Roadside infrastructure for safer European Roads: D03 Critical vehicle and infrastructure interactions

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D03: CRITICAL VEHICLE AND INFRASTRUCTURE INTERACTIONS

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and the RISER Consortium

Project funded by the European Community under the ‘Competitive and Sustainable Growth’ Programme (1998-2002)
**RISER CONSORTIUM:**

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Acronym</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chalmers University of Technology (Coordinator)</td>
<td>CHALMERS</td>
<td>Sweden</td>
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<td>European Union Road Federation</td>
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<td>Helsinki University of Technology</td>
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<td>Finland</td>
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<td>Jarkko Valtonen, Marko Kelkka, Ute Gosse</td>
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<tr>
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<td>Graz University of Technology</td>
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<td>VSRC</td>
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<td>Volkmann &amp; Rossbach GMBH &amp; CO.KG</td>
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</table>
FOREWORD

The purpose of this report is to list the observed response of vehicles during excursion into the roadside environment. An analysis of the RISER detailed accident database is provided. This analysis is broken down into the different roadside objects that are of interest for safety design.

Complementing the database analysis are results from the accident reconstruction and simulation activities. These activities provided key information on the impact conditions for different impact types. This data is necessary for evaluating the relevance of different safety countermeasures.

The final piece of documentation provided in this report is the collection and analysis of standardised crash test reports. A range of different safety products were catalogued with their crash test results. These results were compiled to identify what information is available and how it can be applied for road safety designers.

The results of this deliverable should be used as a technical reference to Deliverable 06 - European Best Practice for Roadside Design, the main output of the RISER project.
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INTRODUCTION

The purpose of this report is to describe the relationship between real world crash situations and the crash tests used to approve road equipment in the European Union. The source of data was the reconstruction of accidents collected directly in the RISER project (TNO and CIDAUT), reconstruction of existing accident cases (Chalmers, TUG, and CETE), the analysis of the RISER detailed accident database (VSRC) and the collection of standardised crash tests (HUT). Other partners contributed directly or indirectly to the different tasks in the RISER project.

In addition to the reconstruction of specific crashes, some partners conducted extended parameter studies using simulation models. These simulations were used to observe the specific performance of some roadside structures during crashes.

Using the collection of information from accidents, reconstructions of accidents in further detail, and specific simulation activities, data relating the current performance of roadside infrastructure were identified. These data should give clues how the safety levels of current roads are related to the different types and positions of roadside structures, obstacles, and hazards. A further step to identify the current performance of roadside safety systems is needed to ensure that these structures are safer than common obstacles in the roadside. In addition, the selection of appropriate safety structures should be made with reference to the level of safety they can provide.
CHAPTER 1 OVERVIEW OF INFORMATION SOURCES

The data sources used in the RISER project come from 3 primary areas: a detailed database, detailed reconstruction information, and a cataloguing of standardised crash tests.

1.1 Detailed Database

One goal of the RISER project was to review available databases for detailed accident information and to create a European database specifically for single vehicle accidents using existing sources. This database would include more specific collision information not available from the databases reporting national statistics.

It was an aim of the RISER project to review available databases for detailed accident information and to create a European database specifically for single vehicle accidents using existing sources. This database would include more specific collision information not available from the databases reporting national statistics. The data collected for this database would then be subsequently used to help formulate harmonised European guidelines for roadside infrastructure design and maintenance.

The software used to create the RISER detailed database was adapted from already existing software used in the ROLLOVER database [1], which includes relevant data fields for vehicle damage (e.g. deformation and intrusion) and occupant injuries. However, data fields for Highway, Infrastructure and Causation data fields were not included. Therefore, these had to be created and the data tables linked to the existing tables in the database.

As this project is mainly involved with investigating single vehicle accidents on major arterial roads, a selection criteria document created for RISER was used by the partners to select the most relevant cases for the database. Over a number of months, partners entered their cases into the database and included photographs and sketches of the scene and vehicle.

The database is now made up of 211 single vehicle accident cases from the 7 partners (and therefore 7 countries) involved in this particular task, these being the VSRC, TUG, Chalmers, HUT, CETE, TNO and CIDAUT. Table 1.1 shows the breakdown of these cases across the countries.
### Table 1.1. Breakdown of cases across the RISER participant countries.

<table>
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<tr>
<th>Participant</th>
<th>Country</th>
<th>Database source</th>
<th>Number of cases</th>
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</thead>
<tbody>
<tr>
<td>Chalmers</td>
<td>Sweden</td>
<td>Swedish Road Administration (SRA)</td>
<td>68</td>
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<tr>
<td>VSRC</td>
<td>UK</td>
<td>Co-operative Crash Injury Study (CCIS)</td>
<td>30</td>
</tr>
<tr>
<td>CETE</td>
<td>France</td>
<td>CEESAR (EDA)</td>
<td>33</td>
</tr>
<tr>
<td>CIDAUT</td>
<td>Spain</td>
<td>New cases</td>
<td>11</td>
</tr>
<tr>
<td>TUG</td>
<td>Austria</td>
<td>TUG database</td>
<td>29</td>
</tr>
<tr>
<td>HUT</td>
<td>Finland</td>
<td>Traffic Safety Committee of Insurance Companies (VALT)</td>
<td>30</td>
</tr>
<tr>
<td>TNO</td>
<td>The Netherlands</td>
<td>New cases</td>
<td>10</td>
</tr>
</tbody>
</table>

### 1.2 Accident Reconstruction

Information listed in the RISER detailed database does not completely describe the accident details. In several cases the information could be complemented through the reconstruction of the crash events. This allowed several parameters of interest to be determined; principally the impact speed and angle the vehicle left the road.

Not all accident cases available to the RISER consortium were suitable for reconstructing. Thus some additional simulation studies were collected to collect information needed for developing the design guidelines. This was achieved through the parametric studies of specific impact conditions.

#### 1.2.1 Software Descriptions

The primary reconstruction tool used by the group was PC-Crash, developed by DSD Austria\(^1\). This is a powerful program for the simulation of motor vehicles during many different accident situations.

PC-Crash contains several different calculation models, including an impulse-momentum crash model, a stiffness based impact model, a kinetics model for realistic trajectory simulations, and a simple kinematics model for time-distance studies. The kinetics model has been used for all the simulations to obtain the most realistic trajectories. This driving model allows the consideration of dynamic influences such as suspension characteristics, tire characteristics and weight transfer. Additionally, different road conditions and different driver inputs can be taken into account. The rollover detection application has also been used to take into account the vehicle body to ground contact forces.

MADYMO\(^2\) is a computer program used extensively in the automotive industry. It has both multi-body dynamics and finite element simulation capabilities. Most noteworthy is the database of validated crash test dummies available to the user. Similar to PC-Crash, the MADYMO program can simulate the contact between different objects and has been used to simulate the interaction between cars and roadside barriers. The combination of multi-body vehicle models and FE barrier models is an effective tool to conduct extensive parameter studies without excessive computer resources.

---

\(^1\) Dr. Steffan Datentechnik Ges.m.b.H, www.dsd.at
\(^2\) TNO MADYMO BV, www.madymo.com
LS-DYNA\textsuperscript{3} and PamCRASH\textsuperscript{4} are two common FE programs used in the automotive and roadside hardware research areas. Both programs allow the user to build up detailed models of physical structures and simulate their interaction. Of particular note is the LS-DYNA library of vehicles that is available without charge from the National Crash Analysis Centre at George Washington University. These models represent common vehicles in North America, but they also can provide information for the European car fleet as well.

1.3 Catalogue of Crash Tests

The RISER partner HUT was the task leader of task 2.3 that covered the documentation of available test requirements and test data. HUT asked all RISER partners to customize as much crash test data as possible. This data was collected, summarized, visualized and compared.

One goal of the task was the comparison and analysis of the vehicle accelerations and occupant risk measurements of various products. Another intention was to represent several roadside infrastructure types and their mechanical behaviour. Task 2.3 is furthermore the basis for the following task 2.4. In that task the real world injuries will be compared with the crash test requirements.

1.3.1 Partners

Table 1.2 below presents the countries and partners that made different crash test data available and the actual source of the data. In total, data out of five individual countries was considered.

Table 1.2. Source of included crash test data.

<table>
<thead>
<tr>
<th>RISER partner</th>
<th>Source of used data</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical University of Graz (TUG)</td>
<td>Delta Bloc Europa GmbH</td>
<td>Austria</td>
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<td>Helsinki University of Technology (HUT)</td>
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<td>Volkmann und Rossbach (V&amp;R)</td>
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<td>Chalmers University of Technology (Chalmers)</td>
<td>Swedish National Road and Transport Research Institute (VTI)</td>
<td>Sweden</td>
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<td>The Netherlands Organization for Applied Scientific Research (TNO)</td>
<td>Ministry of Transport Netherlands (Rijkswaterstaat)</td>
<td>The Netherlands</td>
</tr>
</tbody>
</table>

Some of the mentioned partners made contacts with companies or test centres that could provide crash test data. Other partners could contribute their own crash test results. In that way HUT got different crash test reports with similar content. Out of them the most important values respectively test requirements and test data were chosen and tabulated:

- product, product name, material and profile
- performance level
- permanent and dynamic deflection
- ASI value and ASI class

\textsuperscript{3} Livermore Software Technology Corporation, www.lstc.com
\textsuperscript{4} ESI Group, www.esi-group.com
THIV

PHD (Note that PHD has been deleted from further reporting of crash tests. The results are not discussed further in this report)

- system length and height
- test length
- post spacing (if existent)
- anchorage
- test date and test house

Not all reports had all the information in this list.

The main infrastructure types whose data were contributed from five individual partners is identified in Table 1.3 below.

Table 1.3. Main infrastructure types.

<table>
<thead>
<tr>
<th>Country</th>
<th>Infrastructure Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>Concrete Barriers</td>
</tr>
<tr>
<td>Finland</td>
<td>Steel Guardrails, Traffic Signs, Steel and Wooden Lighting Columns</td>
</tr>
<tr>
<td>Germany</td>
<td>Steel Barriers, Guardrails, Crash Cushions</td>
</tr>
<tr>
<td>Sweden</td>
<td>Concrete and Steel Barriers, Guardrails, Crash Cushions</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>Steel Guardrails</td>
</tr>
</tbody>
</table>

Other road furniture is also included, like for example restraint systems that can not be counted as barriers, guardrails or crash cushions.

The different road infrastructure types and the number of their collected test reports are presented in Table 1.4.

Table 1.4. Amount of crash test reports concerning road infrastructure types.

<table>
<thead>
<tr>
<th>Road infrastructure type</th>
<th>Amount of crash test reports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete barriers</td>
<td>10</td>
</tr>
<tr>
<td>Concrete bridge barriers</td>
<td>1</td>
</tr>
<tr>
<td>Steel barriers</td>
<td>11</td>
</tr>
<tr>
<td>Steel bridge barriers</td>
<td>1</td>
</tr>
<tr>
<td>Steel barrier, computer simulated</td>
<td>1</td>
</tr>
<tr>
<td>Steel guardrails</td>
<td>17</td>
</tr>
<tr>
<td>Steel bridge guardrails</td>
<td>2</td>
</tr>
<tr>
<td>Steel restraint systems (gutter construction)</td>
<td>1</td>
</tr>
<tr>
<td>Crash cushions</td>
<td>12</td>
</tr>
<tr>
<td>Steel lighting columns</td>
<td>2</td>
</tr>
<tr>
<td>Wooden lighting columns</td>
<td>1</td>
</tr>
<tr>
<td>Traffic sign columns</td>
<td>1</td>
</tr>
</tbody>
</table>

It has to be mentioned that most of those reports include several tests. That means that there is always more data behind one report than only one test.

In this report the term "restraint systems" is excluding pedestrian restraint systems, arrester beds, terminals and transitions.
References

1 Project “Rollover” European Community – R&TD-Project – 5th Framework-Programme “Growth” – G3RD-CT-2002-00802; 2003,
CHAPTER 2 RESULTS

2.1 Detailed Accident Data

The results in the following chapter describe the findings from the analysis of the detailed database. The full details of the analysis are presented in a RISER internal report maintained by VSRC.

2.1.1 Overview of Data

As previously mentioned, the database is made up of single vehicle accidents. Therefore, for each of the 211 cases, there is one vehicle record, which means there are also 211 vehicle records in the database. There are 370 occupant ('seat occupied') records in total. However, for the 4 coach/bus accidents in the database, only a driver record has been included.

There are 246 highway details (roadside) records and there are 355 struck infrastructure records.

![Country of origin for the accident cases in the RISER detailed database.](image)

Figure 2.1. Country of origin for the accident cases in the RISER detailed database.
Figure 2.2. Accidents sorted by year.

Figure 2.3. The posted speed limit (kph) for the accident cases.

Figure 2.4. The accident severity of the cases in the RISER detailed database.
In general, the accidents reviewed occurred within the last 5 years and occurred on important rural road sections (principal or national roads) or motorways. The accident severity is biased towards fatal injuries due mainly to the contributions from Finland and Sweden which only had access to fatal accidents.

The following figures and tables indicate that the accidents tend to occur on dry roads and daylight conditions, not unexpected if one considers the exposure of vehicles to these road conditions.
**2.1.2 Vehicle Information**

Most of the vehicles in the database were passenger cars, with a few heavy vehicles and a small number of motorcycles also, see Table 2.6. The vehicles were relatively new as seen in Figure 2.8.
### Table 2.6. Vehicle types.

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Number of vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>194</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>7</td>
</tr>
<tr>
<td>Truck</td>
<td>6</td>
</tr>
<tr>
<td>Bus/coach</td>
<td>4</td>
</tr>
</tbody>
</table>

![Figure 2.8. Manufacture year for vehicles involved in the accident cases.](image)

In general we can conclude that the types of collisions in the database are representative of serious crashes occurring on the road network.

