D06: European Best Practice for Roadside Design: Guidelines for Roadside Infrastructure on New and Existing Roads

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FOREWORD

The European Commission Directorate General for Transportation and Energy (DG-TREN) sponsored a research project to investigate the best practice guidelines for roadside infrastructure. The RISER consortium has compiled the following document which is a synthesis of existing practice in Europe with additional information collected from accident and human behaviour studies. Several technical reports developed in the RISER project were the basis for this document and can provide more technical information.

The following information is presented as a template for future users. There are national and regional issues that arise when it comes to the implementation of European norms or guidelines into the member states. This document should be considered as a starting point for national policies that must be adapted to the local geographical, economic, and demographic conditions. Through the use of a common starting point, commonly accepted best practice procedures will be spread throughout the EU member states and facilitate improved roadside safety design, and – most importantly – safety levels throughout the EU.

In view of the current EU focus on road safety it is important to recognize the 3-pillar concept for road safety being:

- Infrastructure design
- Vehicle design
- Driver (education)

It is evident that the following information addresses the infrastructure aspect for road safety. It should be recognized that the RISER project has included driver and vehicle aspects to not lose sight of the integrated approach that is required to reduce road traffic casualties.

The information contained in this document should be used in conjunction with the document "***European Best Practice for Roadside Design: Guidelines for Maintenance and Operations of Roadside Infrastructure***".

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INTRODUCTION

The relevance of single vehicle accidents (SVA) (also known as run-off-road – ROR or roadside accidents) as a traffic safety issue can be demonstrated in a review of European accident data. In 1998, 33.8 % of all fatalities in the European Union were the result of single vehicle collisions (Eurostat).The data collected on single vehicle accidents in the "Roadside Infrastructure for Safer European Roads" (RISER) project represented about 10 % of the total road accidents reported for the respective countries. If the data is restricted to comprise only fatal accidents, then 45 % of all fatal accidents are SVA. Worse yet, the cases collected in RISER do not represent 100 % of single vehicle accidents and indicate that even higher fatality figures may occur. The over-representation of SVA fatalities (10 % of accidents producing 45 % of all fatalities) cannot be ignored when developing road safety plans.

The objective of the RISER project was to develop best practice guidelines that can be a foundation for national policy and guidelines. The project has synthesized the data and expertise from nine European countries: Austria, Belgium, Finland, France, Germany, the Netherlands, Spain, Sweden, and the United Kingdom. The following information does not reflect one national practice for structuring the roadside area. The documents outlining the technical functions and requirements for roadside will need to reflect the conditions of the local road network. Climatic, geographical, and demographic characteristics for the road sections of interest must be developed by local authorities.

Principles for Safe Road Networks

The goal of any road authority, road operator and road designer is to provide the best service for the travelling public. The capacity of the system must allow the public to reach their destination in a timely manner without creating a safety risk for the vehicle occupants. The challenge for road infrastructure designers is to provide the appropriate road and roadside constructions knowing that the driver is not a perfect operator but is susceptible to mental and physical shortcomings that will create situations leading to accidents.

Figure I.1 illustrates the first requirement for the safe road environment – road safety infrastructure systems must be **designed** using the existing experience from existing roads and **monitored** to ensure the system supplies the functions demanded by the existing traffic conditions. A life-cycle cost analysis comprises the installation, maintenance, and accident (societal) costs. Without a complete documentation of system performance as depicted in Figure I.1, life-cycle cost analyses are not possible.

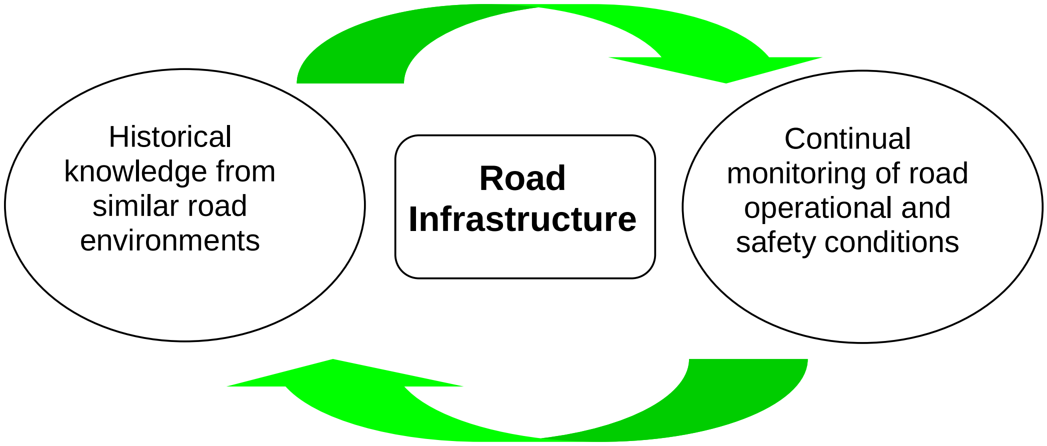

Figure I.1. Design and Operation Knowledge Base

The Self Explaining Road and Forgiving Roadside Philosophies

The physical layout of the road and roadside environment provides visual clues and signals to the vehicle operators. The type of road – a motorway or a small forest road – should be clear to the driver without explicit signs. The road width, types of lane markings, roadside geometry, etc. should provide clues to the driver that signal appropriate driving speeds and lane positioning for the type of road and indicate what type of other road users to expect. As an example, the Netherlands advocate the principle of Sustainable Safety with a road network structure of a limited number of clearly distinguishable road categories, each with its own function (flow function, distributor function, and access function). This explicit function determines the way the road and roadside environment should be designed to induce the appropriate road user behaviour (including speed choice and lateral positioning) on the one hand, and the required safety level of roadside elements on the other. The process of implicitly informing the driver of appropriate driving conditions is necessary to achieve a ***"Self Explaining Road"***. The Self Explaining Road concept advocates a road and traffic environment that elicits safe driving behaviour simply by its design. By maintaining consistent and uniform road and roadside design procedures, the road meets drivers' expectancy and drivers can anticipate changes in operating conditions (expecting at-grade intersections, pedestrians, etc.) even if they have not observed a sign stating that, for example, the motorway has ended. The physical layout of the road environment explains the driving context.

There are aspects of the roadside infrastructure that provide visual clues to the driver that can help "explain" appropriate driving conditions for a road section, but also the opposite may be true (for example: a misleading line of guidance by trees that deviate from the road). The human factors that cause roadside elements to influence traffic conditions should not be ignored in the design of safe roadsides. The two critical traffic elements that can be influenced by roadside objects are the traffic (vehicle) speed and lateral positioning. An overview of Human Factor aspects are presented in Appendix A. Relevant Human Factors design aspects are also provided throughout this document.

A second design philosophy that must be highlighted is the ***"Forgiving Roadside"***. This is simply the requirement that the roadside environment should not contain dangerous elements that will seriously injure or kill vehicle occupants that have unplanned trajectories off the carriageway. A fundamental component of this philosophy is the definition of an obstacle-free safety zone beside the carriageway. Since this is economically and functionally not always achievable, the introduction of passive safety equipment like road restraint systems (safety barriers), crash cushions, and energy absorbing (or break-away) posts to protect vehicles and minimize the consequences from dangerous impact hazards. It is important to recognize that all objects placed near a travel lane are potential impact hazards. The proper engineering design of passive safety infrastructure ensures that any subsequent impact with a safety device is much less severe than the resulting impact if the safety device was not in place.

It is difficult to find examples of roadways which possess both good self explaining characteristics and good forgiving roadsides, As an illustrative example, Figure I.2 shows a road section with separated travel lanes, a pedestrian overpass, wide hard shoulders with gentle side slopes and metal safety barriers protect the overpass supports. The road environment is clear to a western European driver – higher travel speeds (over 80 km/h) are permitted, no pedestrians will appear on the road and no left turning traffic will cross the carriageway. The Forgiving Roadside is partially achieved by the protection of objects (concrete pillars) close to the road with a safety barrier. The shallow ditch leading up to the pillars is blocked by the end treatment of the barrier and "closes the window" where a vehicle can move behind the barrier. The wide hard shoulder provides an area for modest vehicle manoeuvres in case the driver is not attentive. Terrain beyond the paved surface is smooth and free of fixed objects for a distance of about 10 m (to the electrical transmission tower).

Figure I.2. Self Explaining Road with Forgiving Roadside

What should also be noted in Figure I.2 is that the median barriers are close to the lighting columns. If there is not enough space between the barrier and the columns, the safety performance of the median barrier can be degraded during a crash. The buried terminal in the ditch may also present a hazard. Buried terminal ends can cause vehicle rollovers and they should not be placed too close to the travel lanes. Through the application of the knowledge from RISER and other ongoing research activities, the technical requirements for achieving Self Explaining Roads and Forgiving Roadsides will become clearer. Thus each road section, like Figure I.2, can be analysed to improve safety.

The information in this document should assist road designers, safety auditors and reviewers, maintenance personnel, and government officials to build and maintain safe road sections. The goal of this document, and a complementary document for Maintenance and Operations Guidelines, is to provide an overview of identifying potential safety issues as well as provide suggested countermeasures to improve the road traffic environment.

Framework for Roadside Infrastructure Design

The information in this document is structured to follow the analysis procedures for best practice guidelines. This structure may also be useful when conducting road safety audits for roadside safety. The design and analysis process is presented in Figure I.3. The first step in evaluating roadside infrastructure safety needs is to identify the types of fixed obstacles (or objects) adjacent to the road. These objects must be identified and inventoried in terms of type of obstacle and the lateral position to the road. From this information, the appropriate clear and recovery zone criteria should be defined for the road section to identify the critical areas in the roadside environment. From this information the first engineering judgements begin – identifying which obstacles are located in sensitive (affecting safety) areas and determining if these obstacles are a safety hazard.

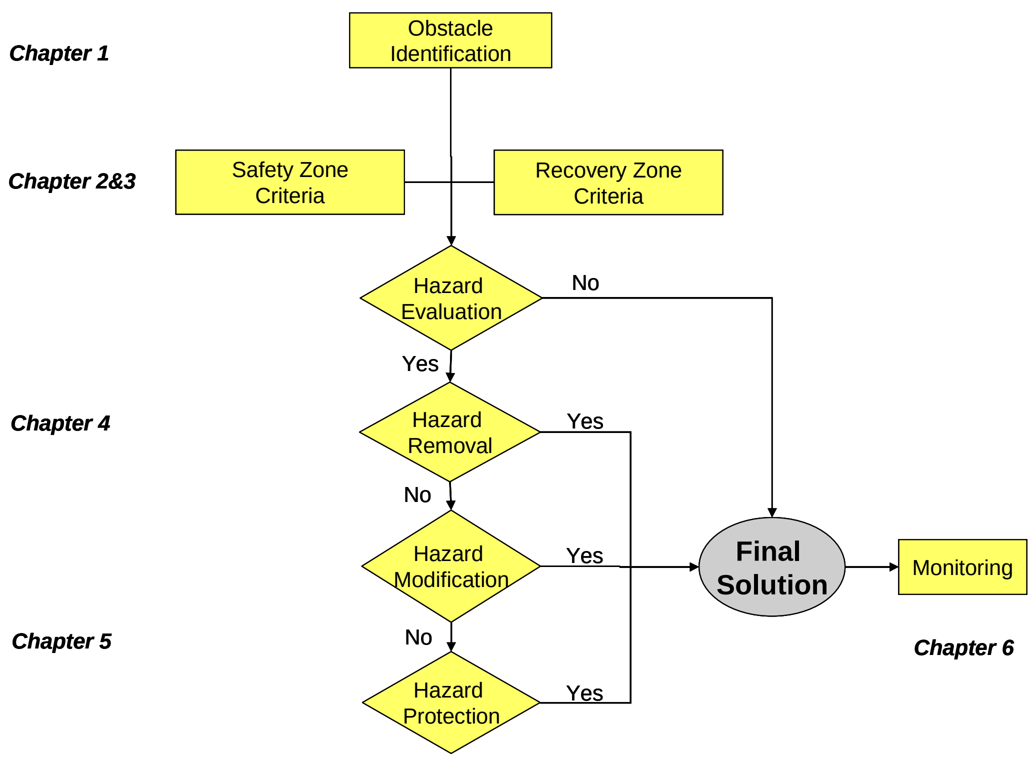

Figure I.3. Procedure for Roadside Infrastructure Design

Chapter 1 describes the special types of roadside obstacles and provides criteria that can be used to determine if these objects are hazardous or not.

Chapters 2 and 3 provide the best practice information regarding the dimensions of suitable safety and recovery zones.

Chapter 4 provides practical information important for the technical (engineering) design guidelines for different roadside environments. These guidelines are intended to provide best practice for determining the suitable type of roadside infrastructure. Specifications for type, placement, and the influence of the features on traffic are provided in this and the supporting technical documents.

Chapter 5 lists information outlining the performance features of different types of safety equipment which can be installed.

Finally the need for monitoring the performance of the road network is described in Chapter 6. The importance of collecting, storing, analysing, and reporting the accident data are highlighted.

CHAPTER 1: DEFINITION AND IDENTIFICATION OF ROADSIDE AND MEDIAN HAZARDS

1.1 Introduction

The general nature of a run-off-road (ROR) or roadside accident is that the vehicle will run-off the road into the roadside and has at least one collision with either roadside equipment or the roadside itself. Therefore, one of the main factors which determine the severity of these types of accidents is the layout of roadside and the type of objects present which potentially could become collision hazards.

Even in the design of new roads, the placement of certain objects (such as lighting and utility poles, sign posts, boundary fences, bridge piers etc.) in the road-side/median can often not be avoided. There are also the natural roadside objects which can not be moved from the roadside (for example, trees with aesthetic/cultural value, water courses etc.). The steepness of the roadside slopes can also be a contributing factor to roadside safety.

Due to the poor energy-absorbing qualities of many roadside objects, an impact would result in serious damage to the vehicle and more severe injuries to occupants. Therefore, the aim of this chapter is to identify which objects often found on the roadside are potentially the most hazardous, and what part of their characteristics makes them hazardous such as size and frequency etc.

1.2 Definitions of Roadside and Median Objects (Point and Distributed Hazards)

This section includes a list of definitions of roadside and median objects frequently found within the roadside. They include objects which were identified in the RISER detailed and statistical databases as being hazardous objects which, when impacted, can lead to serious occupant injuries (see section 1.4). They are also referred to in many current guidelines across Europe as being roadside hazards. They have been divided into 'point' and 'distributed' objects (see glossary for further details and photos).

Point objects includes narrow items in the roadside that could be struck in a collision for example trees, all types of bridge supports, lighting poles, utility poles, sign posts, terminations of barriers, etc.

Distributed objects, also known as 'continuous obstacles', are potential hazards which extend along a length of the roadside, such as all types of embankments, ditches, rock face cuttings, retaining walls, safety barriers not meeting current standards, forest and closely spaced trees.

1.2.1 Point Objects

Trees and Tree Stumps

- Trees are prevalent in roadsides, particularly in rural locations, and can be very unforgiving during an impact, absorbing very little of the energy created by the impact. Although individually they are point hazards, they can also arguably be distributed hazards, especially in the cases where there are rows of trees along the roadside. Often, older established trees are protected by preservation orders, so they cannot be removed or relocated from the roadside. Therefore, methods of protecting the vehicle and occupants from the tree are required.

Poles and Posts

- These include lighting poles, utility poles, gantry poles, high mast lighting columns and sign supports, and all posts of road signs which are not tested according to EN12767. All 'passively safe' posts and poles are deemed not to be roadside hazards.

Rocks and Boulders

- Rocks and boulders are large rounded masses of rock lying on the surface of the ground or embedded in the soil in the roadside, normally detached from their place of origin.

Bridge and Overpass Structures

- A bridge pier or bridge pillar is an upright structure, often a series of columns, which supports a bridge or an overpass. It can be located in the central reserve or in the roadside.
- An abutment is the end of a bridge or tunnel wall.

Culverts and Culvert Ends

- A culvert is a structure to channel a water course. It can be made of concrete, steel or plastic.
- A culvert end is the end of the channel or conduit, also normally a concrete, steel or plastic structure.

Underpass

- A roadway or other path passing under the main roadway.

Other Point Hazards

- Rivers, other water hazards and railway lines passing under the roadway, drainage pipes, headwalls.

Hazardous Safety Barrier Ends

- Poorly designed or positioned barrier ends, including end treatments which do not fulfil the requirements of EN 1317. In RISER Deliverable D05 [9] examples of barriers with blunt ends and terminations which do not flare away from the carriageway are shown.

Figure 1.1. Examples of Safety Barrier Terminations, Blunt End, Ramped not Flared End

1.2.2 Distributed Objects

Slopes and Embankments

- A 'slope' is a general term used for embankments. It can also be used as a measure of the relative steepness of the terrain expressed as a ratio or percentage. Slopes may be categorized as negative (fore slopes) or positive (back slopes) and as parallel or cross slopes in relation to the direction of traffic.
- An embankment is a general term for all sloping roadsides, including cut slopes (upward) and fill slopes (downward).
- A cut slope is an earth embankment created when a road is excavated through a hill, slopes up from the roadway
- A fill slope is an earth embankment created when extra material is packed to create the road bed, slopes down from the roadway.

Drainage Features

- Ditches are drainage features that run parallel to the road. Excavated ditches are distinguished by a fore slope (between the road and the ditch bottom) and a back slope (beyond the ditch bottom and extending above the ditch bottom).
- A drainage gully is a structure to collect water running off the roadway.

Rock and Concrete Hazards

- Rock face cuttings are created for roads constructed through hard rock outcroppings or hills.
- A retaining wall is a wall that is built to resist lateral pressure (especially a wall built to support or prevent the advance of a mass of earth).
- Other distributed rock and concrete hazards include buildings, rock fences.

Non-safety Fences

- Fences on the roadside mainly used to identify boundary edges. Include wooden, metal and wire (wildlife) fences.

Old Design/Poorly Installed Safety Barriers

- Safety barriers which do not fulfil the requirements of EN1317, designs which have been documented with poor performance in real world crashes, and those which have been incorrectly installed are hazards.

Other Distributed Hazards

- Water hazards, such as lakes, reservoirs, the sea, rivers running parallel to the road.
- Parallel roads, railways, rows of trees and forests.

1.3 Overview of Research

1.3.1 Previous Studies

The following list is an overview of a number of previous research studies which investigated collisions involving roadside objects. This search has been restricted to an investigation of published reports from a variety of sources regarding collisions with roadside objects. The summaries reflect the range of information taken from these sources:

- **The Highway Perspective of Side Impacts [1]**
  Fixed object crashes in the USA account for 21 % of all fatalities and 15 % of all injuries. Over 160,000 people are involved in accidents where the side of the passenger car impacts a fixed roadside object such as a tree, utility pole or light support and around 1 in 100 occupants are killed in these collisions. The annual cost is around $3 billion.
- **Forgiving Roadsides [2]**
  This report reviews the extent of the problem involving collisions with street furniture for a number of European countries. In Finland, collisions with road equipment accounted for 24 % of all fatal accidents, with trees and utility poles most frequently struck. In France, collisions with road equipment accounted for 31 % of all fatal accidents, with trees most frequently struck. In Germany, collisions with road equipment accounted for 18 % personal injury accidents, and 42 % road deaths, again with trees being the most frequently struck object. In Great Britain, collisions with road equipment accounted for 18 % of all fatal accidents, with trees and lamp columns most frequently struck. In the Netherlands, collisions with road equipment accounted for 22 % of all fatal accidents. In Sweden, collisions with road equipment accounted for 25 % of all fatal car occupant accidents, with trees, safety fence, and utility poles most frequently struck.
- **Fatality Facts 2003: Roadside Hazards [3]**
  More than 20 % motor vehicle crash deaths result from a vehicle leaving the road and impact a fixed object such as a tree or utility pole. These crashes occur in both urban and rural situations but are more common on rural roads. Around 20 % fixed object crashes also involve rollovers, and 20 % involve occupant ejection. Trees are the most commonly struck objects accounting for around half of all fatalities (4,522 fatal crashes in 2003).
- **Road Environment Safety Update, Fatal Roadside Object Study [4]**
  Roadside object crashes contributed to 33 % of all fatal crashes in NSW in 2000-01. Trees, utility poles and embankments were the most commonly struck objects. In secondary impacts water bodies also featured significantly. In a significant number of fatal crashes the first impact was with a frangible object such as a fence or guidepost, but then other objects struck as secondary impacts contributed to the severity of outcome.

- **Strategic Highway Safety Plan [5]**
  This document identifies 22 goals to pursue in order to significantly reduce highway crash fatalities. Goal 15 is Keeping Vehicles on the Roadway, and Goal 16 is Minimizing the Consequences of Leaving the Road. The goals concentrate on, amongst other factors, crashes with trees in hazardous locations.
- **EuroRAP 2005: British Results [6]**
  The four main types of accidents on single carriageway roads are: head-on collisions, run-off-road accidents involving collisions with roadside objects e.g. trees, collisions at junctions and accidents involving vulnerable road users e.g. pedestrians and cyclists.
- **Single Vehicle Loss of Control Collisions and Passive Safety [7]**
  Data for Great Britain show around 20,000 injury accidents each year with off road objects. The trend is constant over the past 15 years, whilst other accident types have reduced. The collisions have a high severity index, with 24 % collisions resulting in serious or fatal injuries. Trees are the most frequently struck objects, followed by crash barrier, and lamp posts. There is however, a large group of nearly 7,000 collisions where the object struck is “unknown”. Trees also have the highest severity index, with 33 % of all collisions resulting in serious or fatal injuries.
- **Fatal Accidents Against Fixed Objects, CEESAR [8]**
  CETE Normandie-Centre states that on rural two-lane roads, fatal accidents against fixed objects account for 30 % of the total fatal accidents. Of these fatal accidents, 44 % were against fixed objects occur on straight lines and 56 % in curves. Trees are the main impacted objects (60 %), utility poles accounting for 10 %, and safety fences 1 %. When the distance of the obstacle from the edge of the road is ≤ 2 m, the fatal accidents account for 43 % and 78 % when it is < 4 m. On motorways, fatal accidents against safety barriers (metallic fences, fence terminations and central concrete barriers) account for 44 %.

1.4 RISER Analysis

1.4.1 RISER Statistical Database

The RISER statistical database holds nearly 265 000 single vehicle accident cases from seven European countries (Austria, Finland, France, the Netherlands, Spain, Sweden and the United Kingdom). In 67 % of these cases, it was known that the vehicle struck an object. Table 1.1 shows the percentage of cases where an object was known to be struck in the accident.

Table 1.1. Distribution of Struck Infrastructure Types in RISER Statistical Database

	% of ALL accidents	% of Each Struck Object		
Struck Object	**ALL Severities**	**Fatal**	**Serious**	**Slight**
Tree	11.1	17	39	44
Post	8.2	9	31	61
Safety Barrier	15.5	6	20	74
Ditch	10.6	8	32	60
Other natural object[1]	0.9	7	32	61
Other man-made structure[2]	8.0	11	33	56
Other	12.5	-	-	-
Unknown/None/NA	33.2	-	-	-

[1] Include rock faces, stones, water submersion etc.

[2] Include signs, concrete structures, non-safety fences, culverts, underpasses etc.

Safety barriers appear to be the object most often impacted in the accidents. However, this does not necessarily mean that barriers are more dangerous than other roadside objects, because within the safety barrier object type group all safety barriers are taken into account, even those that not fulfil the current standards. The level of exposure (i.e. the number of these objects located in the roadside and the opportunity to come into contact with one) is also not taken into account. Of the objects more frequently impacted, both trees and ditches were impacted in over 10 % of all the accidents sampled and posts in more than 8 %.

When injury severity is taken into account, the results show that a tree was impacted in more fatal accidents than other struck objects (25 % of all fatal accidents). In addition, when looking at tree accidents only, 17 % were fatal accidents, a greater proportion than any other object type (see Table 1.1). Nearly three-quarters of accidents involving safety barriers involved only slight injuries, which show that although safety barriers were involved in a higher proportion of single vehicle accidents than other objects, the impacts generally resulted in only minor injuries.

1.4.2 RISER Detailed Database

The RISER detailed database contains 211 in-depth single-vehicle accidents cases. The main type of objects struck in these cases were trees, post & poles, rock & concrete objects (rock faces, bridge supports, boulders etc.), sloping ground (embankments, ditches etc.), non-safety fences and safety barriers. An overview of the information recorded for the types of roadside infrastructure struck are presented in Table 1.2

Table 1.2. Distribution of Struck Infrastructure Types in RISER Detailed Database

	Tree	Post/ pole	Rock/ concrete object	Sloping ground	Non-safety fence	Safety barriers
No. of Accidents	**38**	**45**	**34**	**71**	**11**	**72**
No. of impacts/ interactions	50	51	37	88	11	86
Only impact[1]	**30[2]**	**20**	**15**	**44**	**1**	**41**
Fatal or serious cases	26	15	12	22	0	21
Non-motorways	28	16	12	35	1	18
Single carriageways	25	12	10	30	1	6
Single run-offs	26	18	13	38	1	29
Greatest set-back in fatal accident [m]	6.8[3]	4.5[4]	6.4[5]	No fatal (6.8 slight)	No fatal (7.2 slight)	1.5[5]
Smallest diameter in fatal accident[3] [m]	0.3	0.2	-	-	-	-
After impact distances [m]	0 - 44	0 - 39	0.6 - 32	0 - 49	1	0 - 208

[1] Cases where specific object was the only impact in the accident

[2] Only or 'main' impact in crash (21 cases where tree impact was the only impact)

[3] Seatbelt worn

[4] Seatbelt not worn but would have made little difference as it was a side impact

[5] Seatbelt not worn

Tree Impacts Only

The majority of tree impacts only cases involved fatal or serious injuries. The narrowest tree diameter involved in a fatal collision being 0.3 m (0.2 m where no seatbelt was worn) and the largest set-back distance from the edge of the road was 6.8 m (10.8 m no seatbelt worn). All fatal accidents involved impacts speeds of 70 km/h or greater (where speed data was known). When serious accidents were also included, impact speeds were 40 km/h or greater.

Post/Pole Impacts Only

In accidents involving posts and poles, posts/poles as narrow as 0.2 m were impacted (0.11 m where no seatbelt worn), and impact speeds in fatal accidents were 70 km/h or above. Impact speeds in serious and fatal accidents were 40 km/h or above. Side impacts with poles and posts were more often fatal accidents than frontal impacts.

Table 1.3. Type and Characteristics of Post/Pole Impacted (RISER Detailed Database)

Material	Post/pole type	No. of cases	Minimum diameter [m]	Accident Severity	Maximum Set-back [m]
Concrete	Utility	3	0.25	Serious	3.3
Metal	Gantry	3	0.35	Fatal	-
	Lighting	5[1] 2[2]	0.20[1] 0.22[2]	Fatal[1] Fatal[2]	4.5[1] -
	Sign	5	0.11	Fatal	2.4
Wood	Lighting	1[2]	Unknown[2]	Fatal[2]	-
	Utility	1	0.22	Slight	2.1

[1] Not passively safe post/pole

[2] Passively safe post/pole

Impacts with Rock/Concrete Objects Only

The majority of the 15 accidents involving impacts with only rock or concrete objects in the database were fatal or serious. The greatest set-back in a fatal accident involving a rock face/boulder was 6.4 m. The greatest set-back in a fatal accident involving a bridge pier or abutment was 1.5 m.

