (EQUS9910208C) (research into head and neck injuries during motorcycle-barrier collisions) are two major examples.

A comprehensive revision of the two regulations was conducted with the aspiration to determine the strengths and weaknesses of the protocols, exploring the relationship between injury severity and impact configurations.
INDEX

SUMMARY: 1
LIST OF TABLES 5
LIST OF FIGURES 6
NOTATIONS 8

1. INTRODUCTION 9
   1.1 Background 9
   1.2 Project aim 9
   1.3 Predicted results 9

2. ACCIDENTOLOGY / DEFINING THE PROBLEM 10
   2.1 Motorcyclist accidents in Spain 10
      2.1.1 Accidentology: motorcyclists with respect to other road users 10
      2.1.2 Accident frequency 15
   2.2 Motorcycle Accident Victims 16
   2.3 Motorcycle accident location, type and severity 20
      2.3.1 Accident locations and types 20
      2.3.2 Urban areas 23
      2.3.3 Rural areas 25
      2.3.4 Other areas 27
   2.4 Analysis and conclusions 28

3. MOTORCYCLIST VS. GUARDRAIL IMPACTS: IN DEPTH STUDY CHARACTERISING PARAMETERS 30
   3.1 Introduction 30
   3.2 Accidentology data source 30
   3.3 In depth study of the accidents 31
      3.3.1 Police report template 31
      3.3.2 Identifying parameters: approach 32
   3.4 Results and analysis 34
   3.5 Other studies 36
   3.6 Conclusions 36

4. CURRENT SYSTEMS REVIEW 37
   4.1 Systems in use 37
4.1.1 Metallic barriers 37
4.1.2 Wire rope barriers 41
4.1.3 Concrete barriers 43

4.2 Material selection 43
4.3 Comments and discussion 45

5. REVIEW OF REGULATIONS 46
5.1 Norm UNE 135900 47
5.1.1 Testing procedure 47
5.1.2 Assessment parameters 48
5.2 LIER protocol (EQUS9910208C) 48
5.2.1 Test protocol 48
5.3 Other studies 50
5.3.1 Polytechnic University of Milan 50
5.4 Comments 51

6. CONSIDERATION OF THE UNE 135900 51
6.1 Strengths 51
6.1.1 Full scale test 51
6.1.2 Impact velocity 51
6.1.3 Trajectories 52
6.2 Weaknesses 52
6.2.1 Impact angle 52
6.2.2 Propelling system 52
6.2.3 Ambient conditions 52
6.2.4 Bio fidelity of the dummy 52
6.3 Comments and discussion 53

7. TEST VALIDATION OF THE UNE 135900 ANALYSIS 53
7.1 Impact angle test 53
7.1.1 Introduction 53
7.1.2 Test general configuration 54
7.1.3 Test at 60kph and 30° angle 56
7.1.4 Test at 60kph and 45° angle 64
7.1.5 Results and analysis 71
7.2 Ambient condition tests 71
7.2.1 Introduction 71
7.2.2 Method 72
7.2.3 Results 72
7.2.4 Interpretation and conclusions 74
7.3 Propelling system 74
7.4 Comments and discussion

8. CONCLUSIONS

APPENDIX A: UNE 135900 NORM

APPENDIX B: TEST RESULTS (60 KPH, 30°)

APPENDIX C: TEST RESULTS (60KPH, 45°)

APPENDIX D: TEST RESULTS (AMBIENT CONDITIONS)
List of tables

Table 1........................................................................................................................................ 13
Table 2........................................................................................................................................ 14
Table 3........................................................................................................................................ 15
Table 4........................................................................................................................................ 16
Table 5........................................................................................................................................ 17
Table 6........................................................................................................................................ 19
Table 7........................................................................................................................................ 22
Table 8........................................................................................................................................ 26
Table 9........................................................................................................................................ 29
Table 10...................................................................................................................................... 31
Table 11...................................................................................................................................... 35
Table 12...................................................................................................................................... 35
Table 13...................................................................................................................................... 39
Table 14...................................................................................................................................... 50
Table 15...................................................................................................................................... 63
Table 16...................................................................................................................................... 69
Table 17...................................................................................................................................... 73
List of figures

Figure 1. Accidents involving motorcycles in Spain (1995-2005) ....................... 10
Figure 2. Number of accidents in Spain, according to the type of vehicle............ 11
Figure 3. Relation between motorcycle accidents and motorcycle number...... 12
Figure 4. Proportion of accidents involving motorcycles within all accidents.... 12
Figure 5. Vehicle park composition in 2003 and 2005 in Spain......................... 14
Figure 6. Number of road traffic related victims in Spain.............................. 16
Figure 7. Number of motorcycle related accidents in Spain.......................... 17
Figure 8. Severity distribution, all vehicles.................................................. 18
Figure 9. Severity distribution, motorcycles.................................................. 18
Figure 10. Death indexes according to vehicle type in Spain........................ 19
Figure 11. Type of accidents depending on the zones..................................... 21
Figure 12. Average distribution of the accidents for the year 2005.................... 22
Figure 13. Average fatalities distribution for the years 2003, 2004 and 2005... 22
Figure 14. Fatality Risk in urban area............................................................ 24
Figure 15. Severe Injury Risk ........................................................................ 25
Figure 16. Fatality risk (FR) according to accident configurations................ 26
Figure 17. Severe Injury Risk (SIR) in different accident configurations........... 27
Figure 18. Fatality Risk in ‘other area’............................................................... 28
Figure 19. Severe Injury Risk ........................................................................ 28
Figure 20. Scheme of the accident ................................................................. 32
Figure 21. Reference points for measurements................................................ 33
Figure 22. IPE 100 post.................................................................................. 37
Figure 23. Sigma post..................................................................................... 37
Figure 24. Z and C-shaped posts.................................................................... 38
Figure 25. W-beam added to the guardrails..................................................... 38
Figure 26. Impact attenuators......................................................................... 39
Figure 27. Steel guard rail post protection)..................................................... 40
Figure 28. Polyethylene Moto tub................................................................... 41
Figure 29. Wire rope barrier............................................................................ 41
Figure 30. Post protectors used by Blue Systems in Sweden.......................... 42
Figure 31. Aluminium covers for wire ropes.................................................. 42
Figure 32. Different types of concrete barriers............................................... 43
Figure 33. Metallic guard rail with composite protection ........................................ 45
Figure 34. Post centred impact trajectory .................................................................. 47
Figure 35. Post off-centred impact trajectory ............................................................ 47
Figure 36. Mid span centred impact trajectory ............................................................. 48
Figure 37. First trajectory defined by the LIER protocol [site www.lier.fr] ............... 49
Figure 38. Parallel impact [site www.lier.fr] ............................................................... 49
Figure 39. Simulation test of the Polytechnic University of Milan .............................. 51
Figure 40. General view of the test track ................................................................. 54
Figure 41. Sled and Dummy before the test ............................................................... 55
Figure 42. Throwing distance of 50cm .................................................................... 56
Figure 43. High speed camera recording the impact and velocity measurements .......... 57
Figure 44. Reference axis ....................................................................................... 58
Figure 45. Resultant Head Acceleration ................................................................. 58
Figure 46. Head acceleration along Y axis ............................................................... 59
Figure 47. Head acceleration along Z axis ............................................................... 59
Figure 48. Upper neck force along Y axis ............................................................... 60
Figure 49. Paint marks due to the contact system – barrier post .............................. 61
Figure 50. Head passing at the height of the barrier post ......................................... 61
Figure 51. Upper neck force in Z direction ............................................................... 62
Figure 52. Upper neck moment around X direction ............................................... 62
Figure 53. Compression force Fz in the upper neck .............................................. 63
Figure 54. Head resultant acceleration ................................................................... 64
Figure 55. Head acceleration in Y direction ............................................................. 64
Figure 56. Head acceleration in the Z direction ...................................................... 65
Figure 57. Upper neck force in the Y direction ....................................................... 66
Figure 58. Upper neck force in the Z direction ....................................................... 66
Figure 59. Compression of the neck during the impact .......................................... 67
Figure 60. Upper neck moment around X ............................................................... 67
Figure 61. Neck moments ...................................................................................... 68
Figure 62. Head – shoulder line angle .................................................................... 69
Figure 63. Compression force in the upper neck ..................................................... 70
Figure 64. Traction force in the upper neck ............................................................. 70
Figure 65. Temperature influence on the Measured Acceleration..................... 73

Notations

DGT  Dirección General de Tráfico (General Traffic Institute)

$E_{\text{friction}}$  Energy dissipated by friction (contact driver – road) (J)

$E_{\text{gravity}}$  Energy corresponding to the work done by the gravity (J)

$E_{\text{kinetic}}$  Kinetic energy (J)

EN 1317  European Norm 1317: Road Side Barriers

EPS  Expanded Poly Stirol

FR  Fatality Risk

FEM  Finite Element Method

HIC  Head Injury Criteria

INRETS  Institut National de Recherche sur les Transports et leur Sécurité

$L$  Distance covered by the rider sliding on the road

LIER  Laboratoire d’essais INRETS Equipement de la Route

MFD  Motorcyclist Friendly Devices

NCAP  New Car Assessment Programme

PU  Polyurethane

PE  Polyethylene

RRS  Road Restraint System

SIR  Severe Injury Risk

SPM  Sistemas de Protección a Motoristas

UNE 135900

$V_i$  Initial velocity (m/s)

$V_f$  Final velocity (m/s)

$(X, Y, Z)$  Coordinate referential

$\alpha$  Slope of the road (°)

$\mu_{\text{rider – road}}$  Friction coefficient (no unit)

$g$  Gravity (m/s2)

$m$  Mass of the rider (kg)
REPORT ON REVISION OF REGULATION EQUS9910208C AND UNE-135900

1. INTRODUCTION

1.1 BACKGROUND

Motorcycles, bicycles and other two wheelers have always been vulnerable on the roads. The improvements that have been brought to the vehicles in terms of passive safety had obviously noticeable consequences on the accident statistics on recent years. Paradoxically, the most vulnerable vehicles received less improvement and attention and are nowadays facing quite a big distress with dramatic consequences for human lives. While it is naturally easier to develop protective devices on cars, trucks, buses etc. by using their metallic structures, vulnerable road users need different development of innovative devices for their protection.

1.2 PROJECT AIM

Based on a statistical study of the accidents carried out in Spain through the DGT Database, this project is aiming at identifying the most worrying type of accident of which the vulnerable road users are victims. In order to develop the protection associated to this type of accident, an in depth study is carried out to determine the characteristic parameters of these accidents, allowing for their better understanding. A general methodology for improving the current approaches that are deployed by the governments and industries is hereby developed to enhance the protection for the road users.

1.3 PREDICTED RESULTS

As a result of the previously described study, some statistical analysis, identification of the problem and suggestions to fight against the problem are expected to be presented in this report. The proposed suggestions will be supported by testing phases and economical features. They will be presented and turned public through conferences and reports.
2. **ACCIDENTOLOGY / DEFINING THE PROBLEM**

2.1 **MOTORCYCLIST ACCIDENTS IN SPAIN**

2.1.1 **ACCIDENTOLOGY: MOTORCYCLISTS WITH RESPECT TO OTHER ROAD USERS**

For almost ten years, safety considerations about road traffic and protection of road users have been growing constantly and take nowadays more and more importance in people’s mind as well as in the governmental and political actions regarding roads. As a first consequence, the vehicle market has progressively seen the introduction of new systems, providing safety and protecting the occupants. Not all the vehicles are equally evolved in this aspect, especially motorcycles, that can hardly be protected by the vehicle’s structure itself or other protective devices. As well as the vehicles, roads have been and are still receiving adaptations, improvements and systems to enhance the protection of the users. In this field, all the road users, and consequently all the vehicles might have been equally concerned by these improvements.

According to these considerations, it is interesting to look at the evolution of accidents and number of victims registered in the databases, keeping in mind that if the safety and protection of the road users has been greatly improved, the number of vehicles on the roads has also experienced a considerable increase. The upcoming graphs show the trends followed by the number of accidents occurring in Spain since 1995, both for motorcycles (Figure 1) and other vehicles (Figure 2).

![Number of Accidents involving Motorcycles in Spain (1995-2005)](image)

*Figure 1. Accidents involving motorcycles in Spain (1995-2005)*

The graph shows a decrease from 1995 to 2003, from 12000 to about 10000 accidents. Unfortunately, this long and slow decrease turns over in 2 years, when the accidents involving motorcycle raised from 10211 in 2003 to 12722 in
2005, representing an increase of more than 20%. It is important to look at the trend followed by the other vehicles graph, to check whether they follow the same growth or their evolution is totally different. Figure 2 represents the same data (annual number of accidents) but this time considering all types of vehicles other than motorcycles.

**Number of Accidents in Spain (1995 - 2005)**

![Accidents Graph](image)

*Figure 2. Number of accidents in Spain, according to the type of vehicle*

This figure shows how different is the accident trend followed by other vehicles: fast increase from 1995 to 1998 (+20.3%), then approximate steadiness until 2003 and considerable decrease after 2003 (-12.5% between 2003 and 2005). From these two previous graphs it is quite obvious that the motorcycle case is not similar to the other vehicles statistics and therefore needs some deeper investigation. While previous figures obviously allow quantifying the recent growth concerning accidents with motorcycles, they do not allow drawing any conclusion or interpretations of the motorcycle accidentology.