#### 2.1.3 Casualty Information

The following information indicates the occupants of the vehicles and their injury severity. More than half of the cases are single vehicle, single occupant crashes, see Table 2.7. There was a 60% seatbelt usage rate for the occupants with documented restraint use, see Table 2.9.
Table 2.7. Number of occupants per case

<table>
<thead>
<tr>
<th>Number of occupants</th>
<th>Number of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120</td>
</tr>
<tr>
<td>2</td>
<td>47</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>40-70</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 2.8. Occupants seat position.

<table>
<thead>
<tr>
<th>Seat position</th>
<th>Number of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 - Driver</td>
<td>211</td>
</tr>
<tr>
<td>1.2 - Front passenger</td>
<td>1</td>
</tr>
<tr>
<td>1.3 - Front passenger</td>
<td>83</td>
</tr>
<tr>
<td>2.1</td>
<td>30</td>
</tr>
<tr>
<td>2.2</td>
<td>9</td>
</tr>
<tr>
<td>2.3</td>
<td>31</td>
</tr>
<tr>
<td>2.4</td>
<td>1</td>
</tr>
<tr>
<td>3.1</td>
<td>2</td>
</tr>
<tr>
<td>3.2</td>
<td>0</td>
</tr>
<tr>
<td>3.3</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2.9. Seatbelt usage.

<table>
<thead>
<tr>
<th>Seatbelt used?</th>
<th>Number of occupants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>196</td>
</tr>
<tr>
<td>No</td>
<td>130</td>
</tr>
<tr>
<td>Unknown</td>
<td>33</td>
</tr>
<tr>
<td>N/A</td>
<td>11</td>
</tr>
</tbody>
</table>

In a number of cases, there was more than one airbag activated in a seat position. Therefore, the following tables show the actual number of airbags which were activated (Table 2.10), plus the type of airbags activated (Table 2.11).

Table 2.10. Airbag activated.

<table>
<thead>
<tr>
<th>Airbag activated?</th>
<th>Driver (1.1)</th>
<th>Front passenger (1.3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>44</td>
<td>7</td>
</tr>
<tr>
<td>No</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>Unknown</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>N/A</td>
<td>140</td>
<td>63</td>
</tr>
</tbody>
</table>
Table 2.11. Location of airbag activations.

<table>
<thead>
<tr>
<th>Location</th>
<th>Driver</th>
<th>Front passenger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steering wheel hub</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>Side-seat mounted</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Side-header rail</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Fascia</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Door</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Unknown</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td>7</td>
</tr>
</tbody>
</table>

2.1.4 Injury Data

The information in Table 2.12 below shows how the injuries to the occupants were distributed. It is important to identify the number of injuries that are higher than an AIS of 2 (moderate risk or higher) or AIS 3 (risk of severe injury or higher).

Table 2.12. Distribution and severity of occupant injuries.

<table>
<thead>
<tr>
<th>AIS Level</th>
<th>0 no injury</th>
<th>1 minor</th>
<th>2 moderate</th>
<th>3 serious</th>
<th>4 severe</th>
<th>5 critical</th>
<th>6 maximum</th>
<th>9 unknown</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIS Body Region</td>
<td>1. Head</td>
<td>5</td>
<td>53</td>
<td>33</td>
<td>48</td>
<td>60</td>
<td>20</td>
<td>17</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2. Face</td>
<td>1</td>
<td>104</td>
<td>31</td>
<td>5</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>3. Neck</td>
<td>0</td>
<td>26</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>4. Thorax</td>
<td>1</td>
<td>28</td>
<td>25</td>
<td>45</td>
<td>62</td>
<td>24</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>5. Abdomen</td>
<td>1</td>
<td>14</td>
<td>39</td>
<td>13</td>
<td>12</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>6. Spine</td>
<td>2</td>
<td>23</td>
<td>12</td>
<td>10</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>7. Upper Extremity</td>
<td>3</td>
<td>105</td>
<td>30</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>8. Lower Extremity</td>
<td>11</td>
<td>84</td>
<td>40</td>
<td>51</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>9. Unspecified</td>
<td>35</td>
<td>12</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>59</td>
<td>449</td>
<td>214</td>
<td>181</td>
<td>143</td>
<td>55</td>
<td>45</td>
<td>30</td>
<td>1176</td>
</tr>
</tbody>
</table>

Summarizing the information in terms of risk of moderate or severe injury, we can see from Table 2.13 that half of the injuries analysed had at least a moderate (AIS 2) injury and about 1/3 had at least a severe injury. Of these injuries, the head and thorax (chest) were the most vulnerable body regions for injury.

Table 2.13. Risk of moderate or severe injury.

<table>
<thead>
<tr>
<th>AIS Body Region</th>
<th>AIS 2+</th>
<th>AIS 3+</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Head</td>
<td>15.5%</td>
<td>12.7%</td>
</tr>
<tr>
<td>2. Face</td>
<td>3.5%</td>
<td>0.8%</td>
</tr>
<tr>
<td>3. Neck</td>
<td>0.9%</td>
<td>0.7%</td>
</tr>
<tr>
<td>4. Thorax</td>
<td>15.0%</td>
<td>12.8%</td>
</tr>
<tr>
<td>5. Abdomen</td>
<td>5.8%</td>
<td>2.4%</td>
</tr>
<tr>
<td>6. Spine</td>
<td>2.7%</td>
<td>1.7%</td>
</tr>
<tr>
<td>7. Upper Extremity</td>
<td>3.3%</td>
<td>0.7%</td>
</tr>
<tr>
<td>8. Lower Extremity</td>
<td>8.3%</td>
<td>4.8%</td>
</tr>
<tr>
<td>Total</td>
<td>55.1%</td>
<td>36.6%</td>
</tr>
</tbody>
</table>
The following table shows the source of the body injury as provided in the detailed database. It has been divided to indicate the number of injuries caused by occupant contacts inside the car, outside the car (due to ejection or rollover), contacts with fixed objects, or other sources. The percentages reported are only for the injuries where the contact source is known.

**Table 2.14. Injury source.**

<table>
<thead>
<tr>
<th>Injury Causing Part</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior parts of vehicle - Windscreen area</td>
<td>26</td>
<td>6.3%</td>
</tr>
<tr>
<td>Interior parts of vehicle - Dashboard area</td>
<td>45</td>
<td>10.8%</td>
</tr>
<tr>
<td>Interior parts of vehicle - Centre console</td>
<td>12</td>
<td>2.9%</td>
</tr>
<tr>
<td>Interior parts of vehicle - Steering wheel rim</td>
<td>29</td>
<td>7.0%</td>
</tr>
<tr>
<td>Interior parts of vehicle - Steering wheel hub</td>
<td>13</td>
<td>3.1%</td>
</tr>
<tr>
<td>Interior parts of vehicle - Footwell</td>
<td>15</td>
<td>3.6%</td>
</tr>
<tr>
<td>Interior parts of vehicle - Roof</td>
<td>11</td>
<td>2.6%</td>
</tr>
<tr>
<td>Interior parts of vehicle - Side between A- and B-pillar</td>
<td>42</td>
<td>10.1%</td>
</tr>
<tr>
<td>Interior parts of vehicle - B-pillar</td>
<td>5</td>
<td>1.2%</td>
</tr>
<tr>
<td>Interior parts of vehicle - Side between B- and C-pillar</td>
<td>7</td>
<td>1.7%</td>
</tr>
<tr>
<td>Interior parts of vehicle - Side between C- and D-pillar</td>
<td>3</td>
<td>0.7%</td>
</tr>
<tr>
<td>Interior parts of vehicle - Rear parcel shelf</td>
<td>2</td>
<td>0.5%</td>
</tr>
<tr>
<td>Interior parts of vehicle - Seat</td>
<td>20</td>
<td>4.8%</td>
</tr>
<tr>
<td>Interior parts of vehicle - Seat belt system</td>
<td>31</td>
<td>7.5%</td>
</tr>
<tr>
<td>Interior parts of vehicle - Air bag system</td>
<td>10</td>
<td>2.4%</td>
</tr>
<tr>
<td>Interior parts of vehicle - Baggage or other loose object</td>
<td>1</td>
<td>0.2%</td>
</tr>
<tr>
<td>Interior parts of vehicle - Penetrating object into interior</td>
<td>17</td>
<td>4.1%</td>
</tr>
<tr>
<td>Parts of environment: Run over</td>
<td>21</td>
<td>5.0%</td>
</tr>
<tr>
<td>Parts of environment: Road surface</td>
<td>4</td>
<td>1.0%</td>
</tr>
<tr>
<td>Parts of environment: Road kerbstone</td>
<td>11</td>
<td>2.6%</td>
</tr>
<tr>
<td>Parts of environment: Post, tree (rigid roadside object)</td>
<td>28</td>
<td>6.7%</td>
</tr>
<tr>
<td>Exterior part of vehicle - Windscreen glass</td>
<td>9</td>
<td>2.2%</td>
</tr>
<tr>
<td>Exterior part of vehicle - A-pillar</td>
<td>1</td>
<td>0.2%</td>
</tr>
<tr>
<td>Exterior part of vehicle - Roof</td>
<td>26</td>
<td>6.3%</td>
</tr>
<tr>
<td>Others</td>
<td>10</td>
<td>2.4%</td>
</tr>
<tr>
<td>N/A</td>
<td>17</td>
<td>4.1%</td>
</tr>
<tr>
<td>Unknown</td>
<td>760</td>
<td>(not included)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1176</td>
<td></td>
</tr>
</tbody>
</table>

This table is relevant for road infrastructure as it indicates that the source of injury is most likely inside the occupant compartment, in particular between the A and B pillar (door). Relatively few injuries (6.7%) are attributed to contact of the occupant to obstacles outside the vehicle while the vehicle is upright and the occupant contained by the vehicle.

### 2.1.5 Intrusion Information

The passenger compartment should be as intact as possible and intrusion increases the risk of injury. In the following Table 2.15, the zone which had the greatest number
The right side of the vehicle had more intrusion records (175) than the left side of the vehicle (154).

Overall, the specific intrusion zone with the greatest number of intrusion records in the database was the area between the A and B pillar, at windscreen height on the left of the vehicle (47).

Table 2.15. Zone and height level of intrusions into the compartment.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Height level</th>
<th>Number of intrusion records</th>
<th>1. Left</th>
<th>2. Right</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Footwell</td>
<td>Windscreen</td>
<td>6</td>
<td>6</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Dashboard</td>
<td>9</td>
<td>7</td>
<td></td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Footwell</td>
<td>15</td>
<td>18</td>
<td></td>
<td>33</td>
</tr>
<tr>
<td>2. A- to B-pillar</td>
<td>Windscreen</td>
<td>47</td>
<td>42</td>
<td></td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Dashboard</td>
<td>22</td>
<td>30</td>
<td></td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>Footwell</td>
<td>14</td>
<td>17</td>
<td></td>
<td>31</td>
</tr>
<tr>
<td>3. B- to C-pillar</td>
<td>Windscreen</td>
<td>18</td>
<td>25</td>
<td></td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>Dashboard</td>
<td>6</td>
<td>11</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Footwell</td>
<td>5</td>
<td>8</td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>4. C-pillar to cell line</td>
<td>Windscreen</td>
<td>9</td>
<td>8</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Dashboard</td>
<td>2</td>
<td>2</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Footwell</td>
<td>1</td>
<td>1</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 2.9. Overview of the intrusion zones and height levels.
2.1.6 Summary

Occupant injuries in the RISER detailed database vehicle are relatively severe. Over half of the reported injuries are moderate (AIS 2 or higher). The head and chest are the most commonly injured areas. Occupant injuries tend to arise from contacts with the vehicle compartment. Most injuries are also related to contact with the door area where there is more reports of vehicle intrusion.

2.2 Highway Detail Information

Details of the road geometry and general accident events are described in Table 2.16 and Table 2.17. There seems to be little correlation between the vertical alignment of the road and the severity of the crash. Fatal accidents were reported in half of the level road, uphill, and downhill collisions.

Table 2.16. Vertical alignment of the road where first run-off occurred.

<table>
<thead>
<tr>
<th>Vertical alignment</th>
<th>Fatal</th>
<th>Serious</th>
<th>Slight</th>
<th>Non-injury</th>
<th>Unknown</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uphill*</td>
<td>19</td>
<td>8</td>
<td>8</td>
<td>2</td>
<td>1</td>
<td>38</td>
</tr>
<tr>
<td>Downhill**</td>
<td>25</td>
<td>2</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>43</td>
</tr>
<tr>
<td>Flat</td>
<td>41</td>
<td>22</td>
<td>33</td>
<td>2</td>
<td>1</td>
<td>99</td>
</tr>
<tr>
<td>Unknown</td>
<td>29</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>31</td>
</tr>
<tr>
<td>Total</td>
<td>114</td>
<td>33</td>
<td>58</td>
<td>4</td>
<td>2</td>
<td>211</td>
</tr>
</tbody>
</table>

* Uphill gradients range from 0.5% to 12%
** Downhill gradients range from -0.2% to -13%

Similar to vertical alignment, curves had about the same risk of fatality as straight roads. Due to exposure, the amount of driving in curves should be lower than straight driving. Thus it must be determined if the number of accidents in curves and straights represent the frequency we would expect.
Table 2.17. Horizontal alignment of the road where first run-off occurred.

<table>
<thead>
<tr>
<th>Horizontal alignment</th>
<th>Accident severity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal</td>
</tr>
<tr>
<td>Left Bend</td>
<td>32</td>
</tr>
<tr>
<td>Right Bend</td>
<td>28</td>
</tr>
<tr>
<td>Straight</td>
<td>44</td>
</tr>
<tr>
<td>Unknown</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>114</td>
</tr>
</tbody>
</table>

Interesting information about the manner in which the vehicles leave the road is provided in Table 2.18. First encroachments to the roadside occur on the near side in 65% of all the cases. However, if a vehicle experiences more than 1 encroachment to the roadside (over-correction) then more than 85% of the time the vehicle crosses over to the opposite road edge. This indicates that vehicles leaving the road once should stay off the road.