There were only 5 collision speeds recorded for impacts with rock/concrete objects. The lowest impact speed which resulted in a fatal or serious accident was 50 km/h.

Impacts with Sloping Ground Only (Embankments, Ditches etc.)

Table 1.4 shows minimum slope measurements and maximum set-back distances for serious or fatal accidents involving sloping ground. The measures in brackets are for accidents involving vehicle rollovers only. Impact speeds were above 40 km/h in all serious and fatal cases (where impact speeds were recorded). Of all sloping ground impacts 50 % were fatal or serious.

Table 1.4. Characteristics of Impacted Sloping Ground (RISER Detailed Database), measures in brackets are for accidents involving vehicle rollovers only

Slope type	Height [m]	Gradient	Set-back[1] [m]
Upward from road level	0.4 (0.6)	1:3	6.1 (5.2)
Downward from road level	2.0 (5.0)	1:7	4.6 (4.6)
Back slope of ditch/gully	1.0 (1.0)	1:2	5.1 (5.1)
Fore slope of ditch/gully	1.0 (0.7)[2]	1:3	6.8 (6.8)

[1] Minimum measure from slight accident. No set-back measurements available for fatal or serious cases.

[2] Non-injury case

All Impacts with Culverts

There were 10 cases in the database which involved an impact with a culvert, including cases where other objects were impacted. Of these cases, 8 were fatal and 1 was serious. In addition, the culvert was the final impact in 8 of the cases. The culvert was also the main impact in the majority of these cases. Only 2 cases had set-back measurements, 3.5 m (slight) and 10.6 m (fatal) and only 2 cases had calculated impact velocities, 77 km/h (slight) and 100 km/h (fatal).

All Impacts with Non-Safety Fences

An impact with a non-safety fence was involved in 11 cases including cases where other objects were impacted. In only 1 of these cases, the impact with the non-safety fence was the main cause of the injuries. In this case, a broken rail from the wooden fence penetrated the windscreen and caused serious facial and head injuries to the driver. No set-back measurements are available for this case. However, this highlights the potential for the posts of wooden fencing to be as hazardous as wooden utility poles during an impact.

Although there are very few impacts with metal fences in the database, metal fence posts also have the potential to be as hazardous as non-break-away or non-energy absorbing posts/poles.

All impacts with wire boundary/wildlife fences did not directly result in serious injuries. It was previous or subsequent impacts with other types of objects that caused the injuries.

Impacts with Safety Barriers Only

There are 41 cases where only a safety barrier was impacted in the accident, of which 21 resulted in fatal or serious injuries. Although it could be concluded from this that safety barriers themselves are hazards, it should be noted that the detailed database is biased towards fatal accidents since many cases were obtained from fatal accident databases. There were also other contributory factors which led to the severity of many of the accidents with safety barriers.

For example, in a number of cases:

- The vehicle was a truck or motorcycle. Therefore the barrier installed may not have been appropriate to contain these types of vehicles.
- The barrier impact led to a vehicle rollover or spin and a resulting secondary impact which caused the occupant injuries.

However, it is inevitable that barriers will often be impacted in accidents because of their quantity and frequency in the roadside. A number of issues were also identified in all accidents involving safety barriers, for example:

- The length of barrier (vehicle travelling behind barrier and impacting hazard or rear of the barrier).
- Poorly installed or maintained barriers, often resulting in vehicles going over or breaking through the barrier.
- Barrier termination – Poorly designed or poorly positioned barrier terminations can become a roadside hazard, resulting in launches off the termination or impacts with blunt barrier ends.
- Older design barriers can be hazards, particularly those which do not comply with EN1317.
- Barriers can be hazardous to occupants of large trucks or riders of motorcycles if the barriers are not designed for motorcycle or truck impacts.

1.4.3 Current European Guidelines

In addition to examining single vehicle accident data, it is also important to take into consideration guidelines covering roadside safety and road restraint systems which are currently used across Europe. By reviewing current guidelines, it can be determined what roadside and median hazards are already identified as hazards across Europe and under what circumstances. Forthcoming UK Standards concerning passive safety, IRRRS and Risk assessment is presented in Appendix B.

Review of Current Guidelines in Europe

As part of RISER, a review of current European Design Guidelines for Roadside Infrastructure was carried out for seven countries and the findings are reported in Deliverable 5 [9]. In this report, the main documents reviewed which identify hazards and objects on the roadside are listed. Table 1.5 to Table 1.8 show an overview of the type of roadside objects which are listed as being hazards in the countries reviewed.

Trees

In all seven RISER participating countries, trees were considered as roadside hazards in the design guidelines. However, the minimum diameter when a tree was considered hazardous varied from 0.1 m to 0.3 m.

Table 1.5. Existing National Guidelines, figures when trees are considered hazardous (Y=Yes)

Hazard	FI	FR	DE	GB[1]	NL	ES	SE
Trees/ tree stumps [m]	>0.1	>0.1 stumps >0.2	>0.07	>0.3[2]	>0.08	Y	>0.1
Rows of trees/forests hazardous	Y	Y		Y		Y	Y

[1] < 4.5 m from carriageway edge line

[2] Measured at a height of 0.3 m above ground level

Posts and Poles

Post and poles on the roadside of varying types were also considered as hazards in a number of the countries. In Great Britain and Finland, traffic sign supports with a minimum diameter of 0.09 m and 0.11 m respectively are considered as hazards. In Spain, trees and poles over 0.15 m diameter are hazards depending on the distance to the carriageway edge line.

Table 1.6. Existing National Guidelines, when posts/poles are considered hazardous (Y=Yes)

Hazard	FI	FR	DE	GB[1]	NL	ES[2]	SE
Utility poles [m]	Y	Y	Y			>0.15	Y
Vertical, Overhead & Luminaire sign supports [m]	Y	Y	Y	Y		>0.15	
Sign gantry legs [m]	Y	Y		>0.09		Y[3]	
Posts of large signs [m]		Y		>0.09 <1.5 m above ground		Y[3]	
High Mast Lighting columns [m]		Y		<10 m from road edge		Y[3]	
Steel columns/High voltage electricity columns	Y	Y				Y[3]	
Non-break-away poles [m]	Y	Y		>0.09	Y	Y[3]	
Traffic sign supports [m]	0.11	Y	Y	>0.09		Y[3]	
CCTV Masts				Y			

[1] Unless stated otherwise, < 4.5 m from carriageway edge line

[2] If the distance between the hazard and the carriageway edge line is less than a minimum value which varies between 4.5 and 14 m depending on the road layout.

[3] If the post is not equipped with a passively safe feature that allows it to detach or bend upon impact.

Rock and Concrete Objects

The following rock and concrete objects found on the roadside are specified in guidelines across Europe as being hazardous.

Table 1.7. Existing National Guidelines, when rock and concrete objects are considered hazardous (Y=Yes)

Hazard	FI	FR	DE	GB[1]	NL	ES	SE
Rocks and boulders	Y		Y			Y	Y
Bridge piers/pillars/abutments	Y	Y	Y	Y	Y		Y
Tunnel entrances		Y	Y		Y	Y	
Culvert ends/headwalls	Y	Y		Y		Y	
Culverts and drainage pipes	Y	Y	Y	Y	Y	Y	
Rock face cuttings/rock fences	Y	Y	Y	<1.5 m above ground		Y	Y
Retaining walls		Y		Y			
Buildings/walls	Y	<0.7 m set-back <1:40	Y		Y		

[1] Unless stated otherwise, < 4.5 m from carriageway edge line

Sloping Ground

Roadside slopes and ditches of varying inclinations are deemed to be hazardous in all of the reviewed countries. Minimum slope gradient varies from 1:3 to 1:8 and minimum slope height from 0.5 to 6 m.

Table 1.8. Existing National Guidelines, when sloping ground are considered hazardous (Y=Yes)

Hazard	FI	FR	DE	GB	NL	ES	SE
Ditch and drainage gullies	>0.5 m >1:3	>0.5 m >1:4	Y	Y[1]	>1:3	Y	Y
Cut (upward) slopes and embankments				>1.0 m >1:1[1]			
Fill (downward) slopes and embankments				All >6.0 m or >1.0 m; >1:1			
All slopes and embankments	>2.0 m >1:3	>4.0 m >2:3	Y		Y	>1:8	Y

[1] See cut and fill slopes

Other Hazards

Many other hazards are also identified in guidelines across Europe, including:

- Water hazards (rivers, lakes, canals, reservoirs, stilling ponds) (FI, DE, GB, NL, ES, SE)
- Underpasses (pedestrian, agricultural) (GB)
- Property fences (FR, NL, ES)
- Other roads and railway lines (FI, DE, GB*, ES, SE) (*Roads <10 m from carriageway edge)
- Electricity transformers (FR, GB, NL, ES)
- Control cabinets (GB) and traffic counting stations (FR)
- Hazardous storage installations (GB)
- Road references points (FR, DE, NL, ES)
- Old barriers and barrier terminations (FI, FR, NL, ES)
- Central reserves with no safety barriers (FI, GB <10 m wide)
- Curves in road (GB - Radius <850 m (with varying roadside slope gradient and height); ES - Radius <1500 m))

1.5 Summary

Using the findings from the statistical and detailed database analyses and the review of current guidelines in Europe, definitions of roadside and median hazards have been produced. This includes minimum measures, impact speeds and set-backs that cause serious or fatal injuries for the accidents studied in RISER.

1.5.1 Proposed Measurements for the Definition of Hazards

Table 1.9 and Table 1.10 outline each roadside object and the characteristics which define it as a roadside hazard (for example, size, location, frequency) according to the detail database analysis and the review of the current guidelines.

NOTE: These MINIMUM measures are conclusions from the RISER analysis. If guidelines within individual countries already include a greater margin of safety than those stated here (for example, smaller diameters, smaller heights, less severe gradients, slower speeds), then those national guidelines should also still apply.

Where possible, dangerous impact speeds have been identified from reconstructed cases in RISER detailed database. The dangerous impact speed is the minimum speed at which a hazard can be impacted and still cause serious injuries to the occupants.

Given the limited cases (211) available in the detailed database, this data may not fully identify the range of impact conditions that cause serious or fatal injuries. Therefore the existing guidelines (see Table 1.5 to Table 1.8) should be consulted to identify specific values for a country or region.

Table 1.9. Point Hazard Characteristics for Serious or Fatal Injuries in the RISER Detailed Database

Hazard	Diameter [m]	Dangerous impact speed [km/h]	Additional comments
Trees and tree stumps	>0.2	40	Typically >0.1 in many national guidelines
The following poles/posts[2]			
- Utility poles - Standard lighting poles (wood, metal and concrete)	>0.2	40	
- Posts of roadside signs	>0.1	40	
- Gantry/large traffic signs - Supports/CCTV masts/High mast lighting columns - Supports/other high mast posts/poles.	>0.1	40	
Rocks and boulders	-	-	
Bridge piers/pillars/abutments		50	
Culvert ends/ headwalls/drainage pipes		-	
Underpasses and other point hazards (rivers, railway)		-	Including those at the foot of an embankment
Safety barrier terminations		-	Blunt barrier terminations and ramped ends which do not bend towards the roadside (see Chapter 4)

[1] Does not include 'passively safe' posts and poles.

In Table 1.10, for slopes (cut and fill), ditches and drainage gullies minimum slope heights & gradients are given to identify when slopes becomes a hazard.

Table 1.10. Distributed Hazard Characteristics Identified in the RISER Detailed Database

Hazard	Height/ Depth [m]	Gradient [m]	Dangerous impact speed [km/h]	Additional comments
Cut (upward) slopes	>1.0	>1:1	40	
Fill (downward) slopes/embankments	>1.0	>1:1	40	In addition, ALL embankments 6 m high or more (i.e. ALL set-backs).
Ditches and drainage gullies (fore & back slope)	>0.75	>1:3	40	
Rock face cuttings/rock fences			50	Any exposed rock face cutting slopes <1.5 m above carriageway level.
Retaining walls			-	Less than 1.5 m above carriageway level.
Buildings/walls			-	
Non-safety fences			-	Wire wildlife/boundary fences not considered as hazards.
Old design safety barriers			-	Barriers not compliant with EN1317 and with poor performance records.
Rows of trees/forests			40	Same measures as for individual trees.
Adjacent roads, railways, water hazards			-	

Median Hazards

- Any of the previously defined point or distributed roadside hazards should also be treated as hazards if present within a central reserve.
- A central reserve on any roads with a speed limit above 70 km/h which has a width of less than 10 m between opposing edges of the carriageway should itself be considered a hazard.

Hazards at Curves

Although few conclusions can be made in this study regarding curves in roads and their potential as hazards, it is apparent from the detailed database analysis and from previous studies that curves in roads do impose an increased risk of a run-off-road accident. It is more difficult for a driver to recover from a run-off in a curve than on a straight section of road. Therefore, roadside hazards should be considered an even greater risk when located near curved sections of roads.

Unfortunately, no conclusions can be made about the relationship between the radius of curves and injury risk from the RISER accident data. Previous studies indicate the higher risk of accidents in curves [10, 11, 12], therefore measures quoted in current guidelines [9] are a useful starting point.

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CHAPTER 2: SPECIFICATIONS FOR SAFETY ZONES

2.1 Introduction

Roadside safety addresses the area outside of the roadway and is an important component of total road design. There are numerous reasons why a vehicle leaves the roadway. Regardless of the reason, a forgiving roadside can reduce the consequences of leaving the roadway. The ideal road has roadsides and median areas that are flat and unobstructed by hazards.

2.2 Definition of Safety Zone

The safety zone (often called clear zone) is defined as the total roadside border area, starting at the edge line of the carriageway, available for safe use by errant vehicles. This area may consist of a shoulder, a recoverable slope, a non-recoverable slope, and/or a clear run-out area. The desired width is dependent upon the traffic volumes, speeds and on the roadside geometry.

Although the safety zone dimension includes the recovery zone, some functions of the recovery and safety zones are different. Thus the recovery zone is treated separately in Chapter 3.

2.3 Overview of Research

2.3.1 The Safety Zone Concept

The safety zone concept is an area free of fixed objects or dangerous slopes, adjacent to the roadway. It provides an area for drivers to control or stop their vehicles if they have had an unplanned departure from the carriageway. The ground should be relatively flat and gently graded. Impacts with hazards or rollovers due to terrain conditions should be eliminated. The desired minimum width is dependent upon traffic volumes and speeds and on the roadside geometry. RISER Deliverable 5 [1] provides the current dimensions recommended in reviewed European countries.

USA research [2] indicates that on high-speed roads (>70 km/h) a safety zone of 9 m from the edge of the carriageway permits about 80 % of vehicles leaving the roadway out of control to recover. Australian research [3] suggests that a clear zone of at least 2 m and preferably 3 m back from the kerb edge will significantly reduce the consequences of vehicles leaving the carriageway. In the USA, the Insurance Institute for Highway Safety (IIHS) [4] suggests that if the 10 foot (3 m) clear zones were increased to 35 feet (10.5 m), collisions with street furniture would be reduced by a further 10 %. A similar study in the UK [5] was performed where the relationship between the width of the safety zone and the reduction of related accident types was made (see Figure 2.1).

Amount of increased roadside recovery distance in metres	Reduction in related accident types (per cent) Straight	Curve
1.5	13	9
2.4	21	14
3.0	25	17
3.6	29	19
5.0	35	23
6.0	44	29

Figure 2.1. Relationship between the size of the clear zone and the accident reduction [5]

In a study on the Routes Nationales in France [6], one third (32 per cent) of fatal collisions with street furniture take place within two metres of the edge of the carriageway, and more than two thirds (70 per cent) occur within four metres (see Figure 2.2).

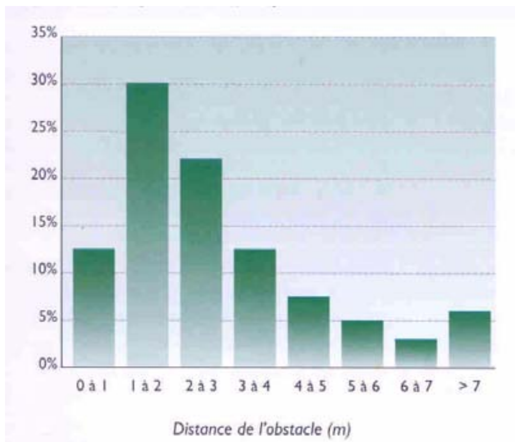

Figure 2.2. Distribution of fatal accidents against fixed obstacles according to the distance to the edge of the carriageway [6]

2.4 RISER Analysis

The risk of injury during a run-off-road event depends on the motions of the vehicle and the type of objects contacted in the roadside area. Chapter 1 provided information on the types and characteristics of obstacles and hazards found on European roadsides. The following analyses will discuss the manner in which vehicles leave the road and the resulting requirements for a safety zone.

There are two main topics of interest for run-off-road events; the conditions under which a vehicle leaves the road (speed, angle, etc.) and the distance they travel in the roadside. These issues are discussed and related to the design criteria necessary for defining the safety zone. Both a theoretical basis for designing the safety zone and accident based information, gained in the RISER project, will be presented.

2.4.1 Criteria to Dimension the Safety Zone

The dimensions of the safety zone must be based on the local terrain, weather conditions and traffic environments, etc. A review of several European countries in RISER provided seven main criteria used to specify the dimensions for the safety zone. The main parameters of interest are:

1. Road type – the class of road (motorway, national road, divided or non divided traffic lanes, etc.).
2. Traffic – the volume and mix of traffic observed on the road usually expressed in Annual Average Daily Traffic (AADT) and percentage of heavy vehicles.
3. Speed – the design speed is usually the most common speed used for designing the road, but redesign of existing roads should use observed speeds unless they are less than the design speed.
4. Side slope – the characteristics of the slopes adjacent to the roadway, typically the gradient and height of the slope.
5. Horizontal alignment – separate criteria may be considered for straight and curved sections.
6. Driving lane width – lateral width of the travel lane(s). Note that this is often associated with the road type.
7. Other – many modifications of the safety zone width may result from the location of bodies of water, industrial areas, residential areas and railway lines, etc.

Table 2.1 provides the application of these criteria for the countries reviewed. For specific details of the national standards, the reader is referred to RISER Deliverable 5 [1]. Most countries specify a safety zone based on the road characteristics (identified above) but Spain uses this information implicitly by evaluating the risk of contacting an obstacle and determining the severity of injuries.

Table 2.1. National Criteria for Dimensioning the Safety Zone

Criteria	FI	FR	DE	UK	NL	ES	SE
Road type	No	Yes	Yes	Yes	Yes	Yes	No
Traffic	Yes	Yes	Yes	No	Yes	Yes	Yes
Speed	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Side slope	Yes	Yes	Yes	No	Yes	Yes	Yes
Horizontal alignment	Yes	No	Yes	No	Yes	No	No
Driving lane width	No	No	No	No	No	No	Yes
Others	Yes	No	Yes	No	Yes	No	Yes

2.4.2 Exit Conditions for Run-Off-Road Accidents

The speed and angle under which a vehicle leaves the road is dependent on many factors. If we focus on the physical (non-driver) parameters then the exit angle is a useful basis for discussion. The angle that a vehicle leaves the road depends on road-tyre friction, travel speed, lateral position of the vehicle to the carriageway, and geometrical road properties (vertical and horizontal alignment). As seen in Table 2.1, many parameters related to the road type become design criteria of interest.

Theoretical Analysis for exit angles

If the behaviour of a vehicle is determined by its steering system, the trajectory of its centre of mass running off the road on a straight road section can be calculated as a function of the distance between its initial straight trajectory and the carriageway edge line (see Figure 2.3). The exit angle depends on the travelled speed and the maximum lateral acceleration for a vehicle, which can be related to the friction coefficient between the road and the vehicle's tyres.

The theoretical maximum exit angle can be expressed from this simplified analysis of the vehicle handling ability. If the maximum lateral friction coefficient between the tyres and the road surface is given as ***f***, and the distance to the carriageway edge line is ***d,*** the principal of centripetal acceleration will yield the following relationship between exit angle (NY) and the travelled speed ***v*** (given in m/s):

$$NY = \cos^{-1}\left[1 - fgd / v^2\right]$$ **Equation 2-1**

g is acceleration due to gravity = 9.81 m/s^2

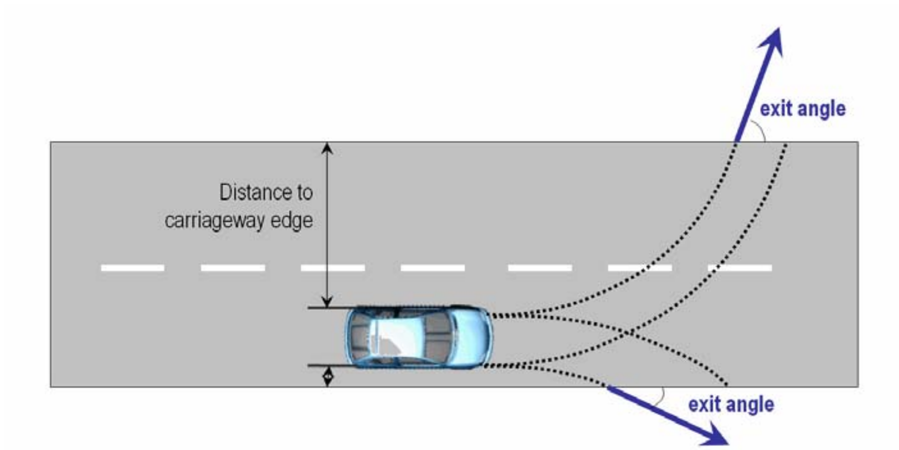

Figure 2.3. Exit angle on a straight road

The results of Equation 2.1 can be plotted for different lateral distances and travel speeds and is shown in Figure 2.4.

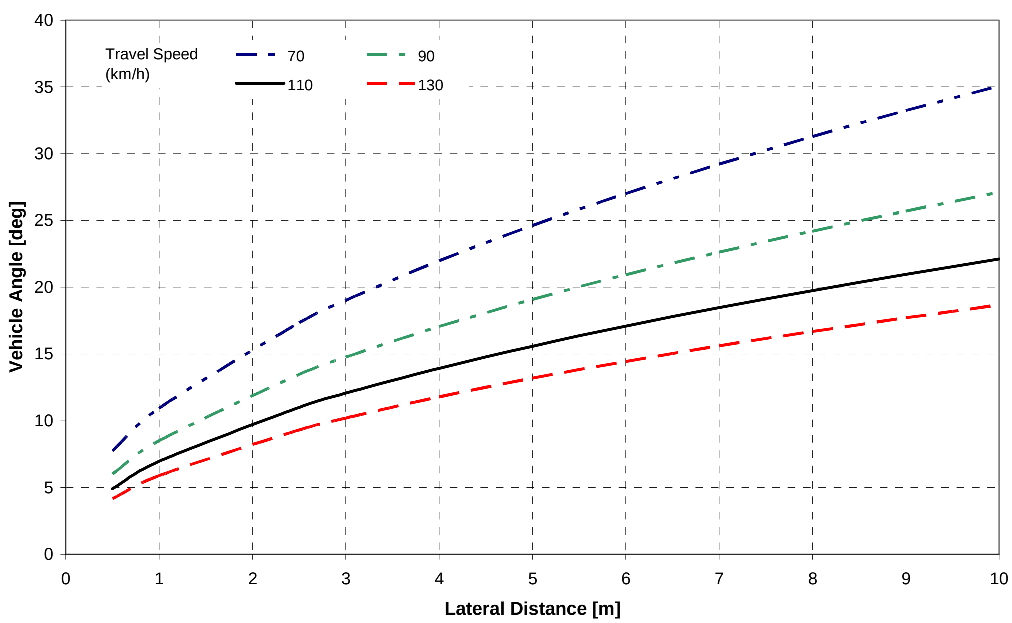

Figure 2.4. Relationship between the trajectory of a vehicle running off the carriageway and the travelled speed. Friction coefficient 0.7

On a straight 2 lane rural roads, the maximum trajectory of a vehicle should not be more than 20 degrees if it leaves the offside of the roadway. This assumes a travel speed greater than 90 km/h and a friction coefficient of 0.7.

In a similar way, the trajectory of a vehicle running off the road on a curved road section can be calculated as a function of the distance between its initial straight trajectory and the carriageway edge line, and the radius of the curve (Figure 2.5). The exit angle does not depend on the travelled speed in this case. It has to be noted that its value can be overestimated in this calculation due to the fact that the curve radius is not constant, but decreasing as the vehicle travels through the curve.

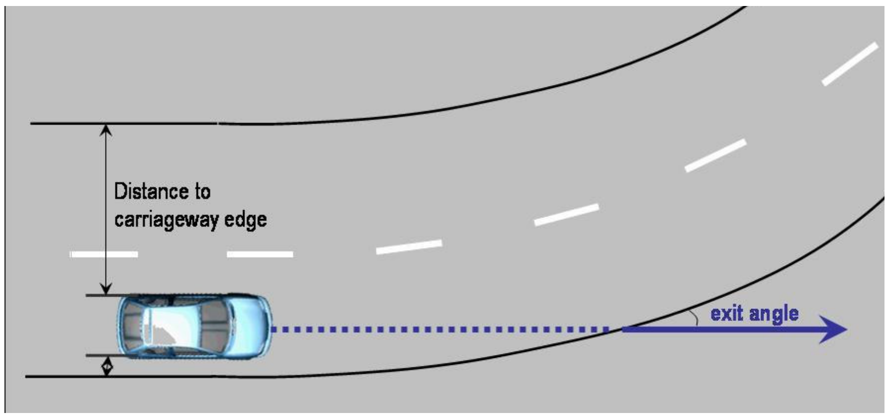

Figure 2.5. Exit Angle for a Curve (no steering)

Theoretical values for the exit angles for curves (as depicted in Figure 2.5) are shown in Figure 2.6.