In fact, it is first important to analyse the vehicle park, since the large growth in motorcycle accidents could be related to a high increase of motorcycles in Spain. The data available on the Spanish vehicle park show that the number of vehicles on the roads in Spain has actually raised from approximately 20,300,000 vehicles in 1997 to 27,700,000 in 2005 which corresponds to a growth of more than 36%; also the vehicle park counted 1,330,000 motorcycles in 1997 whereas the number in 2005 was 1,806,000. Related to these values for the vehicle park, it is necessary to analyse in further details the annual evolution of the numbers for establishing an eventual relationship between the number of motorcycles and the number of accidents.

Figure 3 compares these two trend lines as a function of time (period 1997-2005) plotted on the same graph (using percentages to show the trends, values are obviously not comparable).
Motorcycle Accidents Vs Motorcycle Number

Figure 3. Relation between motorcycle accidents and motorcycle number

From 1997 to 2002, Figure 3 shows different trends between the two variables: the number of accidents involving motorcycles is decreasing even if the number of motorcycles in the vehicle park is constantly growing. During the period 2002-2003 the number of motorcycles in Spain remained quite constant, as the number of accidents does. From 2003 to 2005, the similarity between the two trend lines is obvious. Both curves start increasing at the same time and keep growing at the same rate during this time period. Unfortunately, the last data provided by the National Traffic Department are from the year 2005 and it is therefore still difficult to draw detailed conclusions.

It is notable that the recent jump in the number of accidents involving motorcyclists is related to the sharply increasing number of motorcycles on the roads. While the vehicle park evolution is a cause of the recent accident growth, the decrease in other vehicle accidents consequently results as an increase in the proportion of these accidents, as seen in Figure 4.

Figure 4. Proportion of accidents involving motorcycles within all accidents
Table 1.
Percentage of motorcycle accidents within all accidents

<table>
<thead>
<tr>
<th>Year</th>
<th>Moto Accidents/All Accidents (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>14,3337401</td>
</tr>
<tr>
<td>1996</td>
<td>13,56031219</td>
</tr>
<tr>
<td>1997</td>
<td>13,42674893</td>
</tr>
<tr>
<td>1998</td>
<td>11,71261658</td>
</tr>
<tr>
<td>1999</td>
<td>10,93435299</td>
</tr>
<tr>
<td>2000</td>
<td>10,6223975</td>
</tr>
<tr>
<td>2001</td>
<td>10,6956486</td>
</tr>
<tr>
<td>2002</td>
<td>10,47819329</td>
</tr>
<tr>
<td>2003</td>
<td>10,2123276</td>
</tr>
<tr>
<td>2004</td>
<td>11,26594262</td>
</tr>
<tr>
<td>2005</td>
<td>13,95155011</td>
</tr>
</tbody>
</table>

Once again this data has to be compared to the proportion of motorcycles in the vehicle park. Figure 5 below shows the distribution of the different vehicle types in the national park, in 2003 and 2005 respectively.

National Vehicle Park Composition in 2003

[Diagram showing the distribution of vehicle types in 2003]
National Vehicle Park Composition in 2005

![Pie chart showing vehicle park composition in 2005](chart.png)

Figure 5. Vehicle park composition in 2003 and 2005 in Spain

Table 2.
Values for motorcycle proportion in the park (2003-2005)

<table>
<thead>
<tr>
<th>Year</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>6.0%</td>
</tr>
<tr>
<td>2004</td>
<td>6.1%</td>
</tr>
<tr>
<td>2005</td>
<td>6.5%</td>
</tr>
</tbody>
</table>

During this 3 year time period the proportion of motorcycles in the whole vehicle park grew from 6.013% in 2003 to 6.529% in 2005. This 0.5% growth in the motorcycle proportion might have had a small influence on the accident percentage, and this is therefore only partly responsible for the increase in the amount of motorcycle accidents. In fact this “phenomenon” is the result of the combined decrease of other vehicle accidents and increase of motorcycle accidents.

Actual statistics show that motorcycle accidents are a great concern in Spain, each year more important whereas all other types of vehicles’ accidents are shown to be diminishing by 6% from 2003 to 2004 and 3% between 2004 and 2005 (motorcycle accidents = +3% between 2003 and 2004 and +20.3% between 2004 and 2005).
2.1.2 ACCIDENT FREQUENCY

The comparison between motorcycles and other vehicles when considering road accidents will be estimated by expressing their actual frequency, based on the number of vehicles and their mobility. The numerical values for accidents presented in the previous part are hardly usable to precisely compare two wheeler accidents with other segments.

For an ease of interpretation, it is useful to present the theoretical rates of accident respectively held by motorcycles and other vehicles. In 2003, 10211 accidents involving motorcycles were registered in the national database, which corresponds to a ratio of 674.65 accidents out of every 100,000 motorcycles (sample of 100,000 vehicle considered for ease). In the same conditions, the ratio held by the other vehicles is 379.5 accidents out of every 100,000 other vehicles. In 2005, the ratio for motorcycles is elevated to 704.5 accidents whereas the ratio for other vehicles decreased to 303.5. This way and considering only the number of vehicles, it shows accidents in Spain to be 1.77 times more likely to occur to a motorcyclist than other vehicle’s drivers in 2003, and 2.32 times in 2005.

As mentioned above these considerations only take into account the relative number of motorcycles/other vehicles in the national vehicle park, however, another criteria that has to be considered when doing this estimation is the respective mobility of vehicles: since riding motorcycle is often considered as a leisure more than a mean of transport by the motorcyclists, the recorded mobility of motorcycles is considerably less important than the one for other vehicles, as presented in Table 3:

<table>
<thead>
<tr>
<th>Year</th>
<th>Mobility (official)</th>
<th>Mobility (official)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>moto</td>
<td>other vehicles</td>
</tr>
<tr>
<td>2000</td>
<td>647</td>
<td>104346</td>
</tr>
<tr>
<td>2004</td>
<td>730</td>
<td>119004</td>
</tr>
</tbody>
</table>

**Linear Extrapolation**

|      | 685                  | 114166,6            |
| 2003 | 729,5               | 120805,2            |
| 2005 | 876,9               | 145214,6            |

*The data found concerning the mobility of vehicles only concerned the years 2000 and 2004; the present paragraphs being specifically focused on the years 2003 to 2005, the mobility for this time period has been extrapolated from the two official values (2000 and 2004), considering the vehicle park evolution, as well as the percentage of the total mobility.*

Considering both relative mobility and relative number of vehicles, the rates of accidents held by motorcycle/other vehicles can be determined, as shown in Table 4.
Table 4. Accident frequency

<table>
<thead>
<tr>
<th>Year</th>
<th>Motorcycles</th>
<th>Other Vehicles</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>149.1 accidents</td>
<td>7.86 accidents</td>
<td>19</td>
</tr>
<tr>
<td>2005</td>
<td>145.1 accidents</td>
<td>5.4 accidents</td>
<td>26.9</td>
</tr>
</tbody>
</table>

N.b: the numbers provided in this table correspond to the statistical number of accidents occurring when considering 100,000 vehicles having travelled 10,000,000 kilometres.

In 2003, a motorcyclist was 19 times more likely to be involved in an accident than a car driver. In 2005, this ratio raised to 26.9 times. Motorcycles are definitely more dangerous than other vehicles, but the fact that the accidents rate is increasing from year to year shows the carelessness associated to motorcycles compared to other vehicles. While the studies and improvement brought to the car, truck and bus safety allowed a considerable reduction of the accidents; the motorcycles are still apart and did not receive enough attention through the last years, even though they represent 1 out of every 8 traffic accidents in Spain.

2.2 MOTORCYCLE ACCIDENT VICTIMS

The trend of road accidents’ victims since 1995 is similar to the accident evolution, and therefore shows very different trends between motorcycle and the rest of the vehicles. Figure 6 shows the evolution of road traffic accident victims, considering all types of vehicles.

Figure 6. Number of road traffic related victims in Spain
Motorcycle Accident Victims in Spain

Figure 7. Number of motorcycle related accidents in Spain

In terms of numbers, motorcycle accident victims represent approximately 10% of all road victims, as shown in the following Table 5.

Table 5
Motorcycle accident victims

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Victims of Accidents</th>
<th>Victim of moto acc</th>
<th>% moto victim / all accidents victims</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>127479</td>
<td>14508</td>
<td><strong>11,380698</strong></td>
</tr>
<tr>
<td>1996</td>
<td>129976</td>
<td>13929</td>
<td>10,71659383</td>
</tr>
<tr>
<td>1997</td>
<td>131136</td>
<td>13652</td>
<td>10,41056613</td>
</tr>
<tr>
<td>1998</td>
<td>147389</td>
<td>13260</td>
<td>8,996600832</td>
</tr>
<tr>
<td>1999</td>
<td>148828</td>
<td>12330</td>
<td>8,284731368</td>
</tr>
<tr>
<td>2000</td>
<td>155558</td>
<td>12454</td>
<td>8,006017048</td>
</tr>
<tr>
<td>2001</td>
<td>155115</td>
<td>12346</td>
<td>7,959256036</td>
</tr>
<tr>
<td>2002</td>
<td>152264</td>
<td>11742</td>
<td>7,711606158</td>
</tr>
<tr>
<td>2003</td>
<td>156035</td>
<td>11651</td>
<td><strong>7,466914474</strong></td>
</tr>
<tr>
<td>2004</td>
<td>143124</td>
<td>11890</td>
<td>8,307481624</td>
</tr>
<tr>
<td>2005</td>
<td>137251</td>
<td>14216</td>
<td>10,35766588</td>
</tr>
</tbody>
</table>
In the statistics, accident severity is usually identified as Fatal, Severe and Slight. The following Figure 8 and Figure 9 show the repartition of injuries according to the type of vehicle.

**Injury Severity Distribution (All Vehicles, Spain, 2003)**

![Pie Chart of Injury Severity Distribution (All Vehicles, Spain, 2003)](chart1.png)

**Figure 8. Severity distribution, all vehicles**

**Injury Severity Distribution (Motorcycles, Spain, 2003)**

![Pie Chart of Injury Severity Distribution (Motorcycles, Spain, 2003)](chart2.png)

**Figure 9. Severity distribution, motorcycles**

These figures show that the death toll (ratio of killed persons to the number of victims of accidents) characterizing motorcycle accidents in Spain is 3%, meaning that as an average 1 victim out of 33 was fatally injured in the road traffic accidents in 2003.

In fact these values are difficult to quantify since the definition of “injured” is not fundamentally strict when it comes to slight injuries. Also the results of the accidents are usually different between motorcycles and other vehicles, almost all motorcycle accidents leading to at least slight injuries. Most of the motorcycle
accidents (about 70%) are occurring in urban area, and usually result in slight injuries, which is very different from other vehicles. As a consequence, comments and comparison of the values presented in the previous graphs should be based on the evolution of the death toll (given in Table 6) to avoid the comparison of data which are not perfectly relevant.

Comparison of the death toll might be interesting to carry in more restricted samples of data, as types of road etc. but they are not really relevant considering the whole accidents as a group.

Table 6.  
Death indexes

<table>
<thead>
<tr>
<th>Year</th>
<th>Death Index for Moto</th>
<th>Death index for other vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>3.30</td>
<td>4.66</td>
</tr>
<tr>
<td>1996</td>
<td>3.28</td>
<td>4.33</td>
</tr>
<tr>
<td>1997</td>
<td>3.36</td>
<td>4.38</td>
</tr>
<tr>
<td>1998</td>
<td>3.17</td>
<td>4.13</td>
</tr>
<tr>
<td>1999</td>
<td>3.14</td>
<td>3.92</td>
</tr>
<tr>
<td>2000</td>
<td>3.15</td>
<td>3.76</td>
</tr>
<tr>
<td>2001</td>
<td>3.00</td>
<td>3.60</td>
</tr>
<tr>
<td>2002</td>
<td>3.42</td>
<td>3.52</td>
</tr>
<tr>
<td>2003</td>
<td>3.15</td>
<td>3.49</td>
</tr>
<tr>
<td>2004</td>
<td>3.36</td>
<td>3.31</td>
</tr>
<tr>
<td>2005</td>
<td>3.32</td>
<td>3.23</td>
</tr>
</tbody>
</table>

Death Indexes (Spain)

Figure 10. Death indexes according to vehicle type in Spain
Rmq: the death index for other vehicles is basically higher than the one for motorcycles because it corresponds to the number of killed people relatively to the number of accidents, and not to the number of victims (persons involved in accidents). An accident involving any vehicle other than motorcycle usually implies more people injured or killed, which explains the higher index. While this graph is then not aiming at comparing the values for death indexes but the general trends of the two curves, we can still see that the death toll ends up being greater for motorcycle than for other vehicles in 2005.

The death toll concerning motorcycle accidents remains quite constant (comprised between 3.00 and 3.50) whereas the death index for other vehicles is shown to be constantly decreasing since 1995.

Considering these data, it can be mentioned that accidents involving motorcycles have been annually increasing for the past years, but moreover their severity remains constant while the data standing for the other vehicles show a considerable decrease in number of accidents and their severity, the death index falling from more than 4.5% in 1995 to less than 3.5% in 2005.

2.3 MOTORCYCLE ACCIDENT LOCATION, TYPE AND SEVERITY

It has been seen in the previous part that considering general data for accidents is generally not enough for analysing the accidents. For example calculating the Death Indexes considering all the accidents as a whole gave the same results for cars and motorcycles, which does not represent the reality. It is therefore important to consider more detailed cases, to obtain a clearer feedback from the statistics.