Table 2.18. Side of encroachments for first and second run-off.

<table>
<thead>
<tr>
<th>1st run-off</th>
<th>2nd run-off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nearside</td>
<td>Offside</td>
</tr>
<tr>
<td>Nearside</td>
<td>3</td>
</tr>
<tr>
<td>Offside</td>
<td>2</td>
</tr>
<tr>
<td>Median</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>13</td>
</tr>
</tbody>
</table>

2.2.1 Summary

The road geometry related to the accidents in the RISER detailed database indicates that there is approximately the same risk of fatality for accidents occurring in the different geometrical alignments of roads. About half of all the accidents in curves or tangent sections, horizontal or grade sections, were fatal accidents. Further research of exposure must be explored outside the RISER project to determine if the frequency of the accidents in these locations is consistent with the amount of time vehicles experience these road sections.

2.3 Struck Infrastructure Information

A listing of the objects that were struck by vehicles in the accidents recorded in the RISER detailed database is provided in Table 2.19 on the next page. These objects include safety equipment as well as hazards. This list is not an extensive list of all obstacles that may be found in the roadside as the limited amount of cases did not describe every possible accident type.

Table 2.19 summarises all the impacts reported in the 211 cases of the RISER database. These cases may contain more than one impact and these multiple impacts are not always the same objects. Thus the table indicates how many cases had an impact with a roadside object (Number of cases), and how many impacts in total were found in the database for each object (Number of impacts). The final column only represents the percentage of impacts recorded for each object.
Table 2.19. Summary of all impacts in the RISER detailed database.

<table>
<thead>
<tr>
<th>Struck Infrastructure</th>
<th>Number of cases</th>
<th>Number of impacts</th>
<th>% of impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety barrier - steel</td>
<td>52</td>
<td>61</td>
<td>17.2%</td>
</tr>
<tr>
<td>Safety barrier - concrete</td>
<td>5</td>
<td>5</td>
<td>1.4%</td>
</tr>
<tr>
<td>Safety barrier - termination</td>
<td>13</td>
<td>13</td>
<td>3.7%</td>
</tr>
<tr>
<td>Safety barrier - wire rope</td>
<td>1</td>
<td>1</td>
<td>0.3%</td>
</tr>
<tr>
<td>Bridge parapet</td>
<td>4</td>
<td>4</td>
<td>1.1%</td>
</tr>
<tr>
<td>Safety barrier - other</td>
<td>2</td>
<td>2</td>
<td>0.6%</td>
</tr>
<tr>
<td>Sign post</td>
<td>16</td>
<td>18</td>
<td>5.1%</td>
</tr>
<tr>
<td>Lighting pole</td>
<td>18</td>
<td>18</td>
<td>5.1%</td>
</tr>
<tr>
<td>Telegraph pole</td>
<td>10</td>
<td>11</td>
<td>3.1%</td>
</tr>
<tr>
<td>Tree</td>
<td>38</td>
<td>50</td>
<td>14.1%</td>
</tr>
<tr>
<td>Non-safety fence</td>
<td>10</td>
<td>10</td>
<td>2.8%</td>
</tr>
<tr>
<td>Hedge</td>
<td>1</td>
<td>1</td>
<td>0.3%</td>
</tr>
<tr>
<td>Wall</td>
<td>4</td>
<td>4</td>
<td>1.1%</td>
</tr>
<tr>
<td>Bridge pier</td>
<td>8</td>
<td>8</td>
<td>2.3%</td>
</tr>
<tr>
<td>Rock/boulder</td>
<td>17</td>
<td>18</td>
<td>5.1%</td>
</tr>
<tr>
<td>Fog pole</td>
<td>2</td>
<td>2</td>
<td>0.6%</td>
</tr>
<tr>
<td>Embankment/slope</td>
<td>55</td>
<td>66</td>
<td>18.6%</td>
</tr>
<tr>
<td>Ditch</td>
<td>16</td>
<td>16</td>
<td>4.5%</td>
</tr>
<tr>
<td>Drainage gully</td>
<td>3</td>
<td>4</td>
<td>1.1%</td>
</tr>
<tr>
<td>Foot path</td>
<td>1</td>
<td>1</td>
<td>0.3%</td>
</tr>
<tr>
<td>Pedestrian underpass</td>
<td>1</td>
<td>2</td>
<td>0.6%</td>
</tr>
<tr>
<td>Other</td>
<td>30</td>
<td>35</td>
<td>9.9%</td>
</tr>
<tr>
<td>N/A</td>
<td>5</td>
<td>5</td>
<td>1.4%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>312</strong></td>
<td><strong>355</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>

The first points to note are that combined impacts for safety barriers represented about 24% of all the impacts. Since there is considerable coverage of barriers on the road network we should find that the barriers are a frequently struck object. The combination of tree, sign post, and poles represented 27% of the impacts. This is consistent with previous accident studies indicating that these types of narrow objects are often involved in single vehicle collisions. The other roadside feature that is often reported in the RISER database is the terrain features like ditches, embankments, and gullies.

An enhancement of the RISER database over previous accident databases is the reporting of obstacle position. Two methods are used to record the position of the object relative to the road. The first is the roadside region where the obstacle was located. Figure 2.11 below shows how each identifiable zone beside the road was separated and categorized. In addition, a setback measurement (in metres) for each object was also recorded as much as possible.
In Table 2.20 below, the location of the struck objects are identified by roadside zone. The first three zones adjacent to the travel lane (A, B, C) each contain about 25% of the struck objects. While these zones are acceptable for the safety barriers, it is disturbing to find trees located even in the first zone (A).
Table 2.20. Location of struck infrastructure sorted by roadside zone.

<table>
<thead>
<tr>
<th>Struck Infrastructure</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>AB</th>
<th>BC</th>
<th>CD</th>
<th>ABC</th>
<th>BCD</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety barrier - steel</td>
<td>39</td>
<td>18</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>61</td>
</tr>
<tr>
<td>Safety barrier - concrete</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Safety barrier - termination</td>
<td>2</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Safety barrier - wire rope</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Bridge parapet</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Safety barrier - other</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Crash cushion</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Arrester bed</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sign post</td>
<td>9</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Lighting pole</td>
<td>6</td>
<td>9</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Telegraph pole</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Tree</td>
<td>2</td>
<td>14</td>
<td>25</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Non-safety fence</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Hedge</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Wall</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Bridge pier</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Rock/boulder</td>
<td>2</td>
<td>9</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Fog pole</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Embankment/slope</td>
<td>3</td>
<td>13</td>
<td>24</td>
<td>15</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>Ditch</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Drainage gully</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Foot path</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Cycle path</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Foot bridge</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pedestrian underpass</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>6</td>
<td>10</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>N/A</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td>86</td>
<td>98</td>
<td>82</td>
<td>32</td>
<td>8</td>
<td>13</td>
<td>13</td>
<td>2</td>
<td>1</td>
<td>20</td>
<td>355</td>
</tr>
</tbody>
</table>

| Percentage (%)                        | 24.2| 27.6| 23.1| 9.0| 2.3| 3.7| 3.7| 0.6| 0.3| 5.6 |

Further analysis of the obstacle position can be made from Figure 2.12 on the next page. Here a range of the minimum and maximum setback distances for each obstacle is recorded. Unfortunately, there are too many objects with a short distance to the moving traffic. These distances (1 and 2m) are within the area that is universally accepted as a clear or safety zone which should be free of obstacles.
The primary function of safety barriers is the protection of traffic from roadside hazards. Table 2.21 lists the obstacles close to the road which were protected by barriers, as recorded in the RISER detailed database.

Table 2.21. Obstacles protected by safety barrier.

<table>
<thead>
<tr>
<th>Struck infrastructure</th>
<th>Number protected by safety barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sign post</td>
<td>2</td>
</tr>
<tr>
<td>Lighting pole</td>
<td>2</td>
</tr>
<tr>
<td>Tree</td>
<td>2</td>
</tr>
<tr>
<td>Wall</td>
<td>1</td>
</tr>
<tr>
<td>Bridge pier</td>
<td>5</td>
</tr>
<tr>
<td>Embankment/slope</td>
<td>5</td>
</tr>
<tr>
<td>Pedestrian underpass</td>
<td>2</td>
</tr>
<tr>
<td>Other*</td>
<td>5</td>
</tr>
</tbody>
</table>

* One river, two streams, a cluster of trees and a gantry pole

The protection of barriers is achieved by extending the barrier in advance of the obstacle to create a shield (or shadow area) where the vehicle can not enter because it is blocked by the barrier. Table 2.22 and Figure 2.13 provide some information related to the position of barriers relative to obstacles that were still struck by vehicles. This information is important when designing minimum length of need for a protection system.
Table 2.22. Position of barrier relative to struck obstacle.

<table>
<thead>
<tr>
<th>Struck obstacle</th>
<th>Protection before (m)</th>
<th>Protection beyond (m)</th>
<th>Vehicle action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree</td>
<td>45.9</td>
<td>Unknown</td>
<td>Drove off road before barrier started and hit sign post</td>
</tr>
<tr>
<td>Wall</td>
<td>54</td>
<td>Unknown</td>
<td>Drove off road before barrier started &amp; hit bridge pier under construction</td>
</tr>
<tr>
<td>Bridge pier</td>
<td>53</td>
<td>Unknown</td>
<td>Drove off road before barrier started &amp; hit bridge pier of under-passing road.</td>
</tr>
<tr>
<td>Embankment/slope</td>
<td>95</td>
<td>97</td>
<td>Hit barrier from rear and travelled along top before hitting start of parapet and going down embankment</td>
</tr>
<tr>
<td>Embankment/slope</td>
<td>48</td>
<td>Unknown</td>
<td>Vehicle hit barrier termination</td>
</tr>
<tr>
<td>Stream</td>
<td>62</td>
<td>Unknown</td>
<td>Drove off road before barrier started and goes down embankment into stream</td>
</tr>
<tr>
<td>River</td>
<td>6</td>
<td>26</td>
<td>Vehicle hit barrier termination</td>
</tr>
<tr>
<td>Gantry pole</td>
<td>11</td>
<td>Unknown</td>
<td>Vehicle hit barrier termination</td>
</tr>
</tbody>
</table>

Figure 2.13. Protection distance before obstacle.

A final point to note is the number of times that a vehicle passed through or over different obstacles, as shown in Table 2.23. Safety barriers should contain the vehicle and not allow them to go through into areas behind the barrier. Conversely, breakaway posts should allow this process.
Table 2.23. Impacts resulting in a vehicle going through or over obstacle.

<table>
<thead>
<tr>
<th>Infrastructure type</th>
<th>Through</th>
<th>Over</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety barrier - all types</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>Post/poles</td>
<td>19</td>
<td>3</td>
</tr>
<tr>
<td>Tree</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Rock/concrete objects</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Fences/hedges</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Sloping ground</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Other</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>54</strong></td>
<td><strong>52</strong></td>
</tr>
</tbody>
</table>

2.4 Summary

The accident data collected in the RISER project provided interesting information about the types of obstacles struck in single vehicle accidents. Although some objects are intended to lie in the safety zone, a large number of unsafe obstacles were also located within one metre of the road. A significant improvement in safety could be achieved through just the removal of these obstacles.

Some objects were found to be protected by safety barriers. In several cases, the vehicle was able to come behind the barrier and strike the object that should have been shielded from traffic. Thus the length of barrier installations needs to be addressed.

Finally there were a number of cases where vehicle went through or over the safety barrier. These cases can be due to improperly installed barriers, vehicle types that are incompatible with the barrier, or special cases where, for example, the vehicle climbed up on a ramped barrier end and continued on the top of the barrier.
CHAPTER 3    ACCIDENT RECONSTRUCTION RESULTS

3.1 Accident Reconstruction: PC Crash

The PC CRASH analysis tool has been used for the reconstruction of accidents, allowing describing the impact conditions and also the vehicle kinematics during the event of the impact itself. It takes into account vehicle manoeuvres prior to the crash, and it is convenient for accidents which involved elements of the road environment with complex geometry such as embankments.

The accidents reconstructed for the detailed database were analysed to obtain impact conditions. Details from these reconstructions are stored in the RISER detailed database as well as internal reports maintained by the respective partner. An example of the type of information obtained from these reconstructions is found in Appendix A.

An example of the type of information collected by a detailed reconstruction of the accident is shown in Figure 3.1 below. This is the exit speed of the vehicle compared to the posted speed for the road section.

![Figure 3.1. Vehicles exit speed compared to the posted speed for the reconstructed cases.](image)

Another important piece of information for the accident is the exit angle of the vehicle. The reconstructed cases included the initial departure, re-entry, and subsequent exit speeds and angles for the cases when applicable.

Important information to note is observed in Figure 3.2. The plot shows that 85% of all the reconstructed accidents had initial departure speeds from the roadway under 110 km/h. Figure 3.3 shows similar information for the exit angle for the vehicles. The 85%ile of vehicle initial departure angles are under 20 degrees. Both these distributions provide some justification for the standard test conditions for a heavy passenger vehicle (discussed in Chapter 5).
It is important to recognize that there are two different exit angles of interest, see Figure 3.4. The angle denoted PSI indicates the vehicle's orientation relative to the
road edge whereas the angle NY indicates the vehicle’s trajectory (velocity vector) relative to the road edge. In standard crash tests, PSI and NY are the same value.

Figure 3.4. Visualization of the two exit angles of interest.

Some of the important results collected from the RISER reconstructions are provided in the following results. Results from the simulations are stored in the detailed database as well as internal reports maintained by the respective partners.