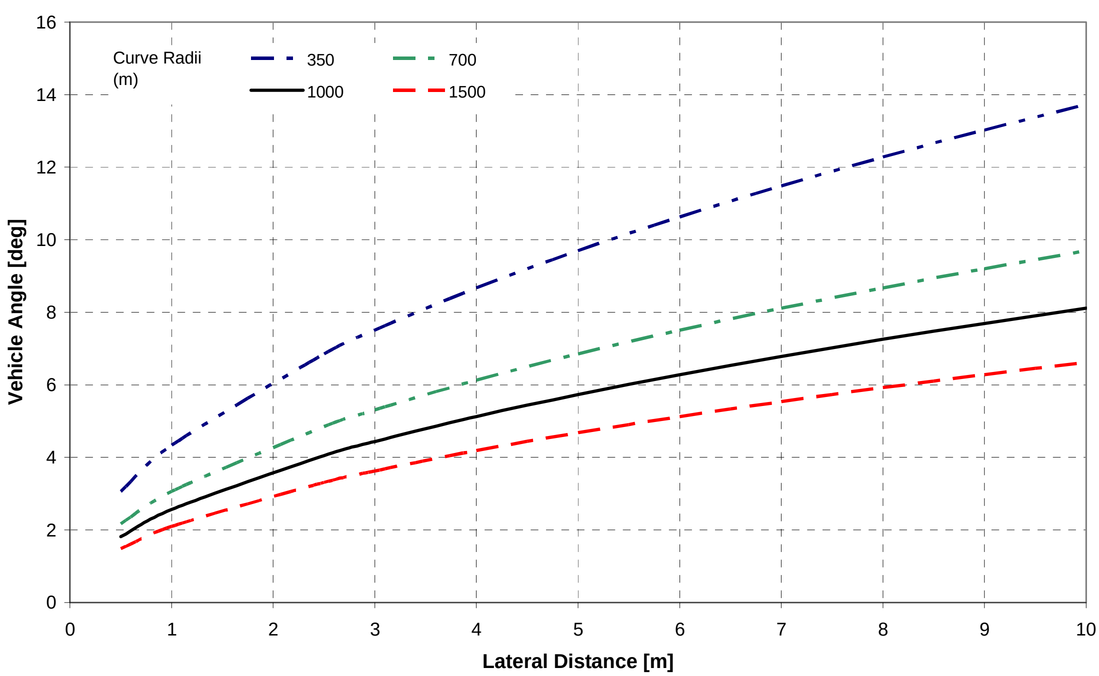

Figure 2.6. Relationship Between Curve Radius and Exit Angle

Again, the exit angle is not generally expected to be over 20 degrees for the usual ranges of curve radii in current roads.

It is important to recognize the inverse relationship between exit speed and exit angle. With increasing speed, the magnitude of the exit angle decreases. The relationship between the exit speed and the exit angle calculated using Equation 2.1 is illustrated in Figure 2.7. This is a conservative relationship since the actual turning manoeuvre creates extra drag forces on the tyres and slows the vehicle. Thus, exit speeds are lower than presented in Figure 2.7

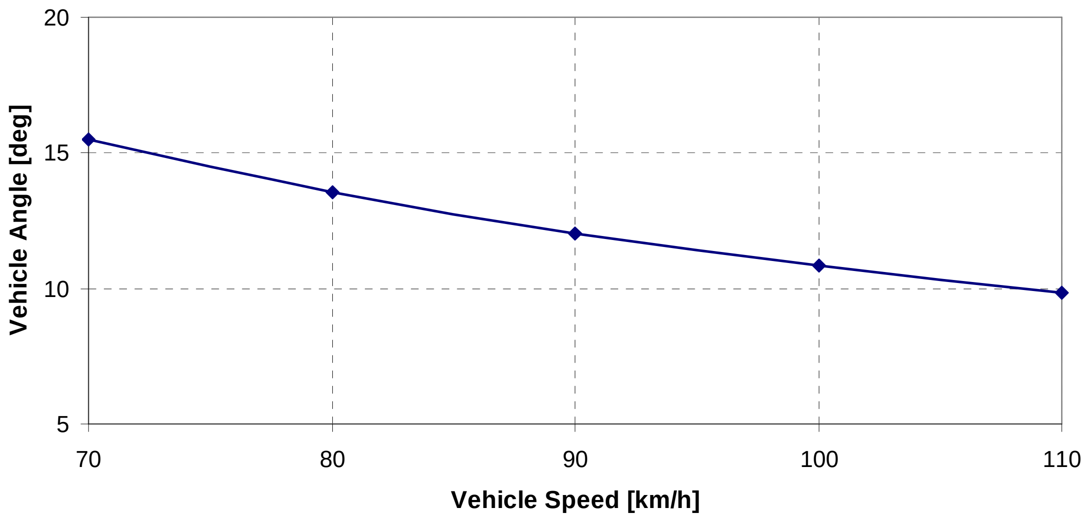

Figure 2.7. Relationship between Exit Speed and Exit Angle (theoretical f=0.7, d=2m)

An important assumption made in the previous analyses is that the vehicle turns due to a large steering input (by the driver) and that the vehicle turns in a stable, non sliding manner. In reality many run-off-road events are due to abrupt steering manoeuvres that result in vehicle rotations (yaw) so that the vehicle leaves the road in a non-tracking manner. This behaviour is presented in Figure 2.8 where the trajectory of the vehicle centre of mass moves at an angle NY to the carriageway edge line while the vehicle heading (orientation) is defined by an angle PSI. These angles are identical if the vehicle is not experiencing any sliding or rotational behaviour (normal tracking).

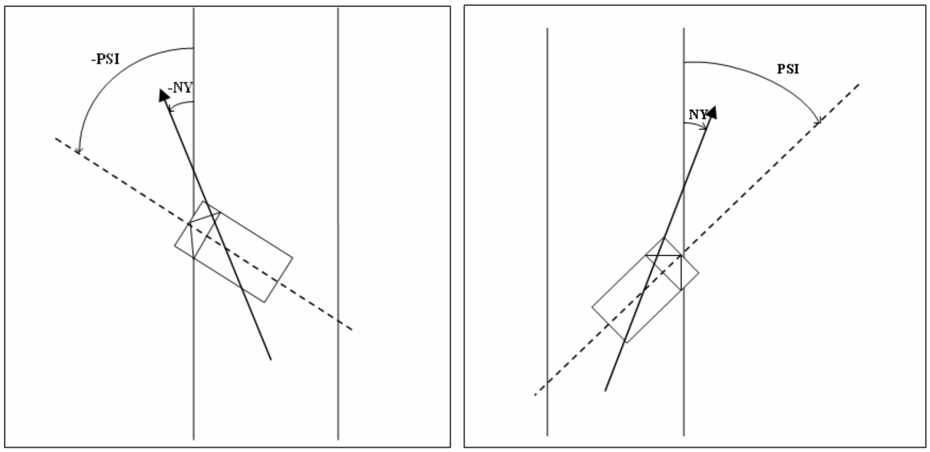

Figure 2.8. Definition of Vehicle Exit Angles

Accident Data from RISER Detailed Database – Exit angles

From the accident data collected in RISER, 82 accidents were reconstructed and tabulated for analysis concerning the first departure from the road. The following information summarizes all road types in RISER and is not broken down by specific road type, posted speed, etc. since the number of cases is too small to conduct more specific analyses.

If the vehicle's first departure from the road is considered, the most critical angle to evaluate is the vehicle trajectory angle, NY (Figure 2.8). This implies the momentum vector for the vehicle and is a strong indicator how far into the roadside the vehicle will travel. The cumulative distribution of exit angles from the accident data is presented in Figure 2.9. It is important to identify the most common exit angles (NY) and Figure 2.9 shows that 90 % of the exit angles are below 20 degrees which identifies a correlation to test standards in Europe (Chapter 5).

The exit angles plotted in Figure 2.9 have not been divided into initial departures to the left or right side of the carriageway. The possible exit angle is increased by a longer lateral distance available for the vehicle to travel. Cases where departures to the offside of the carriageway or departures to the nearside following a lane change tended to have higher exit angles than those where the vehicle left the nearside of the road.

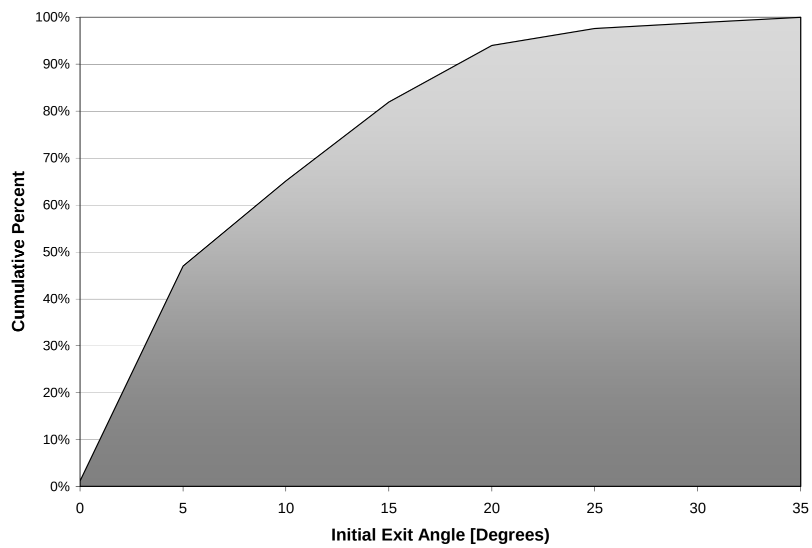

Figure 2.9. Cumulative distribution of initial departure angle from road

Figure 2.10 identifies the amount of spinning or sliding of the vehicle as it left the road. The values presented on the X-axis represent the difference between the vehicle's trajectory (NY) and the vehicle's heading (PSI) angles. A normally operating vehicle has very little difference between vehicle trajectory and heading. The results plotted in Figure 2.10 show that only about half of the vehicles (47%) had less than a 5 degree difference between these angles and thus were tracking in a reasonably stable manner. The remainder of the exits (53%) had significant yaw motions (NY-PSI values over 5 degrees) and are important to consider if there will be subsequent driver steering inputs which lead to a higher rollover risk (Appendix C).

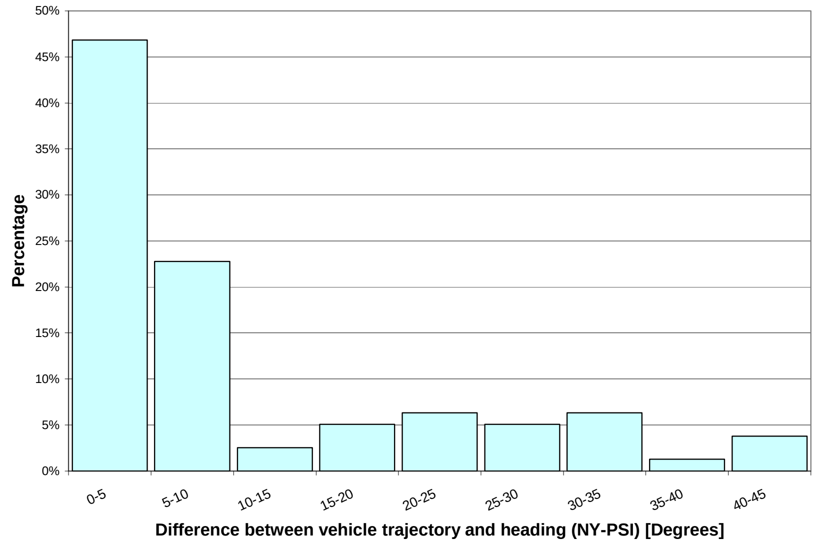

Figure 2.10. Magnitude of lateral sliding

The last issue to consider is the relationship between exit angle and exit speed. Figure 2.7 showed the theoretically relationship between exit angle and exit speed for a given lateral position of the vehicle before a run-off-road event. The reconstructed cases from the RISER investigations are presented in Figure 2.11. Even though the theoretical case represents a low (2 m) lateral motion of the vehicle leaving the road and the RISER data covers a wide range (up to 10 m) lateral motion, the expected exit angles are about half of the theoretical angles. This suggests that any theoretical estimates of exit angle based on maximum cornering capacity are very conservative.

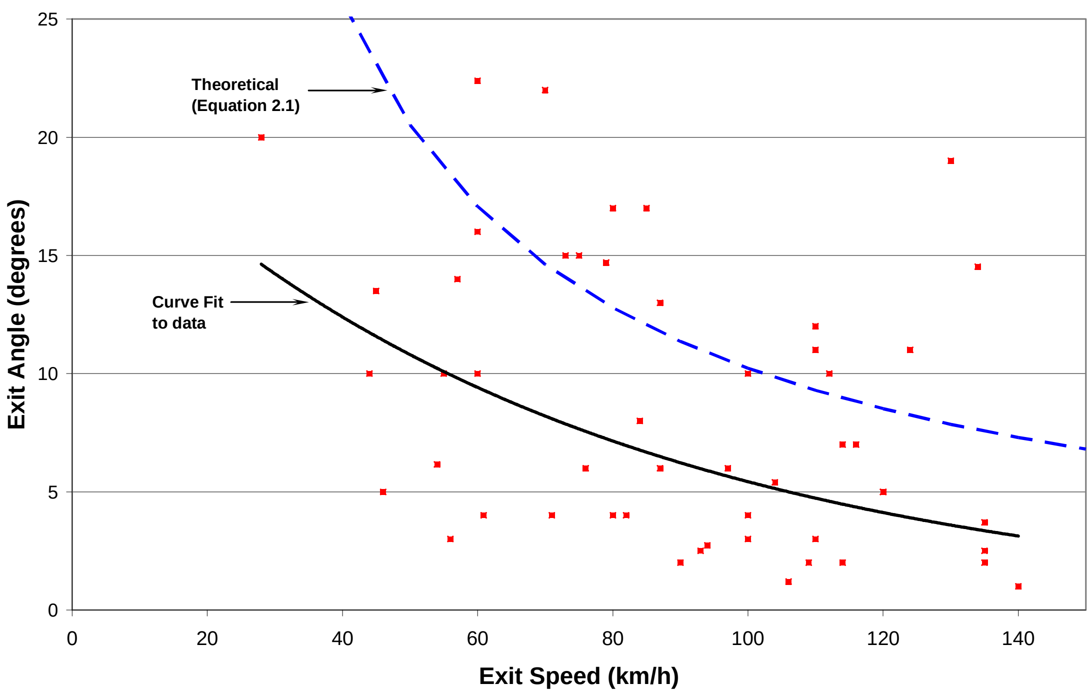

Figure 2.11. Relationship between Exit Angle And Exit Speed (Reconstructed)

Unfortunately, there is a limited amount of information in the detailed database about the levels of increased risk on roads where there is a bend. No measures are available of the severity of the bend. However, from looking at the results of the detailed database analysis, it appears that single vehicle accidents are prevalent at locations where there was a curve in the road. In the RISER database, 105 out of 211 cases occurred at locations where there was a curved road section. In 26 fatal or serious injury accidents, the curve was recorded as being a potential risk factor. In nearly all of these cases (23), the vehicle did not return to the road after its initial run-off.

Exit Speeds

As already presented for exit angles, the exit speed of the vehicle from the road will depend on the vehicle speed and position on the travel way prior to its approach to the carriageway edge line. These factors are linked to the road type as this will affect the lane width and travel speeds on the roadway. Road surface characteristics are implicitly connected to road type since renovation and maintenance of road surfaces are more frequent on higher standards of roads.

It is desirable that roadway designs that result in a more harmonious relationship between the desired operating speed, the actual operating speed, and the posted speed limit. The goal is to provide geometric street designs that “look and feel” like the intended purpose of the roadway (Self Explaining Roads). Such an approach produces geometric conditions that should result in operating speeds that are consistent with driver expectations and commensurate with the function of the roadway. It is envisioned that a complementary relationship would then exist between design speed, operating speed, and posted speed limits [7].

The most common factors in single vehicle accidents are approaching a curve at too high speed, over-correcting and then leaving the roadway. The severity of injuries generally depends on the velocity and the impact configuration. Speed is intimately related to the risk and severity of a crash. A review of international research on the relationship between speed, speed limits and accidents came to the conclusion that a 1 km/h change in the mean speed of traffic produces a 3 % change in injury accidents [8]. Other studies show the contribution of speed variance, vehicles moving much slower or much faster than the median speed, are over-involved in accidents [9, 10, 11, 12].

Definition of Speed

- Design speed

  selected speed used to determine the various geometric design features of the roadway

- Observed speed

  operating, running, average, pace, or 85th percentile speeds is the speed at which drivers are observed operating their vehicles during free flow conditions. The 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed associated with a particular location or geometric feature.

- Posted speed

  the maximum or minimum speed for a road as determined by law (usually shown on speed limit sign)
- Initial speed

  the speed at which the deceleration in an accident begins. It is the observed speed without reaction time and brake lag included.

For the determination of the safety zone for NEW roads the design speed and for EXISTING roads the observed speed should be used.

Accident Data from RISER Detailed Database – Exit Speed

Data from the reconstructed RISER cases were used to develop the distribution of impact speeds presented in Figure 2.12. Again, the data represents single vehicle accidents from all road types and posted speed limits for the RISER cases. The data shows that 90 % of the crashes are below 120 km/h and 80 % are below 110 km/h. For reference, 110 km/h is the test speed for heavy passenger cars against safety barriers (Chapter 5).

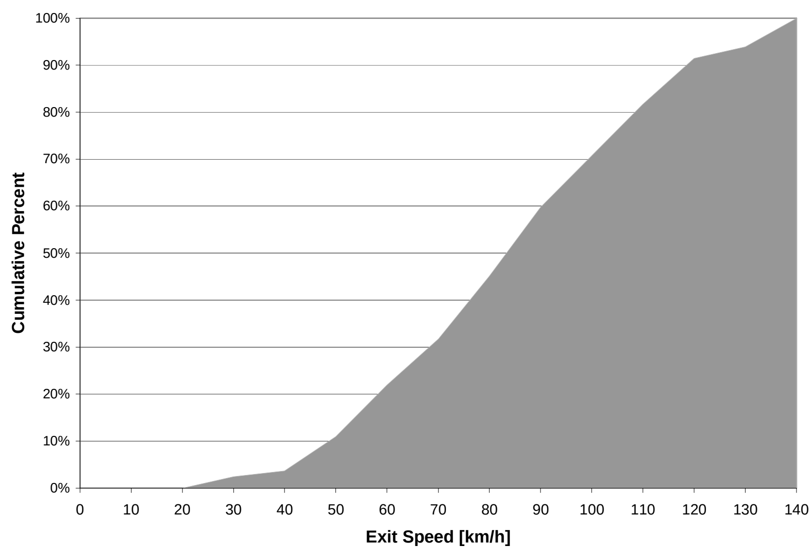

Figure 2.12. Distribution of exit speed for initial run-off-road event

2.4.3 Strategy for Determining a Safety Zone Width

There is a necessity to identify the safety functions when developing the safety zone designs. The explicit idea is that the vehicle will not contact any hazard which results in a collision with serious consequences. This is achieved by preventing rollover and removing fixed objects. The implicit idea is if the vehicle leaves the road and crosses the entire safety zone, it slows down and reduces the consequences of any resulting impact beyond the safety zone. Ideally, the vehicle should not ever leave the safety zone, instead the driver should be able to control and stop the vehicle within the lateral and longitudinal limits of the safety zone.

From these objectives, it is important to identify the parameters affecting the vehicle motions in the safety zone so that they can then be used as criteria for dimensioning the safety zone.

Vehicle Protection Limits

Human survival in a crash depends on how well the crash energies are absorbed by the vehicle. Uncushioned, the human body cannot survive impacts above 40 km/h. If a crash occurs, in modern vehicles some of the energy will be absorbed by the vehicle structure and the restraint systems. But the vehicles are optimized for standard crash tests, and single vehicle accident situations are not well represented in vehicle design requirements. It is important to note that 40 km/h was the threshold for fatal injuries observed for many of the hazards documented in the detailed database (Chapter 1).

It is the energy-absorbing capabilities of the car and the roadside infrastructure taken together that provide optimum protection from the energies of impact. The car is designed and crash tested in frontal and side impact configurations (Appendix D). Modern vehicles are equipped with advanced safety features, but older vehicles (especially those designed prior to 1990) and some special purpose vehicles do not possess these advanced devices. Therefore it is important to consider potential impact speeds which can be considered relevant for setting a desired safety level.

On many continents, vehicles are tested at 50 km/h into a flat, rigid barrier. These tests are quite severe and may be a useful starting point for designing roadside safety zones. However, the accident history relevant for the road section should be reviewed. From the RISER detailed accident database, the most severe accident configuration was with trees and poles. From this data (reported in Chapter 1) fatal and serious injuries were reported for impact speeds over 40 km/h. With increasing financial resources, this impact speed should be reduced further.

Theoretical dimensioning principles for the safety zone

If the goal of the safety zone is to eliminate impacts with objects for impact speeds above 40 km/h, then the lateral distance of the safety zone must accommodate the motions of the vehicles until this speed is reached. The approximate braking distance of a vehicle from the design (or observed) speed of the roadway to 40 km/h (11.1 m/s) may be determined from the following equation:

$$s = \frac{v^2 - 11.1^2}{2 \cdot a} = \frac{v^2 - 11.1^2}{2 \cdot \mu \cdot g}$$ **Equation 2-2**

s = braking distance [m]
v = Design speed or observed speed [m/s]
a = Deceleration [m/s²]
μ = Coefficient of friction
g = Gravity [9.81 m/s²]

The deceleration possible by the vehicle is dependent on the ground conditions. Most side slopes and ditches have surfaces of gravel and topsoil, possibly with grass type vegetation. The rolling resistance on these surfaces are higher than asphalt and tend to slow vehicles at a rate up to approximately 2 m/s^2 (0.2 g) see Table 2.2.

Table 2.2. Rolling resistance coefficient

Tyre on	Rolling resistance coefficient
Asphalt	0.010 – 0.015
Concrete	0.011 – 0.014
Cobbled pavement	0.015 – 0.020
Cobbled pavement, very bad	– 0.033
Gravel, rolled	0.020
Soil way	0.045 – 0.16
Sand	0.15 – 0.30
Field	0.14 – 0.24

Studies documented in the literature show that most drivers decelerate at a rate greater than 4.5 m/s² during braking. Approximately 90 % of all drivers decelerate at rates greater than 3.4 m/s². Such decelerations can be handled by most drivers. The friction levels of the different roadside sections are often not consistent. For a vehicle running out of the road the worst case is a friction coefficient of 0.3 for wet grass (with exception of ice). This results in an available deceleration rate of 2.9 m/s².

Roadside geometrics have a great influence on the frequency of serious injury and fatal crashes; especially the design of the side slopes has influence on the occurrence of rollover, which is one of the most dangerous events in single vehicle accidents. In the US the Roadside Design Guide [13] defines recoverable, traversable and non-traversable slopes. A recoverable slope is a slope on which a motorist may, to a greater or lesser extent, retain or regain control of a vehicle by slowing or stopping. Slopes flatter than 1:4 are generally considered recoverable, where motorists generally can stop their vehicles or slow them down enough to safely return to the roadway. A non-recoverable slope is a slope which is considered traversable but on which an errant vehicle will continue to the bottom. Embankment slopes between 1:3 and 1:4 may be considered traversable but non-recoverable if they are smooth and free of fixed objects. A clear run-out area is the area at the toe of a non-recoverable slope available for safe use by an errant vehicle.

For fill slopes the approximate stopping distance of a vehicle at the design or observed speed of the roadway may be determined from the following equation:

$$s = \frac{v^2 - 11.1^2}{2 \cdot a} = \frac{v^2 - 11.1^2}{2 \cdot g \cdot (\mu \cdot \cos(\varphi) - \sin(\varphi))}$$ **Equation 2-3**

s = braking distance [m]
v = Design speed or observed speed [m/s]
a = Deceleration [m/s²]
μ = Coefficient of friction
g = Gravity [9.81 m/s²]
φ = Slope angle [°]

In the formula above the maximum slope angle for a given coefficient of friction is also contained. If the gradient of the slope is equal to the coefficient of friction, the limit for a safe deceleration is reached.

$$\tan(\varphi) = \mu$$ **Equation 2-4**

This means for slopes inclinations over 1:3 and coefficient of friction 0.3 there will be no safe stop.

The absolute inclination of the slope is not relevant for running off the road situations, but the resulting inclination when driving under a certain course angle as seen in Figure 2.13. The vehicle's heading angle changes while on the slope due to driver input.

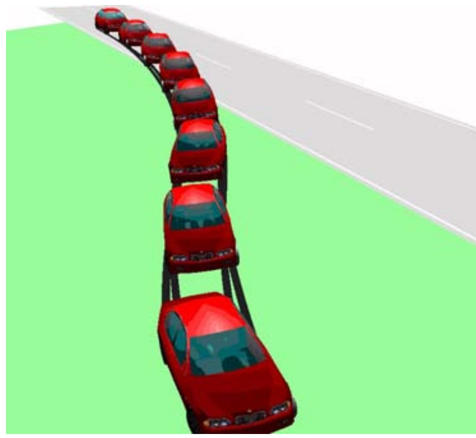

Figure 2.13 Vehicle Course on a Slope

The driven inclination can be determined by the side inclination and the speed direction using the following correlation:

$$\sin(\eta) = \sin(\varphi) \cdot \sin(\alpha)$$ **Equation 2-5**

η = Driven slope angle [°]
φ = Slope angle [°]
α = Vehicle velocity direction [°]

As indicated in Table 2.1, roadside slopes and embankments are a variable in the safety zone criteria. Both the height and gradient of the slope is important. Testing in Finland and Sweden [14] indicates that a vehicle can easily traverse a V shaped ditch only 1 m deep. Similarly for the exit angle and speed, the road type has some effect on the roadside slopes. Higher standard roads like motorways have wider road beds and result in shallower side slopes when compared to smaller rural roads.

Accident investigations have shown that the transitions of slopes and the change in the subsoil are problematic zones. Often the wheels jam into the soil and cause rollover. Therefore the slopes should be homogenous, transitions should be rounded and flattened when possible.

Safety Zone Width Suggestions

From the review of European practice, the width of the safety zone has a strong relationship to speed. As the speed for the road increases, so does the width of the safety zone.

Using the information presented previously, the width of the safety zone can be defined as the width necessary to stop a vehicle to avoid serious impact. As an example, the following table lists the recommended safety zone widths if the road, speed, and slope conditions are:

- Coefficient of friction 0.3 (grass)
- Initial manoeuvre on the road was abrupt steering
- Vehicles decelerate on roadside without manoeuvre
- Impact velocity 40 km/h after crossing the safety zone
- Flat Ground (ideal conditions)

Table 2.3. Theoretical Safety Zone Widths

Exit ang.	Slope	μ	a	Exit Speed from Carriageway (km/h)								
(deg)			(m/s^2)	50	60	70	80	90	100	110	120	130
5	0	0.3	2.9	1	2	4	5	7	10	12	15	17
10	0	0.3	2.9	2	5	8	11	15	19	24	29	35
15	0	0.3	2.9	3	7	11	16	22	29	36	43	52
20	0	0.3	2.9	4	9	15	22	29	38	47	57	69
25	0	0.3	2.9	5	11	18	27	36	47	58	71	85
30	0	0.3	2.9	6	13	22	31	43	55	69	84	100

A comparison of the values in Table 2.3 with actual safety zone dimension in current guidelines [1] indicates that an exit angle of 5 degrees produces 7 m and 12 m safety zones for exit speeds of 90 and 110 km/h. These values are consistent with current practice in many European countries for roads with these posted speed limits. The 5 degree and 90 km/h exit conditions are also the median exit angle and exit speed observed in the RISER reconstructions (Figure 2.9 and Figure 2.12). Thus the theoretical safety zone calculation for 5 degrees is a useful starting point for developing safety zone criteria. The theory produces larger safety zone dimensions for exit angles above 5 degrees which are larger than in common practice. This is a practical problem for the road owner/operator and local conditions must be considered. This approach can be useful for applying local modifications to the safety zone.

Set-back Measurements in RISER Detailed Database

In the RISER detailed database a general distribution of the minimum and maximum set-back distances for the different roadside obstacles struck can be seen in Figure 2.14. This figure illustrates that most impacts occur in the first 10 m of the roadside, measured from the carriageway edge line.