2.3.1 ACCIDENT LOCATIONS AND TYPES

Accidents involving motorcycles are a huge concern, especially the re-increasing trend of the past three years. Data from the year 2005 is taken to provide recent results for an analysis adapted to the actual situation.

The classification of accidents used by the D.G.T. tends to separate the accidents in two major types: collisions and run off road accidents. The ‘collisions’ group contains accidents such as collision with a vehicle, impact into road side barrier, impact against rail way crossing barrier, impact against other signalization object, pedestrian knock over, animal knock over, etc. Run off road group contains all the different run off road possible configurations, classified according to the object the motorcyclist ran into.

Considering all the motorcyclist accidents of the year 2005, the collision group accounts for 86% of the victims, whereas only 14% of the victims were implied in run off road accidents. Paradoxically, this last group of accidents is responsible for 40% of the deaths. While these numbers give an idea of the general trend of the accidents, it is not relevant to base a detailed study on
accident types directly from these data, risking unacceptable approximations. Experience in accident analysis shows it is necessary to consider different locations before entering into a detailed study of the accident types.

The areas where accidents can occur are three: urban area, rural area and other area (in between rural and urban).

Figure 11 shows the need to consider these different zones, as the accident distributions are notably different from one zone to another.

Accident groups locations (number of victims)

![Bar chart showing accident groups by location](image)

**Figure 11. Type of accidents depending on the zones**

Figure 11 clearly shows the difference between urban and rural areas. Another key data to understand motorcycle accidents better is to analyse the implication of each zone in the accident data base, examining the distribution of accidents and fatal injuries on urban and rural zones.

In terms of number of accidents, according to the data for the year 2005, the urban zone handles 67% of all the motorcycle accident victims as shown in Figure 12.
Zone distribution of the victims (Spain, 2005)

Figure 12. Average distribution of the accidents for the year 2005

In terms of fatalities, the result is almost the opposite, as shown by Figure 13.

Fatalities distributions (Spain, 2005)

Figure 13. Average fatalities distribution for the years 2003, 2004 and 2005

These two figures clearly show the difference in severity between the accidents occurring in urban areas and the ones occurring in rural areas: 67% of the victims are involved in accidents occurring in urban areas and represent 18% of the motorcyclist fatalities whereas the accidents occurring in rural areas (only 31% of the victims) are responsible for 78% of the motorcyclist fatalities. The severity of the accidents occurring out of urban areas is hereby shown to be much higher than the severity of urban cases. While all accidents are worrying, the ones occurring in rural areas might clearly be subject of special attention, and particularly because their severity is slightly increasing in number since 2003, as shown by the distribution (see Table 7).
Distribution of accidents and fatalities

<table>
<thead>
<tr>
<th>Distribution of accidents and fatalities (%)</th>
<th>urban</th>
<th>rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>68.7</td>
<td>31.3</td>
</tr>
<tr>
<td>victims</td>
<td>68.7</td>
<td>31.3</td>
</tr>
<tr>
<td>fatalities</td>
<td>27.5</td>
<td>72.5</td>
</tr>
<tr>
<td>2004</td>
<td>67.9</td>
<td>32.1</td>
</tr>
<tr>
<td>victims</td>
<td>67.9</td>
<td>32.1</td>
</tr>
<tr>
<td>fatalities</td>
<td>24</td>
<td>76</td>
</tr>
<tr>
<td>2005</td>
<td>67.7</td>
<td>32.3</td>
</tr>
<tr>
<td>victims</td>
<td>67.7</td>
<td>32.3</td>
</tr>
<tr>
<td>fatalities</td>
<td>24.2</td>
<td>75.8</td>
</tr>
<tr>
<td>Average</td>
<td>67.2</td>
<td>31.3</td>
</tr>
<tr>
<td>victims</td>
<td>67.2</td>
<td>31.3</td>
</tr>
<tr>
<td>fatalities</td>
<td>18.1</td>
<td>78.1</td>
</tr>
</tbody>
</table>

2.3.2 URBAN AREAS

In 2005, 8,856 motorcycle drivers (or occupants) were victims of accidents in urban areas in Spain. In terms of number of victims, the most common accidents are the collision with vehicle (79% of the victims), fall on the road (10% of the victims) and knocked over pedestrians (5.8%); the remaining 10% being approximately equally distributed amongst 12 other types of accidents.

In the objective of the present study, it is of great interest to determine which accident configuration is the most aggressive to motorcyclists. This way it is important to define the fatality risk (FR) criterion, which corresponds to the ratio of deceased persons to the number of victims.

\[ \text{Fatality Risk} = \frac{\text{Number of deceased}}{\text{Number of victims}} \]

This ratio is easily calculated for a specific type of accident considering the number of killed people in this specific accident and the total number of victims of this type of accident. In the same way it is worth defining the “Severe Injury Risk (SIR)” to enlarge the action field of the study and give better understanding of the accidents. Also the severe injury criterion allows the assessment of accidents where no fatalities have occurred.
This criterion is defined as:

\[
\text{Severe Injury Risk} = \frac{\text{Number of deceased or severely injured}}{\text{Number of victims}}
\]

These two criterions are used to evaluate the aggressiveness of the accidents occurred in urban area during the year 2005. They are presented in Figure 14 below.

Figure 14.  Fatality Risk in urban area

Figure 14 shows that considering the fatalities only, the more aggressive accidents for the motorcyclists are the impact against a tree or a post (with one decease every 5.6 victims), the “other impact” (with one decease for every 12.6 victims) and the impact against safety barrier with one death out of every 14.9 victims). It is interesting to notice that the average Fatality Risk for an accident occurring in urban area is about 0.77% (1 deceased out of every 130 victims).
Considering this criterion, the crash into a wall or a building shows a significant aggressiveness, 7 motorcyclists out of every 10 being at least severely injured. In the second position comes the impact in a tree or a post (5 being at least severely injured for every 10 victims). The impact into a safety barrier occupies the third position with 4 severe cases every 10 victims. In general urban areas accidents, the average Severe Injury Criterion in 2005 was about 12% (1 victim out of every 8.3 being at least severely injured).

2.3.3 RURAL AREAS

In 2005, 3,062 persons were victim of motorcycle accidents in rural areas in Spain, where the major part of the victims were involved in a collision with another vehicle (50.1%), as shown in Table 8.
Table 8.
Accident types and proportion in rural areas

<table>
<thead>
<tr>
<th>Accident type</th>
<th>Nb of victims</th>
<th>Percentage of the total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision with vehicle</td>
<td>2045</td>
<td>50.16%</td>
</tr>
<tr>
<td>Safety barrier</td>
<td>26</td>
<td>0.64%</td>
</tr>
<tr>
<td>Rail way crossing barrier</td>
<td>2</td>
<td>0.05%</td>
</tr>
<tr>
<td>Other object or material</td>
<td>46</td>
<td>1.13%</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>32</td>
<td>0.78%</td>
</tr>
<tr>
<td>Animal</td>
<td>45</td>
<td>1.10%</td>
</tr>
<tr>
<td>Fall on the road</td>
<td>408</td>
<td>10.01%</td>
</tr>
<tr>
<td>Tree or post</td>
<td>92</td>
<td>2.26%</td>
</tr>
<tr>
<td>Wall or building</td>
<td>106</td>
<td>2.60%</td>
</tr>
<tr>
<td>Gutter or curb</td>
<td>258</td>
<td>6.33%</td>
</tr>
<tr>
<td>Other impact</td>
<td>362</td>
<td>8.88%</td>
</tr>
<tr>
<td>Dip</td>
<td>86</td>
<td>2.11%</td>
</tr>
<tr>
<td>Roll over</td>
<td>358</td>
<td>8.78%</td>
</tr>
<tr>
<td>Flat (en llano)</td>
<td>123</td>
<td>3.02%</td>
</tr>
<tr>
<td>Other</td>
<td>88</td>
<td>2.16%</td>
</tr>
</tbody>
</table>

Figure 16. Fatality risk (FR) according to accident configurations

According to this graph, the impact into a tree or a post is the most aggressive type of accident, 1 of every 5 motorcyclists impacting such object being killed. The second and third accident types according to this classification are the “other impact” and the “impact into a safety barrier”, with respectively 1 of every
7.2 and 1 of every 8.7 motorcyclists killed. The average Fatal Risk of accident occurring in rural area was about 7.2 (10 times more than the urban area’s FR). The same graph is plotted (Figure 17), according to the Severe Injury Risk ratio:

![Figure 17. Severe Injury Risk (SIR) in different accident configurations](image)

Among this classification, it is showed that considering Severe Injury Risk criteria, the safety barrier reaches the highest ratio of 69.2%, meaning that 7 out of every 10 motorcyclists impacting against a road side barrier will be at least severely injured. In other terms, if both deceased and severely injured people are considered, the road side barrier, which aims at restraining the vehicles from impact against trees or posts or other road side objects are in fact more aggressive to motorcyclists than the objects themselves.

The rural area has been shown to be the main area of interest when considering the safety barrier impact configuration.

### 2.3.4 OTHER AREAS

This category of location corresponds to areas which are in between urban and rural areas. In 2005, 207 victims were involved in accidents occurring in this kind of zone, corresponding to 17 deceased and 57 severely injured. Considering these numbers, the “other area” only represents a few cases compared to the rural and urban areas; some types of accident are therefore not represented in this area. However it is interesting to study the severity of the different types of accident, using the FR and the SIR, as shown in Figure 18 and Figure 19.
2.4 ANALYSIS AND CONCLUSIONS

Although the three different areas are very different in terms of number and general statistics, the definition of the Fatality Risk and Severe Injury Risk ratios allow the analysis of the accidents individually. Among this analysis it has been shown that some types of impact are especially aggressive to the motorcyclists, whichever the zone.
The case of the safety barrier is a special case to consider since it is an installation designed for safety on the road. In other terms, a safety barrier could avoid run off road and posterior impact into a tree or a post, or impact into a wall or a building; statistically and referring to the graphs previously plotted this means that installing safety barriers in locations at which impacts against wall or buildings are most likely to occur could reduce the fatality risk (to 11.5% in rural areas and to 6.7% in urban areas).

On the other hand, installing guardrails where the run off road is likely to be ending against a tree, a post, a gutter or a curb or simply on a flat surface statistically increases the fatality risk. In any case, an FR of 11.5% for a safety installation is a high ratio, and justifies in itself the necessity for special attention and studies. These guardrails are working well for restraining quite safely any types of vehicles but motorcycles, and it can be seen by comparing the Fatality Risks and Severe Injury Risk related to the guardrail impacts of both motorcycles and other vehicles, as done in the Table 9.

Table 9. Fatality and Severe Injury Risks for motorcycles and other vehicles

<table>
<thead>
<tr>
<th>Guardrail</th>
<th>FR (%)</th>
<th>SIR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorcycles</td>
<td>11.5</td>
<td>69.2</td>
</tr>
<tr>
<td>Other vehicles</td>
<td>2.9</td>
<td>12.2</td>
</tr>
<tr>
<td>Ratio</td>
<td>4.0</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Guardrails are 4 times more aggressive for motorcyclists than for car occupants, considering only the death numbers, and 5.7 times more considering both deceased and severely injured. Therefore guardrails should be the systems receiving more attention in terms of motorcyclist protection.

Aware of this problem and aware of the fact that these guardrails work well for other vehicles, the governments and barrier manufacturers are now developing adaptive systems that are usually mounted onto the original barriers, to improve the protection for motorcyclists but also other vulnerable road users. However, it is quite clear through this study that the efforts given to this field are not enough. Before studying the systems themselves and proposing potential improvements, it is absolutely necessary to carry out an in depth study of the guardrail accident cases and determine the important parameters to consider when designing such devices.
3. MOTORCYCLIST VS. GUARDRAIL IMPACTS: IN-DEPTH STUDY CHARACTERISING PARAMETERS

3.1 INTRODUCTION

In order to develop protective systems and contemplate possible new solutions it is important to know exactly what they should be designed for, their expected functions and properties. The analysis of the reported motorcyclists vs. guardrail accidents is therefore a prerequisite for the study. From the database and the police reports of the accidents it is possible to define different model types of accident, according to important parameters which have to be defined.

The major aspect concerns the state of the motorcyclist at the impact time; the restraint system might obviously be different if designed to restrain a driven motorcycle or to restrain a motorcyclist sliding on the road. Considering the state of the art of the systems and the actual types of actions held regarding motorcyclist safety, it is worth considering only the cases where the rider falls on the road before impacting the barrier. From this starting point, the parameters of the accident that might be influencing the design of the system can be determined. An evidently important parameter is the impact speed of the driver into the guardrail. The dynamic of impacts shows the importance of this criterion for the design of the protective device. Also, the trajectory of the driver impacting the barrier will be important in the accident. The trajectory can be represented by the angle with which the driver will impact the guardrail.

These two parameters can therefore be considered as significant characteristics of the impact and will be analysed, considering real cases of accidents reported by the police. The accident sample on which our in-depth study has been based is described as follows:

3.2 ACCIDENTOLOGY DATA SOURCE

In the sample, 58 cases are considered, accounting for 62 deaths. In this database, 20.6% (12 accidents) were “impacts against safety barriers”, including 12 fatalities. In all the impacts against safety barriers studied, the motorcycle was occupied by a single person and in 9 of them, the motorcycle was the only vehicle implicated in the accident. This situation corresponding to a single vehicle accident configuration then represents 75% of the crash against metallic barriers.