### 3.1.1 Tree impacts

Collision speed makes a difference to the severity of the accident. The chart in Figure 3.5 shows the cases which had both impact and post-impact speed recorded for the tree impact. The chart shows that in many cases, much of the vehicle's speed was lost during the impact with the tree. And in the fatal cases, the vehicle generally struck the tree at a greater speed, and therefore lost a greater amount of speed during impact.
Figure 3.5. Speed at impact and after impact in tree collisions.

Figure 3.6 below shows a comparison of the vehicle's initial speed before the accident and the speed at impact, for the cases where data was available. This chart shows how much the vehicle in each accident slowed down from its original speed before impacting the tree. In many cases, the vehicle did not slow down at all.

Figure 3.6. Speed at impact compared to initial speed for tree collisions.
3.1.2 Pole/Post Impacts

Figure 3.7 shows the cases which had impact and post-impact speed recorded for the pole impact.

Of the three poles impacted, one was wooden and three were concrete. None were energy absorbing or breakaway poles.

A comparison of the vehicle's initial speed before the accident and the speed at impact with the pole or post is shown in Figure 3.8.
All poles were metal, apart from 3 which were concrete, and 2 which were wooden. Two were energy absorbing, breakaway poles.

### 3.1.3 Sloping Ground

Figure 3.9 shows the cases which had collision and post-collision speed recorded for the collisions with the slope or ditch. There was no post impact speed data available for any of the fatal cases.

Figure 3.9. Speed at impact and after impact for accidents involving sloping ground.

A comparison of the vehicle’s initial speed before the accident occurred and the speed at impact with the sloping ground can be seen in Figure 3.10 below.
Figure 3.10. Speed at impact compared to initial speed for accidents involving sloping ground.

3.1.4 Safety Barriers

Figure 3.11 shows the cases which had impact and post-impact speed recorded for the barrier impact.

D = Ditch or gully, E = Embankment/cut slope, F = Fatal, S = Serious, Sl = Slight, Non = Non-injury
A comparison of the vehicles initial speed (before the accident occurred) and the speed at impact with the safety barrier is shown in Figure 3.12.
In the database, accidents involving barriers occur more often on dual carriageway roads (motorway and non-motorways). There were more single run-offs than multiple, although the proportion of multiple run-offs was greater than with other types of struck infrastructure.

As expected, barriers tended to be closer to the carriageway edge than other types of struck infrastructure.

Although there were fatal cases involving barriers, some were due to other factors in the accidents (e.g. non-car impacts, other subsequent impacts not recorded in the database). However, some were due to the failure of the barrier to protect the vehicle and its occupants.

### 3.2 Accident Reconstruction: Finite Elements

Simulation tools based on finite element method allow modelling with detail the behaviour of vehicles and structures under impact conditions. The purpose of this
activity was to analyse the response of different roadside features such as metal barriers and poles when they deform under the impact loads that occur in crashes. Infrastructure types that were not well represented in the detailed accident database were also selected for more detailed reconstruction investigations.

### 3.2.1 Pole/Post Impacts

Frontal impacts against narrow obstacles such as poles, posts and trees have been identified as critical accident cases. As it has been shown in the previous analysis, the vehicle (and its occupants) experience a severe speed change during a crash with these small diameter and essentially rigid hazards. There were a significant number of occurrences and casualties observed in the detailed and police level databases.

The resulting vehicle and occupant behaviours during pole and post impacts were analysed in detail. For this purpose, a finite element vehicle model has been used that reproduces the crush behaviour of the frontal part of a small-size light, passenger car so that the most critical impact case is addressed. A control simulation of the vehicle model crashed into a rigid pole was performed and it was checked that its behaviour was consistent with the one observed in different regulations and test analyses (see Figure 3.13).

The vehicle model was then used to simulate impact conditions in order to describe the most critical mechanisms that cause risks to occupants. The reference scenario was the analysis from an existing case in which a car struck a lamp post (see Figure 3.14).

The results represent the behaviour of common metal lighting and support poles, generally built from thick sheet metal (thicknesses up to 4 mm), and fixed to the ground without deformable, breakable or detachable features.

These results, in terms of measured vehicle kinematics (mainly accelerations) are then processed to assess the severity to occupants, according to the procedures defined by standards EN 1317 and EN 12767. Additionally, the measured data are used to simulate occupant behaviour inside the vehicle with the MADYMO simulation tool to assess the potential for occupant injuries.

For the lighting pole, the severity that was determined for a light passenger vehicle impacting against this type of obstacle reached ASI values between 1.5 and 1.8 for speeds between 44 and 50 km/h. The risk for injuries are beyond the levels recommended by EN 1317 and 12767.

Also in this study, to assess the potential risks of injuries in these accidents, some different scenarios were analysed. Simulations were performed considering the possible different values for the relevant aspects, of the system: different anchorages to the ground, with different levels of strength, so that they can break up under different loading conditions; different vehicle impact velocities, different vehicle masses. The results contain information such as observed deformations, accelerations and velocities, and impact forces.
The first impact pattern addressed was one representing objects with extremely little deformation upon impact. This model would comprise, for example, poles made of materials such as concrete and cast metal, which can often be found in urban and non-urban roads. Their structural design, including the fixing elements to the ground, is regulated by European Standard EN 40-3 for lighting columns, which specifies the characteristic loads to be considered. On the other hand, in many cases, these products are not compliant with standard EN 12767 and so do not include any specific deformable or breakaway feature.
Simulations were performed in order to analyse poles of this type that are currently present in the market (Figure 3.15). Results in terms of severity concluded that in general they would clearly cause to the occupants of a light passenger vehicle risks of injury beyond the acceptable limits according to EN 12767 passive safety standard, with ASI values up to 2.1 – 2.2.

A review of certain typical designs that are currently sold and installed on roads was conducted from the point of view of Standard EN 40-3. It was concluded that these items tend to be clearly overly-stiff, thus more threatening in impact in comparison with the minimum structural resistance that would be required to carry in their normal operational loads.
Following the results of the previous simulations, new analysis models were built in order to address the response of breakaway systems as an alternative. Generic designs for the poles' attachment to the ground were modelled according to the specifications of EN 40-3 Standards, introducing the effect of calibrated breakable bolts that were at the same time able to support the characteristic loads. This way, the potential modification for safety performance was assessed.

Results show that the potential for safety improvement is highly dependent on the design of the support structure. Poles of small or medium size, which are less exposed to weight and wind loads, can implement breakable connections to the ground and fulfil EN 40-3 at the same time. This improves the severity indices measured in the vehicle and safety for occupant (see Figure 3.16).
Figure 3.16. Sequence showing the impact of a small passenger vehicle against a breakable post.

In this case, the results show that the use of calibrated bolt connections in the pole base can result in an improved severity index, with an ASI value of 1.0 or less.

Pole designs with larger sizes have demonstrated more difficulty for safety improvement, because of their geometries and masses. In these cases, stronger structural design requirements introduce that difficulty.

The breakaway scheme was analysed in various setups changing parameters such as the resistance of the link to the ground, impact conditions and vehicle mass. When vehicles impact at a higher velocity, it has been observed that they have a greater capacity to break the anchorages of the post, but for those systems with a calibrated breakaway level for the bolts in the post base, severity is not necessarily increased with velocity. The momentum transfer occurs rapidly, involving to the inertial forces from the most forward parts of the vehicle. The forces transferred to the occupants are not clearly more risky. On the contrary, for pole systems that do not have a safe breakaway behaviour at lower speeds, vehicles impacting at greater velocity may be able to detach the system, but this does not mean that this behaviour is safe enough, and generally the severity indices are still above the acceptable values. Vehicles with
structural designs tailored for their size and weight have been shown to have quite similar results in terms of occupant severity measurements.

As a conclusion, it is observed that a most critical interaction mode between poles and vehicles is the direct impact of vehicles against non-deformable or detachable posts. Breakaway mechanisms in the base are a convenient way to improve their safety in those locations where the detachment of a pole does not cause additional risks of eventual secondary impacts.

Other types of post impacts were addressed in the study. Sign posts, although they have not been found as aggressive as strong lighting and utility poles, were involved in several accidents and so their impact behaviour was analysed.

Sign posts can be hazardous when vehicles leave the carriageway and impact them, because this interaction is able to cause the vehicle to lose control and stability. The survey of support elements that are currently regulated or allowed to be placed on roads showed that structural metal profiles are commonly installed on the roadsides to support small signs, but generally not shielded by safety barriers. In order to determine the risks of an eventual impact against these objects, simulations of a light passenger vehicle impacting a common traffic sign were performed (Figure 3.17).

![Figure 3.17. Sequence showing the impact of a light passenger vehicle against a sign post](image)

The vehicle acceleration time histories show that in this type of accidents, there is a low risk for severe injuries due to the direct impact, but it has to be noted that, for instance, a small light car hitting a 4 mm-thick steel profile which can be currently
installed on roads, would experience an estimated ASI value up to 1.2. It was also observed in these simulations that the post impact causes the vehicle’s wheels lift off the ground and affect the vehicle’s trajectory.

3.2.2 Safety barrier impacts

When addressing this kind of impacts with safety barriers, finite element simulation allows modelling components directly related with potential problems because a more detailed description of the geometry and material properties are implemented. Phenomena such as vehicle deformation or snagging and barrier deflection or failure in materials or joints are modelled with these analyses. The results obtained include the time history of the vehicle motions and permits the calculation of injury assessment parameters. The images from Figure 3.18 illustrate the results of a finite element simulation of a safety barrier impact.

Using the finite element analyses, the results show the influence on the vehicle response due to certain barrier characteristics:

1. Bearing capacity of the beam and its anchorages to the ground
2. Post spacing
3. Post – beam connection
4. Spacer: featured / not featured, and geometry.
5. Calibrated frangible joints.

The mechanical interaction between a vehicle and a safety barrier can studied assuming that the vehicle is a moving body that is leaving the road with a velocity V. The velocity vector (the direction of which does not necessarily have to be equal to the vehicle’s heading direction) determines the vehicle’s momentum vector. It can be expressed by its longitudinal and transversal components (Figure 3.19).
Figure 3.18. Sequence showing the impact of a small passenger vehicle against a steel guardrail.
Figure 3.19. Vehicle velocity vector.

If a vehicle, during its interaction with a safety barrier, is to be prevented from leaving the road, then the transversal momentum has to be made equal to zero during its interaction. This implies that redirecting forces are exerted on the vehicle and these are the contribution of:

- Contact forces between the barrier and the vehicle
- Forces acting in the contact between the vehicle’s wheels and the ground.

These forces can be either contributing or hindering to redirection.

In the redirection process, the vehicle’s trajectory is altered and its kinetic energy can be decreased (dissipated) because of:

- Energy absorption due to deformation of the vehicle and the barrier,
- Friction forces working between the vehicle’s wheels and the ground
- Momentum transferred to elements of the barrier that get detached

The finite element analyses of safety barrier impacts allow the detailed description of the loading conditions (stresses, strains) of the materials through the impact phenomena. This is useful to explain cases of barrier failure and for proposing improvements to the systems.

A failure mechanism observed in the accident analysis was used as a reference case. The vehicle not contained because of barrier terminal detachment. The impact behaviour for varying barrier terminal anchorage capacity was analysed. The actual impact conditions that take place on the road differ from standard conditions in which road restraint systems are tested and approved.

Figure 3.18 and Figure 3.21 show the behaviour of a barrier which is able or unable to contain and redirect a vehicle, respectively. The difference in the two cases is the anchorage capacity of the terminal. It has to be noted that in this accident in particular, the impact point is closer to an end terminal than it would be in a typical crash test installation. This means that worse conditions than the tested ones can take place on roads.
Figure 3.20. Impact against an end section of a safety barrier. Terminal anchorage to the ground performs according to its design.
Figure 3.21. Impact against an end section of a safety barrier. Terminal anchorage to the ground fails to perform according to its design.
3.3 Accident reconstruction – Madymo

The MAYDMO simulation tool is able to analyse the phenomena that take place inside the vehicle during its interaction with the infrastructure. The above mentioned tools (mainly finite element simulations) can provide a description of the overall vehicle kinematics, and then MADYMO assesses the interaction of the occupants with its envelope by using surrogates (crash test dummy models).

The mechanical interaction between the occupant and the vehicle parts involved, being a result of the behaviour of such different components as vehicle body and door structures, inner trimmings, and even restraint systems, is modelled by unified contact laws that reproduce a sample vehicle. The outputs of these simulations are an additional source of data that are analysed together with the standard injury parameters that are obtained from the vehicle motion.

Measurements are obtained from the behaviour of the main parts of the occupant body that are affected by the accident scenarios of the project, i.e. head and chest. Human surrogate (dummy) models are inserted in a vehicle that represents the typical envelope that occupants have inside a car (Figure 3.22).

![Figure 3.22. MADYMO model for the analysis of the vehicle-occupant interaction](image)

### 3.3.1 Pole/post impacts

MADYMO was applied to the analysis of the interaction between vehicles and identified critical elements of infrastructure such as posts and poles. From the point of view of the vehicle, finite element reconstruction described in Section 3.2.1 identify the vehicle motions and allowed the calculation of severity indices according to different safety standards (EN 12767, EN 1317). From these results, MADYMO models are able to describe the occupant behaviour inside the car for the given vehicle kinematics.

Three representative cases were analysed. The first one involves a lighting pole, non-breakable and built in sheet metal. The second one is a rigid -cast iron- lamp post. The third one is a modified version of the second, in which a breakable fixing to the ground is implemented, using specific calibrated bolts. Figure 3.23 shows the comparison of the behaviour of the three cases.
Figure 3.23. Comparison of the occupant response in impacts against poles. Case 1 (left): sheet metal pole. Case 2 (centre): cast iron pole. Case 3 (right): cast iron pole with breakaway system.