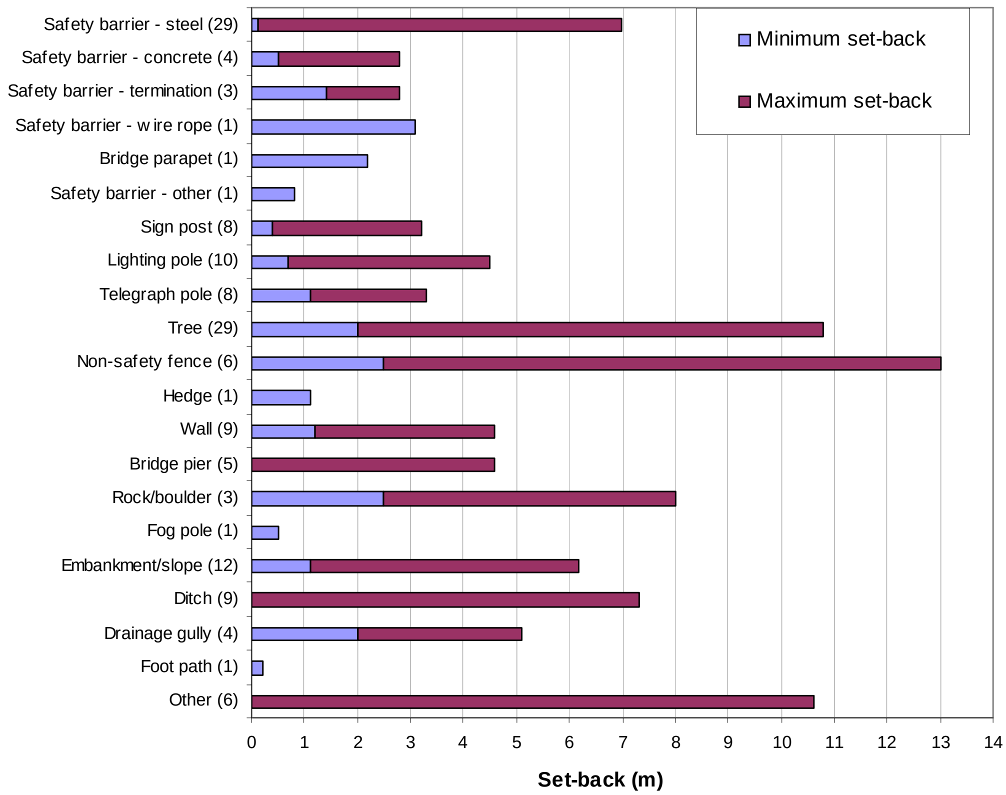

Figure 2.14. Set-back Information for Obstacles recorded in RISER Detailed Database

The cumulative distribution of the set-back distance is provided in Figure 2.15. The 85th percentile set-back distance is identified by the dashed lines and is seen to be 7 m. This is consistent with information from other countries like France and the Netherlands.

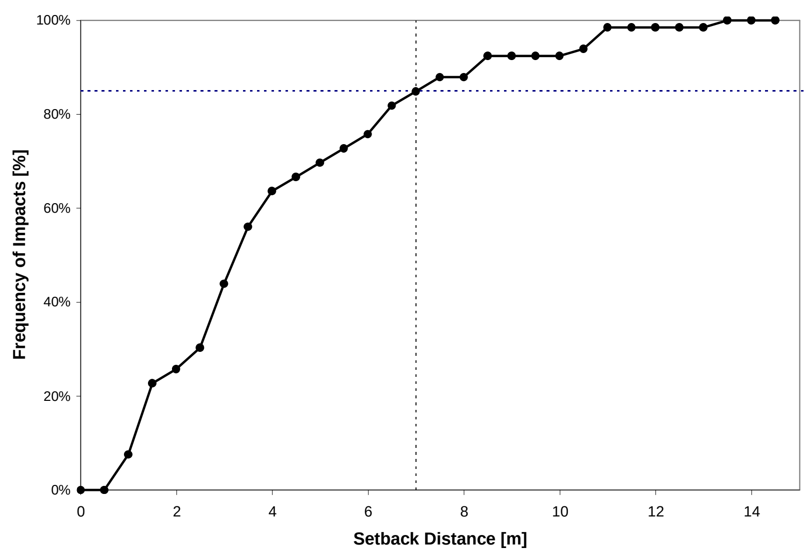

Figure 2.15 Cumulative Distribution of Struck Obstacles

The information presented in Figure 2.14 and Figure 2.15 are indicative of accident data on roads generally following the safety zone concept. This means that we would expect that most impacts with roadside hazards would be beyond the 4.5 m limit which is the smallest safety zone in the reviewed countries. The fact that 50 % of all impacts are within the 4.5 m range can partly be explained by the number of safety/road sign objects listed in Figure 2.14. The data collected in RISER have only addressed impacts, the maximum distance that a vehicle travelled into the safety zone during an uncontrolled exit from the road was not measured in the RISER project.

2.5 Summary

The dimensioning of a safety zone is a difficult process. A theoretical process using vehicle dynamics and human tolerance information provides results consistent with current practice if vehicle exit angles from the road are 5 degrees, which is the median value for the data collected in RISER. An alternative is to use the struck object set-back distance obtained from the accident data. In this latter approach, the data coming from RISER appear to support information from France, the US, and the Netherlands which shows that the risk of contact with an obstacle drops dramatically after the first few meters and most impacts with roadside obstacles occur in the first 10 m.

Most safety zones in Europe are specified to be between 6-10 m for travel speeds around 100 km/h. Safety zones are smaller for lower speeds and for 80 km/h roads, the same countries use 4.5-7 m as a safety zone width.

The RISER analysis provides two alternatives for designing the roadside safety zone.

1. Based on the risk of injury during an impact with a hazard, the safety zone can be dimensioned for allowable impacts with hazards. In this case the allowable impact speed for striking a hazard is given in Chapter 1 and the impact speeds are calculated from the information provided earlier in this chapter.
2. The safety zone can be dimensioned as the risk for a fatal impact with an object of a given set-back. Based on the RISER database, the set-back distances can be grouped into the categories based on the road characteristics.

2.5.1 Safety Zone Requirements

The requirements for a well designed safety zone are that:

- the consequences of a run-off are reduced
- the width should be designed that most vehicles that leave the road do not leave the safety zone
- there should only be slopes that do not cause rollovers
- the surface should be homogenous and even to prevent rollover
- there should be no unprotected fixed objects located within the safety zone

Legislators and authorities should ensure that a safety zone only contains artificial structures that will collapse or break away on impact without significantly damaging an errant vehicle. Where allocation of the desired safety zone is not practicable, they should consider erecting an appropriate road restraint system.

Accident data collected in RISER indicates that most vehicle departures from the road were less than 20 degrees and 110 km/h. These run-off roads events involve a non-tracking (yawing) vehicle in about half of the cases. Impacts with roadside obstacles were observed up to 10 m from the road and 85 % of all roadside impacts happened within the first 7 m of the roadside. A roadside safety zone should be dimensioned to the local road conditions using the local accident data when possible.

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CHAPTER 3: THE RECOVERY ZONE

3.1 Introduction

For some known or unknown reasons road users sometimes leave the running carriageway. The human factor (drowsiness, drinking and drugs driving, fatigue, distraction, medication, etc.) is admittedly important in road departure but the influence of the roadside area should not be underestimated.

There are many opportunities for mitigating roadside accidents, in particular once the run-off does occur, by providing opportunities for the driver of the vehicle to recover and return to the road without incident.

This chapter provides road designers with guidance on the design of the roadside environment, which includes elements to allow for recovery. Road equipment which is intended to reduce the severity of the roadside collision is addressed in Chapter 4 and Chapter 5.

3.2 Definition of the Recovery Zone

The recovery zone is defined in two different ways according to European policies: in most countries it is a narrow roadside zone beside the carriageway considered as an integral part of the total clear, hazard-free safety zone design described in Chapter 2. In a few countries the recovery zone is a hard shoulder that allows limited vehicle manoeuvres and is considered as a separate issue.

A hard shoulder is defined as being an asphalt or concrete surface immediately beyond the carriageway edge line. Shoulder pavement surface and condition as well as friction properties are intended to be as good as the road surface. An example of a recovery zone/hard shoulder is illustrated in Figure 3.1.

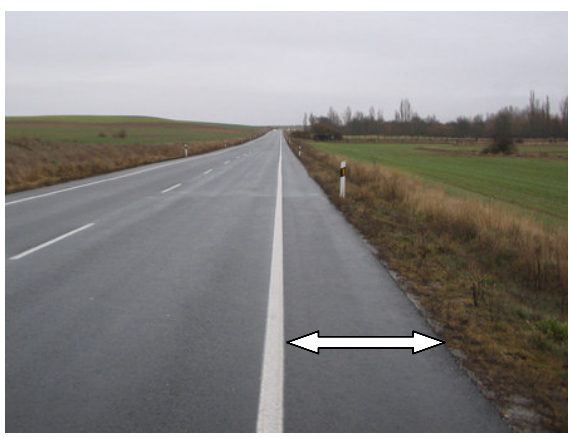

Figure 3.1. Example of a Recovery Zone/Hard Shoulder in Spain

3.2.1 The Main Functions of a Recovery Zone

On motorways, the hard shoulder, referred to as the emergency lane, provides extra space for emergency vehicles and unexpected stopping.

On dual carriageway or single carriageway roads, paved shoulder is generally used to accommodate driving errors when the vehicle goes off the road, but it also provides extra space to:

- help car drivers to avoid potential conflicts with errant vehicles veering away from their normal paths
- increase lateral clearance during overtaking manoeuvres
- avoid vehicles making a turn towards minor roads and private accesses
- accommodate stopped vehicles for emergency use under unexpected circumstances (mechanical failures, flat tyres, etc.)
- be used by cyclists and pedestrians off the carriageway
- improve highway capacity and facilitate road maintenance and rural activities
- maintain an access to rescue vehicles in case of emergencies
- increase sight distance and clear visibility from minor roads

3.3 Overview of Research

This subsection is divided into seven parts, each of which treats a different aspect of the roadside safety research:

1. The first section is dedicated to the positive effect of hard (paved) shoulder on accident rates
2. The second section discuss the negative effect of soft shoulder on run-offs
3. The third section is dedicated to the positive effect of paved shoulders on accidents involving vulnerable road users
4. The fourth section points out the positive effect of paved shoulders on other types of accidents
5. The fifth section gives some information about the best locations to construct pavement shoulders
6. The sixth section is dedicated to the width of a recovery zone
7. The last section discusses the surface characteristics of a recovery zone

3.3.1 Hard Shoulder Positive Effects on Accident Rates

Several reports have shown that the presence of hard shoulders is recommended because of their positive safety effects. Some of them refer to the positive influence of the combination of reducing each traffic lane with widening of the hard shoulder widths.

In 1998, the SAFESTAR European project [1] highlighted the findings of a great number of roadside research on rural single carriageway roads from different countries: In Germany Brannolte [2] detected that two-lane roads with shoulders had an approximately 10 % lower accident rate compared to similar roads without shoulders. In the USA Foody and Long [3] found that the mean accident rate for stabilized shoulder sections was significantly lower that for sections of unstabilised shoulders. The same research project also quoted several authors [2, 4, 5] and found decreasing accident rates with increasing paved shoulder widths.

Brüde and Larsson [6] studied the safety effects of an increase in lane width (from 3.75 m to 5.5 m) and a simultaneous reduction of shoulder width (from 2.75 m to 1 m): the findings indicated that accident severity increased strongly in connection with the widening of the road. This confirmed the findings of German research undertaken in 1993, which concluded that accident rates and accident cost rates were higher on over wide roads.

In the Handbook of Road Safety Measures [7] researchers have studied the effects of constructing hard shoulders on the number of accidents. According to the report roads with hard shoulders which were usually 0.3 to 1 m wide, had an accident rate around 5 to 10 % lower than roads without hard shoulders (this applied to rural roads). They also quoted a number of studies evaluating the effect of narrower traffic lanes combined with wider hard shoulders.

A special report issued in the American Transportation Research Board headed Designing Safer Roads, Practice for Resurfacing, Restoration and Rehabilitation [8], states that prior research on lane and shoulder width and shoulder type indicates that accident rates decrease with increases in lane and shoulder width.

In France, within the framework of the Users' Safety on Existing Roads process, a team of researchers carried out a before/after study in order to evaluate the effect of constructing paved shoulders on 7 national trunk roads all across France. As a result the conclusion of the report to be published [9], states that the pavement surfacing of shoulders improved safety on the seven roads and statically representative figures show that the implementation of paved shoulders has an effect on 43 % of the number of injury accidents, and shows a decrease by 65 % of the accident severity, in confirmation of comparable positive findings provided by a number of foreign studies.

The study "Evaluation of pavement shoulders" [10], was intended to determine the effect of pavement shoulders on the safety and the structural strength of highways. The University of Wyoming performed the effectiveness of pavement shoulders on the safety of highways in Wyoming for a five-year period. It was determined that significant reductions in accidents could be expected when shoulders widths were increased. If a 1.8 m shoulder was in place instead of a 0 m shoulder, there would be a 47 percent reduction in accidents. The first 0.6 m (2 feet) of shoulders is most effective in reducing accident numbers (a 19 percent reduction in accidents). These results are consistent with similar studies performed at a national American level.

Recommendation:

A great number of studies show the positive effect on road accident rates of hard or paved shoulder beside the travel lanes.

3.3.2 Soft Shoulder Negative Effects on Run-off-road Accidents

RISER developed a detailed database fed with 211 in-depth investigations of accidents. An in-depth analysis of the data in the detailed database was undertaken and a number of areas were investigated, including the type of infrastructure impacted, set-backs of hazards and objects, recovery zone width when existing, accidents involving safety barriers and an overview of accidents where there is an evidence of an initial run-off with no impact. In the analysis of the recovery zone, the

European consortium particularly focussed on single and multiple run-offs. Single run-off is where the vehicle directly travels on nearside or offside of road with no return onto the road. Multiple run-off is an accident where the vehicle runs off the road, then returns to the road, and then runs off the road at least one more time. There are two descriptions of multiple run-offs: one is where the initial encroachment is with no impact; the other is with impact.

In the database 37 multiple run-off cases were scrutinized. In 20 cases, the vehicle had an initial encroachment without impact on roadside furniture, and in the further 17 cases, the vehicle had an initial encroachment with an impact on roadside furniture.

The study reveals that on single carriageway roads, 11 of the 13 multiple run-offs without impact occurred on unpaved shoulders (asphalt strips of 0.5 m or less), with 2 having unknown shoulder widths. The study also reveals that no multiple run-off without impact on roadside furniture during initial encroachment occurred on paved shoulders.

The research highlights several cases in which roadside environment did play a role in the accident occurrence. In 18 accidents the vehicle had the initial encroachment on one side of road before travelling across the road and having the main impact. In 13 of these 18 cases, the vehicle initially left the nearside and had impact in offside. A step-by-step scrutiny of the cases clearly shows that multiple run-offs generally occur on roads with unpaved shoulders where grass and gravel shoulders are prevailing.

Some accurate information on this road design issue is also available from other sources.

In 2004, CETE Normandie-Centre and CEESAR carried out a study on the influence of roadside conditions and surface on run-off-road accidents in rural areas [11]. A total of 56 single and multiple run-offs (corresponding to abovementioned definition) have been studied. The report concludes that a recovery zone would have played a key role in the accidents, because when travelling off the road the vehicle was still controllable in 56 % of the cases. In the multiple run-off cases, 10 to 15 vehicles travel less than 1.5 m-deep onto the roadside at the initial encroachment. The report also states that when looking closely at the accident mechanisms, the presence of rolling stones and gravels is originating a second run-off-road. The second part of the conclusion is related to road restraint systems and energy absorbing road equipments (see Chapter 5): regarding final exit speeds 38 values out of 39 are inferior to 100 km/h, and regarding exit angles, in 74 % of the cases the final exit angle is inferior to 20°.

In 1997, CETE Normandie-Centre and CEESAR analysed 81 detailed accidents [12]. The main figures show that there were 38 run-offs on straight and 43 on bends, in which there are 41 multiple run-offs (50 %), this accident mechanism being more frequent on left bends. The study points out that the initial encroachment angle is shallow (<4° on average) and it occurs on less than 2 m of the roadside; the second encroachment angle is much higher than the previous one during multiple run-off accidents. In almost 50 % of single vehicle run-off accidents (SVA), the driver is still capable to maintain control of his car when the car is going onto the roadside after leaving the road. Road safety experts assert that the roadside design can be efficiently improved on this specific area where any slight encroachment of a vehicle onto a soft shoulder can turn an assumingly 'controllable' situation into a real loss of control. The report concludes that paved shoulders may have had a positive effect in 50 % of the single vehicle accidents.

Another research entitled Exploration of In-Depth Investigations of Accidents [13], was led in 2000 by INRETS on 84 detailed accidents on bends. In 45 % of the run-offs, the vehicle can still be controlled while initially encroaching the roadside area. It also points out that the roadside environment has played a key role in the accident causation, insisting on that grass or loose shoulder material should be rejected when designing this part of the road.

3.3.3 Hard Shoulder Positive Effect on Accidents against Pedestrians, Bikes and Mopeds

A Danish study [14] quoted calculated that a paved shoulder increase from 0.2 to 0.5 m showed a significant reduction of accident risks for vehicle accidents by about 25 % and for pedestrian and cycling accidents by 40 %.

The abovementioned Handbook of Road Safety Measures [7] shows that both bicycle accidents and accidents involving motor vehicles were reduced when the width of the hard shoulder was increased from 0.2 m to 0.5 m.

In 1992, Sécurité des Routes et des Rues [15], Safety on Roads and Streets, by SETRA, France, asserts that pedestrians and pedal cyclists (both 8 % of the fatal accidents in France) may travel in safer conditions if roadside conditions were improved. It is shown that in 50 % of the pedestrian accidents in rural areas, people involved were walking along the driving lanes.

3.3.4 Hard Shoulder Positive Effect on Other Accident Types

In addition to pedestrian and cycling accidents Safety on Roads and Streets [12] draws up a list of a number of accident types in which there is a relationship between safety and roadside design: sideswipe and head-on accidents after a loss of control, multi-vehicle collisions where the roadside environment could not provide extra space for avoidance (meeting errant vehicles, left-turning vehicles, rear-end collisions in tail-backs, overtaking accidents). All these accident scenarios have been described in several international studies [16, 17, 18, 19].

In accidents at junctions, a French experimentation has shown a reduction in accidents in private accesses and junctions after constructing paved shoulders alongside particular roads.

Recommendation
Several studies show the positive effect of a paved shoulder on accidents involving vulnerable road users, but also on other types of accident, such as single vehicle accidents, head-on collisions and rear-end collisions.

3.3.5 Accident Locations and Road Types

Research carried out by INRETS [20] show that the abovementioned accidents occur most frequently on:

- national two-way rural roads
- high-traffic roads
- straight roads
- the outside of curves with radius ≥ 200 m
- roads with no hard shoulders.

These elements confirm the conclusions provided by RISER's police database analysis: most of RISER single vehicle accidents are reported on single carriageway roads, with high fatality rate on this road type as well. RISER's report also states most of the single vehicle accidents occur on straight roads.

RISER's detailed database analysis of accidents on bends showed that there are a sizeable number of accidents where the initial run-off occurred in curves where roadside was not paved (18 cases out of 104, 17 %)

Recommendation

Paved shoulders should be constructed in priority:

- on main roads
- on the outside of curves
- opposite T-junctions
- where vulnerable road users may travel

3.3.6 The Width of a Recovery Zone

What is important to know is whether hard shoulder width is related to safety and whether increasing shoulder width improve or degrade safety. Answers to this crucial issue are available from different international sources. Most of them highlight the positive effect of widening the recovery zone - to some extent, though - while fewer others show that widening shoulders is less effective than widening lanes.

Several authors found decreasing accident rates with increasing paved shoulder widths, quoting "an optimum value for the shoulder widths was not determined unambiguously, but a total pavement width of 10 m (3.5-3.7 m wide lanes and paved or stabilized shoulders of 1.3-1.5 m) is mentioned as the pavement width beyond which further widening does not improve safety.

American studies [4] have shown the relationship between accident rate and paved shoulder width. A compilation of additional studies (Zeeger, Deen and Mayes (1981), Barbaresso and Bair (1983) and Rosbach (1984) shows that increasing the width of the hard shoulder by around 0.3 m appears to reduce the number of injury accidents by about 20 %, and both bicycle accidents and accidents involving motor vehicles are reduced when the width of hard shoulder was increased from 0.2 to 0.5 m.

In the USA, the Traffic Safety Toolbox [21], by the Institute of Transportation Engineers and Designing Safer Roads shows that accident rates decrease with increases in lane and shoulder width, and widening shoulders is less effective than widening lanes.

In-depth investigations of accidents have shown the initial encroachments in single vehicle multiple run-off accidents were about on average 0.7 m-deep on bends [20] and 1.2 m-deep on straight, with an exit angle of 5° at a speed of 80-90 km/h [22].

From 1992 to 2002, CETE Normandie-Centre has undertaken in-situ studies to evaluate the effects on driver behaviours of constructing 0.80 m to 1.2 m-wide paved shoulders along five different two-lane road sections. As a result there were no variation in traffic speeds and the lateral position of the vehicles was closer to nearside area (Influence of Paved Shoulders on Driver Behaviour, several cases in Seine-Maritime, France [23].

In their Handbook of Road Safety Measures [7], Elvik and Vaa conclude that increasing the width of the hard shoulder by around 0.3 m appears to reduce the number of injury accidents by about 20 % while increasing the width of the hard shoulder by around 1 metre does not lead to statistically significant changes in the total number of accidents (injury and property damage only accidents. It has to be noticed however that the initial width is unknown and the result referring to injury accidents comes from just one study.

3.3.7 The Roadside Surface Characteristics

Skid Resistance

In 1998, a report titled Roadside Environment and Light Vehicles Kinetics by UTAC, France [24] points out that once the vehicle has encroached onto the pavement edge drop, the driver gives a violent turn of the wheel in such a disproportionate amplitude that his vehicle goes back onto the road (or onto the roadside) under a far greater angle. In-depth investigations of accidents also reveal that during the initial encroachment, the steering manoeuvre is violent and shows the need for skid resistance on the roadside too.

In 2004, the CETE de Lyon (France) carried out a study of skid resistance on grass or gravel shoulders [25]; grass and gravel shoulders provide a skid resistance respectively 30 % and 40 % inferior to asphalted carriageways. The report concludes that one of the run-off accident causes could lay in insufficient skid resistance of loose material shoulder where initial encroachment angle are low.

Recommendation
Gravel and grass shoulders do not offer a good level of skid resistance. In case of a slight encroachment onto the roadside, it is then almost impossible to recover in a safe way

Shoulder Rumble Strips

According to a number of reports based upon in-depth investigations of accidents (RISER Deliverable 4 [20, 26], 27]) human factors (mainly alcohol, fatigue and distraction) was prevailing in accidents where the vehicle was leaving the road at a low run-off angle but was still controllable.

In 1991, research by CETE Normandie-Centre on French motorways has shown that the number and the lateral extent of encroachments onto emergency lane was reduced after implementing jiggle-barred shoulder strips [28]. The report concludes that this type of edge marking would increase the efficiency of a paved shoulder.

In a literature review on recovery zone performed by CETE Normandie-Centre and the Eastern Paris Regional Laboratory LREP reporting to the French ministry for Transport, a document [29] quotes two American safety evaluations after installing shoulder rumble strips: the influence of rumble strips on monotonous main roads is estimated by 12 % on run-off-road accidents after a migration effect of the accidents. In another reference, the influence of rumble strips is estimated by 6 %, without accident migration [30]

In the Safety Evaluation of Rolled-In Continuous Shoulder Rumble Strips Installed on Freeways, by FHWA in 1999, a before-after field study on 55 locations shows the positive effect by 13 %.

RISER's detailed data shows that inappropriate speed or speeding is not the main factors of accidents. Heavy workload, panic (9 cases), internal or external distraction (16 cases) and above all fatigue (31 cases out of 189) are other factors of risk. One can estimate that audible road markings may have played a positive role in some of these accidents.

3.4 Summary

RISER's analysis of different criteria for dimensioning the recovery zone has shown that the design of roadside environments is complex. For a road designer evaluating alternative designs and choosing among them is difficult because there are many levels of interaction between different road design components such as the road itself, speed, traffic volumes and terrain etc.

The information collected among RISER contributing partners' national policies clearly show that the width of the recovery zone is different one country from another, some of the reviewed countries using the general roadside geometry to describe the safety risks for roadside environment.

From the abovementioned research findings, the recommended width of paved shoulders on non-motorway roads should be between 1 m and 1.5 m, value beyond which further widening does not seem to greatly improve safety (see Table 3.1 and Table 3.2). However these values can be smaller, above all in the outside of curves, and keep a significant efficiency. With paved shoulder widths greater than 1.5 m speeds and subsequent accident rates may increase. Further research should be conducted to confirm this assertion.

Table 3.1. Recovery Zone Width on Non-Motorway Roads

Usage	Recommended values
Recovery of errant vehicles	1 m to 1.50 m
Avoidance of overtaking and meeting vehicles	1 m to 1.50 m
Avoidance of vehicles making a turn	1 m to 1.50 m
Travel of vulnerable road users off the driving lane	0.5 m to 1.5 m

Table 3.2. Recovery Zone on Motorways

Usage	Recommended values
Emergency lane	3 m to 4 m

3.4.1 Good Condition, Good Surface for Paved Shoulders

Shoulder condition and surface must have the same quality as the road. It must be constructed so as to bear the static load of heavy trucks.

3.4.2 No Grass, No Gravel, No Loose Material on Paved Shoulders

The material used to construct paved shoulders is very important. The recovery zone should have the same surface quality as the pavement and skid resistance should be identical to the carriageway.

Loose materiel or grass shoulders degrade recovery and avoidance manoeuvres. In addition, bikers and cyclists are reluctant to travel on such uncomfortable material.

3.4.3 Paved Shoulders opposite T-Junctions and Private Accesses

Extra space should be installed opposite T-junctions and private accesses to enable avoidance of vehicles making a turn towards minor roads and private accesses.

3.4.4 Audible Road Markings as Additional Corrective Actions

In combination with paved shoulders, audible road markings can be implemented alongside the main roads in order to alert the driver of an errant vehicle.

Rumble strips or edge markings with jiggle bars should be provided to alert a motorist who is driving in a deteriorated driving situation.

3.4.5 Paved Shoulders on the Outside of Curves

Paved shoulders should be implemented preferably on the outside of curves with radius greater than 200 m on single carriageway roads.

3.4.6 Discussion

Road designers must recognize that the roadside environment and its design have a vital role to play in improving roadside safety. A great number of research clearly show that a recovery zone has a positive effect on both accident rates and driver behaviour, provided that the abovementioned conditions of implementation are respected: a smooth and resistant surface made of asphalt or concrete, with no loose material, wide enough to allow vulnerable road users to make short trips off the carriageway but not too wide so that car drivers do not understand this roadway improvement as an extra driving lane.