According to other studies, this percentage usually varies between 70 and 100% of fall alone situations. Finally, among these 9 fall alone situations, a remark on the accident report in 8 of them mentioned the velocity, which was estimated to be inadequate to the road configuration. As police reports did not precisely mentioned the injuries suffered by the victims, it is difficult to carry an in-depth study regarding this criterion. However the location of the main injuries was mentioned in 8 of the 12 cases, as shown in Table 10.
Table 10

Body part injury distribution

<table>
<thead>
<tr>
<th>Body part</th>
<th>Cases</th>
<th>%age of the total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>1</td>
<td>8.33%</td>
</tr>
<tr>
<td>Neck</td>
<td>2</td>
<td>16.67%</td>
</tr>
<tr>
<td>Abdomen</td>
<td>2</td>
<td>16.67%</td>
</tr>
<tr>
<td>Chest</td>
<td>1</td>
<td>8.33%</td>
</tr>
<tr>
<td>Whole Body</td>
<td>2</td>
<td>16.66%</td>
</tr>
<tr>
<td>DK</td>
<td>4</td>
<td>33.33%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>12</td>
<td><strong>99.99%</strong></td>
</tr>
</tbody>
</table>

The injuries mentioned above are the ones which have been directly caused by the contact with the barrier. Another important note about this sample is that in all the cases, the motorcyclist had been separated from its motorcycle before impacting the barrier.

3.3 IN DEPTH STUDY OF THE ACCIDENTS

The in-depth study of the accidents is based on the accident reports made by the Police. The first part shows the contents of such report and then a methodology for analysing these reports and classifying the important parameters is defined. These explanations are based on a real fatal accident case, which occurred in 2007 and has been reported by the police.

3.3.1 POLICE REPORT TEMPLATE

This part of the document presents the typical information that is obtained from the police report of the accident and useful for the case reconstruction and analysis.

**ACCIDENT:**

*Accident Consists in:* fall on the road, run off the road by the right hand side and posterior impact against the safety barrier post.

*Consequences on the Driver:* deceased

**MOTORCYCLE**

Supposed State of the vehicle before the accident: good state, no defects
Motorcycle cc: 600

**ROAD CHARACTERISTICS:**

*Type of road:* 2 lanes in the concerned way
*Width of the road:* 12.70m
*Width of the lanes:* 3.50m
**Configuration:** smooth curve on the left  
**State:** good state  
**Conditions:** dry and clean, daylight  
**Speed limit:** 90km/h

**ACCOUNTS OF THE WITNESSES:**
From the accounts of the witnesses, it is possible to understand what happened: the rider was overtaking when he lost control of the slipping rear tyre of the motorcycle. He fell down and slipped on his back, head on to the right hand side barrier. He impacted the barrier post with the head. In accordance to one of the witnesses, the rider was driving at a speed of about 140kph. Another witness would estimate a speed of maximum 130kph.

**MARKS ON THE ROAD:**
The marks on the road allow the police to simply reconstruct the accident: point of fall, slide trajectory and point of impact into the barrier. From this information the police agents draw a sketch of the scene as shown in Figure 20.

*Figure 20. Scheme of the accident*

The pictures attached to the reports are also of great use for a better understanding of the accident.

**3.3.2 IDENTIFYING PARAMETERS: APPROACH**

**TRAJECTORY**
For analysing the trajectory of the driver from the fall until the impact with the barrier the police report and measurements can be used directly. In terms of measurements the triangulation method allows a detailed reconstruction of the trajectory. When investigating the accident, the police agents consider two fixed points (on the road, or barrier, or roadside, see Figure 21) as the references of...
the measurement origins. Each other determining point (fall, impact into barrier, end position) is then defined by two coordinates, representing the distances from both of the fixed points.

Figure 21. Reference points for measurements

From the positioning of these two points and the coordinates of all the other determining points it is simple to define the trajectory followed by the rider (and/or the motorcycle) during the crash. Any design software (CAD) allows entering the coordinates and getting the overview of the trajectory.

**ANGLE OF INCIDENCE**

By having the reconstructed trajectory of the rider, the angle of incidence is directly measurable with the design software; in this particular case the angle found was 15°. Though, the simplest way to get the angle of impact would be to measure it directly on the accident site and include it into the police report.

**VELOCITY OF IMPACT**

In this document, the important velocity to be considered is the velocity of impact, right at the contact point between the driver (and/or the motorcycle) and the barrier post. This velocity is difficult to estimate precisely since the driving velocity just before the fall on the road is not really known. Under this consideration, two possible ways of estimating the velocity of impact are available.

The first method consists of carrying out an analytic calculation based on the accounts of the witnesses (in this special case 130 – 140 kph) by applying the energy conservation law, as shown by Equation 1.

\[
E_{\text{Kinetic (Point of fall)}} = E_{\text{Friction}} + E_{\text{Gravity}}
\]  (1)
\[
\frac{1}{2} m (v_i^2 - v_f^2) = \mu_{\text{rider-road}} mgL \cos \alpha + mgL \sin \alpha
\]

\[
V_f = \sqrt{V_i^2 - 2\mu gL \cos \alpha - 2gL \sin \alpha}
\]

*With the following variables:*

- \(m\): Mass of the driver
- \(\mu\): Friction coefficient between the driver and the road
- \(g\): Gravity
- \(L\): Distance covered
- \(\alpha\): Slope of the road

Considering a speed of 130kph (at the time of the fall), a sliding distance of 35.9 meters (from trajectory determination), a friction coefficient of 0.6 between the rider and the road and a positive slope of 6.3% (from police report), and the result is a speed of 102.3 kph at the time of impact, which is very high. This result is a rough approximation since the friction coefficient depends on the clothes the driver was wearing and other varying parameters. The closest approximation in this method consists of taking the speed evaluated by the witnesses of the accident, which is only a rough estimation.

The second method consists of using numerical simulation in order to recreate the accident scene and simulate the crash using all the parameters (point of fall, point of impact, final position of the driver). PC Crash software allows quite a good reconstruction of the crashes and can therefore be used for this purpose. This method also allows determining the angle of incidence.

### 3.4 RESULTS AND ANALYSIS

The in depth analysis of the accidents provides detailed information about the course of the accident, especially concerning the impact speed and angle, to be able to bring improvements to the guardrail and MFD. In that way, the in depth analysis has been centred on all the run off road accidents in which at least one fatality happened, instead of restraining the analysis to the guardrail cases only. The important parameters of the accidents at the run off timing are the same whether a barrier is installed or not. The data about such accidents being quite difficult to obtain, the in depth analysis has been carried out for the accidents recorded during the year 2007 only. The results of this study are presented in Table 11.
These cases will be split into different categories, according to the angle of impact, as shown by the Table 12.

### Table 11

*Data of the accidents resulting from the in depth study*

<table>
<thead>
<tr>
<th>Case number</th>
<th>Impact angle</th>
<th>Estimated impact speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>&gt;40kph</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>60kph</td>
</tr>
<tr>
<td>4</td>
<td>43</td>
<td>DK</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>60kph</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>&gt;46kph</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>DK</td>
</tr>
<tr>
<td>8</td>
<td>25</td>
<td>DK</td>
</tr>
<tr>
<td>9</td>
<td>between 40 and 45</td>
<td>50</td>
</tr>
<tr>
<td>10</td>
<td>&gt;45</td>
<td>45</td>
</tr>
<tr>
<td>11</td>
<td>18</td>
<td>60</td>
</tr>
<tr>
<td>12</td>
<td>30</td>
<td>65</td>
</tr>
<tr>
<td>13</td>
<td>30</td>
<td>55</td>
</tr>
<tr>
<td>14</td>
<td>35</td>
<td>50</td>
</tr>
<tr>
<td>15</td>
<td>&lt;20</td>
<td>75</td>
</tr>
<tr>
<td>16</td>
<td>90°</td>
<td>DK</td>
</tr>
<tr>
<td>17</td>
<td>6°</td>
<td>80</td>
</tr>
<tr>
<td>18</td>
<td>&lt;10°</td>
<td>70</td>
</tr>
<tr>
<td>19</td>
<td>DK</td>
<td>DK</td>
</tr>
<tr>
<td>20</td>
<td>DK</td>
<td>DK</td>
</tr>
<tr>
<td>21</td>
<td>15</td>
<td>40</td>
</tr>
<tr>
<td>22</td>
<td>&gt;35</td>
<td>DK</td>
</tr>
</tbody>
</table>

According to these data, the most common accidents occur with an impact angle of less than 25° (50% of the accidents), then the ranges of 25° to 35° and 35 to 45° both represent 1 case for every 5 crashes into guardrail.

### Table 12

*Categories of angles*

<table>
<thead>
<tr>
<th>Angle of impact</th>
<th>Percentage</th>
<th>Average velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>angle&lt;25°</td>
<td>50%</td>
<td>64 kph</td>
</tr>
<tr>
<td>25°&lt;angle&lt;35°</td>
<td>20%</td>
<td>60kph</td>
</tr>
<tr>
<td>35°&lt;angle&lt;45°</td>
<td>20%</td>
<td>50kph</td>
</tr>
<tr>
<td>angle&gt;45°</td>
<td>10%</td>
<td>54kph</td>
</tr>
</tbody>
</table>

The velocity of impact presented in the Table 11 and Table 12 have been calculated as described before, i.e. based on the accounts of the witnesses when possible, and if not based on the limit speed of the concerned road. This
might tend to underestimate the velocities since run off road accidents are usually due to a velocity inadequate to the situation, meaning higher than the speed limit. Moreover, only the accidents involving fatalities are reported in detail by the police, therefore the analysis has been based on these accidents only.

As a consequence, the sample is somehow not fully representative of the reality and for a better understanding of the guardrail impacts, detailed reports should be done also for accidents with severe injuries. The fatal cases are more likely to occur at higher speed, meaning on faster roads; including the cases involving severe injuries would extend the data to smaller road accidents and might therefore include a wider range of impact angles, especially in the high angle range. Aiming at improving the safety of the motorcyclists, both the fatal and severe cases should be considered and studied.

In order to improve the analysis of the accidents and therefore the solutions to these accidents it is necessary to know the kind of injuries suffered by the victims; information from the accidents during the year 2007 was mentioned in 65% of the reports only, which could be improved in the next years.

3.5 OTHER STUDIES
Since the study presented in the previous part was based on few cases (22 cases), it is interesting to look through the equivalent studies carried out by other institutes. According to the DIANA database, 9 cases with angles comprised between 5 and 20°, the average angle of impact of was 13°.

3.6 CONCLUSIONS
From this in depth analysis of the accidents, a considerable knowledge of the guardrail cases has been developed, leading to a better understanding of the typical accidents occurrence. It is then possible to make a state of the art of the different solutions that are nowadays available to diminish this problem.
4. CURRENT SYSTEMS REVIEW

4.1 SYSTEMS IN USE

4.1.1 METALLIC BARRIERS

BARRIER PROFILES

POSTS

In the field of Road Restraint System (RRS) we can currently observe 4 major types of barrier posts which are widely used in Europe. The IPE post (Figure 22), although very cheap to build, is the one that shows the highest injury potential to vulnerable road users, due to its extremely aggressive edges.

![Figure 22. IPE 100 post](image)

A study conducted by Ellmers in 1994 showed that these IPE posts caused fractures and amputations and recommended the use of Sigma-posts (Figure 23), which in the same impact configuration only caused bruising.

![Figure 23. Sigma post](image)
As seen on the figure this shape presents smoother edges and therefore allows reducing injury severity caused by the impact. The Z-posts and C-posts (Figure 24) are less harmful than the IPE 100 posts as well but are less used in Europe than the Sigma shaped ones.

![Figure 24. Z and C-shaped posts](image)

As a consequence, the idea when designing systems for protection of the motorcyclists is to isolate the holding posts of the barrier from any contact with the motorcyclist. The following lines show some of the existing systems (basically the main systems that are used in Spain) called Motorcyclist Friendly Devices (MFD). Adding W-beams to the lower sections has been one of the first designs to isolate the posts, as shown in Figure 25.

![Figure 25. W-beam added to the guardrails](image)

This device has been shown to reduce the injuries by increasing the potential for energy absorption. However the potential for energy absorption remains low, mainly because of the small compressible distance proposed by this design.

Then, as a second step in the field of motorcyclist protection, and in order to provide adapted systems, researches have been conducted on separated devices that could be mounted on the existing posts previously discussed. Two types of system can be considered: a device to absorb the rider energy (punctual device mounted on each single post) during the impact with posts, and devices that redirect the rider (long ribbon that covers the whole length considered as dangerous) along the barrier, preventing from any contact with the posts.
**PUNCTUAL ENERGY ABSORBERS**

Nowadays two models of crash barrier impact attenuators exist (Figure 26), they are made of foam (polystyrene, polyurethane, polyethylene, neoprene or other synthetic materials) and in addition to absorbing rider energy when being compressed they prevent him from impacting the sharp edges of the posts.

![Figure 26. Impact attenuators](image)

This positive effect is however reduced with the speed of the impact since the amount of energy which is absorbed is limited by the size of the device (up to speed about 50 to 60 kph). This makes those systems suitable for urban areas or tight bends.

An evaluation conducted in 2000 by Jessel on these devices reported that impact deceleration and force were halved while the impact time was doubled, allowing the deceleration felt by the chest to drop down to 472 m/s², in contrast to the unprotected post deceleration of 860 m/s² (biomechanical limit between 600 and 800 m/s²). Other results published by Jessel and Batelle (Institut Frankfurt) obtained during a test for new absorbing material (Expanded Polystyrene EPS) are shown in the following table (Table 13).