Case 1 (sheet metal pole) was analysed via finite element simulations, with a severity index obtained of ASI=1.6. This would mean a considerable risk of injury for occupants, as is it observed in Figure 3.23, left column. Despite the action of
occupant restraint systems (seat belt), the occupant motion implies high probability of
direct impact of the head on the steering wheel. Case 2 (cast metal pole) is a
dangerous impact. Previous analyses yielded an ASI value over 2, and the occupant
simulations also predict high risk of occupant due to head impacting the steering
wheel. Finally, case 3 demonstrates how a breakable—or eventually, deformable-
pole would improve the safety performance. Predicted ASI value was 0.9, and Figure
3.23, right column, shows how the vehicle is slightly decelerated by the crash, but
then continues its motion causing not so serious loads for passengers.

Figure 3.24 shows a comparison of various injury criteria that describe the risk of
occupant injury in head and thorax.

![Comparison of occupant injury criteria for analysed impacts.](image)

### 3.3.2 Safety barrier impacts

Following the finite element analysis in a safety barrier impact (Section 3.2.2),
MADYMO has been used to study the occupant response inside the vehicle. Figure
3.25 shows what happens in an impact of a vehicle against a still vehicle restraint
system, at a speed of 100 km/h and an impact angle of 20 degrees, which are
standard conditions. It can be observed that there is an impact against the door and
that the head is projected towards the window. It is observed that the injury
assessment parameters for head and chest are threatening for the occupant, as they
are more critical than those obtained in a sample frontal impact crash test under the
EuroNCAP protocol.
Figure 3.25. Occupant motion inside a vehicle that is crashing against a stiff safety barrier.
3.4 Introduction Madymo simulation

This section describes the research work carried out at TNO Automotive as part of the EC project ‘Roadside Infrastructure for Safer European Roads’ (RISER) and contributes to the work package to investigate the technical performance data for roadside infrastructure. Simulations with computer models were executed to get insights in the injury criteria. This report gives an overview of the performed simulations and the results.

The objective of this research is to investigate the influence of various parameters on the car’s occupant response in collisions with roadside infrastructures.

B.1 Research setup

A computer model is built in the modelling and simulation tool ‘Madymo’ and the model parameters are varied with each simulation.

Two roadside objects are chosen as subject of research: a guard rail and a rigid pole structure.

The choice of these structures has been made on the information available in the RISER national statistics database. The analysis results from this database show that tree- and pole impacts happen with a high frequency and with a high probability the occupants will not survive the accident. The guardrail is a device, which is commonly used to protect motor vehicles from hazards along the roadside. The purpose of the guardrail is to redirect the vehicle away from the hazard and slow down along the guardrail.

Two MADYMO models of the roadside devices, the guardrail and the pole were developed and simulations with a combination of the roadside models and a car model were performed. Before using the guardrail, the performance of the guardrail has been tested and has to fulfil the criteria described in the European normalisation document EN 1317. The criteria are related to human body criteria but the relationship with the commonly used automotive criteria, like Head Injury Criterium (HIC) is not clear. This research should give some insights in the relationships between guardrail criteria and automotive criteria.

The research has been divided in several steps to accomplish the objectives of this project. The following tasks were performed:

1. Implementation of roadside infrastructure in Madymo;
2. Validation of models against tests;
3. Set up of a simulation matrix;
4. Investigation of dummy behaviour in:
   a. Frontal impact;
   b. Side impact.
5. Stochastic simulation with the Madymo tool ADVISER: Parameter variations of the models in order to determine potential improvement directions;

6. Conclusions.

B.2 Modelling of vehicle-infrastructure collisions

To perform a simulation the configuration can be split up in a model of the vehicle with an occupant and a model of respectively the guard rail and the pole. The different models used in the simulation are described in this chapter.

3.4.1 Vehicle model:

Roadside accidents involve all types of vehicles, e.g. small or large passenger car, vans and trucks. They differ significantly due to mass, structure and geometry. Different roadside restraint systems and different vehicles have to interact properly to ensure safe operation during collisions in an accident. The vehicle structure has to be compatible with the roadside hardware in geometry and crash stiffness to ensure safe operation during the interaction with the roadside safety barriers.

TNO has developed a MADYMO car fleet of seven multibody cars for NHTSA. These models represent the American vehicle fleet and they are used effectively for compatibility studies. From this fleet the smallest model has been chosen, because its weight came closest to the regulatory weight described in European protocol EN 1317.

In this section the existing model of the Geo Metro, a small passenger car, and the major steps to modify its existing MADYMO model are described. The modified vehicle model was used to simulate as well as the lateral as the frontal pole impacts.

3.4.1.1 GEO Metro existing models:

3.4.1.1.1 GEO Frontal impact model:

Huibers developed MADYMO models of the GEO-Metro for frontal and side impact [1]. He used the NHTSA open public, finite element model to build the Multi body model (Figure 3.26). The vehicle model is built up of rigid bodies connected by kinematic joints, within each system of multi bodies, or by means of spring dampers (restraints) in the connection of the two systems. The rigid bodies represent the undeformed part of the vehicle structure. The joints positions and connections are chosen at locations where a structural collapse can be expected, as researched in the past by finite element calculations or from tests. The restraint characteristics in the joints and connections are calculated by means of components calculations of the vehicle structure at the location of joints or connections. It should be noted that the multi body model is not as accurate as the finite element model, but the required simulation time is reduced drastically. Madymo is a good tool to make simulations, especially with the long simulation time needed for car –guardrail simulations because a crash takes more or less 0.5 second. The lack of details has to be accounted for in another way. For example, for the contacts a small local deformation is accounted for by the contact stiffness. In this model there are some finite element systems present. At the front of the models a facet surface is modelled, this midway
of finite element and multibody surface is for contact interactions between vehicle and barrier or other vehicle. This surface does not have any stiffness characteristics. Such a facet surface consists of a mesh of quads and triangles. The nodal points of the mesh are connected to bodies especially defined for this purpose and which are connected to the structural bodies by means of spring dampers restraints.

The tunnel and the firewall are more detailed and they have the function to transfer the load from an intruding engine. The front suspension is a realistic representation of the real suspension. The bumper and the radiator are modelled to simulate the intrusion through the front surface. The knee bolster and the steering wheel are modelled to take the intrusion into account and to better represent the human kinematics. Besides, the windshield is added to restrain a deploying airbag. Finally a driver seat is modelled to take the interaction with the human surrogates into account and to study the injury mechanism during the impact. Zweep Van Der and Kellendonk G. optimized this vehicle model for the compatibility study [2, 3].
The side impact model is derived from the finite element model\cite{1;2;3}. It is validated against full-scale crash tests. The model is built up for use with European test procedures and also for the American standards. The major undeformable car mass is modelled with a surface plane attached to one rigid body located in the center of gravity of the vehicle structure. The seat is also modelled to make realistic load transfer to the dummy possible.

The deforming side structure of the car is modelled in more detail. A facet surface is attached to the side bodies to provide the contact interaction with incoming vehicles or barriers. The model is equipped with two seats, a driver's seat and a rear passenger seat.
3.4.1.1.2 *Geo Metro Suzuki swift; real car, Multibody and finite elements models*

The GEO Metro models presented in the section above is developed to simulate a frontal or a side impact. Therefore, only the main components involved in one of these collisions are modelled in detail. The center of gravity of the vehicle approximately agrees with the real GEO Metro. Concerning the oblique impact analysis with the roadside hardware, the crashworthy structure consists of fender, wheel house, upper longitudinal beams, cross beams, etc. Furthermore, the distribution of the mass should be adjusted so that the center of gravity matches the real car.

In the model of Geo Metro frontal model, the major components of the front part, such as the front surface, the longitudinal beam, the frontal steering and suspension system were copied into the modified model. The model of the outdoor left side is added to take the intrusion of the side structure into account. The focus is on the driver compartment as a first start in optimizing car-roadside furniture. Consequently, the left-hand sill and B-pillar is modelled in detail (Figure 3.29).

![Figure 3.29. B-pillar, and sill of the old and the modified model](image)

The left side of the frontal model is connected to the right part by means restraints. These MADYMO features represent a combination of a simple system of a spring-damper. The modified vehicle structure should maintain this connection. The restraints are connected to several bodies of the sill structures instead (Figure 3.30). B-pillar, and sill of the old and the modified model of two in the frontal model. The B-pillar is connected to the roof structure by means of a restraint. (Figure 3.31).
In addition, the door panel was included in order to take the intrusion of the door into account during the impact (Figure 3.31-a). It is modelled with a surface plane attached to rigid bodies and connected to each other by 1 degree of freedom rotational joints and connected to the B-pillar by means of free joints. The stiffness of the door panel was modelled by means of restraints (spring/damper systems). A facet surface was also attached to the left side structure in order to represent in detail the interaction of the left side structure with the roadside barrier during an oblique collision (Figure 3.31-(b)).

The left side window is also included to represent the interaction between the human surrogates and the door. A rigid body represents the window and a surface plane is attached to this body to represent the contact interaction with the human surrogates. The plane is attached to the rest of the car body by means of restraints (Figure 3.33). The contact characteristics of the window were derived from literature.

L, Rooij van et al, adopted the curve of Mizuno for the pedestrian head on impact with the windshield (Figure 3.32).
Actually, Mizuno developed force-deformation characteristics from headform impact with the windshield on a small passenger car at a speed of 40 km/h. The first peak is chosen in the curve since that represents the windshield up to the point of shattering. The second peak in the curve is caused by the stiffness from the layers of the windshield, which is not present in side window glass.

The window is attached to the roof, B-pillar, and A-pillar by means of three point restraints (Figure 3.33).
Finally, validation is performed to compare the performance of the modified vehicle model against the front and the lateral impacts with the pole. The mass added was adjusted so that the distribution of the mass remains equal to the old model.

The validation consisted of simulations with a rigid pole in frontal and lateral pole impact.

**Discussion**

The modified vehicle model of the Geo Metro was validated for the frontal crash scenario. It is uncertain whether in case of oblique impact the vehicle will interact well with roadside barriers that present a curb, such as the New Jersey Barrier (Figure 3.35. New Jersey Barrier).

Therefore future work should include the modelling of other vehicle components such as:

Steering system: The steering system plays a crucial role in determining the trajectory and the stability of the Geo Metro especially during redirection events. If the
redirection of the wheel is too abrupt, the vehicle may experience a tripping mechanism that can lead to rollover.

Rear suspension: The rear suspension of the vehicle should be modelled in detail because it is involved in the redirection of the errant vehicles.

Drive shaft: Modelling this feature is important to replicate the rear axle compliance otherwise the resulting response is too stiff.

Human Surrogates

Safety engineers needed something that could simulate the human reaction without using a living human being. The human surrogates that replaces the human being is the crash test dummy. The first crash test dummies appear in the jet fighters tests. Later, General Motors developed the new crash test dummies used in automotive industries. This section gives an overview of the anthropometric test dummies used in this research study. The two dummies are the Hybrid III 50th Percentile male for frontal collisions and the EuroSID-2 (ES-2) for lateral impacts. Since there is no existing test dummy designed for oblique impact, both side and frontal impact dummy are used and their responses are compared.

3.4.2 Hybrid III 50th percentile dummy:

The Hybrid III 50th Percentile male crash test dummy, representing the average adult male, is the most used dummy in frontal crash and automotive safety restraint testing. The Hybrid III 50th male features a neck design that simulates the human dynamic moment / rotation, flexion and extension response characteristics of an average size adult male. The shoulder structure was designed for improved fidelity of shoulder belt interaction. The neck can incorporate a six-axis neck transducer at the top and bottom. The upper torso has 6 high strength steel ribs with polymer based damping material to simulate human chest force-deflection characteristics. The lower torso has a curved cylindrical rubber lumbar spine that provides human-like slouch of a seated person and mounts to the pelvis through an optional three axis lumbar load cell. The pelvis is vinyl skin/urethane foam molded over an aluminium casting in the seated position. The ball-jointed femur attachments carry bump stops to reproduce the human leg to hip moment/rotation characteristics. The femur, tibia and ankle can be instrumented to predict loads in the lower extremities. The foot and ankle simulate heel compression and ankle range of motion.
3.4.3 EuroSID-2 (ES-2):

The ES-2 is a Side Impact test device designed as a lateral impact dummy and meets the specifications stated in EURO NCAP.

The ES-2 represents a 50th percentile adult male without lower arms. The head is modified from the Hybrid III 50th percentile dummy and the legs are modified from the Hybrid II 50th. The shoulder has low-friction sliding clavicles that carry the half arm. The thorax consists of three identical rib modules, which can be assembled onto the spine box for either left or right side impacts. The rib modules consist of a spring and damper design. The abdomen is constructed of polyurethane foam that incorporates curved, weighted rubber slabs. The shape of the pelvis assembly is representative of the human pelvis at points impacted in a side impact, and at points where the car seat and the belt interact with the pelvis. The removable iliac wings are constructed of special polyurethane plastic. A straight rubber lumbar is used. A Neoprene suit covers the thorax, upper arms and lower pelvic region.
B.3 Guardrail model:

This section describes the development of the double w-beam guardrail model. This type of guardrail is used on Dutch motorways. First a real world model is presented and then the MADYMO model is described.