For economical grounds, further research could be carried out to answer to the question: what is the optimal paved shoulder and lane widths?

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CHAPTER 4: TECHNICAL DESIGN STRATEGIES WITH CASE EXAMPLES

4.1 Introduction

The development of a safe roadside environment depends on the identification of the hazards in the roadside environment (Chapters 1-3). Once these hazards are identified and are known to be in the safety zone, suitable strategies (or countermeasures) are needed to protect traffic from these hazards. The purpose of this section is to provide guidance for the technical treatment of hazards on both new and existing roads.

As described in Chapter 1 the hazards that are most common on European roads can be divided into 2 classifications: point hazards and distributed hazards. These two classifications create different procedures for selecting a countermeasure for the hazard. However, the general strategy illustrated in Figure 4.1 can be applied to both cases.

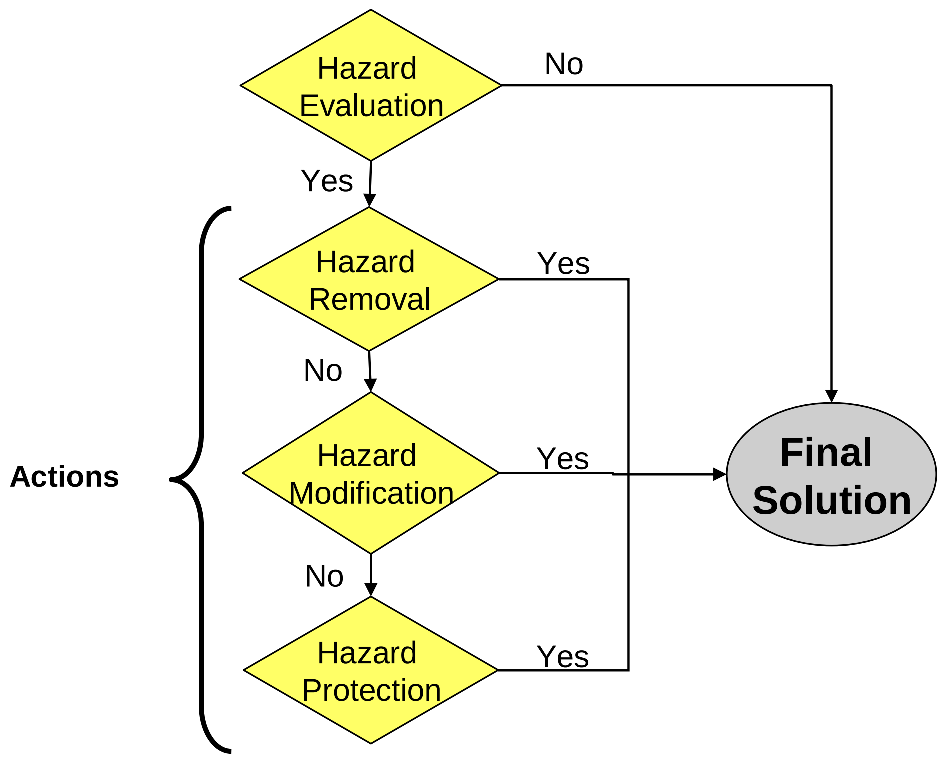

Figure 4.1. Strategy for Hazard Countermeasures

In a review of the accident statistics in the RISER project, a great number of accidents involved collisions with hazards located in the safety zone. This indicates that there is a considerable problem at the first decision point in Figure 4.1 – identifying the hazard. Once the hazard is identified, the selection of appropriate actions usually is uncomplicated. The initial identification of the hazards is a common problem throughout the world. When several hazards are identified and priorities need to be set, it is useful to review the risk of an impact with the type of object and then the consequences of an impact with that object. Figure 4.2 shows the frequency of impacts versus the consequences of impacts based on the information in the RISER statistical database. The dashed lines are constant risk curves, the points in the upper right corner are high frequency, high fatality hazards. Trees are thus an important priority for improving roadside safety, but the "No object" point indicates vehicles rolling over in the terrain. As expected, safety barriers have a high frequency but a lower fatality frequency.

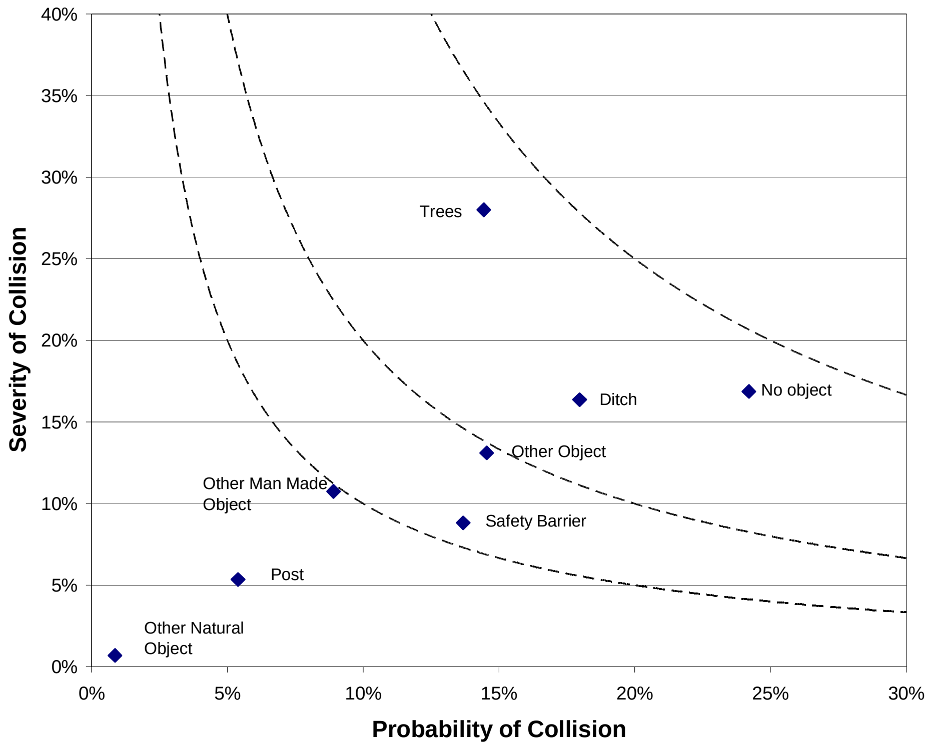

Figure 4.2 Risk Information for Various Struck Objects

A brief introduction to the issues of technical design of roadsides will be presented followed by a more specific description of the different designs.

4.2 Overview of Hazard Protection

4.2.1 Point Hazards

Hazards that are restricted to a small area as identified in Table 1.9 can be subdivided into man made and natural features. From the RISER statistical database, the two primary point hazards overlooked in roadside areas are narrow objects like trees and poles. It is important that the safety zone is properly dimensioned for the road classification and that any trees or poles are removed from this area.

Action 1 Remove the hazard. Man-made features in the roadside safety zone should only be there because of a functional requirement (lighting, signs, bridge support, etc.). If they are not required, then they should be removed. Trees and poles that are located in the safety zone but cannot be removed (aesthetic or functional requirements) need to be made less harmful to vehicles.

Action 2 For man-made hazards, modify the hazard becomes the next step. For lighting and utility columns, energy absorbing and break-away structures are important structures to incorporate into the roadside area. The two different structures – deformable and rigid – are shown in Figure 4.3. The outcome from these two motorway accidents was quite different even though the impact speeds were quite similar.

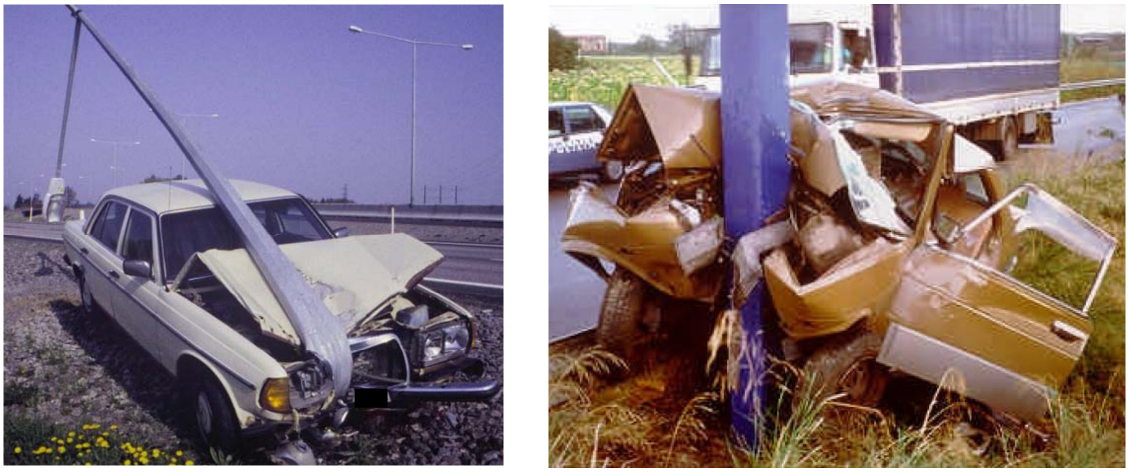

Figure 4.3. Passive Safety Infrastructure
(picture to left courtesy Jan Wenäll, VTI Sweden)

Action 3 Natural features like trees are sometimes difficult to remove from the roadside area due to historic and aesthetic requirements. Therefore the third task is sometimes more applicable – protect the road user from the hazard (see Figure 4.4).

Figure 4.4. Rigid Lighting Columns protected with Guardrail

Protecting the point hazard introduces added complexity to the roadside design. In addition to selecting a type of road restraint system, the designer must also consider the placement of the safety feature and the size of the area to be protected (see Figure 4.5). An important issue is the transition from single point hazards to distributed point hazards (such as a group of trees or lighting poles).

Figure 4.5. The culvert is protected with a short guardrail but the gantry pole and the old rigid lighting column are unprotected (Photo, HUT)

4.2.2 Distributed Hazards

Distributed hazards by their nature encompass larger areas than point hazards (see Figure 4.6). This can result in higher costs than for the point hazard. A similar process, Figure 4.1, can be applied to distributed hazards as for the point hazards.

Action 1 Remove the hazard: As for point hazards, the nature of the hazard will determine what is possible. Man-made distributed hazards should be designed so that they are not located within the safety zone. Similarly, natural hazards (rock faces, groups of trees, etc) should be set back from the road so that they are not located in the safety zone.

Figure 4.6. Examples of the distributed hazards. Left: unprotected rock cut very close to the carriageway. Right: untested guardrail with concrete posts and too low positioning (Photo, HUT)

Action 2 Modify the hazard: Almost all distributed hazards of concern are related to the roadside geometry. RISER statistical accident data indicate that roadside geometry; including slopes, embankments and ditches (or no specific impacted object), contribute to almost half of all run-off-road accidents involving injury or fatality. These roadside features are believed to be the leading cause of rollover in single-vehicle, run-off-road accidents. The layout of the side slopes and ditches adjacent to the road are the main features that can be modified from a dangerous situation to a more gentle geometry.

Action 3 Hazard shielding: The application of road restraint systems (safety barriers) to protect distributed hazards is the best alternative when a hazard cannot be relocated outside the safety zone. The safety barrier must be selected to provide suitable protection for the exposed traffic and the dimensions of the hazard.

4.3 Analysis and Recommendations of Specific Hazard Protection

4.3.1 Point hazards Case Examples

Trees

RISER statistical database shows that trees are the most commonly impacted object in fatal single vehicle accidents among RISER countries (28 % of fatalities).

RISER detailed database includes 30 accidents (of 211) where tree was the main or only impacted object. The set-back of trees from the edge of the carriageway ranged from 2.0 m to 10.8 m. In all fatal accidents with reconstruction data the vehicle struck the tree at a speed greater than 70 km/h.

In all RISER countries the trees are considered as the main concern when they are too big and too close to the carriageway.

Recommendation:

1. Remove trees which are inside the safety zone
   Usually the easiest and best method to decrease the risk of collision to trees is removal of all trees inside the safety zone (see Figure 4.7).

Figure 4.7. Example of a Clear Safety Zone when trees have been removed (Photo, HUT)

2. Shielding with safety barrier
   In some cases the trees (row of trees) are considered as an important aesthetic part of the roadside area. They can also have an important role in functionality of a self-explaining road scene.

Boulders

All boulders and smaller hazardous stones inside the safety zone should be removed. If that is not possible for some reason the boulders must be shielded with a safety barrier.

Bridge Abutments and Bridge Piers

Earlier studies indicate that the risk of fatalities is outstandingly high in crashes to bridge abutments and bridge piers (Figure 4.8) compared to most other roadside obstacles [1, 2, 3]. The easiest, most cost-effective and usually also the only way to protect the bridge abutments and bridge piers is shielding it with a safety barrier.

Figure 4.8. Example of hazardous, unshielded bridge pier and bridge abutment

Recommendation:

1. Shielding with guardrail
   All bridge abutments and bridge piers must be shielded with a safety barrier. Special attention must be paid to the sufficient working width and sufficient length of the safety barrier.

Underpasses

The underpassing minor road or small water course – especially their opposite embankment or retaining wall - is extremely dangerous for the encroaching vehicles (see Figure 4.9).

Figure 4.9. Hazardous underpass on motorway, notice too short safety barriers

1. Shielding with guardrail
   Travelling on the roadside or on the median and encroaching to the underpass must be prevented by using safety barriers which are long enough for this purpose. The length of need and the flaring of the safety barrier will probably ensure that an errant vehicle cannot collide into the underpass (see Figure 4.10).

Figure 4.10. Underpass opening on motorway median protected with safety barriers. (Photo, HUT)

Culvert Ends

Culvert ends are very hazardous impact objects, e.g. on minor road junctions (Figure 4.11). If the vehicle runs off the road into the ditch, there is a risk of an impact to the culvert end or to the minor road side slope.The solutions are to remove the obstacle, design or redesign of the culvert location or use of safer construction in the ends of the culvert.

Figure 4.11. Examples of culverts in minor road junctions: traditionally the ends are vertical and the side slopes of the minor roads steep which makes them very hazardous objects in collisions (Photo, HUT)

Recommendation:

1. Reduction of the number of minor road junctions (and culverts) by the means of traffic planning. The safest solution is always the removal of minor road junctions and culverts, if that is possible with reorganisation of the entrances to the major road.
2. Culverts parallel to the main road: new design or redesign of the position. Culverts must be positioned far enough from the main road so that an errant

vehicle which is travelling along the ditch cannot collide with the termination of the culvert (Figure 4.12).

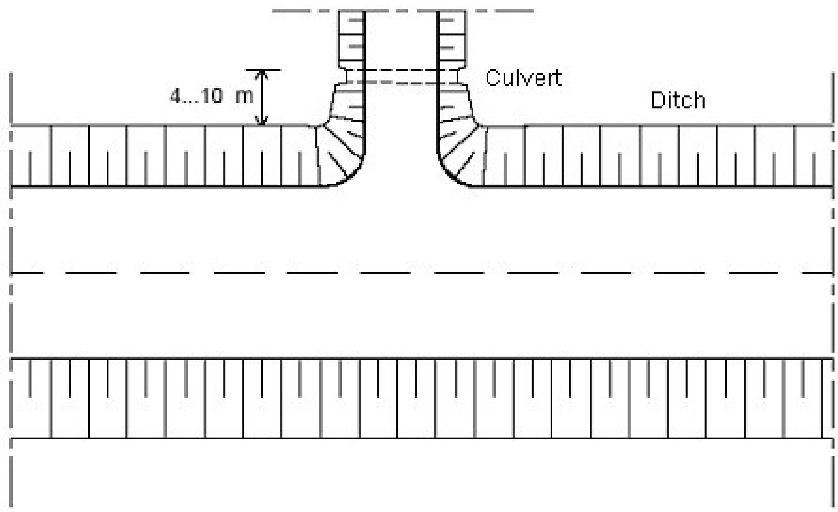

Figure 4.12. Errant vehicle is prevented to impact the end of the culvert by adequate set back of the culvert. Safe set back of the culvert depends on the width of the ditch and width of the safety zone (figure: Finnish Road Administration; TYLT 6800-6870).

3. Culverts parallel to the main road: design or redesign of the terminal. The bevelled ends of the culverts and gentle side slopes of the minor roads are safer in collision than traditional vertical culvert ends and 1:1 – 1:2 side slopes (Figure 4.13)

Figure 4.13. Bevelled culvert ends in minor road junctions (Photo, HUT)

4. On existing roads it may be more cost effective to protect the culvert terminals than reshape them and the side slope or relocate the culverts. Some experimental applications exist, but as far as is known there are no generally accepted applications yet in any European design guidelines. Culverts transverse to the main road
   As stated in RISER deliverable 5 [4] culverts which are transverse to the road should have the terminal bevelled with gradient 1:1 to 1:4 (Figure 4.14).

Figure 4.14. Bevelled end of a concrete culvert: safer design than traditional vertical end shape (Photo, HUT)

Lighting Columns

Rigid lighting columns and utility poles are very common and severe hazards in the roadside. On new roads all poles should be located beyond the safety zone. If the location inside safety zone can not be avoided only passively safe columns should be used. All columns should be tested according to the current EN standards (EN 12767).

Case Finland: today more than 90 % of new lighting columns installed for Finnish Road Administration are break-away ones. Most of them are wooden poles or yielding steel columns, not many slip base ones. Break-away columns are only slightly more expensive than columns with no passive safety [5].

Recommendation:

1. New installation or replacement to passively safe columns
   If installation into safety zone is necessary only passively safe columns should be used (see Figure 4.15). Energy absorbing columns should be preferred if there is pedestrian path or hazards (e.g. trees) not far behind a column. Old rigid steel, concrete and wooden lighting columns can be replaced with energy absorbing or break-away steel, aluminium, wooden or composite columns.

2. Modification of rigid columns
   Wooden and steel columns can be modified to break-away ones (see Figure 4.16). There are several techniques for that purpose.

Figure 4.15. Left: Break-away wooden column; glued and laminated. Right: Yielding, energy absorbing steel column (Photo, HUT)

Figure 4.16. Left: old wooden lighting column. Right: old steel lighting column, both are modified to break away at impact.(Photo, HUT)

Utility Poles

Utility poles are commonly located along roadsides. Nowadays there is no traffic-related reason for the location, but due to the huge number of utility poles it is not possible to relocate all the poles in the near future. In TRB Guide for Reducing Collisions Involving Utility Poles, the objectives to reduce the number and severity of impacts include:

- reduce the hazard of specific utility poles in high-crash and high-risk locations
- prevent placing new utility poles in high-risk locations
- treat several utility poles along a road to minimize the likelihood of crashing into a utility pole when vehicles run-off-road

Recommendation:

1. Remove poles inside the safety zone
2. Locate/relocate poles beyond the safety zone
3. Place the utilities underground
4. Decrease the number of poles
   - sometimes it is possible to decrease the number of utility poles by widening the spacing or relocating the utilities to be placed only on one side of the road
5. Use break-away poles
   - recommended alternative for the new installations if the poles for some reason must be located inside the safety zone
   - old poles can also be modified to break-away ones
6. Shield a pole with a safety barrier
   - option if an utility pole cannot be removed, relocated or modified with reasonable costs

Gantry Poles

Gantry poles are normally rigid, very strong steel or concrete supports without any energy absorbing properties. In most cases they are located close to the roadway (see Figure 4.17). It is recommended that all kind of impacts to rigid gantry poles are prevented.

Figure 4.17. Unprotected gantry poles in the safety zone are fatal hazards (Photo, VALT)

Recommendation:

1. Shielding with safety barrier (see Figure 4.18) note that the use of unflared, turned down barriers is not recommended from the results of RISER accident studies.

2. Use break-away gantry poles. Nowadays there are also break-away gantry structures on the market.

Figure 4.18. Gantry pole shielded with safety barrier, note that the use of unflared, turned down barriers is not recommended (Photo, HUT)

Small Sign Supports

Traffic sign supports are considered as hazards if they are not proved to be safe in impact or if their dimensions exceed the limits presented in Chapter 1.

Recommendation:

1. Relocate the sign support beyond the safety zone.
   Locating the traffic sign or other sign support outside the safety zone is preferable if it is possible to carry out without degrading the visibility of the sign.
2. Use passively safe supports
   If sign support must be located inside safety zone, the impact severity can be significantly reduced by using a passively safe device (see Figure 4.19).

Figure 4.19. Small break-away sign support

4.3.2 Distributed Hazards Case Examples

Fill Slopes

Fill slopes and fore slopes of the ditches are considered as recoverable if they are 1:4 or flatter. Slopes from 1:3 to 1:4 are considered as non-recoverable, but traversable. Slopes steeper than 1:3 are critical; possibility to rollover of the vehicle increases substantially [6].

Recommendation:

1. Low traffic main roads, design speed 70 km/h or less
   – embankment height < 3.0 m: side slope 1:3 or flatter
   – embankment height ≥ 3.0 m: also fill slopes steeper than 1:3 can be used with an appropriate safety barrier (see Figure 4.20)
2. Busy main roads
   – embankment height < 3.0 m: side slope 1:4 or flatter, toe of the slope(or bottom of the ditch) rounded but note that heights over 1 m were hazardous in the accident analyses (Chapter 1)
   – embankment height > 3.0 m: fill slopes steeper than 1:3 can be used with an appropriate safety barrier

Figure 4.20. Fill slope with a safety barrier, height exceeds 3.0 m.

Ditches and Cut Slopes

Ditches are needed for the drainage of the road structure. Ditches cause two kinds of severe accidents: rollovers and crashes to the back slope. To decrease these kinds of accidents the geometry of the cross-section must be gentle enough. When a traversable shape of the ditch is considered, the terrain behind the ditch (trees, pedestrian path etc.) must also be taken into account.

The behaviour of errant vehicle in 1:3 fore slope and 1:2 back slope ditches is investigated with full-scale tests [7]. In V-shaped ditch it was discovered that passenger car tends to crash to the back slope and then overturn, if the speed exceeds 80 km/h and exit angle is 20°. With smaller angles the vehicle travelled in a 1:2 back slope beyond the height of 1.5 m. Next tests proved that rounding of the bottom prevents a car to overturn. As a conclusion it was decided to prefer rounded bottom ditch shape with fore slope 1:4, bottom width 1.0 m and back slope 1:2.

Particularly in cases when a deep ditch is needed the use of a covered drainage system should be considered.

Recommendation:

1. Ditches and cut slopes along busy main roads
   If the back area allows the traversable design then it is very preferable: fore slope 1:4 or flatter, width of the bottom 1 m or wider, back slope 1:2 or

flatter. Examples of the preferable design are shown in Figure 4.21 and Figure 4.22.

Figure 4.21. Recoverable ditch shapes: 1:4 fore slope, rounded bottom and 1:2 back slope. (Photo, HUT)

Figure 4.22. Recoverable fill slope; bottom of the ditch is rounded, no hazardous obstacles in fill slope. (Photo, HUT)

2. Ditches and fill slopes along low volume main roads, design speed 70 km/h or less. On low volume and low speed road sections also the V-shape ditch with fore slope 1:3 and back slope 1:2 can be considered.

Forest/Line of Trees

Recommendation:

1. Removal
2. Shielding with safety barrier
   In some cases the trees (row of trees) are considered as an important aesthetic part of the roadside area. They can also have an important role in functionality of self-explaining road scene (see Figure 4.23).

Figure 4.23. There is evident need for better roadside safety because of trees and steep slope. In this road section the only solution for better roadside safety is safety barrier – by choice the guardrail with aesthetical value

Rock Face Cuttings

Recommendation:

1. Removal from safety zone (new roads) (see Figure 4.24)
2. Shielding with safety barrier (see Figure 4.25)
3. Protective earth slope (see Figure 4.25)

Figure 4.24. Rock face cutting removed from the safety zone (Photo, HUT)

Figure 4.25. Rock face cutting shielded with safety barrier (Photo, HUT)

Retaining walls (parallel to the road)

Recommendation:

1. Safety barriers are needed when retaining walls are within the safety zone.

4.3.3 Roadside and Median Road Restraint Systems Considered as Hazards

Existing guardrails may have many critical weaknesses in their positioning, dimensioning and crash safety properties.

Recommendation:

1. Installation of guardrail at the places where there has been no guardrail before
2. Increasing the length of pre-existing guardrail i.e. extension of guardrail (Figure 4.26)
3. Modernisation of old guardrails

Figure 4.26. Left: too short guardrail, Right: lengthened guardrail (new section with weaker posts). (Photo, HUT)

Transition

Figure 4.27. Left: good solution of transition structure, the guardrail is overlapped with the concrete barrier and fastened with steel bolt. (Photo, HUT) Right: poor solution of the transition from steel guardrail to the concrete pillar of the bridge parapet. (Photo, VALT)

Terminations of Safety Barriers

Safety barrier ends which do not fulfil the requirements of EN 1317 (or NCHRP 350) can be point hazards themselves. Blunt ends of safety barriers are well-known hazards, but also ramped ends of guardrails parallel to the road can easily cause a vehicle vault or rollover and hence lead to more severe consequences.

In RISER detailed accident database there are 41 accidents where the barrier was the only obstacle involved. In 14 cases the termination of the barrier was impacted; in four of those cases the vehicle travelled along the top of the barrier until it came to a stop or impacted another object, in 10 cases the vehicle was launched into the air.

The injury risk of impact to the safety barrier end can be reduced by flare the end into the roadside or installing tested end treatments like energy absorbing terminals

Recommendation:

1. Replacement with tested energy absorbing end treatment
   Energy absorbing end treatments are safer than ramped ends if an errant vehicle collides with the end of the guardrail (see Figure 4.28).
2. Bending the end to the slope
   The ramped ends can be turned to the slope so that the straight impact onto the ramped end is prevented. With this treatment the vehicle is also disabled to travel behind the barrier and possibly collide with the shielded object (see Figure 4.28).

Figure 4.28. Energy absorbing guardrail terminal and flared guardrail terminal (Photo, HUT)

3. Replacing the blunt end with ramped end
   The blunt ends should not be used on the European main road network. As a minimum requirement it is recommended that those terminations are replaced with ramped ends. Recommendations 1 and 2 should be the choice for any new design or redesigned road sections.

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CHAPTER 5: PASSIVE SAFETY ROAD EQUIPMENT

5.1 Introduction

Passive safety road equipment includes Road Restraint Systems (RRS), breakaway equipment supports, energy absorbing supports, and arrester beds. The equipment included in RRS can be divided into two groups, vehicle and pedestrian restraint systems. Vehicle restraint systems comprise safety barriers and bridge barriers (parapets), terminals for barriers, crash cushions, transitions among different RRS, and Motorcyclist Protection Devices (MPD). Pedestrian restraint systems include pedestrian parapets and guardrails for separation of pedestrians and traffic. Passive safety structures constitute, together with road markings and signing, a basic element for road safety.

Passive safety road equipment (or road equipment) is implemented at locations where there are serious consequences when a vehicle makes an uncontrolled exit from the roadway. It must be recognized that passive safety equipment represents objects that can be struck by a vehicle. However, they are constructed and tested to ensure that any collision with a passive safety structure is less severe than with a hazard located on the side of the road.