<table>
<thead>
<tr>
<th>Impact Obstacle</th>
<th>Impact Speed</th>
<th>Max. Deceleration</th>
<th>Max. Force</th>
<th>Impact Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare IPE 100 steel post</td>
<td>32 km/h</td>
<td>2500 m/s²</td>
<td>18.1 kN</td>
<td>13 ms</td>
</tr>
<tr>
<td>IPE 100 post with protector</td>
<td>32 km/h</td>
<td>1214 m/s²</td>
<td>9.4 kN</td>
<td>23 ms</td>
</tr>
<tr>
<td>Percentage difference</td>
<td></td>
<td>51%</td>
<td>48%</td>
<td>77%</td>
</tr>
</tbody>
</table>

The maximum deceleration experienced by the rider during the crash is halved as well as the maximum forces; the absorbing material allows increasing
considerably the impact time. These post impact protectors are mostly used in Austria and Germany nowadays.

**CONTINUOUS SYSTEM TO REDIRECT THE RIDERS**

Energy absorbers are very efficient up to a certain impact speed limit but above this limit it becomes difficult to absorb the rider energy and damp the impact since it would require an important volume of material, most probably impossible to be mounted on the barriers since the size of the device is restricted by the norm.

Therefore, research has been leaded on how it was possible to redirect the riders on the road or along the barrier, preventing them from any contact with the aggressive posts. The most used solution consists of a lower flat rail which is added to the conventional W beam barrier (see Figure 27). Made in steel, this device is light and quite flexible and redirects the driver preventing him from getting off the road underneath the barrier posts.

Figure 27. Steel guard rail post protection)

Sala and Astori (1998) stated that these devices were shown to reduce both the number and the severity of motorcycle crashes. While the main function is, as mentioned above, to redirect the riders on the road, these systems are designed to absorb energy during the impact by flexion of the steel holding the plates. Nowadays, the studies and researches carried out on this field are working on systems that combine the absorption during the impact and the redirection of the riders on the road.

**COMBINING ENERGY ABSORPTION AND REDIRECTION OF THE RIDERS**

Moto.Tub, developed in France, consists of polyethylene tubes that connect the posts of the guardrail to protect motorcyclists from injury following the impact (Figure 28). They have been designed considering both energy absorption for “low speed” impact and redirection of the rider during high speed (and low
angle) impact. A five year trial has been carried out in France and the Moto.Tub has been crash tested following the European regulation. An important effort has been made on the cost efficiency of these devices, making them directly adaptable to traditional barrier and easy to assemble. Some kilometres have been installed in France but this device is still not widely used.

Figure 28. Polyethylene Moto tub

4.1.2 WIRE ROPE BARRIERS

Wire Rope Safety Barriers are non rigid systems comprising a number of tensioned ropes, supported on frangible posts (Figure 29). Upon impact with a vehicle these barriers deflect more than traditional ones, resulting in relatively less vehicle damage and occupant injury. A recent review of motorcycle crashes involving wire rope barriers (FEMA, 2000) found that no motorcyclist fatalities had occurred as a result of a collision with a flexible barrier.

Figure 29. Wire rope barrier

Recently there have been cases of motorcyclists being killed in crashes involving wire rope barriers but there is no evidence yet available to reveal the potential role of the barrier or its design features in the injury mechanisms. As noted earlier, it is clear that motorcyclist impacts with wire rope barriers have the potential to cause serious injury to errant riders, and motorcyclist associations usually criticise them as being a “human scale cheese cutters”.
However, there is no reliable evidence to indicate that wire rope barriers present a greater or less risk than other barrier types, or indeed, no barrier at all (Larsson et al, 2003).

In order to increase the rider protection in case of impact with flexible barrier, some manufacturers are producing energy absorbers covering the lower part of the post, as shown on the Figure 30 (protection for lower post from Blue System, Sweden).

![Figure 30. Post protectors used by Blue Systems in Sweden](image)

At this stage no incident has been recorded of motorcyclist impacting this kind of protected post. Another type of Wire Rope Safety Barrier protection, also developed in Sweden, consists of aluminium protection surrounding the wires as shown in Figure 31.

![Figure 31. Aluminium covers for wire ropes](image)
4.1.3 CONCRETE BARRIERS

Presenting a flat surface with no sharp edges, the concrete walls shown in Figure 32 have the advantage of replacing a point impact with a surface impact. Consequently, they appear a lot safer to a motorcyclist, especially with small impact angles (< 20°).

Figure 32. Different types of concrete barriers

They cost more to install but less to maintain than the standard metallic barrier. They also prevent heavy vehicles from crossing into the opposing traffic lane. As a consequence they are often used on central reserves, or where there is no room for a metal barrier to deform. On another hand, this type of barrier is totally unable to absorb any kinetic energy from the rider and should therefore be limited to the cases where small impact angle is the typical crash configuration.

4.2 MATERIAL SELECTION

Restraint barriers actually seen in the market are usually rigid steel structures that redirect vehicles as cars or trucks on a safer trajectory, but concerning post protectors and more generally all types of punctual impact attenuators intended to motorcyclists, research is continuously being leaded considering new materials and their potential for energy absorption improvement.

Synthetic materials such as Polyurethane (PU), Polyethylene (PE) or Neoprene present good properties for energy absorption and are usually the materials used for the impact attenuators. On the other hand, work still has to be carried out on their durability, to ensure that consequences of the rodent attacks and weather do not lead to weakened safety properties. However, following the statements of Sala and Astori (1998), posts protected by polymeric dampers might not be very effective for velocities higher than 50-60km/h, their cost is very high and therefore their installation has to be limited to the more dangerous stretches of road.

To reduce the consequences of an impact to the crash barrier posts and therefore raise the impact speed leading to rider injury, Jessel (Batelle Institut
Frankfurt) conducted a scientific investigation on an impact absorbing material. The material consists of EPS (Expanded Polystyrene), a foamed plastic similar to the inner shell of a crash helmet, but three times as thick; this material contains only 2% of plastics and the rest consists of air, it has a density of 20kg/m$^3$. The tests carried out showed very good results (Christine Mulvihill and Bruce Corben, Monash University).

More than these punctual barrier protections, the continuous barrier intended to redirect the riders are also subjected to material evolution. The upper parts of the barriers are made of relatively thick steel since they have to withstand the kinetic energy of the cars or even trucks without letting them go through. However in the case of the lower part, intended for motorcyclist protection, a much more flexible structure is required not to hurt the riders.

Therefore thinner steel sheets should be used, however for reasons of production, installation, maintenance and drilled holes corrosion, a minimum attainable thickness exists. Due to these considerations it became necessary to consider a lighter material than steel. However, the aluminium alloys are costly and susceptible to galvanic corrosion once put into contact with the main structure which is made of zinc plated sheet.

Composite materials appear to be a good alternative to steel for this kind of barrier since they have high damping coefficients and do not suffer corrosion. Sala and Astori (Motorcycle and Safety Barrier Crash Testing: feasibility Study 1998) studied a new barrier system that uses a lower ribbon made of continuous glass fibres and polyester resin added to the metallic higher barrier as shown in Figure 33. To absorb the energy of an eventual impact the ribbon is attached to the post by means of steel spacers.
Figure 33. Metallic guard rail with composite protection

Nowadays, companies as Cellbond Composite Ltd. (Huntington, Cambridgeshire) are working on several projects to develop and adapt energy absorbers used in crash testing (crash barriers) to roadside barriers use. These devices are usually based on honeycomb or press loaded made structures. The advantage is to be able to control the energy absorption accurately by varying the design parameters. According to the company, durability and cost effectiveness are better than with polystyrene foam devices.

4.3 COMMENTS AND DISCUSSION

The major brake to a massive installation of safety barriers along the roads remains the same with many systems: the cost effectiveness of the device and its installation on the roads. A study undertaken through the Ministry of Transport in France estimated “the cost of equipping all the crash barrier with Motorcycle Friendly Devices would be 600 million euros. With an average of 60 death motorcyclists due to crash barriers and a pessimistic hypothesis that these devices would halve the number of deaths […] it would take 20 years for a full installation to be cost effective. With the given estimated durability of 4 years for the MFD, this seems economically not sound”.

Although this economic viability contradicts the VicRoads concept of creating a “safe system” (Victorian Motorcycle Road Safety Strategy), it enforces the
authorities to define the “black spot zones” regarding motorcyclist crashes into barriers in order to prioritise the installation of safety devices in these areas. However it turns out that while some black spots can be clearly identified, the major part of motorcyclists-barriers impacts are randomly distributed along the roads.

In response to that economical brake, industries should aim at improving the cost efficiency of these products. Different actions could be led along the life cycle of the devices:

- **Design**: the devices should be easily adaptable to existing barriers in order to maximally reduce the installation difficulty and duration. The materials that are used also have to be considered for questions of production rate, manufacturing duration, eventually recycling and reusing.

- **Manufacturing**: optimisation of the manufacturing process

- **Life**: the duration of the devices installed is actually of 4 years in average, which is usually far away from the calculated period required to be cost effective. Research about materials and maintenance of the systems is required to improve the durability of the systems.

Although the lack of scientific knowledge of the motorcyclist-guardrail’s impacts is partly responsible for the difficulties to improve the devices, it has been noted that a lot of studies and research has been focusing on developing MFDs, which lead to good motorcyclist protection. If the systems installed on our roads nowadays are somehow not always adapted, it is maybe due to the way of homologating them more than the way they are designed. This remark pointed our attention on an analysis of the regulations, norms and protocols for homologation of MFDs.

5. REVIEW OF REGULATIONS

As a response to the numerous motorcyclist crashes with road side barriers, the Spanish government elaborated a legislation to define the requirements of such Motorcycle Friendly Devices mounted on the side barriers. This regulation has been elaborated by the technical committee *Equipamiento Para la Señalización Vial* (AEN/CTN 135, Equipment for the Road Signalisation) in 2005. Its principal objective is to define the methodology for evaluating the behaviour of the protective barrier systems for motorcyclists. This legislation applies to both punctual and continuous protection systems.

In France, the “Institut National de Recherche sur les Transports et leur Sécurité” defined an experimental test of motorcyclist impacts against metal barriers. This test protocol has been carried out by the “Laboratoire INRETS d’Équipements de la Route” (LIER), belonging to INRETS. It has been defined based on an accident study developed by INRETS in 1995 through the medical observation 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.

5.1 NORM UNE 135900

5.1.1 TESTING PROCEDURE

The assessment of the systems is based on several tests consisting in impacting a dummy (Hybrid III with some modifications, see Appendix A) leaning on its back against the system to be assessed at a speed of 60 kph and with an impact angle of 30°. This general idea is then derived into 3 different trajectories, as described below.

Trajectory 1: post centred impact, applicable to punctual and continuous motorcyclist protective systems. The trajectory is the horizontal line that goes by the centre of masses of the section of the post at level of the floor or, the projection on the floor of the centre of masses of the anchorage element or of connection of the safety barrier or railing, with an approaching angle equal to 30°, as shown in Figure 34.

![Figure 34. Post centred impact trajectory](image)

Trajectory 2: Post off-centred impact, applicable only to punctual systems. It is the horizontal line that goes at a distance “W” of the centre of masses of the section of the post at the level of the floor or, of the projection on the floor of the centre of masses of the anchorage element or of connection of the safety barrier or railing, with an approaching angle equal to 30°, as shown in Figure 35.

![Figure 35. Post off-centred impact trajectory](image)
**Trajectory 3:** Mid span centred impact, applicable only to continuous systems. It is the line that goes by the intersection point among the middle of the segment that connects the centres of masses (On and On+1 of the Figure 36) of the sections at level of the floor of two posts or, the projections on the floor of the centres of masses of anchorage element or of connection of safety barrier or railing and of the face of the MPS or of the safety barrier or railing closed to the traffic.

![Figure 36. Mid span centred impact trajectory](image)

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5.1.2 **ASSESSMENT PARAMETERS**

The assessment of the system is based on the biomechanic measurements of the HIC 36 and of the neck forces and moments. Limit values are defined and measured signals have to be contained into template curves defined by the norm (see Appendix A). The legislation finally assesses the system as being of level I (very good protection of the motorcyclist) or level II (homologated but protection could be better).

5.2 **LIER PROTOCOL (EQUS9910208C)**

5.2.1 **TEST PROTOCOL**

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 Sécurité) 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.

![First trajectory defined by the LIER protocol](site www.lier.fr)

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.

![Parallel impact](site www.lier.fr)

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 next.

### Table 14.

**Biomechanical criteria used in LIER test**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Biomechanical limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resultant head acceleration</td>
<td>220 g</td>
</tr>
<tr>
<td>HIC</td>
<td>1000</td>
</tr>
<tr>
<td>Neck flexional moment</td>
<td>190 Nm</td>
</tr>
<tr>
<td>Neck extension moment</td>
<td>57 Nm</td>
</tr>
<tr>
<td>Neck lateral flexion</td>
<td>-</td>
</tr>
<tr>
<td>Neck Fx traction</td>
<td>330 daN</td>
</tr>
<tr>
<td>Neck Fz traction</td>
<td>330 daN</td>
</tr>
<tr>
<td>Neck Fz compression</td>
<td>400 daN</td>
</tr>
</tbody>
</table>

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.