3.4.4 Double w-beam guardrail:

The device undergoing modelling is a double w-beam guardrail. It consists of three main parts:

3.4.4.1 Tubular Post:

The tubular post consists of a circular tub with a diameter of 76 mm and a thickness of 5mm. The post is formed into an oval at the top in the mounting area of the guard. The length of the post is 1,710 meter. The lower part of the tube is flattened over a length of 0.930 meter. It is beaten placed into the soil every 1.33 meter [4]. The posts are driven 1.00 meter deep into the ground (Figure 3.38).
3.4.4.2 Block out:

The blockout is a bent double guardrail spacer, which is made from 3mm sheet metal, and the main dimensions are 780 mm length, 194mm and 113mm [4]. The spacer is fitted at the top end of each post with three bolts. The w-beam guard rails are fitted at an angle of 6 degree to each of these supports on both sides with a bolt, (Figure 3.39).
3.4.4.3 W-beam guardrail:

Two guardrail elements comprise the two facing rail elements that are connected together by 8 round head bolts with ergot and 8 M16 washers [4]. Each guardrail is secured on each side of the blockout by one bolt and a washer, (Figure 3.39)
The w-beam guardrail is made of steel. The material properties are defined in the table below:

Table 3.1. Material properties of the w-beam guardrail.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density [Mg/mm³]</td>
<td>7.86E-09</td>
</tr>
<tr>
<td>Young's Modulus [MPa]</td>
<td>200E+03</td>
</tr>
<tr>
<td>Poisson's Ratio</td>
<td>0.33</td>
</tr>
<tr>
<td>Yield stress [MPa]</td>
<td>315</td>
</tr>
</tbody>
</table>
MADYMO model of the w-beam guardrail:

3.4.5 The Post system:

The post system consists of one rigid body positioned at a ground level height, which is the center of gravity of the real post. The post soil-interaction, which plays a key role in the response of the guardrail system during the impact, was modelled by means of spherical joints. The joint is positioned at ground level height with respect to the norm NEN 5190 and has a resistance to bending for rotation around x, y and z-axes. The stiffness of the joint was modelled by means of rotational springs (Cardan restraints in MADYMO terminology). The properties of the springs are defined from literature [5]. The value of the stiffness is influenced by many factors such as the relative density, moisture content, and cohesiveness of the soil and depth below the grade. Others factors that affect the stiffness modulus are the nature of the applied load, the post deflection, and the properties and geometry of the post. For granular, non-cohesive soils typically used as roadway base material the properties are shown in Table 4.

<table>
<thead>
<tr>
<th>Dry unit weight of soil [N/mm3 ]</th>
<th>0.98E-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content</td>
<td>0.08</td>
</tr>
<tr>
<td>Specific gravity of soil</td>
<td>2.65</td>
</tr>
<tr>
<td>Degree of saturation</td>
<td>0.6</td>
</tr>
</tbody>
</table>

*Table 3.2. Properties of the soil used in the model of the post*

The stiffness that was implemented in post systems is presented in table 5.

<table>
<thead>
<tr>
<th>Springs direction</th>
<th>Stiffness (N/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Around x</td>
<td>1.75E+04 N/m</td>
</tr>
<tr>
<td>Around y</td>
<td>1.75 E+04 N/m</td>
</tr>
<tr>
<td>Around z</td>
<td>2.5 E+04 N/m</td>
</tr>
</tbody>
</table>

*Table 3.3 Stiffness of the springs used in post soil interaction*

The total number of posts implemented is 25; the shape is represented by means of an ellipsoidal surface. The post system is shown in Figure 3.40.
3.4.6 The block-out system:

The block-out in the double w-beam guardrail is fitted with the post. The block-out is modelled by an ellipsoid surface attached to a rigid body mounted at the height of 610 mm with respect to the ground. The block-out is connected to the post system by means of break-joint, which means no displacement of the block-out with respect to the post is allowed. This simplification hypothesis is chosen because there is a small deformation of the block-out during guardrail collisions (Figure 3.41).

3.4.7 The W-beam guardrail:

MADYMO model of the w-beam guardrail consists of 25 posts and only 36 meters of the safety fence was modelled.

The beam system consists of different portions connected to each other by means of bolts. Since the deformation in multibody systems is represented in the joints each rail portion was divided into 4 rigid bodies connected to each other by means of
kinematic joints. The left-hand rail MADYMO model consists of 168 joints, which are positioned at the same height level. The beam is divided into 97 parts of 0.665 meter length each. The ellipsoids, which model the beam, are attached to each rigid body and connected each other by means of spherical joints. In these joints certain characteristics are defined to take into account the bending and the torsion stiffness of the beam. To model the tensional or the axial stiffness of the beam translational joints are introduced. The gap between the translational and the spherical joint is almost equal to zero (Figure 3.42).

![Figure 3.42. MADYMO Guardrail model](image)

The bending stiffness is derived from the basic formula of a beam

\[ K_{\text{bending}} = \frac{E \cdot I}{\text{length}} \]  

(8)

The axial stiffness is derived from the following formula:

\[ K_{\text{axial}} = \frac{E \cdot A}{l} \]  

(9)

Where A is the cross section, E is young modulus and l is the length of the safety fence.

The values of the stiffness implemented in the model are presented in Table 3.4:
Table 3.4. Stiffness of the springs used in rail model

<table>
<thead>
<tr>
<th>Type</th>
<th>Stiffness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending stiffness</td>
<td>6.22E+05 N/m</td>
</tr>
<tr>
<td>Axial stiffness</td>
<td>2.54E+07 N/m</td>
</tr>
<tr>
<td>Torsional stiffness</td>
<td>6.22E+05 N/m</td>
</tr>
</tbody>
</table>

The connection between the rail and the post system is modelled by means of restraints. The stiffness of these springs is obtained from component tests [23].

The stiffness of the spring implemented in the MADYMO model of a guardrail was derived from the curve of experiment [5] (Figure 3.43) the value of the stiffness is about 6.22E+05 N/m.

![Figure 3.43. Force-deflection results from uni-axial load tests on bolted connection [5]](image)

The simulation test set up of the w-beam guardrail consisted of 36 meters guardrail section. The MADYMO model of the entire system should include the end effect. Accurate simulation of the w-beam guardrail is very much dependent on the accurate representation of the unmodelled portions. Since the w-beam redirects impacting vehicles primarily through beam tension, elastic springs are attached to the ends of the unmodelled w-beam to simulate its continuation in both directions. Initially, the behaviour of the unmodelled portion of the W-beam is assumed to be in the elastic range during impact. The stiffness of the spring is derived from the following relationship:

\[ K = \frac{E \cdot A}{l} \]  

(10)
Where $E$ is the steel modulus of elasticity, $A$ is the w-beam cross-section area, and $L$ is the length of the unmodelled portion of the beam that normally interacts with the vehicle during a crash event. The model of guardrail is build up of left and right half parts where the right is a copy of the left part. Finally the model of the double w-beam guardrail is implemented (Figure 3.44):

### 3.4.8 Discussion

The MADYMO model of the w-beam guardrail contains the major characteristics of the real guardrail. However, this model represents the basic structure of the w-beam guardrail that is used at Dutch motorways and there are a lot of versions of this barrier. Future work should take the variety of these models into account.
3.5 Rigid pole model

Trees and utility poles present a serious roadside hazard due to the unforgiving nature of existing pole designs worsened by the large number of poles and trees located in close proximity of the roadways. The purpose of this section is to present a MADYMO model of the rigid pole used in this research.

The pole is modelled by a rigid body and a surface cylinder is attached for contact interaction. Figure 3.45: MADYMO model of rigid pole

The model is available in a MADYMO database (Figure 3.45). The diameter of the pole is 0.3 meter. The deformation of the pole is considered negligible with respect to the vehicle structure deformation. The pole is embedded in the soil and connected to the soil by a break joint, which means that there is no relative displacement of the pole during the collision event.

The friction of the pole is 0.3, and its contact stiffness is about 1E+07 N/m.

The simplification of the rigid pole with no deformation is the worst case scenario of an utility pole. Future research should take into account variability in pole geometry and material parameters by modelling a deformable pole.

3.6 Frontal pole impact:

The purpose of this section is to present the first simulation scenario; the frontal pole impact. A correlation between the simulation results and a full-scale test is made.

The Geo Metro was positioned to strike the pole structure in the middle of its front surface. The car impacted the pole with a speed of 35 km/h at an angle of 0 degrees with respect to the pole structure. The impact scenario is shown in the Figure 3.46.
Figure 3.46. The maximum deformation of the front surface of the car at 75 ms after impact.

The vehicle model was instrumented with a restrained anthropometric test dummy Hybrid III 50 percentile male. It was equipped also with a driver air bag and a seat belt. Besides, the car is instrumented with accelerometers in order to compute the acceleration pulse. The accelerometers are positioned in the B-pillar left hand side, right hand side, and in the front surface. The dummy is also instrumented with accelerometer in order to compute the acceleration acting on the human surrogates during the crash event. The total mass of the vehicle and the dummy is 883kg; the total mass of the pole is 150kg. The duration of the simulation is about 200ms.

3.6.1 Simulation results:
3.6.1.1 Structural adequacy:

At the impact the vehicle structure of the Geo Metro began to deform in response to the collision with the rigid pole. During the loading of the car, the front surface of the Geo Metro is crumpled. The maximum deformation of the contact surface is reached at 75 ms. Vehicle damage is confined to the front surface. No occupant compartment intrusion occurred at this low speed of impact. shows the behaviour of the car at 75ms.
Figure 3.47. The maximum deformation of the front surface of the car at 75 ms after impact.

The B-pillar in the pole frontal impact is considered to be a part of the undeformable structure of the vehicle and therefore the average of these signals is considered to be the vehicle deceleration profile. The acceleration time history plot is shown below in Figure 3.48.

Figure 3.48. Linear acceleration of the B-pillar of the Geo Metro against rigid pole

The velocity profile of the B-pillar is depicted in Figure 3.49. It is visible that the velocity is decreasing, so the kinematic energy of the vehicle model is decreasing until the vehicle stops at 75ms (velocity =0). The Geo Metro start then bouncing back in motion.
It has been well established that simple tubular structures crumple with a uniform average crumpling force independent of the crash depth. Therefore, the front of the vehicle model can be considered as consisting of an infinite number of tubes linked together, each of which crumples under the action of the constant force applied by the rigid pole.

### 3.6.1.2 Evaluation criteria

Figure 3.50 illustrates the acceleration of the dummy head in the direction of the crash loading. The time history plots shows that the head acceleration start decreasing at time 25 ms and reaches a maximum of 325 m/s² at 85 ms, and then increases until it becomes equal to zero.
The head velocity profile is depicted in Figure 3.51. The velocity of the dummy head starts decreasing after 25 ms instead of 0 ms like the vehicle velocity (Figure 3.49). Actually, the speed of the dummy is roughly equal to the vehicle speed before it comes in an abrupt stop. Thus, the dummy keeps moving, until it hits the airbag, and then it is bounced back after 80 ms.

Figure 3.51. Dummy Head velocity

In MADYMO simulation the value of injury criteria are directly computed and stored in the PEAK file. The following table gives the value of injury criteria with the tolerance for each parameter:

<table>
<thead>
<tr>
<th>Dummy Injury parameters</th>
<th>Value</th>
<th>Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMBINED THORACIC INDEX</td>
<td>0.66624</td>
<td></td>
</tr>
<tr>
<td>HIC_36 (d) (T1 =73.300ms, T2 =106.40 ms)</td>
<td>149.11</td>
<td>1000</td>
</tr>
<tr>
<td>Viscous Injury Response (m/s)(VC)</td>
<td>0.15589</td>
<td>1.0</td>
</tr>
</tbody>
</table>

The table above shows that the value of the HIC predicts low lateral acceleration of the head, because of the lower impact speed and also because the dummy is restrained by a seat belt and the car is instrumented with a driver air bag.

3.6.2 Validation against tests

L. Rooij van (2004) validated the Geo Metro frontal model for frontal pole impact. The validation procedure used in this research is based on the results of the old validation, and actually used the same steps. The simulation of the frontal pole impact with the Geo Metro was compared to the results of test carried out at TNO test laboratory. The test involved the collisions of a Suzuki Swift with a rigid pole made of steel. The diameter of the pole was 290 mm, and the height was greater than the contact surface of the deformed car front.
3.6.2.1 Qualitative validation:

A comparison of sequential photographs (overhead) is depicted in Figure 3.52. The comparative figures indicate that the MADYMO model of the modified Geo Metro reasonably captures the basic sequences of the event. The vehicle ceases to contact the pole at about the same time. The deformation of the front surface replicates reasonably the real deflection of the front surface. In conclusion, the MADYMO simulation replicates the basic phenomenological behaviour of the actual full-scale test.

3.6.2.2 Quantitative validation:

While qualitative validation of the Multibody model is conducted, the simulation must also be quantitatively validated. This was accomplished by comparing the acceleration plots obtained from the full scale test and simulation. The test vehicle was instrumented with a triaxial accelerometer in the left and right side of the B-pillar, the vehicle was not instrumented with a dummy and therefore only structural adequacy of the vehicle was quantitatively validated.

The velocities plots of the test and the simulation are depicted in Figure 3.53. The comparison of the velocity time histories shows that there is a good agreement between the test and the simulation.

Figure 3.52. Comparison of sequential overhead views in test and simulation
3.6.3 Discussion

The MADYMO simulation demonstrated that the MADYMO model replicates the basic phenomenological behaviour of the system in a frontal pole impact with the Geo Metro modified model. There was a good agreement between the test and the simulations with respect to the velocities histories, event timing.

The qualitative validation and the quantitative comparisons of the MADYMO simulation and the physical crash test indicate that the simulation results reasonably replicate the crash sequences.

3.6.4 Lateral pole impact:

The purpose of this section is to present the second simulation scenario; lateral pole impact, and the result of the simulation. The validation of the model was not carried out because no full scale crash test was performed for this scenario.

3.6.4.1 Set up simulation scenario:

The Geo Metro was positioned to strike the pole structure with the side surface. The car impacted the pole with a velocity of 29.5 km/h at an angle of 90 degrees with respect to the pole structure, at the centre of the vehicle door. The head of the dummy strikes the pole which represents the worst case of a lateral pole impact. The set-up simulation is in accordance with the EuroNCAP test protocol. The impact scenario is shown in Figure 3.54.
The vehicle was instrumented with an anthropometric test dummy ES_2, 50th percentile. It is equipped with a driver frontal air bag. Besides, the test vehicle was also instrumented with accelerometers. The accelerometers were positioned in the B-pillar left, right, and sill left. The total mass of the vehicle and the dummy is about 883kg.