The necessity of installing road equipment is made when the roadside area cannot be made safer using the safety zone concept (Chapter 2). As described in Chapter 4, some roadside hazards can be removed or made less dangerous through different countermeasures. However many situations arise where the hazard cannot be removed or when it is more economical to install road equipment. The purpose of this chapter is to identify the criteria and design implications for road restraint systems.

5.2 Classification and Function of Passive Safety Road Equipment

The main categories of passive safety road equipment are presented to provide information on the system structure and typical installation locations.

5.2.1 Safety Barriers

Safety barriers are installed lengthwise on the roadsides or the central reservation of a roadway. They are designed to restrain an errant vehicle from leaving the roadway and redirect the vehicle towards the traffic lane. Safety barriers are developed and designed for oblique impacts only.

Safety barriers can be:

- Longitudinal barriers
  - barriers designed for vehicle impacts to one side only and are installed on the edge of the carriageway.
- Median barriers
  - barriers designed to be mounted between opposing travel lanes and can be impacted on both sides.
- Bridge parapets
  - specialised longitudinal barriers designed to be installed on bridge decks.

Safety barriers can be subdivided into temporary or permanent barriers, depending on the intended lifetime for their installation. The main difference between these systems is the type of anchorage to the roadbed and the designed impact protection level. Temporary barriers are almost exclusively installed in work zones where lane widths and traffic speeds limit the severity of a vehicle impact.

5.2.2 Crash Cushions

Crash cushions (sometimes called energy absorbers or impact attenuators) are designed for protecting a point hazard (see Figure 5.1). In contrast with safety barriers, crash cushions are designed for impacts at the end points of their structures, as well as impacts along their sides. Their performance for oblique impacts is used to divide crash cushions into the following categories:

- Redirect
  - designed for oblique impacts and can behave like a safety barrier for short sections.
- Non redirect
  - no capacity for oblique impacts.

Crash cushions should only be installed at a location when the protection of vehicles from a hazard cannot be solved by the regular process outlined in Chapter 4. When protection of a hazard is required, safety barriers should be the first option if space permits. Crash cushions are notably more expensive than safety barriers.

Figure 5.1. Example of Crash Cushions

5.2.3 Terminals/End Treatments

The terminals or end treatments for safety barriers are special constructions applied to the end of the barriers (see Figure 5.2). All safety barriers have ends and these sections should not represent a hazard for the traffic. The terminal sections are designed to be impacted by a vehicle in both "end on" and oblique trajectories.

Figure 5.2. Safety Barrier Terminal

A terminal can work by:

a. reducing the speed of the vehicle.
b. allowing a controlled penetration of the vehicle behind the barrier.
c. retaining and redirecting the vehicle.
d. combining the functions a, b and c.

The terminal type is categorized by means in which it operates and if it is designed to allow the vehicle behind the barrier. A Non-Redirecting end treatment will not fully redirect the vehicle during an oblique impact but a Redirecting does not permit the vehicle to stop behind the barrier.

5.2.4 Transitions

A transition is defined as the structure that connects two safety barriers of different geometry and/or containment levels and/or lateral deformation. A transition is designed so that there are no abrupt changes in the safety performance if a vehicle strikes the area between two different barrier types (see Figure 5.3). Common locations for transitions are connections between bridge parapets and roadside safety barriers.

Figure 5.3. Transition

5.2.5 Arrester Beds

Arrester beds are areas adjacent to the roadway section in areas with long downgrades (see Figure 5.4). These facilities are used for vehicles (typically heavy goods vehicles) that have lost their braking capacity. When braking problems are identified, the driver intentionally drives onto the arrester bed which has a specific surface material that allows the vehicle to be brought to a stop.

Figure 5.4. Arrester Bed

5.2.6 Break-Away or Energy Absorbing Structures

Break-away or energy absorbing structures are typically used for lighting columns, utility posts, sign posts, etc. These structures are designed so they break or deform in a controlled way when impacted by a vehicle (see Figure 5.5).

Figure 5.5. Break-Away Utilities

5.3 European Standards Applicable to Roadside Infrastructure

The objectives of the European Standards EN 1317 - Road Restraint Systems [1] and EN12767 - Passive Safety of Support Structures for Road Equipment [2] are to provide a common testing and reporting system and to provide clear understanding of the design, performance, production, and construction of road restraint systems. The current EN1317 document contains 5 parts relevant for roadside design guidelines. Parts 1-4 describe how the crash protection of different types of RRS is determined during full scale crash testing. Part 5 describes the durability and documentation for conforming to the standard. Part 6 applies to pedestrian protection and only relevant for the separation of pedestrians and traffic. EN12767 lists testing requirements for passive safety structures like break-away and energy absorbing lighting columns. The following discussion of these standards reflects the printed version of the standards listed in the reference. These standards are continuously reviewed and subject to change.

5.3.1 Requirements and Test Methods

It is important to note that the standards are developed to describe the performance of road equipment using parameters that are appropriate for the protective behaviour of the specific equipment type. These parameters are relevant for the installation of the equipment in accordance with the geometric characteristics particular to the road and traffic conditions. The standard was not developed to provide direct information on the implementation (installation) of the equipment other than specific details, like the anchorage of the system, which are specified in the test and conformity reports. The installation location and selection of a specific product for that location are not covered by the standards and are the role of guideline documents (like this document). The role of a standard is to provide a method for comparing different products that are relevant for a specific installation location.

Structure of EN1317

The European Standard EN 1317 is organized in six parts that are:

1. Terminology and general criteria for test methods.
2. Performance classes, impact test acceptance criteria and test methods for safety barriers and vehicle parapets.
3. Crash cushions - Performance classes, impact test acceptance criteria and test methods for crash cushions.
4. Impact tests acceptance criteria and test methods for terminals and transitions of safety barriers.
5. Durability criteria and evaluation of conformity.
6. Pedestrian road restraint systems.

At the time of publication, parts 1, 2, and 3 are official European standards while part 4 is published as an ENV (Experimental Standard for a 3-5 year period). Part 5 is in the final stages of becoming a formal standard. Any information presented in the following sections reflects the current printed status of the standard [1].

The products regulated in part 6 (Pedestrian road restraint systems) are not intended to protect the occupants of a vehicle during a run-off-road event. The pedestrian restraint systems are implemented to separate pedestrians from road traffic and are thus only dimensioned to restrict people from walking onto the roadway. This part is not applicable for roadside design guidelines.

The following description of the RRS requirements and characterization are based on parts 1 and 2 and are relevant for safety barriers. Corresponding requirements are valid for crash cushions, transitions, etc. and more details can be found in the relevant part of the standard EN1317. It is recommended that manufacturers and suppliers of road restraint systems are consulted when selecting road equipment and their components so that no performance conflicts are created.

5.3.2 Performance Criteria

The parameters used to evaluate the effectiveness of the RRS, to define the limits of acceptance, and to identify the technical classes are:

- Containment level of RRS
- Impact severity
- Deformation of the barrier

In addition, there are requirements that the vehicle is redirected smoothly without rolling over.

The crash tests are conducted using vehicle masses prescribed in the test standards. Depending on the intended application of the system, vehicle test masses range from 900 kg to 38000 kg. Additional vehicle characteristics such as wheel base and centre of gravity height are specified for each vehicle type. Test speeds and impact angles are defined for the different test categories for specific vehicle types.

Containment Level of RRS

The containment level of RRS is the capacity of the system to redirect a test vehicle with a prescribed mass, impact speed and impact angle, see Figure 5.6. It should be noted that the containment level indicates the most severe (in terms of lateral kinetic energy) loading capacity of the system. In addition to the severe loading condition, a test with a small (900 kg) vehicle is required for the system to ensure that vehicle occupants are suitably protected. Thus the containment level indicates the maximum loading of a RRS while providing safe protection for smaller vehicles.

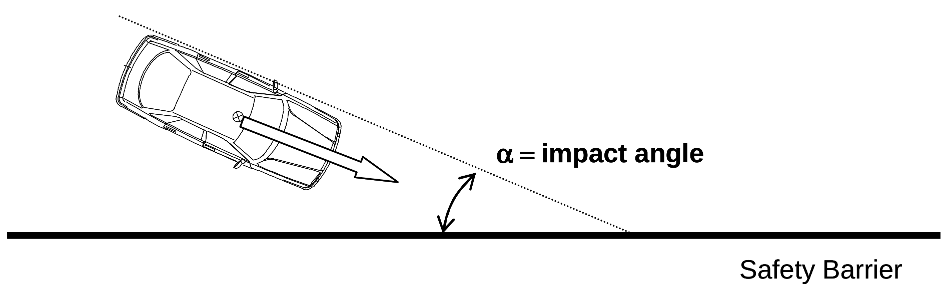


Figure 5.6 Impact Configuration

Suitable behaviour of the RRS requires that the vehicle never penetrates or overrides the system. No deformation of the system shall cause parts of the RRS to penetrate the vehicle passenger compartment. The system shall contain or redirect the test vehicle in a controlled and predictable manner.

The European standard establishes that a RRS tested and meeting the desired containment level is also qualified for application for less severe containment levels.

Containment levels for a road restraint system can be determined from the test conditions described in the following 2 tables. Table 5.1 describes the test configurations with the specific vehicle, speed and impact angle and Table 5.2 provides the test combinations that define the different containment levels for longitudinal barriers. Similar information is available in EN1317 for crash cushions and barrier end terminals.

Table 5.2 also provides information about the lateral kinetic energy for the test and the vertical position (height) of the vehicle's centre of gravity above the ground. The lateral kinetic energy is a useful reference for comparing the impact severity of a crash test and is calculated by the equation:

$$T = \frac{M_{veh}}{2}(V \sin(\alpha))^2$$ **Equation 5-1**

where T= lateral kinetic energy, M_{veh} = vehicle test mass [kg], V = test speed [m/s], and α = impact angle

Table 5.1. Vehicle Impact Test Criteria

Test	Impact speed (km/h)	Impact angle α [deg.]	Total Test mass M_{veh}[kg]	Type of Vehicle	Lateral Kinetic Energy T [kJ]	Centre of Gravity Height [m]
TB 11	100	20	900	Car	41	0.49
TB 21	80	8	1 300	Car	6	0.53
TB 22	80	15	1 300	Car	22	
TB 31	80	20	1 500	Car	43	
TB 32	110	20	1 500	Car	82	
TB 41	70	8	10 000	Rigid HGV	37	1.50
TB 42	70	15	10 000	Rigid HGV	127	1.50
TB 51	70	20	13 000	Bus	287	1.40
TB 61	80	20	16 000	Rigid HGV	462	1.60
TB 71	65	20	30 000	Rigid HGV	572	1.9
TB 81	65	20	38 000	Articulated HGV	725	1.9

Table 5.2 Containment Levels for Longitudinal Barriers

Containment levels	Acceptance test
Low angle containment	
T1	TB 21
T2	TB 22
T3	TB 41 and TB 21
Normal containment	
N1	TB 31
N2	TB 32 and TB 11
Higher containment	
H1	TB 42 and TB 11
H2	TB 51 and TB 11
H3	TB 61 and TB 11
Very high containment	
H4a	TB 71 and TB 11
H4b	TB 81 and TB 11
NOTE 1: Low angle containment levels are intended to be used only for temporary safety barriers. Temporary safety barriers can also be tested for higher levels of containment. NOTE 2: A successfully tested installation at a given containment level shall be considered as having met the test condition of a lower level, except that N1 and N2 do not include T3. NOTE 3: Because testing and development for very high containment safety barriers in different countries has taken place using significantly different types of heavy vehicles, both tests TB 71 and TB 81 are included in the standard at present. The two containment levels H4a and H4b should not be regarded as equivalent and no hierarchy is given between them.	

By using the energy values presented in Table 5.1 and Table 5.2, the lateral kinetic energies associated with the different containment levels can be presented graphically as in Figure 5.7. This figure shows the exponential increase in lateral kinetic energy as the containment level increases.

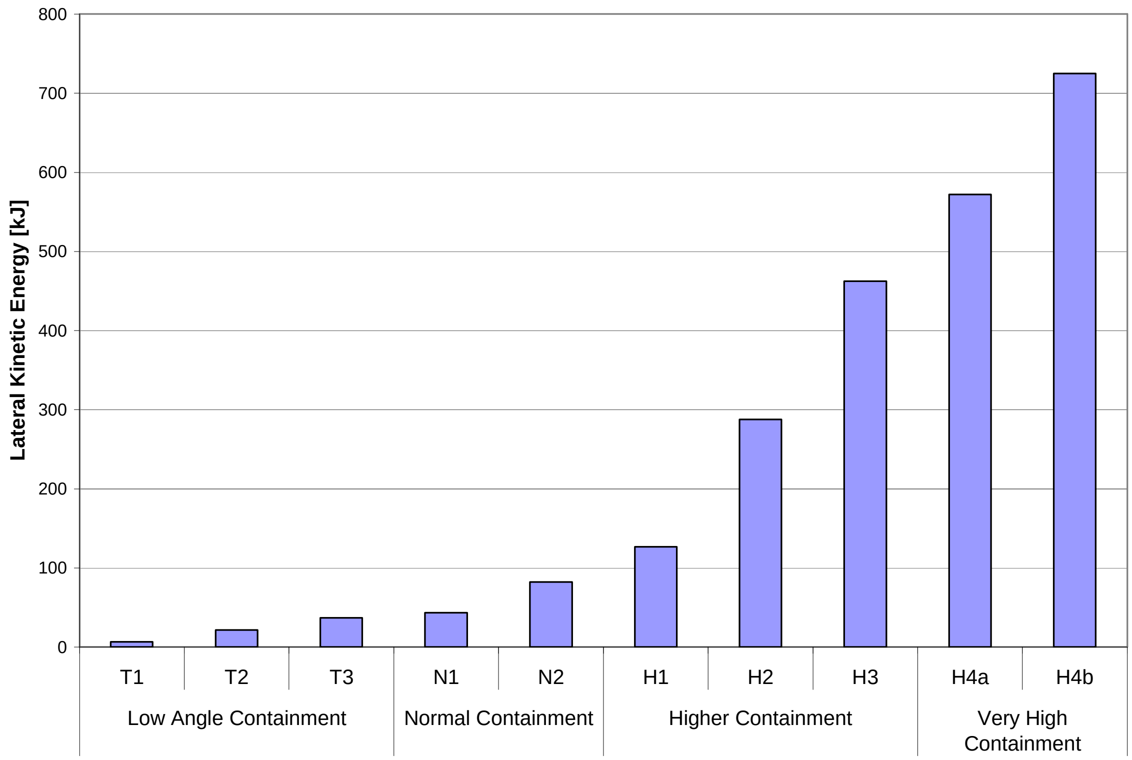


Figure 5.7 Comparison of Lateral Kinetic Energy for the Different Containment Levels

Impact Severity

The severity of the impact is defined as the injury risk for the vehicle occupants. There are 3 parameters used to evaluate injury risk, mostly based on the accelerations measured at the vehicle's centre of gravity. In addition to these parameters, one other criterion on vehicle deformation is provided as information so that the end user can learn more about the system performance.

Normative Information:

- ASI (Acceleration Severity Index)
  The objective of the ASI is to compare the maximum acceleration levels that an occupant is exposed to during the impact. ASI is a function of time, computed using an equation based on limit acceleration values and the acceleration of a selected point P of the vehicle, averaged over a moving time interval of 50 ms.
- THIV (Theoretical Head Impact Velocity)

  THIV is the calculated impact speed of a free moving mass with an interior surface of the vehicle. The objective of the THIV is to indicate the risk of injury for an unbelted occupant inside the vehicle. It attempts to recreate the motions of an occupant head inside the vehicle.

- PHD (Post-impact Head Deceleration)

  PHD is a parameter that is reported in conjunction with the THIV. At the time the THIV is calculated, the vehicle decelerations are subsequently monitored and the maximum resultant of the lateral and longitudinal vehicle accelerations is reported. The objective of the PHD is to indicate the severity of occupant loading after they have contacted the vehicle interior.

Informative information:

- Deformation of the cockpit

  The deformation of the cockpit of the vehicle is measured through the index VCDI (Vehicle Cockpit Deformation Index). It describes how much the interior surfaces of the passenger compartment are deformed inwards toward the occupants. This reduction of the passenger compartment space is strongly linked to occupant injuries in all motor vehicle accidents.

How to report the impact severity, shown in Table 5.3, is under discussion at the time of publication (February 2006). The official version of standard currently classifies the impact severity into two classes. This classification is currently under review.

Table 5.3. Impact Severity Levels [1]

Impact severity level	Index Values		
A	ASI ≤ 1.0	and	THIV ≤ 33 km/h PHD ≤ 20 g
B	ASI ≤ 1.4		
NOTE 1: Impact severity level A affords a greater level of safety for the occupants of an errant vehicle than level B and is preferred when other considerations are the same. NOTE 2: At specific hazardous locations where the containment of an errant vehicle (such as a heavy goods vehicle) is the prime consideration, a vehicle restraint system with no specific impact severity level may need to be adopted and installed. The index values recorded in the test of the restraint system shall however be quoted in the test report.			

Deformation of the Safety Barrier

The deformations of the safety barrier are described by the working width and the dynamic deflection and are recorded during the crash test. Figure 5.8 illustrates the parameters of interest during a crash test.

The working width (W) is the distance between the side facing the traffic before the impact of the road restraint system and the maximum dynamic lateral position of any major part of the system. If the vehicle body deforms around the vehicle restraint system so that the latter cannot be used for the purpose of measuring the working width, the maximum lateral position of any part of the vehicle shall be taken as an alternative (lower images in Figure 5.8).

During impact tests using buses and Heavy Gods Vehicles (HGV), the extreme lateral position of the system and the extreme lateral position of the test vehicle shall be recorded separately in the test report.

The dynamic deflection (D) is the maximum dynamic lateral displacement of the side facing the traffic of the restraint system. For narrow restraint systems, the dynamic deflection can be difficult to measure and if such is the case, the dynamic deflection may be taken as the working width.

The purpose of these measurements is to identify the amount of lateral space that is required for the system to operate properly. If the system is installed beside a hazard, but the hazard is within the working width of the system, then the system cannot properly protect the hazard since it may come into contact with the hazard during an impact.

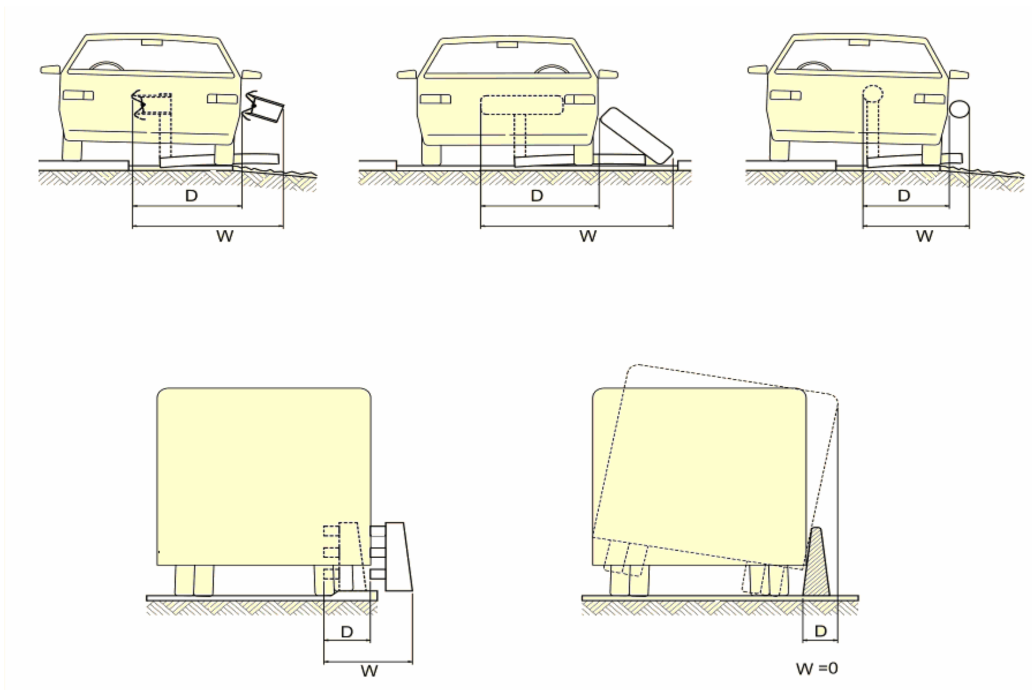


Figure 5.8. Barrier and Vehicle Deflection Parameters

Test Vehicle Behaviour

Since the purpose of the RRS is to contain and redirect a vehicle, the motions of the vehicle during the test should not result in hazardous conditions for the vehicle occupants. For these reasons the vehicle behaviour during a test must fulfil the following criteria:

- The centre of gravity of the vehicle shall not cross the centreline of the deformed system.
- The vehicle shall remain upright during and after impact, although moderate rolling, pitching and yawing are acceptable.

The vehicle shall leave the safety barrier after impact so that the wheel tracks of the vehicle are within a prescribed "exit box" (Figure 5.9). The exit box is determined from the contact locations on the barrier and the size of the vehicle prescribed for the test.

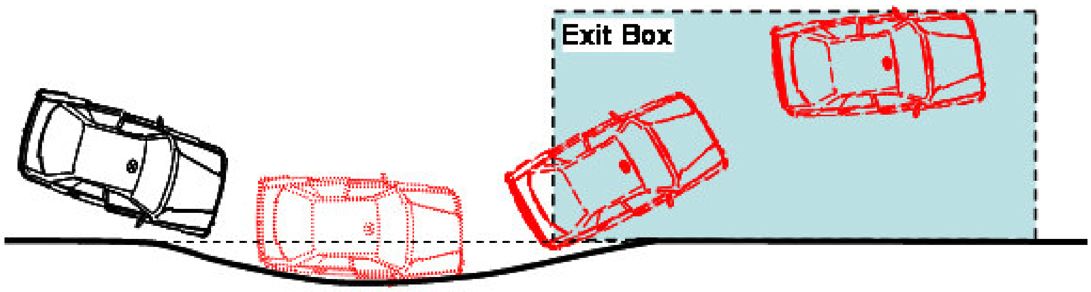


Figure 5.9 Vehicle Redirection Requirements

5.4 Influence of Passive Safety Road Equipment on Road Safety

The presence of road equipment should not have, in general, any influence on the frequency of vehicles leaving the travel lanes and entering the roadside area in an uncontrolled manner. They should, however, affect the consequences of the vehicle encroachments into the roadside. The role of road equipment is to improve the survivability of vehicle occupants during a single vehicle accident.

The driver simulator study (RISER Deliverable 4 [3]) demonstrated that the presence of a safety barrier can have minor influences on the traffic positioning and speed. Improper placement of the barriers can conceivably increase this effect and care should be taken when placing the barrier along the carriageway that it does not adversely affect the traffic flow.

5.4.1 Cost Benefit

It is difficult to accurately determine the cost/benefit ratios for road infrastructure in Europe. The complete life-cycle cost analysis of a specific safety feature must include the installation cost, maintenance costs and the changes to the injury (societal) costs. As demonstrated in RISER Deliverable 1 [4], there is a lack of maintenance information for developing European wide cost/benefit figures. The information provided for one region of Spain showed that 5 times the number of encroachments are identified by maintenance workers than reported to the police. Until this type of data becomes easily accessible, the information from regional studies must be used for reference purposes.

Some general information can be obtained from Table 5.4 and Table 5.5 which show the benefit cost ratios for different road infrastructure in the USA and Spain, respectively.

Table 5.4. Benefit of some RRS Measures of Road Safety Programme in the USA (FHWA, 1993)

Action Type	Benefit/Cost %
Improvement of median barriers	1370
Installation of median barriers	850
Improvement of safety barriers	790
Crash Cushions	760
Improvement of bridge barriers	710

Table 5.5. Benefit/Cost of some Infrastructural Safety Remedial Measures in Spain

Action Type	Benefit/Cost %
Signalling & Traffic Guidance Equipment	460
Road Restraint System	390
Pavement	180
Geometric Characteristics	30
Grade separated interchanges and intersections	20

Effect on accidents

Elvik and Vaa [5] have evaluated the effects of roadside and median safety barriers on the accident severities. These meta-analyses prove that installing or improving the safety barriers reduce significantly severe injuries caused by running off the road (see Table 5.6)

Table 5.6. Effects on accidents of guardrails along the roadside. Percentage change in the number of accidents [5]

Accident severity	Types of accidents affected	Best estimate	95 % confidence interval
New guardrail along embankment			
Fatal injury	Running-off-the-road	-44	-54…-32
Any injury	Running-off-the-road	-47	-52…-41
Accident rate	Running-off-the-road	-7	-35…+33
Changing to softer guardrails			
Fatal injury	Running-off-the-road	-41	-66…+2
Any injury	Running-off-the-road	-32	-42…-20

5.5 Installation Recommendations for Passive Safety Road Equipment

The following sections describe the procedures for selecting and installing passive safety road equipment. The main process of treating roadside safety issues is covered in Chapter 4. The most involved implementation issues are involved with road restraint systems. Since these must be located on the road to protect traffic from an obstacle, their positioning is crucial to their performance. Equipment such as energy absorbing or breakaway poles replaces the hazard directly. Therefore equipment positioning is usually defined by their purpose (i.e. gantry support or lighting column).

The criteria for installing road equipment in European countries were reviewed in RISER Deliverable 5 [6]. The results of this review are summarized in Table 5.7.

Table 5.7 RISER Review of Installation Criteria for Road Equipment

Classification	FI	FR	DE	GB	NL	ES	SE
Road class	Yes				Yes		
Traffic flow	Yes	Yes	Yes		Yes	Yes	Yes
Type of obstacle	Yes	Yes	Yes		Yes		
Distance from edge		Yes	Yes	Yes	Yes	Yes	Yes
Position in curves or straight lines		Yes	Yes			Yes	
Design speed			Yes	Yes			Yes
Risk assessment		Yes		Yes		Yes	
Estimation of the safety effect	Yes						
Severity of potential accident						Yes	

The steps for installing road equipment recommended by RISER results are developed by combining the observed best practices in Europe with the information gained in the RISER project. The following procedures only apply when the obstacle or hazard being treated can not be removed from the roadside safety zone or replaced by a non-hazardous (i.e. passively safe) structure.

The procedures in the following section have a natural logic if they are followed in the order they are presented. The first step is to identify the hazards that must be addressed. This will determine which type of road restraint system is necessary, protection of a point hazard or a distributed hazard. The second step determines the containment level, or strength of the system. The lateral location of the hazards is necessary to determine the working width of the system, identified in step 3. Finally in step 4, the length of the system is determined based on the size of the hazard.

5.5.1 Identification of Hazards

The most important elements of roadside safety design are the identification of the roadside features that could be struck by vehicles. The focus in the RISER accident studies has been the protection of the vehicle occupants, but it should also be noted that third party injuries or damage require special considerations. Railway lines, sensitive buildings (schools, hospitals, etc), and dangerous goods storage facilities are often located near a roadway. The results of a vehicle impact with these structures may lead to casualties beyond those in the vehicle.