### 5.3 OTHER STUDIES

#### 5.3.1 POLYTECHNIC UNIVERSITY OF MILAN

The Polytechnic University of Milan carried out a study which consisted of a test performed by computer simulation. In this test, the motorcyclist is leaning on its side and turned to the barrier, as shown in Figure 39. The impact angle is 15°.
Figure 39. Simulation test of the Polytechnic University of Milan

It is unfortunately unknown whether the definition of this test is based on some accident studies or not.

5.4 COMMENTS

The UNE 135900 and the LIER testing protocol, both based on analysis of real accidents, are defining similar testing procedures. By definition and to ensure the systems homologated under these procedures provide good protection to the motorcyclists, it is crucial for the testing procedures to be good representations of real cases accidents.

6. CONSIDERATION OF THE UNE 135900

The aim of this assessment is to define the strengths and weaknesses of this testing procedure in order to bring improvements to it, or in other words try to make it more reliable.

6.1 STRENGTHS

6.1.1 FULL SCALE TEST

The procedure defined by UNE 135900 defines a full scale test with an entire dummy (instead of body part impacts) which allows a complete analysis of the dummy’s behaviour at the impact time but also its trajectory after the impact. The behaviour of the tested system can be analysed as well. Situations as dummy over passing the barrier, or body parts of the dummy being blocked into / under the barrier, or detachment of some of the system’s parts are directly noticed.

6.1.2 IMPACT VELOCITY

The impact velocity used for the test is 60 kph. According to the previous in depth study, this velocity is quite representative of the real cases analysed. By considering the cases involving severely injured victims, a velocity of 60 kph would probably be higher than the average of real cases, tending to give
empiric situations, consequently leading to development of good protecting systems.

6.1.3 TRAJECTORIES

Testing the systems under several trajectories allows assessing the system under different impact locations, which is good for the structure analysis of the whole system.

6.2 WEAKNESSES

6.2.1 IMPACT ANGLE

As demonstrated in the in-depth study, real cases attest the variety of impact angles which can be found in motorcyclists – barrier crashes. However the norm is defining only one angle of impact, whichever the system to be tested. This point of the norm is therefore representative of 20% of the real cases, according to Table 12. Systems homologated through a 30° impact angle are probably not as efficient when being impacted with another angle, especially higher angles. The procedure as such is consequently only covering a fraction of the real accident situations.

6.2.2 PROPELLING SYSTEM

Quoting the norm, the propelling system (of the dummy) has to ensure that the dummy is released from the propelling device at not less than 2 meters before the theoretical impact point. However, two meters is a considerable distance and might lead to considerable variations (position, angle, velocity) from one test to another, compromising the repeatability of the legislation. With some systems, slight variations in the impact angle or in the dummy position might lead to considerable changes in the results.

6.2.3 AMBIENT CONDITIONS

Ambient conditions as temperature, humidity etc. during the tests are not defined by the UNE 135900. The instrumentation for bio mechanic measurements on the dummy is however dependent on these criteria. Depending on the conditions under which the tests are carried out, the results might change and therefore the assessment of the system also.

6.2.4 BIO FIDELITY OF THE DUMMY

The dummy used for the tests is a Hybrid III 50th percentile, which is usually designed for frontal crashes, with adapted parts as the clavicle and pelvis. The test configuration and the impact are considerably different to frontal crashes.

The measuring points in the dummy concern the accelerations experienced by the head and the forces and moments in the upper neck. It has been shown in the in-depth study that injuries in the abdomen and in the rest of the body are as
frequent as head and neck. Potential improvements or adaptations of the dummy could investigate this area as well.

6.3 COMMENTS AND DISCUSSION

This analysis of the norm UNE 135900 has been based on a comparison with the previously presented state of the art. The definition of strengths and weaknesses rely upon this analysis and the experience of crash testing and crash procedures. More than being mentioned, these propositions have to be verified and supported by results of real tests.

7. TEST VALIDATION OF THE UNE 135900 ANALYSIS

7.1 IMPACT ANGLE TEST

7.1.1 INTRODUCTION

It has been shown in the previous in depth analysis of the crashes into barriers that quite a wide range of cases happen, according to the important parameters as speed and impact angle. In order to optimize the safety of the motorcyclists regarding these types of accident there are then two options:

- Ensure that the systems are working well in all the different configurations of angle and speed
- In the case of a system aiming at protecting the driver in one special situation, ensure that it is working well in this specific situation

The actual norm that is certifying the good functioning of the systems is basically testing them under one specific situation (30° angle and a velocity of 60 kph). It is quite obvious that the different types of impacts described in the in depth study cannot result in the same injuries. Since the impacts are different, the systems might be designed according to these considerations. This part of the study is aiming at testing the ability of a system to protect in different impact configurations.

The trend with the actual regulation is to encourage the protecting devices which redirect the riders (high speed and low angle of impact). A homologated system will be tested at a different angle of impact, to check its ability to protect in a different situation than the homologation typical test. In order to carry out this study, two full scale tests will be carried out, impacting a motorcyclist into a barrier (as defined by the norm) at a speed of 60 kph and an impact angle of 30° and then 45°. The comparison of the results of these two tests will allow some conclusions and give some clues about the behaviour of the barrier, and the corresponding consequences on the rider protection.
7.1.2 TEST GENERAL CONFIGURATION

**TEST TRACK**

A roadside barrier has been mounted on an outside track as shown in Figure 40. The flexibility of this installation allows changing the barrier angle and the barrier type at any time in a limited timing. The angle tests have therefore been carried out on this test track.

![General view of the test track](image)

**DUMMY AND SLED**

As defined in the UNE 135900, the dummy used for these tests is a Hybrid III, with the modified shoulder and pelvis. It is equipped with a homologated helmet and a leather body suit to protect the dummy skin and components. A special sled simulating the rider sliding on its back is used, as shown in Figure 41.
According to UNE 135900, the dummy has to be released from the sled at a maximum distance of 2 meters from the theoretical impact point with the barrier, up to some centimetres from it. For our tests, it has been decided that this release distance should be minimised as much as possible in order to ensure the desired trajectory and speed of the dummy before the impact. The distance between the theoretical impact point and the barrier during these tests was of about 50 cm, as shown in the Figure 42.

*Figure 41. Sled and Dummy before the test*
Figure 42. Throwing distance of 50cm

MOTORCYCLIST FRIENDLY DEVICE (MFD) USED

The system used during these tests was a homologated steel MDF. This system consists of a metallic plate fixed to the original barrier through metallic arms absorbing the energy of the impact when compressed.

7.1.3 TEST AT 60KPH AND 30° ANGLE

CONFIGURATION

This test corresponds to the “Post Centred Impact Trajectory” defined by the UNE135900 norm.

DATA RECORDED

The data recorded concern the head accelerations, neck forces and moments in the 3 axis (X, Y, and Z). The rest of the acquisition concerns the movie recordings, two high speed cameras were used as shown in Figure 43.
Figure 43. High speed camera recording the impact and velocity measurements

On Figure 43 the two arrows show the speed measuring tool, placed as closed as possible to the barrier, in order to capture the speed just before the impact. The speed measured in this test was 60.07 kph.

DATA ANALYSIS

With the help of Diadem Software (Data acquisition and analysis), it is possible to observe each parameter measured as a function of time. Relating these data to the movies and pictures taken during the test helps to understand the crash in a first time. The main goal of the first analysis is to have a point of comparison for the other tests, in this way the analysis of this first crash will be detailed, following this procedure:

- Visualisation of the head resultant acceleration
- Identification of the important points of this graph (general shape, acceleration peaks, atypical behaviour…)
- Analysis of the different component (along X, Y and Z axis) to identify occurrence direction of peaks and other important points previously defined.
- Analysis of the forces and moments experienced by the neck, correlation with the points observed previously
- In parallel to this analysis, viewing of the video recording and pictures for correlating the data measured with the behaviour of the barrier and dummy

This procedure allows a good understanding of the crash and will serve as a base for comparison with other crashes. After this analysis step, the forces and moments required by the norm for the validation of the system will be plotted.
and compared to the limit values. The referential used for the data acquisition and analysis is hereby reminded, the fact that during the test, the dummy is leaning on his back has to be reminded as well (X will then be the vertical direction, Y the lateral and Z the longitudinal, see Figure 44).

Figure 44. Reference axis

Head accelerations:
The first parameter to be analysed is the head resultant acceleration.

Note: for the analysis of the head acceleration, the scaling of the graph is from 0 (impact moment) until 75ms.

Figure 45. Resultant Head Acceleration

The first peak occurs at about 3ms and is more than 100 g. This corresponds to the main impact against the barrier (1). Later on, three particular peaks (2, 3 and 4) are noticeable. View of the three components of this acceleration allows a better understanding of what the cause of these peaks are. The accelerometer failed measuring acceleration in the X direction (see Appendix B, Figure B2) and the graph is therefore not presented here.
In the Y direction we can visualize clearly the different peaks observed on the first graph, meaning the impact peak (more than 85 g) and the second, third and fourth peaks at 40, 50 and 60 ms respectively. These acceleration peaks (2, 3 and 4) show hard contact points acting in the Y (lateral) direction. In addition to the forces and moment analysis, the movie analysis might allow a good understanding of these curves.

Along the Z axis (longitudinal), the previously observed peaks are still noticeable but with less intensity. The first impact acceleration value is about 55g, and the others are in the range of 10 to 20 g. Other peaks are however occurring at 20, 32 and 68 ms, of amplitude 25g. While these ones have less influence than the marked ones on the resultant acceleration it is still interesting to interpret their origin. We clearly see from these previous graphs that the...
acceleration is distributed along the Y and Z axis, whereas the dummy does not experience any acceleration in the vertical direction. The acceleration in Y direction was the strongest one (85g compared to 55 in the longitudinal direction Z).

**Neck forces:**

*Force in Y*

The forces in Y have no influence on the homologation assessment procedure; the present analysis is therefore just aiming at understanding better the behaviour.

![Figure 48. Upper neck force along Y axis](image)

The first peak on this curve represents the impact of the head against the barrier at 10ms, and then the second bump will begin at 30 to 35 ms until it reaches a local peak at 40ms. This local peak represents the moment where the metallic system impacts against the barrier post.

To visualize the contact between the system and the barrier post, paint was put on the system and after the crash paint marks ended up on the barrier post as shown in Figure 49. Also, the folded shape of the system after the crash proved the strong contact that occurred between the system and the barrier post, as shown in Figure 49.
Figure 49. Paint marks due to the contact system – barrier post

After the metallic system impacted the barrier post, there is not much room left for energy absorption, the driver then experiences an indirect contact with the post when passing at the height of the post, which explains the point 3 of the previous graph (peak of force in Y direction at about 50 ms.).

Figure 50. Head passing at the height of the barrier post

This Y forces are directly linked to the accelerations observed in the previous part. Each peak of the Y acceleration has been identified thanks to the movie records.
**Force in Z direction**

![Graph of upper neck force in Z direction](image)

*Figure 51. Upper neck force in Z direction*

The force in this direction is obviously the strongest experienced by the driver, about 3500N at its peak, which occurs right at the impact moment. After this impact point the oscillations are in the range 0 to 1kN.

**Upper Neck Moments**

![Graph of upper neck moment around X direction](image)

*Figure 52. Upper neck moment around X direction*

The moment around the X direction being directly related to the force in Y direction, this graph shows a close behaviour, with the two major peaks at the impact time and at about 50ms, when “contacting” with the post. The graphs for moments around Y and Z directions are presented in the Appendix B Figures B9 and B10.
ASSESSMENT OF THE SYSTEM

Table 15.
Assessment of the tested system, according to UNE 135900

<table>
<thead>
<tr>
<th>Cabeza</th>
<th>Cuello</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nivel</td>
<td>HIC36</td>
</tr>
<tr>
<td>Level I</td>
<td>650</td>
</tr>
<tr>
<td>Level II</td>
<td>1000</td>
</tr>
<tr>
<td>Results</td>
<td>318,3</td>
</tr>
</tbody>
</table>

The first part of this table shows the limit values for passing the homologation. Two levels are defined; depending on the results the system can be of level 1 or level 2. In this special case, the barrier tested is of level II, because of the extension moment around Y. In terms of forces, the norm defines graph with limit values (function of time), the measured force during the test is plotted onto these template curves in order to ease the comparison (See Appendix B). The green curve represents the limit value corresponding to the level I whereas the red one represents the limit curve for the level II. In addition to the extension moment around Y, Figure 53 also shows the over passing of the Level I of the compression force Fz of the upper neck.

![Figure 53. Compression force Fz in the upper neck](image)
7.1.4 TEST AT 60KPH AND 45° ANGLE

The test conducted at a 45° angle will be compared to the results obtained in the previous 30° angle impact. The main goal is to show and quantify the difference between a crash at 30° and a crash at 45°, in order to motivate the adaptation of the systems to the real case of accidents, supporting the arguments stated in section 6.5.2.1. In all the graphs, the blue curve represents the test carried out at 30° and the red one represents the present test, at 45° angle.

DATA ANALYSIS

Head accelerations

![Head resultant acceleration](image1)

*Figure 54. Head resultant acceleration*

The peak in the resultant acceleration is about 1.5 times bigger than the one experienced in the previous test. Over the whole time period this resultant acceleration remains higher.

![Head acceleration in Y direction](image2)

*Figure 55. Head acceleration in Y direction*
In the Y direction, the impact peak accelerations are quite close from the first test to the second one (1.4 times bigger in the 45° configuration).