3.6.4.2 Simulation results:
Structural adequacy:

At the impact the vehicle side structure of the Geo Metro begins to deform in response to the collision with the rigid pole. During the loading of the car, the driver compartment of the Geo Metro bent laterally. Vehicle damage is confined to the side part of the driver compartment. The pole side impact result in an extensive intrusion into the occupant compartment. Figure 3.55 shows the behaviour of the car when the deformation of the side structure reaches its maximum.
After the collisions the vehicle continues moving. When the amount of energy is absorbed the car is rebound with a post impact rotation. This post impact rotation is dependent on the impact severity and the vehicle inertial properties (Figure 3.56).

In the Figure 3.57 the acceleration profile of the front sill is depicted. It is visible that the impact results in a higher deceleration. This is explained by the fact that the crash load is concentrated in the outdoor side structure. Therefore, it results in an extensive intrusion.
The velocity profile of the front sill is depicted in Figure 3.58. The velocity profile shows that the time separation of the vehicle and the rigid pole is 85ms.

3.6.4.3 Evaluation criteria:

The acceleration of the head center of gravity shows the trend of the dummy head acceleration (Figure 3.59).
The deceleration of the head reached 9000 m/s² after 65 ms, which is the time when the head strikes the pole. Then it decreases until becoming equal to zero.

In MADYMO simulation the value of injury criteria are directly computed and stored in the PEAK file. The following table gives the value of injury criteria:

<table>
<thead>
<tr>
<th>Dummy injury parameters</th>
<th>Results</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTI (g)</td>
<td>154.47</td>
<td>85</td>
</tr>
<tr>
<td>HIC_36 (d) (T1 =65.500ms, T2 = 66.700ms)</td>
<td>9423</td>
<td>1000</td>
</tr>
<tr>
<td>Viscous Injury Response (m/s) (VC)</td>
<td>51.000</td>
<td>1.0</td>
</tr>
</tbody>
</table>

The higher value of the HIC could be explained by the fact that the head strikes directly the pole structures.

### 3.6.4.4 Validation against tests:

The validation of the model could not be carried out because no full scale crash test was performed for this scenario.

The modified model of Geo Metro reasonably replicates the sequence of lateral pole impacts. However, full-scale crash test data is needed to validate the current model.

The results show that the lateral pole impact is a dangerous crash. Therefore, RISER project team should focus on reducing the severity of such collisions.
3.6.5 Car to guardrail impact:

The purpose of this section is to present the third simulation scenario; guardrail impact. The validation of the model could not be carried out because no full-scale crash test was performed for this scenario.

3.6.5.1 Set up simulation scenario:

The Geo Metro impacted the guardrail at a velocity of 100 km/h at an angle of 20 degrees. The impact scenario is shown in Figure 3.60.

The vehicle was equipped with a driver air bag. Besides, the test vehicle was instrumented with accelerometers. They are positioned in the B-pillar left, right, and sill left. The total mass of the vehicle and the dummy is about 883kg. Since there is no dummy designed for the oblique impact, two simulations were carried out in this scenario, one with the Geo-Metro instrumented with a frontal impact dummy Hybrid III 50th percentile and the second with a side impact dummy ES-2. The results were compared.

3.6.5.2 Simulation results:

Structural adequacy:

At impact the w-beam began to deform in response to the collision with the vehicle. During the loading of the w-beam, posts involved in the impact started to bend laterally. Consequently, posts absorb only slight forces and are moved in the ground. Therefore, the restraint system remained very elastic and the deformation of the Geo Metro was continuous. Figure 3.61 shows the maximum deformation of the w-beam guardrail; sequential overhead view snapshots of the simulation are shown in Figure 3.62.
The direction of travel of the vehicle was safely deflected along the running direction of the system by the crash barrier. The vehicle continued to move along the system until it came in a stable position.
The acceleration time history plots shown are obtained from accelerometers located in the B-pillar left and right hand side of the Geo Metro.
Table below show that the values of the injury based criteria are in accordance with the tolerances. This is explained by the fact that the vehicle deformation is not very large

Table 3.7. Vehicle based criteria

<table>
<thead>
<tr>
<th>Vehicle based criteria</th>
<th>Results</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASI (g)</td>
<td>0.9 g</td>
<td>1.1</td>
</tr>
<tr>
<td>THIV (km/h)</td>
<td>26 km/h</td>
<td>33</td>
</tr>
<tr>
<td>PHD (g)</td>
<td>6.8 g</td>
<td>20</td>
</tr>
</tbody>
</table>

3.6.5.3 Evaluation criteria:

In Figure 3.64 and Figure 3.65, dummy head acceleration time history plots show that there is a difference between the two dummies in such collisions. The Hybrid III present more flexibility to represent the kinematic of the crash because of the neck is more detailed compared to ES_2. Figure 56 present the acceleration of center of gravity of the Hybrid III and the Figure 57 represents the head acceleration of the side impact dummy.
It is visible from the Figure 3.64 and Figure 3.65 that there is difference between the two dummies head acceleration. The ES-2 acceleration is higher than those of Hybrid III. This is explained by the fact that the ES_2 represent the intrusion of the side door during the collision event.

The following table gives the value of injury criteria derived from both the ES-2 and Hybrid III:

<table>
<thead>
<tr>
<th>Injury parameters</th>
<th>Frontal Impact dummy</th>
<th>Side Impact dummy</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIC_36</td>
<td>313</td>
<td>565</td>
</tr>
<tr>
<td>VC (m/s)</td>
<td>6.71E-02</td>
<td>45.455</td>
</tr>
<tr>
<td>CTI</td>
<td>0.50336</td>
<td></td>
</tr>
<tr>
<td>HIC_36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TTI (m/s²)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VC (m/s)</td>
<td></td>
<td>4.7E-02</td>
</tr>
</tbody>
</table>
The value of the HIC predicted by ES_2 is higher than was predicted by Hybrid III. Actually, during the collision scenario the dummy slides in the lateral direction with respect to the car and strikes the window, and therefore the ES_2 represent better this part of the collision. The values of VC are quite similar. In addition, the TTI predicts high lateral acceleration in the upper torso, which might be caused by the high shoulder loads.

### 3.6.5.4 Validation against tests:

The validation of the model could not be carried out because no full scale crash test was performed for this scenario.

### 3.6.6 Discussion:

The MADYMO model of the w-guardrail replicates reasonably the sequence of guardrail impact. The vehicle was successfully redirected. Future work should take this measure into account.

The kinematics of the two dummies was different, the ES-2 slides better. Future work might investigate the use of the MADYMO human model as a human surrogate for the assessment of the severity of the oblique impacts. The human model are multi-directional and are therefore applicable for frontal, lateral and rearward impacts well as intermediate impact collisions.

### 3.6.7 Simulation test Matrix:

The purpose of this section is to present the test matrix. The results of the test matrix help us to determine the parameters that influence most the model and the most severe collisions. The results will give an idea about the parameters and their tolerances that should be varied in the stochastic simulations. First a presentation of the matrix set up and then a presentation of the simulation results.

#### 3.6.7.1 Matrix set up:

The Matrix set up was very basic, The Geo Metro impacts the two road side devices; pole and guardrail, in three scenarios, frontal pole, lateral pole impact, and guardrail impact at 20 degrees. Two impact speeds were chosen in this matrix: 50km/h and 100 km/h. This research is focussed on motorways, therefore the value of impact speeds chosen in the Matrix represent the lower and the higher velocities before an impact.

In the collisions involving the guardrail, two human surrogates were chosen, Hybrid III, and The ES_2. Table 3.8 below shows the test matrix.
Table 3.8. Test Matrix for Pole and Barrier Impacts

<table>
<thead>
<tr>
<th>Test</th>
<th>Vehicle</th>
<th>Human surrogates</th>
<th>Roadside devices</th>
<th>Impact conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Restraint systems</td>
</tr>
<tr>
<td>1</td>
<td>Geo Metro</td>
<td>Hybrid III, 50%</td>
<td>Pole</td>
<td>Belt &amp; airbag</td>
</tr>
<tr>
<td>2</td>
<td>Geo Metro</td>
<td>Hybrid III, 50%</td>
<td>Pole</td>
<td>Belt &amp; airbag</td>
</tr>
<tr>
<td>3</td>
<td>Geo Metro</td>
<td>ES_2, 50%</td>
<td>Pole</td>
<td>Belt &amp; airbag</td>
</tr>
<tr>
<td>4</td>
<td>Geo Metro</td>
<td>ES_2, 50%</td>
<td>Pole</td>
<td>Belt &amp; airbag</td>
</tr>
<tr>
<td>5</td>
<td>Geo Metro</td>
<td>Hybrid III, 50%</td>
<td>W-beam guardrail</td>
<td>Belt &amp; airbag</td>
</tr>
<tr>
<td>6</td>
<td>Geo Metro</td>
<td>Hybrid III, 50%</td>
<td>W-beam guardrail</td>
<td>Belt &amp; airbag</td>
</tr>
<tr>
<td>7</td>
<td>Geo Metro</td>
<td>ES_2, 50%</td>
<td>W-beam guardrail</td>
<td>Belt &amp; airbag</td>
</tr>
<tr>
<td>8</td>
<td>Geo Metro</td>
<td>ES_2, 50%</td>
<td>W-beam guardrail</td>
<td>Belt &amp; airbag</td>
</tr>
</tbody>
</table>

3.6.7.2 Simulation results:

Table 3.9 gives the value of injury parameters.

Table 3.9. Injury Parameters Resulting from Simulation Matrix

<table>
<thead>
<tr>
<th>Test</th>
<th>Dummy injury measures</th>
<th>HIC_36 (d)</th>
<th>VC (d)</th>
<th>TTI (d)</th>
<th>CTI (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>370</td>
<td>0.1775</td>
<td></td>
<td>0.4107</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>13525</td>
<td>6.3647</td>
<td></td>
<td>1.2480</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>30187</td>
<td>3.5074</td>
<td>319.2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>84691</td>
<td>9.3301</td>
<td>651.0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>100</td>
<td>0.0410</td>
<td></td>
<td>0.2905</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>313</td>
<td>0.0672</td>
<td></td>
<td>0.5034</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>64</td>
<td>0.0398</td>
<td></td>
<td>19.0</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>566</td>
<td>0.0474</td>
<td></td>
<td>45.5</td>
</tr>
</tbody>
</table>

The results show that the lateral pole impact is a dangerous collision. It results in higher values of the injury parameters.
Figure 3.66. Test Matrix results

The results in Figure 3.66 show that the value of the HIC36 is very high for the lateral pole collisions, because the head of the dummy strikes the pole structures which is very stiff. In addition, the frontal pole impact becomes severe in high impact speeds. This is explained by the fact that there is an extensive intrusion in the occupant compartment. Finally the guardrail impact is less severe.

Figure 3.67. Results of Viscous Injury response

The viscous injury response predicts high velocity in the chest for the lateral pole impact and frontal pole impact. For the guardrail collisions the viscous injury response value is small.

3.6.7.3 Discussion:

The value of injury parameters increases with impact speed, which is intuitively normal. Besides, collisions against guardrails are less severe compared to pole collisions.

In addition, vehicle based criteria are more severe for the lateral pole impact than for the frontal and guardrail impacts. Actually, the crash loads are more concentrated in
the lateral direction and the side vehicle structure is less stiff compared to the frontal part.

Finally, the test matrix results show that the impact speed is an important parameter that should be taken into account for the parameter variation task.

### 3.6.8 Stochastic simulation:

The model chosen for this study is the frontal pole impact scenario. The parameters that were varied are given in Table 3.10. The velocity, the stiffness of the pole, the diameter of the pole

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Abbreviation</th>
<th>Unit</th>
<th>Nominal Value</th>
<th>Min</th>
<th>Max</th>
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<td>Impact speed</td>
<td>@velocity@</td>
<td>m/s²</td>
<td>27.78</td>
<td>9.8</td>
<td>27.78</td>
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<tr>
<td>Pole radios</td>
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<td>m</td>
<td>0.45</td>
<td>0.125</td>
<td>0.45</td>
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<tr>
<td>Pole stiffness</td>
<td>@stiff@</td>
<td>N/m</td>
<td>1.0E+09</td>
<td>5.0E+0</td>
<td>1.0E+0</td>
</tr>
<tr>
<td>Pole position</td>
<td>@dist@</td>
<td>m</td>
<td>0.4</td>
<td>-0.4</td>
<td>0.4</td>
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<tr>
<td>Orientation of</td>
<td>@ori@</td>
<td>rad</td>
<td>1.0</td>
<td>-1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Table 3.10. Stochastic Simulation Parameters

Samples were generated with the Best Latin Hyper curve method, creating a random and uniform distribution that fills the whole parameter space. A total number of 20 samples were generated. Figure 3.68 shows the parameter in the vehicle model.

![Figure 3.68. Description of the parameters](image)

### 3.6.8.1 Results:

The linear correlation matrix in shows the linear correlation between variables and responses.
Figure 3.69. Linear correlation matrix for frontal pole collisions

The table below gives the variables and the responses,

<table>
<thead>
<tr>
<th>Variables</th>
<th>Abbreviations</th>
<th>Responses</th>
<th>Abbreviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td>vel</td>
<td>Head Injury Criterion; HIC&lt;sub&gt;36&lt;/sub&gt;</td>
<td>HIC</td>
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<tr>
<td>Pole radius</td>
<td>Rad</td>
<td>Viscous injury response</td>
<td>VC</td>
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<td>Pole stiffness</td>
<td>Sti</td>
<td>Acceleration Severity Index</td>
<td>ASI</td>
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<td>Car orientation</td>
<td>Ori</td>
<td>Chest deflection</td>
<td>Ches</td>
</tr>
<tr>
<td>Car distance</td>
<td>dist</td>
<td>Post-impact Head Deceleration</td>
<td>PHD</td>
</tr>
<tr>
<td>Tibia index</td>
<td></td>
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</tr>
<tr>
<td>Theoretical Head Impact</td>
<td></td>
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<td>THIV</td>
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<tr>
<td>Velocity</td>
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</table>

The most important human responses are HIC, VC, and the chest deflection. Namely, the frontal impacts often result in fatal injury in head and chest. In addition, the important vehicle based criteria are the ASI and THIV.