The type of object that is being investigated in the roadside design process will influence the implementation criteria. The main information that must be determined are:

1. Where is (are) the structure(s) located relative to the roadway?
2. What are the consequences of the impact to the passengers of a vehicle?
3. What are the dimensions of the object?
4. What are the consequences of an impact to the object itself (third party damages)?

These points must be resolved to fulfil the following procedure for selecting passive safety road equipment.

Set-back (Lateral) Position of the Hazard

The set-back of obstacles from the roadway is the first issue that must be addressed for ensuring safe roadside environments. The safety zone for the road section should have been identified (Chapter 2) as this allows the surveying of roadside obstacles to be focused to a corridor adjacent to the roadway. All obstacles and their set-backs should be recorded. Characteristics of the obstacle that influence their risks of causalities (Chapter 1) in an impact should be recorded as this will influence the subsequent selection of the containment level. It is important that no further design solutions are determined until the remaining information for the obstacles is collected. A common mistake in the roadside safety process is solving a local problem without investigating potential problems in the vicinity. A small incremental cost to a road equipment installation may create larger savings in casualty and property damage costs. One example discussed in Chapter 4 (Figure 5.10) is presented again to highlight the importance of creating an inventory of all hazards in the vicinity.

Figure 5.10. The culvert is protected with a short guardrail but the gantry pole and the old rigid lighting column are unprotected (Photo, HUT)

5.5.2 Selection of Containment Level

The containment level is an important characteristic of a road restraint system. The containment level identifies the strength of the system, essentially specifying the maximum capacity for redirecting a vehicle. As presented in Section 5.3.2, the containment level is specified by the crash test conditions (vehicle mass, impact speed, impact angle). Higher containment level produces stronger restraint system.

Background

The main consideration when specifying a containment level is to assess the risk for a severe impact with the system and a subsequent penetration of the vehicle through the protective equipment. Thus the containment level must be assigned with considerations to:

1. Type of vehicles operating on the road (usually the percentage or number of Heavy Goods Vehicles –HGV observed in annual average daily traffic).
2. Type of roadway (motorway versus rural road).
3. Roadway speeds.
4. Local information affecting risk of accidents (weather, road geometry, etc.).
5. Additional factors of risk (identified above in terms of third party damages).

Once this information has been collected, a containment level selection for the particular location can be determined. Most national road administrations will have some general policy on the containment level for their road network [7]. However a more detailed selection procedure should be available for local installations. A good example of such a selection process is presented in RPS 2003 [8] for Germany (Figure 5.11). This flow chart contains all the elements identified above. The process starts at the left side with the obstacle or hazard of concern. Then the roadway type is defined by the speed and AADT. Specific conditions leading to higher risk of accidents are included as well as the influence of heavier vehicles. It is important to note that there are solutions that do not require the installation of a road restraint system.

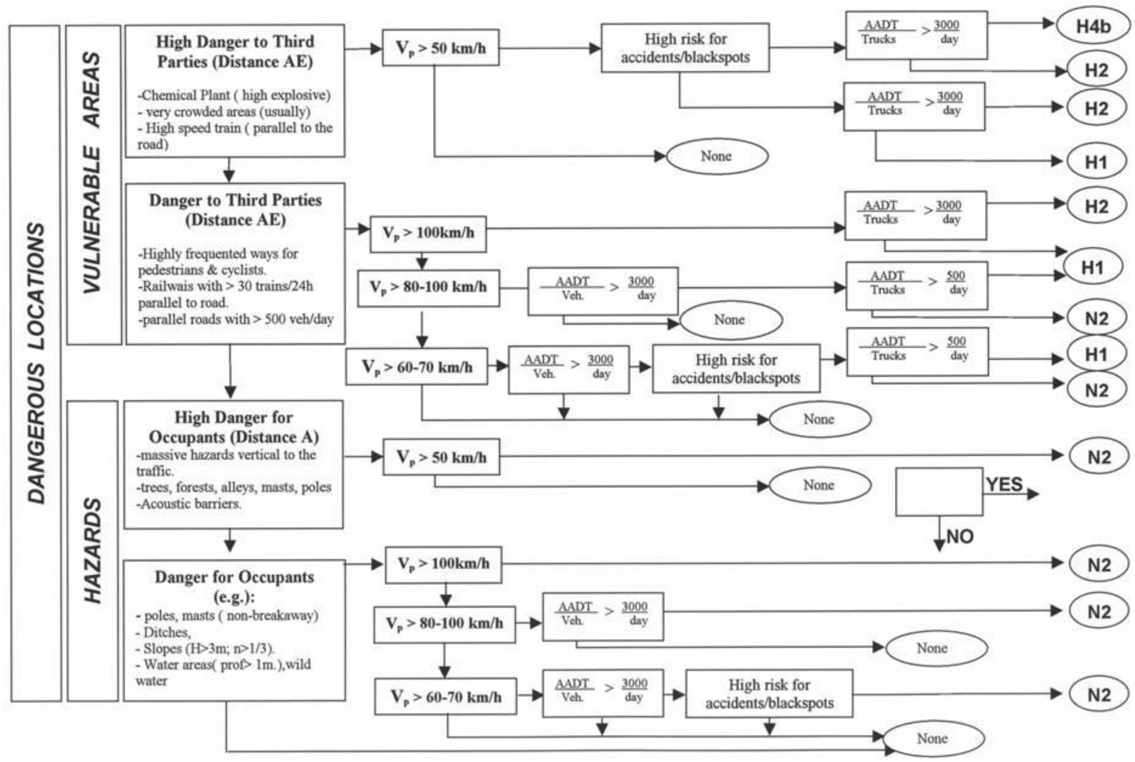


Figure 5.11. Selection Criteria for Safety Barrier Containment Level in Germany (RPS 2003)

Another approach to selection of containment levels is applied in Spain. When a hazard is identified, it first is necessary to determine minimum distance from the hazard and the roadway edge that justifies the installation of a safety barrier. In the case of bridge parapets, their installation is always justified. The installation criteria presented below are fully described in the Spanish national document O.C. 321/95 T. and P. [9].

For Spain, the containment level depends on: carriageway features, roadway environment features, roadway design speed and AADT[9]. As well as for the layout of the RRS, the Spanish guidelines take into account a critical distance between the hazard and carriageway as seen in Table 5.8.

The Spanish guidelines [9] establish the containment levels as a function of the accident type. Three accident types are defined according to the risk level - normal, serious and very serious. This guideline was developed before European Standard EN1317-2 approved 1998. Thus the Spanish criteria were based on the containment levels existing at that time (L1=N1, L2=N2, M=H2, P=H4b) and the draft version of European Standard in 1995. More containment levels are found in the current standard than the draft in 1995, thus Spanish guidelines [9] could be further refined to specify more containment levels.

Table 5.8 Critical Distances between Carriageway and Hazards [9]

Road Alignment	Slope Gradient of Shoulder Embankment [horizontal:vertical]	Minimum Distances for Given Accident Severity [m]	
		Serious or Very Serious	Normal
Single Carriageway			
Straight, Inside Curves, Outside Curves Curve Radius > 1500 m	> 8:1	7.5	4.5
	8:1 to 5:1	9	6
	<5:1	12	8
Outside Curves Curve Radius < 1500 m	> 8:1	12	10
	8:1 to 5:1	14	12
	<5:1	16	14
Dual Carriageway			
Straight, Inside Curves, Outside Curves Curve Radius > 1500 m	> 8:1	10	6
	8:1 to 5:1	12	8
	<5:1	14	10

The containment levels can be assigned to the accident severity type defined in O.C. 321/95[9], according to the following severities.

- Normal Severity Accidents = N1 - N2
- Serious Accidents = H1 - H2 - H3
- Very Serious Accidents = H4a - H4b

Some (but not all) examples of these accident categories are:

Normal Severity Accidents	Design speeds> 80 km/h, collisions with trees and post over 15 cm in diameter, masonry walls, foreslopes steeper than 5:1, backslopes steeper than 3:1, etc.
Serious Accidents	Collisions that result on significant debris on the roadway, collisions causing structural damage to buildings or bridge structures, possible encroachments on neighbouring roads or opposing traffic lanes, etc.
Very Serious Accidents	Proximity to railways, dangerous goods, proximity to below grade motorways, intersections at bridges, etc.

The development of a specific, European containment level selection procedure was not pursued in the RISER project since the information is very sensitive to regional issues. However, the 5 pieces of information identified above are readily available for the regional administrations and the information in Chapter 1 provides relevant information for determining the consequences of striking different obstacles. Chapter 2 also provides important information for determining the likely impact configurations (speeds and angles) that determine the strength requirements for different road conditions. It is apparent from the information in Chapter 2 that the actual impact speeds and angles experienced by road restraint systems are lower than those used in the performance standards.

5.5.3 Lateral Placement of Road Equipment

The positioning of any road equipment near the roadway must take into consideration the influence of the structure on surrounding traffic and the maintenance implications of the structures. Many safety barriers are located very close to the carriageway edge line (typically around 1 m). Driver simulator studies in RISER [3] included the influence of the lateral position of guardrails. When an emergency lane is placed between the safety barrier and the traffic lanes, drivers tended to driver closer to the edge lines as opposed to conditions without an emergency lane. Thus the lateral position of the safety barrier can affect the lateral positioning of traffic. Chapter 3 (Recovery Zone) discussed the advantages of a paved shoulder beside the travel lanes that allowed for vehicle manoeuvres. The recommended width of a paved shoulder was 1-1.5 m and it is advisable to provide this amount of space between the safety barrier and the carriageway edge line.

The distance behind a safety barrier (or other passive safety system that deflects) is important for the proper operation of the system. As defined in Section 5.3.2, the working width and dynamic deflection are determined from a crash test. These distances must be used when selecting a safety barrier to ensure that there is enough free space behind the system. As shown in Figure 5.12, there must be sufficient space for the safety barrier and vehicle to deflect during the crash without contacting the hazards placed behind the system.

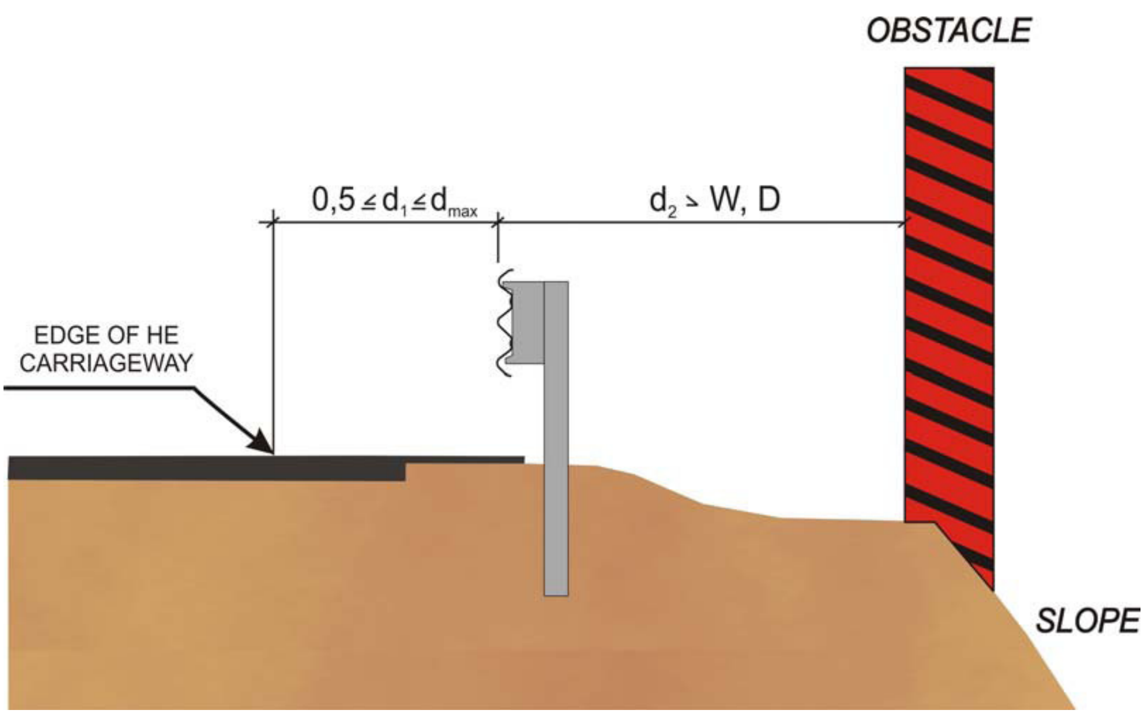


Figure 5.12 Lateral Distance Behind a Road Restraint System

Information about the deflection characteristics (W, D) for any road restraint system is available from the manufacturer.

5.5.4 Installation Length of Need

An important requirement for any road restraint system, particularly safety barriers, is the length of installation. This parameter can be determined from characteristics of the roadside environment, the expected impact conditions, and the road restraint system:

1. What is the length of system tested and reported for compliance with EN1317?
2. What is the length of the obstacle?
3. What are the expected impact angle and impact speed?
4. What is the potential for the vehicle driving behind the barrier?

The length of need should be understood as the length of a road restraint barrier without the accompanying anchorages or end terminals. The length of need identifies the barrier section that is expected to be struck by a vehicle leaving the roadway. End conditions and anchorages can also be struck, but they should not be considered as part of the primary protection purpose of the barrier.

Minimum Test Length

The length of the safety barrier that is used in the test report should always be the smallest length of safety barrier to be installed. The evaluation criteria are usually sensitive to the length of system installation and it is important that the field performance can be predicted from the test results. The relevance of this length is also discussed in a following section.

Shielding of Hazardous Zones

The roadside features that must be shielded from traffic will influence the length of the system installation. Figure 5.13 shows a roadside hazard protected by a safety barrier. Length "***a***" is the projected length of the hazard onto the road and is never the length of a system installation. Length "***b***" is required to protect a vehicle that may run off the near side of the road prior to the obstacle. The length of "***b***" will depend on the expected exit angle and exit speed. Similarly, "***c***" represents the length of safety barrier to protect a vehicle crossing over the oncoming traffic lanes and striking the hazard. Thus the system length of need is defined by lengths ***a,b,*** and ***c***. Lengths denoted "***d***" represent the end terminals of the system required for structural strength as well as protecting the vehicles from impacts with the end of an unprotected safety barrier.

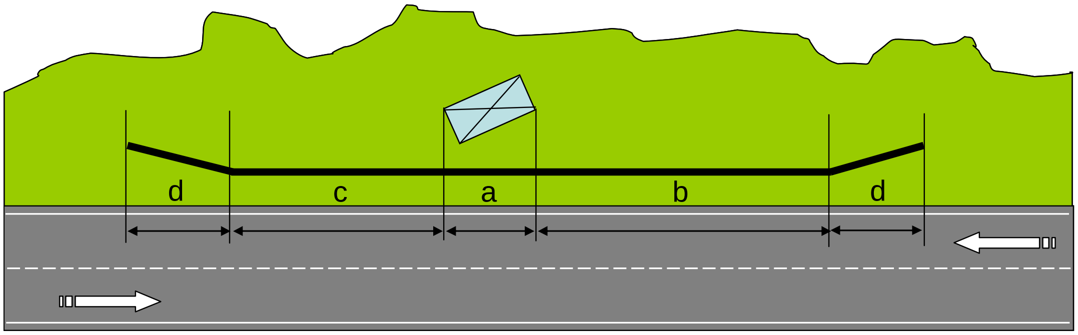


Figure 5.13 Hazard Length and Dimensions for Road Restraint Systems

The principle for dimension ***b*** (and ***c***) is illustrated in Figure 5.14. The angle α is determined from expected exit angles for the road section and is not the angle used for the crash tests in EN1317. The speed that the vehicle will strike the hazard after leaving the road is also important to take into consideration since there can be considerable braking effects in off-road terrain, reducing the length required for ***b***. These exit angles and possible impact speeds should be determined for local conditions using Chapter 2 as a reference. The 5 degree value (representing the median value of vehicle exit angles) is a good reference value for α.

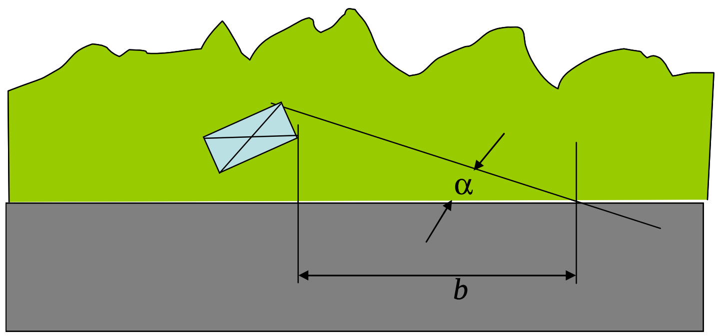


Figure 5.14 Approach Length to Shield Hazards

Referring again to Figure 5.10, one should make sure to consider all obstacles in the vicinity of an identified hazard to determine if the installation length should be reconsidered. Figure 5.15 depicts 4 point hazards in the roadside area. If one considers a radius of influence around each hazard, then one can identify if there are cases where separate point hazards can be combined. Items ***c*** and ***d*** should obviously be treated as one distributed hazard. Cost analyses can be conducted to see if the two additional crash cushions needed to protect ***a*** and ***b*** are more expensive than a safety barrier installation extending from ***a*** to ***d***.

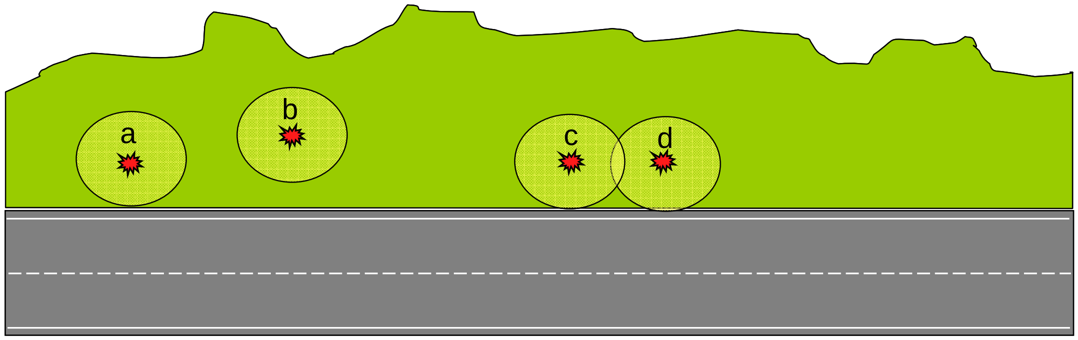


Figure 5.15 Review of Multiple Hazards

Supplementary Concerns

As listed at the start of Section 5.5.4, the possibility of vehicles moving behind the system should be considered. Experience from the RISER data collection indicated that vehicles drove off the road prior to an installation of safety barrier and struck a hazard behind the barrier. This is depicted in Figure 5.16 where the barrier length ***x*** extending before a hazard is too short. When the terrain is flat behind the safety barrier, the vehicle may move behind the barrier, striking the hazard. This is particularly problematic for overpass supports or culverts in motorway medians. RISER accident analyses [10] found cases where safety barrier installations of 50-60 m from the hazard were insufficient to protect against this type of collision.

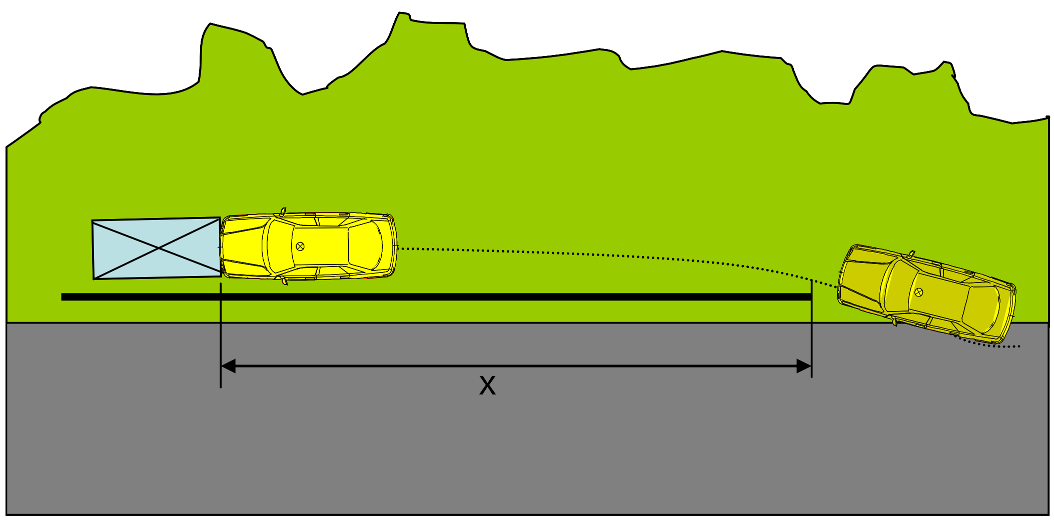


Figure 5.16 Possible Vehicle Motions Behind Safety Barrier

The two alternative solutions for the problem depicted in Figure 5.16 are shown in Figure 5.17. In one case the barrier is angled away (flared) from the road – indicated with the red dotted line. This will result in a vehicle impact on the barrier terminal which is less severe than the impact with the hazard. The other alternative is to extend the barrier in front of the hazard (dashed black line). This may still allow the vehicle to move behind the barrier, but the potential braking distance available for the vehicle allows the resulting impact to be of lower severity. The use of a flared barrier installation to provide extra shielding of an obstacle may also reduce the required length of barrier to be installed. The flare rate (expressed in lateral shift of the barrier for the installation length) should be made in consultation with the test barrier manufacturer. The use of a flared barrier will increase the impact angle of the vehicle against the barrier so modest flare rates are recommended.

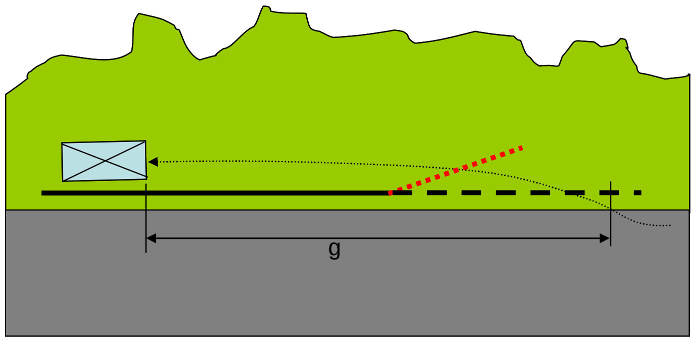


Figure 5.17 Design Solutions

The length ***g*** of a barrier needed to protect a vehicle can use the hazard information from Chapter 1 in combination with off-road braking distances calculated from the procedures in Chapter 2. An example is presented in Figure 5.18.

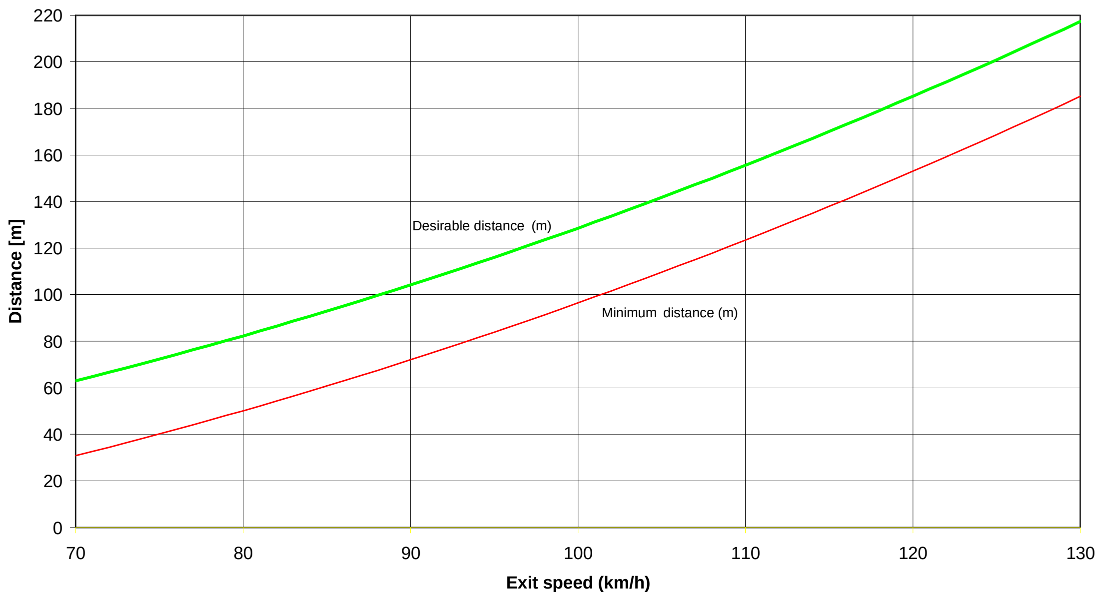


Figure 5.18 Length of Need Prior to a Hazard

The minimum distance curve represents the distance needed when an impact of 50 km/h with a hazard is considered acceptable. The desirable distance represents the case where the vehicle stops before reaching the hazard. These curves both assume a braking acceleration of 3 m/s^2.

The concept that barrier length must be adjusted for hazards that would be near the end of a barrier installation has been recognized by some countries already. In Germany, the standard [8] specifies a minimum length of need based on the tested length of barrier. However the risk of hitting a hazard by driving up on to the barrier or driving behind the barrier is known if the hazard is less than 1.5 m from the traffic face of the barrier. A deviation for the standard barrier length is required according to this risk. The new lengths of barrier segments surrounding the hazard are given in Figure 5.19and Table 5.9. This requirement provides sufficient length of barrier to prevent the vehicle coming in contact with the obstacle in close proximity to the barrier installation. Without this deviation from regular requirements, the terminals of the safety barrier may be too close to the obstacle and allow the vehicle to impact the hazard. Examples of these collision types have been identified in the RISER accident analysis[10] where barrier lengths were too short. Referring to Figure 5.18, the distances quoted in the German standard are consistent with the suggested barrier lengths when exit speeds are 100-110 km/h.