![Figure 56. Head acceleration in the Z direction](image)

In the Z direction (longitudinal), the maximum acceleration reached at the moment of impact is also about 1.5 times bigger than in the previous test, reaching more than 100g.
Upper neck forces

Figure 57. Upper neck force in the Y direction

The first impact is 1.5 times stronger in this direction, we observe much less variations of the force intensity during the impact duration, the force remaining quite high (1.5 kN) during the whole duration. The maximum peak (observed previously when the head passes the barrier post) is in this case less important (about 250N less) and occurs earlier. The force goes back down to zero about 20 ms before the previous test, marking a faster impact.

Figure 58. Upper neck force in the Z direction

The force acting on the neck in the Z direction is the most affected by the change in impact angle, being 2.7 times greater in the case of 45° compared to the case 30°, reaching 9000N. Because of this high angle of impact, the head of the dummy is not directly redirected along the barrier, during the first
milliseconds of the impact the dummy is considerably compressed into the system (see Figure 59) instead.

![0 ms](image1)  ![10ms](image2)

**Figure 59. Compression of the neck during the impact**

**Upper neck moments**

![Graph](image3)

**Figure 60. Upper neck moment around X**

Directly related to the Y force, the moment around the X axis reaches a very high value in this test, fact that is easily observed on the movie, as shown by the following extracts. This peak of moment at about 15ms starts making the head turn around its X axis, the moment is high so that the head ends up being totally tilted compared to the previous test, as shown in Figure 61.
Apart from the increase in angle which obviously induces an increase of the forces and moments at the impact, another responsible of these notable differences is the morphology of the dummy. Indeed, according to the design of the dummy Hybrid III, the shoulder and head of this dummy are most likely to impact the barrier at the same time. In the case of 45° impact angle, the head impacts considerably before the shoulder of the dummy, which also explains the higher peak of acceleration experienced by the head (see Figure 62).
30º test     45º test

Figure 62. Head – shoulder line angle

On these pictures the angles between the barrier and the head-shoulder line are shown. In the 30º case angle this angle is small, explaining a quasi-simultaneous impact of the head and shoulder, whereas the 45º configuration clearly shows an angle between the barrier and the head-shoulder line, assigning the head to more energy absorption from the beginning of the impact.

ASSESSMENT OF THE SYSTEM

The following table (Table 16) shows the results for the HIC and the neck maximum acceptable values.

<table>
<thead>
<tr>
<th>Level</th>
<th>HIC36</th>
<th>Mcox [Nm]</th>
<th>Mcoy ext [Nm]</th>
<th>Mcoy flex [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level I</td>
<td>650</td>
<td>134</td>
<td>42</td>
<td>190</td>
</tr>
<tr>
<td>Level II</td>
<td>1000</td>
<td>134</td>
<td>57</td>
<td>190</td>
</tr>
</tbody>
</table>

Results

| Results (30º, 60kph) | 318,3 | 103,5 | 47,7 | 50 |
| Results (45º, 60kph) | 859,6 | 160,7 | 46,5 | 95,5 |

Ratio

| Ratio | 2,7 | 1,5 | -0,97 | 1,9 |

According to this table, the system does not pass the norm since the moment experienced by the upper neck in the X axis is above the limit values (+20%).
Figure 63 and Figure 64 also show over passing of the limit for two of the measured forces.

**Figure 63. Compression force in the upper neck**

![Graph of compression force over time](image)

**Figure 64. Traction force in the upper neck**

![Graph of traction force over time](image)

These forces are over passing the limit values imposed by the legislation and the system can therefore not be accepted as it is, in the configuration 45°. While the system was working in the first test configuration, the protection of the driver is in that configuration not ensured.
7.1.5 RESULTS AND ANALYSIS

These two tests showed the influence of the impact angle on the severity of the crash and the injuries to the victim. The cause of these differences have been discussed and showed by the different graphs presented in this part of the document. Using the limit values and templates defined by the UNE 135900 allowed to determine if the system passed the norm or not.

These values have been used as references for the protection of the motorcyclist, and then used as base for the comparison of the system under the two different configurations. It has been shown that the system fulfils the requirements for the norm but it is not necessarily protecting a motorcyclist impacting with an angle of 45º, at the same speed. In addition to that, it has been pointed out that the testing procedure defined by the UNE 135900 is representing the specific case in which the motorcyclist impacts both its head and shoulder at the same time. This case probably occurs in a few configurations, depending on the angle of impact but also on the morphology of the motorcyclist and its position at the moment of impact. An evolution of this norm should increase the overall representativity of the testing procedure to real life cases, in order to cover a wider range of scenarios.

Studies from other institutes, presented in the Deliverable D421A of the Aprosys Project (2007) showed cases of motorcyclists impacting the barrier with angles of 60º or more. Tests with such angles were basically planned within this project, but experience and numerical simulations of such situations showed great risk for the dummy integrity, even at low speed of impact, and therefore compromised the necessity of carrying out these tests.

7.2 AMBIENT CONDITION TESTS

7.2.1 INTRODUCTION

Depending on the laboratory in which are carried out the barrier impact tests, the ambient conditions (temperature and humidity) may be different. For example some facilities might be using outdoor test tracks, of which test conditions are considerably depending on the season, the location of the track and its climate. Tests carried out in summer under sunny conditions may present very hot temperatures (especially under the helmet of the dummy) whereas the same tests carried out in winter are under cold temperatures and high humidity (depending on the local climate).

As seen in section 6.5.2.3, the UNE 135900 norm does not take into account these ambient condition potential variations and therefore does not impose any range of values for temperature and humidity to be maintained during the tests. However the protocol bases the assessment of the roadside barrier on the
biomechanics criteria measured on the dummy (HIC, Neck forces), therefore any influence of ambient conditions on the sensors would distort the measurements and consequently the assessment of the barrier. Hereby analysing the UNE 135900 norm, it has been decided to carry out simple tests to study if there is or not influence of the ambient conditions on the measurements realised on the dummy. The performed test aimed at analysing and comparing the sensor response measured for three different temperature conditions.

The **Head Drop test**, as being the calibration method for dummy’s heads, allows a high level of steadiness and repeatability and has therefore been chosen for analysing the ambient conditions influence. Also when calibrating a dummy’s head, the norm defines the acceptable range of values for the resultant acceleration measured, which can be used to evaluate and relate the results obtained in the test.

This test being carried out to prove the existence of an ambient conditions-measures dependency, a set of three different temperatures (10ºC, 20ºC and 30ºC approximately) have been chosen.

### 7.2.2 METHOD

The head of the dummy equipped with a 3-dimensional accelerometer is dropped from a height of 400 mm to a flat metallic surface; the X, Y, Z and Resultant accelerations are recorded by a 3D accelerometer placed in the centre of the head, and plotted.

First, the head of the dummy has been cooled down to about 10ºC for the low temperature test, or warmed to about 35ºC for the high temperature test, whereas the medium temperature test have been carried out under the laboratory ambient conditions, climate chamber at about 20ºC.

### 7.2.3 RESULTS

The temperatures appearing in Table 17 are the temperatures measured right before dropping the head, at the sensor location (centre of the head). The accelerations concern the acceleration peak measured (see the results in Appendix D).
Table 17
Temperature test results

<table>
<thead>
<tr>
<th>Temp (ºC)</th>
<th>Res Accel (g)</th>
<th>Average Values</th>
<th>Fluctuations</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW</td>
<td>11,6</td>
<td>92</td>
<td>11,75ºC</td>
</tr>
<tr>
<td></td>
<td>11,9</td>
<td>89</td>
<td></td>
</tr>
<tr>
<td>AMBIANT</td>
<td>20,1</td>
<td>120</td>
<td>21ºC</td>
</tr>
<tr>
<td></td>
<td>21,9</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td>HIGH</td>
<td>36,3</td>
<td>93</td>
<td>36,3ºC</td>
</tr>
<tr>
<td></td>
<td>36,3</td>
<td>95</td>
<td></td>
</tr>
</tbody>
</table>

Temperature influence on the Measured Acceleration

Figure 65. Temperature influence on the Measured Acceleration

This test shows an obvious influence of the temperature on the measurements, the resultant acceleration measured at the centre of the head variation reaching 25% in the case of low temperature test and 22% in the case of high temperature test. Moreover, for this type of test (calibration), the norm defines the calibration as acceptable when the resultant acceleration is included in the range 100 to 150 g. Considering these values, we can also state that starting from a reference value centred in the range defined by the norm (120.5g at 21ºC), a 10ºC decrease or increase in the temperature brought the measured values out of this acceptable range which represents a considerable influence. Also in both cases (low Temperature and high Temperature) the temperature acts in the same way, leading to an underestimation of the acceleration.
Nevertheless, lowering the temperature has more significant effect on the sensors measurements than increasing it: lowering the temperature to 9.25°C led to acceleration values 24.8% less important whereas a 15.3°C increase led to a 22% cut.

7.2.4 INTERPRETATION AND CONCLUSIONS

According to this test, it is actually difficult to explain accurately the exact cause of that temperature influence but the two major issues are the following:

- Head structure and materials properties changes with temperature
- Sensor stability

The relative influence of these two possible issues need further research to be determined and could then be developed in a deeper study. The humidity was quite hard to manage during this test (way of cooling or warming the dummy’s head) and it is therefore still unclear whether it may have influenced the results, and in what proportion.

This test was aiming at proving the existence of ambient conditions influence on the measurements carried out during the tests, which has been reached. However, the values obtained should not be considered as official reference values since the influence of humidity and temperature has not been quite identified and quantified. So if feasible further more specific testing shall be undergone in order to determine the individual influence of both variable (temperature and humidity) separately. From which conclusions may be drawn that stricter regulations during testing and the ambient conditions may be required.

7.3 PROPELLING SYSTEM

As mentioned in the section 6.5.2.2, the requirements for the propelling system are quite flexible (propelling distance) and might potentially lead to some variations from test to test compromising the robustness of the norm. As the angle and ambient conditions, this remark should be supported by real tests to be reliable.

Two possible ways of testing this are possible. The first one consists in realising the official test (UNE 135900) several times by changing the propelling distance each time, and analyse the influence on the impact point location on the barrier and the velocity before the impact. Locating the impact point on the barrier can be done by covering the dummy’s helmet with paint, which will then mark the barrier at the impact point. This method being barrier and time consuming, a second possible way of testing has been investigated. Throwing the dummy as defined by the norm but without any barrier installed and tracking accurately the trajectory followed by the dummy. An accurate tracking will then allow analysing the trajectory and speed variations along the regulated distance of 2 metres.
7.4 COMMENTS AND DISCUSSION

The tests carried out in this part clearly support the proposition made in the previous chapter, and the attended results for ambient conditions and impact angle dependency have been validated through this phase. Apart from validating the arguments proposed earlier, carrying out these tests showed the difficulty for developing systems through full scale testing. While full scale tests are absolutely necessary for homologation of the systems, their preparation is quite long and therefore restrictive during development phase of an MFD. Moreover full scale testing represents quite high expenses which can clearly slow down the development of the systems.
8. CONCLUSIONS

Assessment programmes as NCAP (New Car Assessment Programme) make the manufacturers improve the degree of protection of their cars by publicly publish their assessment. Basically, the safety of the road user is divided into three major fields, the primary, secondary and tertiary safety. From one type of vehicle to another, the requirements in terms of occupant protection are clearly not the same which obviously makes some vehicles safer than others. However when it comes to road infrastructures designed for safety of the users, all the road users must receive the same degree of importance.

The first part of this study, by analysing the Spanish database of the accidents, comparing the motorcycle accidents with the other vehicles accidents and progressively focusing to the more aggressive accidents has shown in an obvious way that in several accident configurations the motorcyclists really do not receive the same attention as other vehicles: the impacts into guardrails which prevent the vehicles from running out the road and impact into road side objects are especially aggressive to motorcyclists. From this evidence, the study has been oriented to a general state of the art concerning this guardrail accident configuration. Actual protective devices, material, norms and other related actions are identified and described in this document.

These two main steps formed the basis of the project, comparing the accidents facts and the solutions actually proposed by the industrial and the government, in terms of safety. This assessment led to a critical analysis of the actual norm, defining eventual improvements or directions of improvement which could be followed in a near future, in the interest of making it representing the real cases and therefore leading better protective systems.

These propositions have been supported by a testing phase. Along these tests, an outside test track was developed, installing a permanent guardrail. Some of the propositions for improvement of the norm such as the bio mechanic fidelity of the dummy or the propelling system variations have not been tested yet, because of the tight time schedule.

At this point a complete set of improvements of the norm, validated by real tests can be presented and suggested to the authorities. While improving the norm is one part of the safety improvement, it is also important to develop the industrial tool for seeking new concepts of protective devices. The actual simulation model used is working but still need to be improved and validated with real tests.

However, the actual conclusions we can set from the present study are positive and the knowledge of the motorcyclists – guardrails impacts has been considerably developed through the analysis. The future step of this project
mostly concerns the simulation part. The task of modelling the test (UNE 135900 configuration) represents a considerable project in itself and will require some time to be set up and validated. When validated, a great support will be offered to the industrial designing Motorcyclist Friendly Design and the associated reduction of the costs (design / development, homologation, improvements) will hopefully lead to their wider use on the Spanish and later, European roads.