As is shown in the Figure 3.69 above there is good correlation between the variables and the responses. The highest linear correlation was observed for the chest deflection relative to the impact speed.

A high correlation was also observed between the injury parameters and the velocity, the injury parameters increase with the highest impact speed.
Figure 3.70. Scatter plot of the HIC with respect to the velocity

In Figure 3.70 the HIC-values are plotted. The plot shows that the HIC-value has the tendency to increase with velocity. This tendency is also present for all injury parameters and vehicle based to the same amount. Consequently, the velocity influences the responses.

Figure 3.71. Relationship between velocity and ASI and: Linear correlation between HIC and ASI

In the simulations also the HIC-values are calculated from the Hybrid III dummy model. A strong relationship between HIC and ASI exists as shown in Figure 3.71. Most of the test runs have ASI-values below 2.00 and HIC-values below the tolerance limit of 1000. The spread on the results is caused by the complexity of the three variables that are altered within this study; impact velocity, impact direction and vehicle orientation. The injury parameters taken into account in this study are HIC, VC and chest deflection and also the vehicle based criteria ASI, THIV and PHD. As shown in Figure 3.71 a reasonable correlation between the varied parameters (such as velocity) and the responses (such as HIC and ASI) can be observed.
Figure 3.72. Scatter plot of the HIC with respect to the pole radius

Figure 3.72 shows that the correlation of the HIC with the pole radius is a weak correlation. The same thing is present for all the injury parameters and vehicle based to the same amount. In conclusion the radius of the pole does not influences responses.

Figure 3.73. Scatter plot of the HIC_36 with respect to the distance of the pole

In addition the lateral distance of the pole during the frontal impact does not influence the responses, although there was no big effect (see Figure 3.73). Consequently these parameters are considered as weak parameter that have no major effect and therefore it does have a big effect on responses.
Stochastic results:

The results show that the impact has the same effect on vehicle based criteria and the human based criteria. Consequently, Full-scale crash test could be performed without dummy.

3.6.9 Conclusions:
Modeling of vehicle infrastructure collisions:

The modified vehicle model of Geo Metro was used for frontal, lateral and oblique impact. The vehicle reasonably replicates the major sequences of the collision event.

The w-beam guardrail model replicates the basic phenomenological behaviour of the real interaction.

Frontal pole impact:

The Geo Metro modified model was validated against the rigid pole for frontal impact scenarios. There has been found a good agreement between the test and the simulations with respect to the velocities histories and event timing.

Lateral pole impact:

It has been noticed from the simulation results that the lateral pole impact is the most severe collision. The higher values of the injury parameters are caused by the extensive intrusion in the occupant compartment.

The modified model of the Geo Metro reasonably replicates the major scenes of the collisions.

Car to guardrail impact:

It has been shown from the simulation results that the Geo Metro reasonably replicates the real sequences of the oblique impact.

Simulation matrix

The results of the matrix show that the lateral pole impact is the most severe crash. In addition, the injury parameters increase with impact speed.

Stochastic simulation:

The stochastic simulation shows that there is a strong correlation between injury criteria and impact speed. It has been noticed also that there is a strong correlation between the vehicles based criteria and the impact speed. However, the lateral position of the pole does not change the injury risks.
3.6.10 Recommendations:

Vehicle model:

The modified vehicle model of the Geo Metro was validated for frontal impacts. It is uncertain whether in case of oblique impact the vehicle will interact well with roadside barriers that present a curb, such as the New Jersey Barrier (see Figure 3.35). Therefore, future work should include the modelling of other vehicle components.

Guardrail model:

The current model should be validated against full-scale test. In addition, the w-beam guardrail is used on Dutch motorways. Future work should focus on the modelling of other versions of the safety fence. The current model can be used as a start.

Lateral pole impact:

Future work should investigate the use of the side air bag.

Guardrail impacts:

Two dummies, Hybrid III 50th Percentile male and EuroSID-2, represented the human interaction in the car. Since these two human surrogates were designed for a specific collision, the future work should investigate the capability of the human model in oblique impacts.

Parameters variation:

In the future full-scale test for frontal pole impacts could be performed without dummy.

In addition, future stochastic simulation should include a large number of samples.

References

1 J.Huibers, “Geo Metro frame model description”, TNO Automotive, Delft, The Netherlands 2002


4 K. Nije, ”Handboek Bermbeveiligings-voorzieningen”, CROW, Oktober 2000

CHAPTER 4 RESULTS FROM CRASH TEST DATA CATALOGUE

4.1 Analysis

The collected crash test data is fully documented in a RISER internal report maintained by HUT. It should be noted that not all the data can be used for analysis. Some product groups / test information are not easily compared. The reasons and problems are obvious:

- High range of products
- High range of materials and profiles
- High range of crash tests and test requirements
- Too little crash test data, about one test per product or product groups

An analysis was only possible for product groups with enough data for comparison. Those requirements were mainly fulfilled by the product groups ‘barriers’ and ‘guardrails’. All the other product groups like ‘columns’ and ‘crash cushions’, were excluded from the analysis in that task. The following vehicle restraint systems were analysed:

- Concrete barriers
- Steel barriers
- Steel guardrails
- Parapets (bridge rails, bridge barriers made out of concrete or steel)

The target of the analysis was to get an idea about the vehicle accelerations and occupant risk measurements (ASI, THIV) of different products and their status in comparison. Therefore the following relations of those safety values were chosen as the outcome of the analysis:

- Relation permanent deflection / ASI
- Relation permanent deflection / THIV

After the decision to consider only the information about barriers, guardrails and parapets, all the data without a permanent deflection and/or ASI-value were excluded. The next step was the comparison of the left data under the same test performances respectively vehicle impact test criteria. The following crash tests were taking into account:

- 19 crash tests about concrete barriers (left from 28)
- 21 crash tests about steel barriers (left from 32)
- 18 crash tests about one sided guardrails (left from 23)
- 6 crash tests about double sided guardrails (left from 9)
- 4 crash tests about different parapets (left from 5)
This data was not complete either. When the permanent deflection and ASI-value were available, THIV values were sometimes missing. The following tables (Table 4.1 to Table 4.5) point out the availability of ASI and THIV values regarding the crash tests.
Table 4.1. Available adequate crash test data for concrete barriers.

<table>
<thead>
<tr>
<th>Barriers, concrete</th>
<th>Crash test</th>
<th>Number of tests</th>
<th>No. of tests with perm. defl., ASI, THIV, PHD</th>
<th>No. of tests with perm. defl., ASI, THIV</th>
<th>No. of tests with perm. defl., ASI</th>
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Table 4.2. Available adequate crash test data for steel barriers.

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Table 4.3. Available adequate crash test data for one sided guardrails.

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<tr>
<th>Guardrails, one sided</th>
<th>Crash test</th>
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<th>No. of tests with perm. defl., ASI, THIV, PHD</th>
<th>No. of tests with perm. defl., ASI, THIV</th>
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Table 4.4. Available adequate crash test data for double sided guardrails.

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<th>Crash test</th>
<th>Number of tests</th>
<th>No. of tests with perm. defl., ASI, THIV, PHD</th>
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Table 4.5. Available adequate crash test data for parapets.

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<tr>
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<th>Number of tests</th>
<th>No. of tests with perm. defl., ASI, THIV, PHD</th>
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Relations between Permanent Deflection and ASI Value

The relations between permanent deflection and ASI value for the cases with adequate data are shown in the following charts (see Figure 4.1 to Figure 4.10).
Figure 4.1. All crash tests. Comparison permanent deflection / ASI.

Figure 4.2. TB 11 crash tests. Comparison permanent deflection / ASI.
Figure 4.3. TB 21 crash tests. Comparison permanent deflection / ASI.

Figure 4.4. TB 22 crash tests. Comparison permanent deflection / ASI.
Figure 4.5. TB 31 crash tests. Comparison permanent deflection / ASI.

Figure 4.6. TB 32 crash tests. Comparison permanent deflection / ASI.
Figure 4.7. TB 41 crash tests. Comparison permanent deflection / ASI.

Figure 4.8. TB 42 crash tests. Comparison permanent deflection / ASI.
Figure 4.9. TB 51 crash tests. Comparison permanent deflection / ASI.

Figure 4.10. TB 81 crash tests. Comparison permanent deflection / ASI.
4.2 Relations between Permanent Deflection and THIV Value

The relations between permanent deflection and THIV value for the cases with adequate data are shown in the following charts (see Figure 4.11 to Figure 4.17).

Figure 4.11. All crash tests. Comparison permanent deflection / THIV.

Figure 4.12. TB 11 crash tests. Comparison permanent deflection / THIV.
Figure 4.13. TB 21 crash tests. Comparison permanent deflection / THIV.

Figure 4.14. TB 31 crash tests. Comparison permanent deflection / THIV.
Figure 4.15. TB 32 crash tests. Comparison permanent deflection / THIV.

Figure 4.16. TB 42 crash tests. Comparison permanent deflection / THIV.
A first look to the charts points out that the data is fairly widespread. There are big differences even between the same or similar products. This is explainable with the unequal test requirements of the products like anchorage, post spacing, test length and so on.

Another reason for the widespread data is the special distribution of the crash test groups. The analysis had shown that every crash test group has its own place inside the spreading, see Figure 4.18.
The distribution of the crash tests depends on the different impact speeds and impact angles. The crash test group TB 21 for example, has the very low impact angle of 8 degree. The impact speed of 80 km/h is quite low as well and so are the safety values in the charts.

This data arrangement of the different crash tests does not only occur at the relations permanent deflection / ASI as shown in Figure 4.1 to Figure 4.10 – a similar distribution is noticeable in the other both relations concerning THIV and PHD.

Another important and expected outcome of this analysis is the general trend that is visible in all of these relation charts: the greater the permanent deflection, the lower the ASI or THIV value.

Another option of comparison would have been an analysis based on the working width. This option was excluded because the working width is given in a range and does not have an exact value like the permanent deflection has. The idea of an analysis based on the containment level did not seem to be useful, because the containment level has no mathematical value and one level includes sometimes two acceptance tests.

4.3 Summary

Because the inequalities of the products and their test circumstances were really high, the collected crash test data was only partly comparable. Most and adequate test data was available about barriers and guardrails. Therefore this both groups have been focused in the evaluation. Other road infrastructure elements have been also collected and illustrated, but they are not included in the analysis. The examination is illustrated by various charts that are showing relations between the permanent reflection and the vehicle accelerations respectively occupant risk measurements (ASI, THIV). All together 68 crash tests were analysed.

The result of the evaluation is an overview of the distribution of the safety values of road restraint systems like barriers and guardrails. Further the trend of the increasing ASI or THIV value, when the permanent deflection is decreasing, was affirmed.

4.4 Discussion

The objective of task 2.3 was the documentation of available test requirements and test data of several European roadside infrastructure types. Sufficient data of five different countries were obtained. The collection of this information gives a good overview about the most important roadside support systems and their mechanical behaviour. The documentation illustrates the tremendous range of products that must be available on the European market. The differences between the products and their respective test procedures are evident.

The test data collection should not be considered as a database. Because of the inadequate data of the 134 crash test reports, applicable for an overall evaluation were only (see table 15):

- 8 crash tests about concrete barriers
6 crash tests about steel barriers
16 crash tests about one sided guardrails
5 crash tests about double sided guardrails
2 crash tests about parapets

Since the listed tests have different test performances (and sometimes even different test requirements), it was not possible to create a satisfying overall analysis respectively a fully comparison between all products. A potential for a European database about road-side infrastructure types is obvious. American databases (FARS and NASS) are a good example how to meet this need of researchers, road administrations, policy makers, insurers and car industry.

However, the collected crash test data could be an appropriate basis for the developing guidelines where test data should be compared with real accident data. A similar roadside element to the accident obstacle could be chosen and a comparison between the in common permanent deflection values and test/accident circumstances could be made. In this way an evaluation of the test requirements respectively test criteria would be possible.
CHAPTER 5 CONCLUSIONS

The data collected and analysed in Work Package 2 is summarized in this report. In addition to this document, internal working documents of the partners can also contribute additional details of infrastructure performance.

The detailed database analysis provides a thorough analysis of the 211 accidents collected for the RISER project. This analysis describes the critical patterns in single vehicle collisions that must be addressed in future guidelines for roadside safety.

Complementing the detailed database, reconstructions and simulations were conducted to identify some of the important impact parameters, such as speed and angle, that were not part of the original data collected.

The analysis of existing safety features was conducted to determine the type and quality of data available. It was difficult to find complete test data for all the intended infrastructure items. For the few product groups that contained the data, only a simple analysis was permitted. However, the data provides some general trends that can be used to assist in selection of suitable products for roadside safety applications.
APPENDIX A: EXAMPLE OF RECONSTRUCTIONS

This example is the road departure of a small passenger vehicle, which leaves the road, then hits a signal post and finally rolls over. (Figure A.1). Two critical aspects of the vehicle-infrastructure interaction are identified here. One is the unevenness of the ground on the roadside, with embankments that cause the vehicle to leap upwards and lose stability. The other is an impact against a signpost.

The embankment causes vehicle to lift off the road even though the road departure speed is below the speed limit of the road. This shows that a vehicle travelling across slopes is likely to lose its upright position.

![Figure A.1. Reconstructed sequence of the interaction between vehicle and infrastructure](image)

The impact against the signpost is not a critical one in terms of damage to the vehicle body. The post is structurally weak and is easily bent down by the car. On the other hand, this contact has a certain influence on the vehicle trajectory, so that, together with the embankment, they cause the vehicle rollover.