Data about motorcyclist accidents is relatively hard to find and we have seen that accidents reports are still limited to fatal accidents, and sometimes difficult to interpret. Contribution could then be brought by implementing the accident reports with new information and also extend the reports to non fatal accidents, which could allow a better understanding of the crashes.
References


APPENDIX A: UNE 135900 NORM

This regulation defines the evaluation test for Motorcyclist Friendly Devices for road side barriers and has been elaborated by the technical committee Equipamiento Para la Señalización Vial (AEN/CTN 135, Equipment for the Road Signalisation) in 2005.

Its principal objective is to define the methodology for evaluating the behaviour of the protective barrier systems for motorcyclists. This legislation applies to both punctual and continuous protection systems.

Part 1: Testing Procedure

1) Injury criteria used to evaluate the severity of motorcyclist-barrier impact

Head Injury Criteria (HIC36)

This criterion is based on the accelerations felt by the head and is defined by the Equation A.1:

\[
HIC = \max \left[ \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a \, dt \right]^{2.5} (t_2 - t_1)
\] (A.1)

Where a is the resulting acceleration (ax, ay, az) measured at the centre of gravity of the head (as shown in Figure A.1), and \( t_2 - t_1 \leq 36 \text{ms} \):

![Figure A.1 Axis of reference for acceleration measurement head (Driver)](image)

Neck injury criteria

The forces and moments are measured by a load cell placed in the upper neck as shown in Figure A.2:

- \( F_x \): antero-posterior shear force
- \( F_y \): lateral shear force
- \( F_z \): Traction/Compression force
- \( M_x \): lateral flexion momentum
**Mₜₚ**: Flexion/Extension momentum

*Figure A.2 Reference axis for force measurement in the neck*

From these measurements the Neck injury criteria are calculated as follows:

\[ M_{COx} = M_x + F_y D \quad \text{(A.2) Lateral flexion momentum the upper neck.} \]

\[ M_{COy} = M_y - F_x D \quad \text{(A.3) Flexion/Extension momentum at the upper neck.} \]

(with D being the distance between the measurements location and the upper neck).

### 2) Testing procedure

The procedure consists of throwing a dummy leaning on the floor at a determined speed and determined angle against the barrier to be tested.

**Test site**

The track divided in 2 zones (sliding zone and barrier zone) has to be flat (no difference in height more than 2.5%), no presence of rain, ice or snow on the track. The track sheathing might be smooth, and no obstacle that may modify the velocity of the trajectory of the dummy should appear on the track; on the barrier side of the zone the legislation imposes the type of floor to be used.

**Propelling system**

The propelling system has to ensure that the dummy is released from any propelling device at not more than 2 meters before the theoretical impact point.

### 3) Description of the dummy and its equipment

**Dummy and instrumentation**

The dummy to use will be the Hybrid III 50th Percentile Male, with the following modifications:

- In this type of test configuration the *shoulder* and head of the dummy are most likely to impact the barrier. In the original Hybrid III dummy the shoulder is rigid and does not break. For bio-fidelity it is important that the shoulder presents the same resistance as the human shoulder; otherwise it would resist more forces and give unrealistic results for the head measurements. The clavicle of the dummy is changed to a “fuse part”: assembled with screws that have the same resistance as real clavicle.

- The hybrid III dummy is basically designed for car’s frontal crash in a seated position. In the case of the motorcyclist test the dummy has to be leaning on the floor and this requires changing its *pelvis*, to allow the leg rotation around the pelvis axis.

The resulting acceleration in the dummy’s head will be calculated from the tri-axial components recorded with a Channel Class of frequency 1000 (CFC 1000) and an Amplitude of 500 g (CAC 500g).

The forces and moments of the upper part of the neck will be recorded as follows:

- \( F_x \) and \( F_y \): CAC of 9kN, CFC of 1000
- \( F_z \): CAC of 14kN, CFC of 1000
- $M_x$, $M_y$, and $M_z$: CAC of 290Nm and CFC of 600
- For the translation to the upper neck, both forces and moments will have a CFC 600
- The distance $D$ is 0.01778m for the load cells installed in the skull base and 0.008763m for the load cells mounted on the inferior area of the skull basis.

**Dummy equipment**

The dummy will wear an integral helmet of mass 1300kg +/- 0.050 kg with a polycarbonate shell and a motorcyclist suit.

4) **Testing relative data**

Table A.1

<table>
<thead>
<tr>
<th>Type of data</th>
<th>Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous data</td>
<td>Mass of the dummy</td>
</tr>
<tr>
<td></td>
<td>Mass of the helmet</td>
</tr>
<tr>
<td></td>
<td>Mass of the motorcyclist suit</td>
</tr>
<tr>
<td></td>
<td>Mass of the equipped dummy</td>
</tr>
<tr>
<td></td>
<td>Pictures of the dummy</td>
</tr>
<tr>
<td></td>
<td>Pictures of the mounting and barrier location</td>
</tr>
<tr>
<td>Test data</td>
<td>Impact velocity</td>
</tr>
<tr>
<td></td>
<td>Approximation angle</td>
</tr>
<tr>
<td></td>
<td>Position angle</td>
</tr>
<tr>
<td></td>
<td>Acceleration of the dummy’s head</td>
</tr>
<tr>
<td></td>
<td>Forces in the dummy’s neck</td>
</tr>
<tr>
<td></td>
<td>Momentum in the dummy’s neck</td>
</tr>
<tr>
<td></td>
<td>Recording of the video of the barrier</td>
</tr>
<tr>
<td>Posterior data</td>
<td>Description of the damages on the barrier</td>
</tr>
<tr>
<td></td>
<td>Description of the damages on the MFD</td>
</tr>
<tr>
<td></td>
<td>Description of the damages on the dummy and its equipment</td>
</tr>
<tr>
<td></td>
<td>Position and mass of the eventual detached element</td>
</tr>
<tr>
<td></td>
<td>Pictures of the dummy and barrier and MFD</td>
</tr>
</tbody>
</table>

5) **Precisions and tolerances**

**Angle and velocity**

Acceptable impact velocities: 60km/h – 0% + 6%
Acceptable approximation angle deviation: +/- 2º
Acceptable position angle deviation: +/- 2º

**Real impact point**
The real impact point may not be deviated more than 60mm from the effective impact, measured along the barrier, the measure being +/- 15mm accurate.

**Part 2: Test conditions**

1. **Theoretical trajectories**

   The legislation defines three different testing trajectories, as defined below.

   **Trajectory 1: central impact**

   ![Post centred impact trajectory](image)

   *Figure A.3  Post centred impact trajectory*

   In this configuration the trajectory is directed to the centre of the post with an angle of 30°. This trajectory is applicable to both punctual and continuous Motorcycle Friendly Devices.

   **Trajectory 2: Off-centred impact**

   ![Post off-centred impact trajectory](image)

   *Figure A.4  Post off-centred impact trajectory*

   The trajectory of the rider is offset by a distance W from the centre of the post, the angle of impact is still 30°. This trajectory is only applicable to punctual devices.

   **Trajectory 3: Mid span centred impact trajectory**
The trajectory in this case is directed so that the theoretical impact occurs right at the centre between two posts. This is only applicable to continuous installations.

2. Position of the dummy

The dummy is leaning on the ground, aligned with the trajectory line, with the head first in the direction of the impact, as shown in Figure A.6. The dummy has to be laid down on the floor, in horizontal position, completely stretched, lying on its back.

3. Velocity of impact

The velocity of impact is fixed to 60 km/h for all the different tests carried out with barriers.

4. Assessment of the barrier – Behaviour Classes

Assessment of the system from bio mechanical measurements

From the testing procedures described in the previous paragraphs, the legislation defines an assessment of the Motorcycle Friendly Devices: 2 major criteria appear in this assessment:
- The level of protection: result presented in a table form (Table A.2), states the speed of impact and the tests performed (Trajectory 1, Trajectory 2 or Trajectory 3).
- The levels of severity: these levels are obtained from a combination of the biomechanical values obtained. Two levels of severity are defined, depending upon the maximum values that are indicated in Table A.2.

Table A.2
Levels of protection attributed according to the level of severity

<table>
<thead>
<tr>
<th>Nivel</th>
<th>Cabeza</th>
<th>Cuello</th>
<th>Fx  (N)</th>
<th>FzTrajección (N)</th>
<th>FzCompresión (N)</th>
<th>Mcox (N.m)</th>
<th>Mcoy extensión (N.m)</th>
<th>Mcoy flexión (N.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>650</td>
<td>Diagrama 1</td>
<td>Diagrama 2</td>
<td>Diagrama 3</td>
<td>134</td>
<td>42</td>
<td>190</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>1 000</td>
<td>Diagrama 4</td>
<td>Diagrama 5</td>
<td>Diagrama 6</td>
<td>134</td>
<td>57</td>
<td>190</td>
<td></td>
</tr>
</tbody>
</table>

For instance the system will be of a level of severity I if all the biomechanical values are inferior or equal to the ones presented in the table. ‘Diagrams 1 to 6’ refer to the diagrams presented in the next section (Figures A.7 to A.12).

Acceptance criteria for the impact test
No element of the barrier or MFD, weighting more than 2 kg, should be thrown away during the crash. No intrusion, dismembering, or cuts in the dummy should have been induced by the barrier or protection system, except the fuse clavicle. In the continuous systems, no over passing of the dummy is accepted.

Level of protection I

![Figure A.7](image-url) Limit values for the shear force in the neck
Figure A.8  Limit values for traction force in the neck

Figure A.9  Limit values for compression force in the neck

Level of protection II

Figure A.10  Limit values for shear force in the neck
Figure A.11 Limit values for traction force in the neck

Figure A.12 Limit values for compression force in the neck
APPENDIX B: TEST RESULTS (60 KPH, 30°)

Test results are presented in this Appendix, plotted with the help of Diadem tool.

1. Accelerations

Figure B.1  Head resultant acceleration

Figure B.2  Head acceleration along the X axis
Figure B.3  Head acceleration along Y axis

Figure B.4  Head acceleration along Z axis
Forces

Figure B.5  Upper neck force along X axis

Figure B.6  Upper neck force along Y axis

Figure B.7  Upper neck force along Z axis
2. Moments

Figure B.8  Upper neck moment around X axis

Figure B.9  Upper neck moment around Y direction

Figure B.10  Upper neck moment around Z direction

3. Assessment
### Table B.1
Assessment of the tested system, according to UNE 135900

<table>
<thead>
<tr>
<th>Nivel</th>
<th>Cabeza</th>
<th>Cuello</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\text{HIC}_{35}$</td>
<td>$M_{\text{cox}}$ [Nm]</td>
</tr>
<tr>
<td>I</td>
<td>650</td>
<td>134</td>
</tr>
<tr>
<td>II</td>
<td>1000</td>
<td>134</td>
</tr>
<tr>
<td>Resultados trayectoria de impacto de 30º</td>
<td>318.3</td>
<td>103.5</td>
</tr>
</tbody>
</table>

**Figure B.11** Assessment of the force $F_x$ (with template)

**Fuerza cortante [N]**

<table>
<thead>
<tr>
<th>Time [ms]</th>
<th>0</th>
<th>500</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>2500</th>
<th>3000</th>
<th>3500</th>
<th>4000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force [N]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fuerza Compresión [N]**

<table>
<thead>
<tr>
<th>Time [ms]</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
<th>110</th>
<th>120</th>
<th>130</th>
<th>140</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force [N]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure B.12  Assessment of the compression force $F_z$ (with template)

Figure B.13  Assessment of the traction force $F_z$ (with template)
APPENDIX C: TEST RESULTS (60KPH, 45°)

Test results are presented in this Appendix, plotted with the help of Diadem tool.

1. Accelerations

Figure C.1  Head resultant acceleration

Figure C.2  Head acceleration in X direction
2. Forces

Figure C.3  Head acceleration in Y direction

Figure C.4  Head acceleration in the Z direction

Figure C.5  Upper neck force in the X direction
Figure C.6  Upper neck force in the Y direction

Figure C.7  Upper neck force in the Z direction

4. Moments

Figure C.8  Upper neck moment around X
Figure C.9  Upper neck moment around Y

Figure C.10  Upper neck moment around Z
### Table C.1
Assessment of the tested system, according to UNE 135900

<table>
<thead>
<tr>
<th>Nivel</th>
<th>Cabeza</th>
<th>Cuello</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HIC&lt;sub&gt;36&lt;/sub&gt;</td>
<td>M&lt;sub&gt;cox&lt;/sub&gt; [Nm]</td>
</tr>
<tr>
<td>I</td>
<td>650</td>
<td>134</td>
</tr>
<tr>
<td>II</td>
<td>1000</td>
<td>134</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resultados trayectoria de impacto de 30º</td>
<td>318.3</td>
<td>103.5</td>
</tr>
<tr>
<td>Resultados trayectoria de impacto de 45º</td>
<td>859.6</td>
<td>160.7</td>
</tr>
<tr>
<td></td>
<td>+ Incremento</td>
<td>+ 2.7</td>
</tr>
<tr>
<td></td>
<td>- Decremento</td>
<td></td>
</tr>
</tbody>
</table>

**Figure C.11** Assessment of the compression force
Figure C.12 Assessment of the traction force
APPENDIX D: TEST RESULTS (AMBIENT CONDITIONS)

To ensure reliability of the results, two tests have been carried out for each temperature level. Figures D.1, D.2 and D.3 show the results obtained after data acquisition.

**Figure D.1** Tested at 11.9°C, acceleration peak of 90g

**Figure D.2** Tested at 21.9°C, acceleration peak of 120g
Figure D.3  Tested at 36.3°C, acceleration peak of 94g