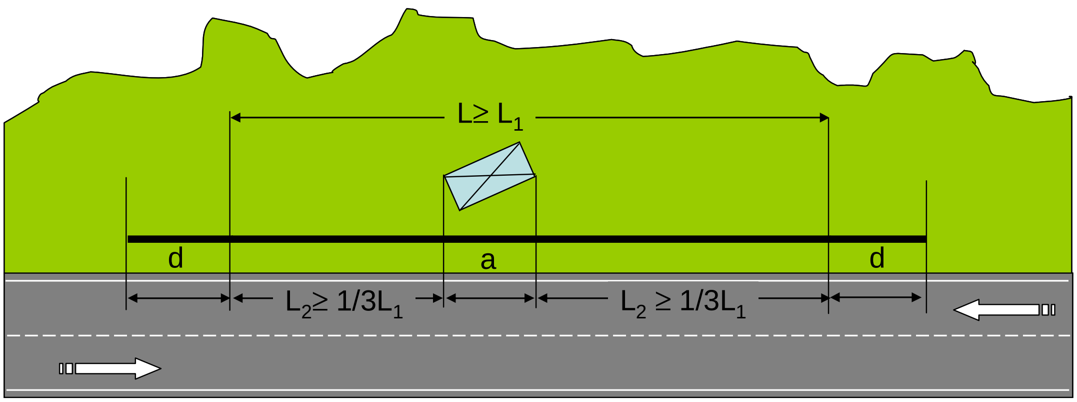
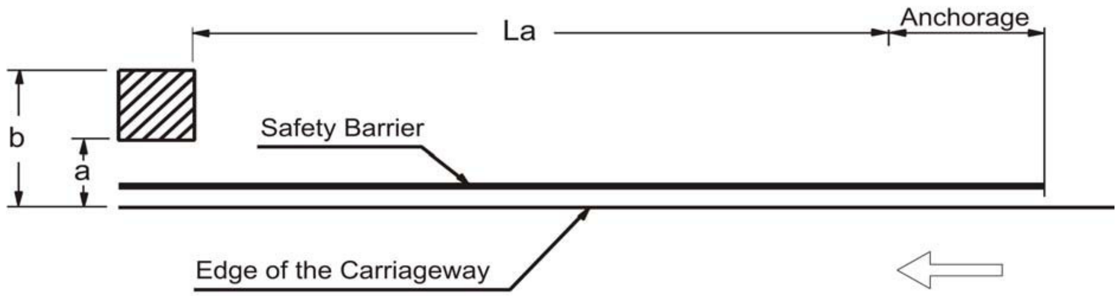


Figure 5.19 German Dimensions for Road Restraint Systems

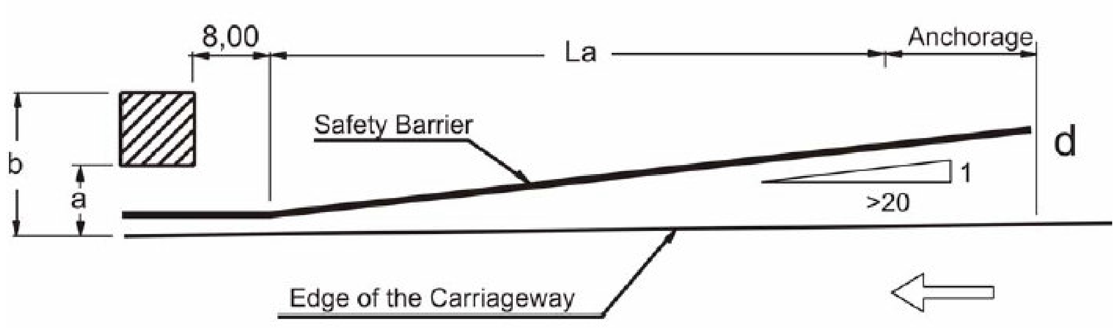
Table 5.9 Safety Barrier Lengths (L_2) Before and After Hazards

Criteria for deviation from test length (Figure 5.19)	Type of Road	Lengths for Safety Barriers: Parallel to Road	Lengths for Safety Barriers: Angled from Road
Riding on the barrier <u>and</u> Hazard ≤ 1,5 m behind front section of the barrier	Single Carriageway	**100 m**	**-**
	Dual Carriageway	**140 m**	**-**
Driving behind the barrier (if possible)	Single Carriageway	**80 m**	**60 m**
	Dual Carriageway	**100 m**	**60 m**

The Spanish guidelines also use a look up table for the installed lengths of barriers preceding the obstacles. As shown in Figure 5.20, the Spanish guidelines include elements of the two previous approaches. The location and size of the obstacle are used to determine the length La required before the obstacle. Both parallel and angled approach lengths for the barrier are permitted.



a) Barriers Installed Parallel to the Road



b) Barriers Angled from the Road

Figure 5.20 Spanish Dimensions for Road Restraint Systems

Table 5.10 Barrier Approach Lengths for Spain (Figure 5.20a)

Setback from Carriageway to Hazard		Minimum Distance for La (Figure 5.20)	
		Single Carriageway	Dual Carriageway
a	< 2 m	100	140
b	2 to 4 m	64	84
	4 to 6 m	72	92
	> 6 m	80	100

Table 5.11 Angled Barrier Approach Lengths for Spain (Figure 5.20´b)

Maximum Setback (b) to Hazard [m]	Distance ***La*** of the Angled Barrier Section [m]	
	Single Carriageway	Dual Carriageway
< 4	36	40
4 to 6	44	52
> 6	52	60

Barrier Components

The installation of a safety barrier length of need would have end points as shown in Figure 5.13 just prior to the sections marked "***d***". These would be blunt objects and these points should be treated as hazards (Chapter 1). There are two different methods to protect the end of the length of need section of the barrier. The first method is to employ a flared barrier section, thus eliminating the risk of an end on impact to the barrier. This is shown schematically in Figure 5.13. This requires that the end of the flared section does not present a new hazard to the vehicle. One approach is to move the end of the flared section outside of the safety zone. When a flared end terminal is not possible, an energy absorbing barrier end terminal can be installed (Section 5.2.3). This is an effective solution when the barrier end must be placed close to traffic. The barrier end terminals have containment and deformation classes, similar to safety barriers, which should be used to select the end terminal suitable for the road section.

Often the installation of a safety barrier is adjacent to another type of safety barrier or bridge parapet that has different characteristics (containment level, structural configuration, etc.). The transition between different safety barriers systems (Section 5.2.4) should be tested in accordance to EN1317 to ensure there is no degradation in the crash performance in the transition section.

The selection of barrier components should be done in conjunction with the equipment manufacturer to ensure compatible structures are selected. The maintenance personnel should also be involved to identify that any training, inspection, and part logistics issues are resolved.

Structural Issues for the Length of Need.

As described previously, the length of need is the total length of a longitudinal barrier needed to shield a hazardous location. However, the installed length must also have the structural capacity required for the crash conditions. The length of the safety barrier to be installed must be longer than the length tested to demonstrate compliance to EN1317. This is because when a vehicle restraint system is tested, its technical description comprises not only the design of the parts (beams, posts, bolts, etc.), but also other important details such as the anchoring conditions, end sections, and the total installed length.

A typical installation length in crash tests is 60 m plus terminals. The impact point is at approximately one third of the length, i.e. 20 m from the initial terminal. In this situation, the entire system carries the loads caused by the vehicle impact during the test. Impact loads are distributed along the barrier elements and transferred to the ground. However, real world crashes on safety barrier installations do not duplicate the EN1317 crash test conditions and thus result in different load distributions than observed in the crash tests. It is commonly expected that for example, when vehicle mass, speed and impact angle increase from their standard testing values, the system is overloaded and may not ensure a safe performance. But variations in other impact parameters such as impact point and end anchorage resistance can have a strong influence in its safety performance and should be taken into account

Crash analyses were performed for RISER using a metal safety barrier. Simulations were carried out for a standard EN1317 crash test and simulation where the point of impact was shifted closer to the terminal. The results indicated that higher tensile forces were predicted for the second simulation case. When this happens, it is critical that the end anchorages of the barrier can withstand these conditions and is dependent on the system design, material resistance, and installation process. If the end sections fail to constrain the system, then there is a high probability that the barrier deflects more or becomes detached from the ground and is unable to contain the vehicle. This highlights the need for a barrier installation length that is greater than the tested length in EN1317. It is preferable to provide an installation length that reduces the probability of vehicles impacting close to the end sections of the barrier. Otherwise, a barrier design performing successfully in an EN 1317 Part 2 test for structural adequacy may be exposed to failure of its anchorages due to impacts near the terminals. This failure would not be due to the barrier design, but due to an improper installation. In all cases, it should be assured that the barrier that is selected to be placed on a roadside includes all the design and installation characteristics that were featured in the EN 1317 tests.

The issues of short barrier sections and end anchorage failure have been identified as a possible cause for some cases in which barrier end anchorages were detached in the analysed accidents (see Figure 5.21). They were cases in which the vehicle impacted the system near the end anchorage and the barrier system was not able to contain the vehicle.

Figure 5.21 Failure in end sections

Barrier performance is even more critical when safety barriers that are designed to include ramped or tied-down terminals are installed with unrestrained end sections. When this happens, there is an important risk that the structural resistance of the system is dramatically decreased: barrier posts can experience large deformations and unable to support the loads transferred by the longitudinal beams. This results in larger deflections than expected, and eventually, breaking of the barrier. Simulation results (see Figure 5.22) show how in a barrier with terminals not anchored to the ground, the loads caused by a vehicle’s impact cause the system’s failure.

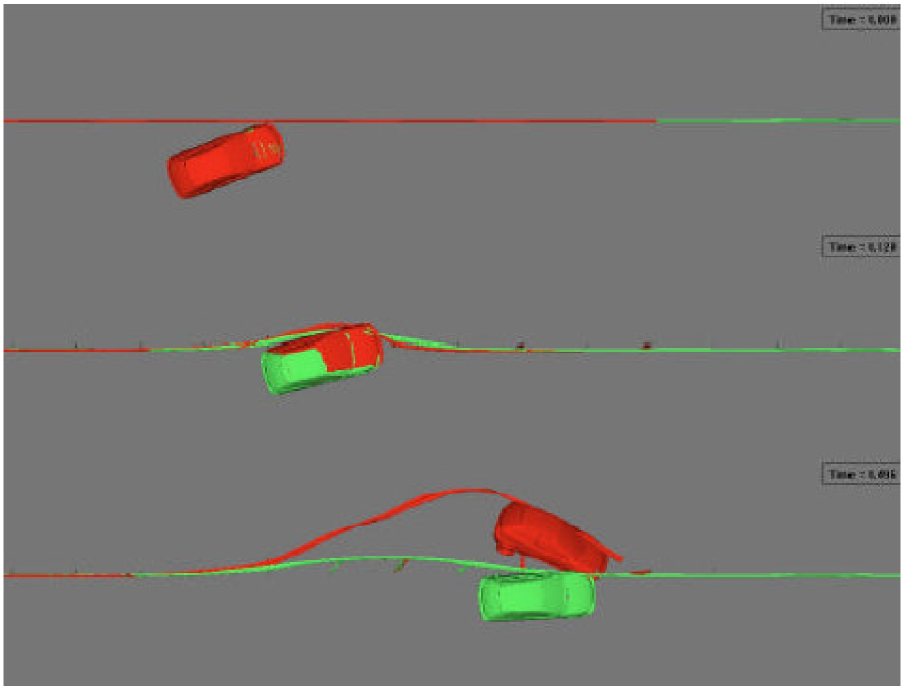


Figure 5.22 Comparison between the behaviour of safety barriers with (green) and without (red) end terminal fixation

Soil conditions

Road restraint systems work by transferring impact loads to the terrain on which they are installed. It can be concrete, asphalt or soil of varying composition and compaction. Due to its resistance during deformation, a soil has capacity to absorb some of the impact energy. However, the working mechanism of road safety barriers comprises a combined, balanced deformation of the barrier elements such as rails, posts, and the ground.

The performance of road restraint systems to be installed on roads is described by their behaviour in tests according to EN 1317. It has to be noted that in the crash tests, the ground conditions are controlled and reported. Consequently, in order to ensure that safety barriers offer their best performance in the event of a vehicle impact, the road and roadside soil properties should be defined carefully so that they can match the characteristics that are required by the barrier for a good passive safety protection.

5.6 Summary

An overview of passive safety road equipment was presented in this section with a focus on road restraint systems, particularly safety barriers. The procedures for selecting other passive road equipment generally follow the same procedure. The first step is to identify the hazards that must be addressed. This will determine which type of passive safety road equipment is necessary. The hazard may be a lighting pole that can be replaced with an energy absorbing column or a rock cutting that needs to be shielded by a safety barrier.

The second step in selecting passive safety road equipment is to determine the containment level, or strength of the system. Safety barriers and crash cushions are classified by the size of the largest test vehicle used in the crash testing program. Energy absorbing poles are classified by the amount of impact energy they absorb in the crash test. Both of these ratings identify the structural capacity for the system.

The third step for selecting equipment is to identify the amount of space available for the systems dynamic performance. This is established by the proximity of the hazards being shielded. The location of the hazards is necessary to determine the working width of the system (for safety barriers), and the deflection classes for crash cushions.

The final step for determining the installation requirements of passive safety road equipment is to identify the length of the system. This is most relevant for safety barriers and is determined by the size and position of the hazard(s) and the expected accident configuration for the specific location.

Experience has shown that typical problems associated with road equipment are:

- Insufficient length of systems to shield hazards.
- Installations shielding hazards neglect neighbouring hazards.
- Insufficient free distances behind the system.
- Inappropriate end terminals for barriers.

Any passive safety structure used for protecting roadside hazards must be tested to European test requirements specified in EN 1317 (road restraint systems) and EN12767 (passive safety supports). Accident data and causation information analyzed in the RISER project (Deliverables 3 [10] and 4 [3]) can be used to develop local policies for the selection and installation of roadside infrastructure.

The selection of road restraint systems should include maintenance and operation program of the road function (RISER Deliverable 8 [11]). Safety performance or roadside infrastructure can only occur if the equipment is maintained in good working order. This requires regular inspections and repairs when necessary. A reliable source of replacement parts and qualified service personnel is thus needed to keep all safety equipment within the manufacturers' specifications.

References

1 EN1317 – Road Restrain Systems (Parts 1-6), CEN - European Committee for Standardization, Central Secretariat: rue de Stassart 36, B-1050 BRUSSELS, ©1998

2 EN12767 Passive safety of support structures for road equipment -Requirements and test methods, CEN - European Committee for Standardization, Central Secretariat: rue de Stassart 36, B-1050 BRUSSELS, ©2000

3 D04: Identify envelope of vehicle and driver response prior to collisions, European Community R&TD Project, 5th Framework Programme “Growth”, Project "RISER" GRD2/2001/50088, 2005

4 D01: Accident Databases For Collisions With Roadside Infrastructure, European Community R&TD Project, 5th Framework Programme “Growth”, Project "RISER" GRD2/2001/50088, 2004

5 Elvik.R & Vaa.T. The Handbook of Road Safety Measures. Elsevier 2004. ISBN 0-08-044091-6

6 D05: Summary Of European Design Guidelines For Roadside Infrastructure, European Community R&TD Project, 5th Framework Programme “Growth”, Project "RISER" GRD2/2001/50088, 2003

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CHAPTER 6: ACCIDENT DATA COLLECTION

6.1 Introduction

A road accident data collection system is required to monitor the performance of newly designed as well as existing roads. Through data collection, it is possible to learn more about the road transport system and help identify the need for safety countermeasures. For re-designed roads it is important to compare the safety levels of the road before and after the changes to find out if the changes were successful and quantify the benefit obtained with these modifications. The information in this chapter gives an overview of the purpose of accident data collection, the information to collect, and organisations that can collect it.

6.2 Overview of Accident Data Collection

Road safety data analyses are usually separated into two categories. The first (and most common) monitoring approach involves collecting large numbers of events that are processed to identify the number of accidents, types of vehicles involved and other easily tabulated variables. This approach generally intends to cover the whole population of accidents occurred in one country. These databases are usually carried out by the Governments and they are referred to as national, intensive, statistic or police accident databases. This kind of data is essential to understand the magnitude and the relevance of the different traffic safety problems, although the level of detail of the information registered within this databases for each accident is not enough to understand completely all the events contributing to the accident.

The second approach addresses several specific issues that are not present in the national accident databases as they are less easily compiled. Detailed data collection programs provide specific technical details and more understanding of the accident event, i.e. the cause of the accident, information about the occupants of the vehicles involved in the accident, the vehicles themselves and the environment are registered within these so called in-depth or extensive accident databases. These information systems are usually created to address specific problems, thus, depending on the specific purpose of the database, more information of certain topics will be compiled.

The combination of these two approaches provides answers to "who", "when" and "where" using statistical databases while the "what" and "why" questions are addressed from in-depth accident reports.

There are three main processes which should be considered when creating or analyzing road safety information systems. These processes can lead to improvements in traffic safety when they are implemented and optimized: accident prevention eliminates accidents before they happen, severity reduction minimizes the risk for serious injuries when an accident does occur and post-crash treatment provides the best possible medical attention to accident victims. Through the collection of accident data, information to improve our knowledge of these three processes is gained.

6.2.1 Accident Prevention

To prevent accidents there is a need to understand the factors contributing to accidents. Through this knowledge, it is possible to develop (active) safety systems and implement countermeasures for the road, vehicle and driver. In an accident analysis, the understanding of the human factors interaction with the vehicle and road environment is essential. Identifying the factors that generate accident scenarios and establishing the methods to address these factors will prevent accidents from happening.

6.2.2 Severity Reduction

When a collision is unavoidable within the road network, it is necessary that the passive safety systems for the road, as well as in vehicles, are reducing the risk of injuries. Many years of in-depth data collection has focused on the vehicles and has led to the development of passive safety systems in vehicles. However, not as many studies have been made for the development of safer roadsides. There is still a need for in-depth studies focusing on the passive safety aspects of the road environment.

Test methods have been developed and are mandatory for road restraint systems. In tests, vehicle impact conditions such and speed and angle are controlled, and they are meant to ensure that roadside equipment provides protection in as many accident conditions as possible. But in reality, actual accident conditions are not generally known, because few accident scene data include this kind of information (e.g. exit angle, exit speed, guardrail deformation etc.). Other information about the roadside is also often lacking e.g. shoulder width, slope gradient, ditch depth, material properties etc. To reduce the injury risk when an accident occurs, it is important to have real-world accident data that help to refine, validate and develop test methods. It is also important to collect accident data to monitor the safety of the road and different road and roadside designs.

6.2.3 Post-Crash Treatment

When an accident has occurred it is crucial that the rescue services arrive at the accident scene as quickly as possible to decrease the injury outcome. The most direct contribution from road infrastructure to this objective is to incorporate automatic or direct warning systems that notify the event to the emergency systems. Data collection activities can contribute to improve the post-crash treatment systems by providing medical personnel with accurate information about injuries, that can help identify and locate the injuries more precisely. Other important issues to take into account are, for example if the road design contributed to delays for the rescue services and ambulance to get to the scene, if the vehicle design contributed to any delays for rescuing the occupants and to what extent the traffic flow was affected by the accident. Some of these post-crash factors should be taken into account for the design of roadside infrastructure.

6.3 RISER results

The different levels of accident data collection was used in RISER to get a broad base of information about single vehicle accidents and to obtain detail information about the accident event.

6.3.1 RISER Databases

Two databases were developed in the RISER project , one containing a high number of base level data from the police (referred to as the statistical database) and one containing a smaller number of in-depth cases (referred to as the detailed database). From seven countries (Austria, Finland, France, Spain, Sweden, The Netherlands, United Kingdom) almost 265 000 single vehicle accidents were collected and stored in the statistical database. From the same countries 211 in-depth cases were reported in the detailed database.

RISER Statistical database

A comparison of the variables collected by the police from the seven countries was undertaken [1]. The criteria used when selecting the variables for the statistical database was that they should be of interest for road infrastructure design and be available from at least two countries. All of the important variables for road infrastructure were chosen. Fourteen variables were selected for general information about the crash and six variables were selected for information about the occupants.

Crash Data

- Date
- Time
- Road Type
- Carriageway Type
- Road Conditions
- Weather
- Speed Limit
- Light Conditions
- No of Vehicle Occupants
- Accident Type
- Road Alignment
- Hit Object
- Vehicle Type
- Deformation Location

Casualty Data

- Person Class
- Age
- Gender
- Alcohol Involvement
- Injury Severity
- Seatbelt Usage

Each country has different ways to code these variables within its own national accident database. A recoding procedure was undertaken by the countries before the data was merged into the database, in order to have the same variables with the same values within the RISER database. It was found that the different organisations of the police in the different countries make it very difficult to obtain all data from all countries. Some of the abovementioned variables could only be collected by a few countries, and in some cases, it was not possible to merge one specific variable from one country with the same variable from the others, as the information contained in that specific field was rather different. This makes it a difficult task to perform complete analyses on the results.

RISER Detailed Database

Before the RISER project, no in-depth databases has been developed containing thorough information about the road infrastructure involved in accidents. RISER has developed a unique variable list [1] for detailed analyses of accidents involving road infrastructure especially for run-off-road (ROR) accidents. In the detailed database, detailed information about the accident, vehicle, occupant, roadway, struck infrastructure and causation was reported. The database was fed with detailed accident information that the involved organisations collected from different sources. As a result, having seven different countries and organisations reporting to the same database some issues arose. In the RISER detailed database some organisations had very thorough information about the vehicle (external and internal deformations etc.) and the occupant injuries but less information about the road environment, whereas other organisations had much information about the road environment and the occupant injuries but not so much information about vehicle deformation.

6.4 Conclusions

The current situation regarding accident data collection in European roads shows that, in order to find countermeasures to improve safety, more thorough information about the road infrastructure and the causation of the accident is required.

Statistic or base-level accident data are the most commonly available sources of information. These accident data, usually collected by the police, are often very general and the type of information differs considerably among European countries. All variables proposed to describe accidents in RISER statistical database are not fully available in national databases across Europe. Harmonised data elements describing European roadside infrastructure allow European-wide statistical studies. The information gathered in RISER provides a base to further develop this resource.

The data collected by the police is not sufficient for improving roadside infrastructure safety. Other information sources (i.e. road maintenance and detailed investigations, etc.) are needed to have a complete overview of the traffic environment. A valuable resource would be to have a system which collects data of all maintenance performed on road equipment and store it in a computerised database. When this data is compared to the police data, unreported accidents can be identified found and the frequency of accidents can be identified, independently of the injury severity. This makes it possible to monitor the actual accident rate, the performance of the road and roadside, and calculate the real costs raised by accidents on the road.

In-depth level accident data provide specific information that helps improve the knowledge of the accident event, and makes it possible to design or improve safety measures for identified problems. Detailed databases do not cover populations as large as the statistical ones, but the information they provide allows describing and analysing specific safety problems.

To reach a complete description of accident scenes and outcomes, it is important to not only have collection procedures covering a broad scope of information, but also a co-ordinated approach is desirable among the different collecting actors. The following procedures are a proposal to improve the type and quality of data collected for roadside safety issues.

6.4.1 Police

Road accidents are reported differently in the European countries. Even if the police are often called to an accident scene, in some countries the police only report injury accidents, where in other countries they also report property damage accidents. It is preferable to register all of the accidents to get reliable statistics. By considering all types of accidents, it is possible to improve the usefulness of statistical indicators for accident risk rates and accident severity. These are used for the safety effectiveness evaluation of roads and road infrastructure.

When nationwide collection of accidents is not possible, an alternative is to collect data from all the accidents within a limited region. The geographical area selected should be representative of the whole country. Using statistical methods, the data can be scaled from the region to the whole country.

6.4.2 Maintenance and Operation Organisation

In many countries the road maintainers report all repairs that are due to a road accident. Unfortunately not many countries have a system to store this data. Use of this data can contribute to finding:

- the safety performance of the road
- the actual cost for a road
- unreported (property damage) accidents

6.4.3 Hospital and Rescue Services

Many injuries, especially to vulnerable road users, are never reported to the police. If a cyclist or a pedestrian falls on the road/pavement for example (without involvement of a motor vehicle) the injured person will probable be taken to hospital without being reported injured to the police. Only some of the countries (e.g. Sweden) have a system where both the police and the hospital report road accidents to the same database. Combining police and hospital data makes it possible to:

- improve the statistics on vulnerable road users
- compare injury outcome (police reported injury severity versus real injury severity)
- find unreported (injury) accidents

In order to improve the relevance of injury databases, it is important that unified procedures and criteria are set. Victims classified as “injured” should be followed up over fixed periods of time to report the final actual outcome of injuries, including eventually death. Currently, different methods are used throughout the European countries to report injuries.

6.4.4 In-depth Investigations

When special studies are required, in-depth accident investigations must be performed. To find countermeasures for the road network it is important to include variables related to the road environment. Most of the existing variable lists are focusing on vehicles and the injuries to the road user e.g. the STAIRS protocol [2]. Within the RISER project an in-depth study on single vehicle accidents was performed. From the in-depth study a minimum set of road infrastructure variables was identified that is essential when investigating single vehicle accidents [1].

6.5 Variables

The variable matrix presented below (see Table 6.1) is a proposal and should not be seen as a complete list. Fundamental variables are assumed to be collected by the police. Additional variables can be collected by road operators and the hospital and rescue services. In-depth accident investigations should collect all or part of the variables listed in Table 6.1, depending on the aim of the data collection.

All forms of accident data collections should include:

- date
- time
- type
- place (preferable GPS coordinates)

If the police for example could include more environmental variables to gain better statistics on road and roadside infrastructure it would enhance national databases and benefit the whole traffic safety area.

The colour coding for Table 6.1 is as follows:

Police
Road operators
Hospital and rescue services

Table 6.1. Variable Matrix for Accident Data Collection

	Background factors	Pre-crash	Crash	Post-crash
Human	Age	Driver under the influence of medicine, alcohol, drugs	Injury severity	Evacuation
	Gender	Time of accident within the drivers normal circadian rhythm	Type of injuries (AIS code if possible)	Rescue
	Type of road user	Driver familiarity to the road system (surroundings)	Injury cause	Care
	Placement in vehicle	Vehicle speed compared to posted speed	Impact points in the interior	Died at scene
	Type of trip	Usage of passive safety equipment	Function of passive safety systems	Post-crash times (alarm, to/from scene, to hospital)
	Driving licence (type, possession time)	Death because of illness or suspicion of suicide	Ejection, ejection path	
Vehicle	Make	Technical failures	Collision type	Trapping
	Model	Tyres (make, dimension, track depth)	Collision speed	Rescue delayed due to the vehicle
	Model year	Tachograph data	Vehicle movement during collision	Possibility to open doors
	Colour	Load (weight)	Rollover movement	Fire
	Kerb/gross weight	Load contributed in accident	Hit object	Water submersion
	Vehicle characteristics (driven axles, type of gearbox, effect)	Vehicle movement on road before collision	Principal direction of force (PDOF)	
	Type and position of passive safety systems		Rest position (wheels, side, roof)	
	Type of active safety systems		Vehicle deformation (Collision Deformation Classification CDC if possible)	
			Load influence on injury extent	
Environment	Road location (urban/rural)	Light condition (daylight, darkness)	Points of collision	Problem for rescue services to get to the accident scene
	Type of road (classification)	Weather condition	Roadside type/outline	Traffic effected by the accident
	Traffic flow	Road condition	Hit object	Distance to medical rescue service
	Posted speed	Traffic flow at time of accident	Distance to object in roadside	Temperature
	Road characteristics (geometry, surface type, width, camber, deformations)	Type of road- signs, signal system, markings present	Object protected by road restraint system	Cost of the damage or repair
	Roadside type	Brake/skid marks	Road restraint system (type, containment level, deformation, function, effect, failure)	Repair time
	Roadside characteristics (shoulder width and material, fore/back slope gradients, ditch depth)	Exit angle	Road equipment influence on injury extent	
	Type of road equipment/ restraint system	Preventive maintenance actions		
	Road construction or maintenance zone			
	Vehicle heading (north, south, west, east)			

The background factors are a description of the condition of the including components. Some of the background factors are the same for all accident types e.g. age, gender and type of road user etc. Other background factors are more specific depending on the accident type e.g. vehicle type, road geometry and roadside area etc. The background factors can also be placed under the different accident phases respectively if they are considered to be contributing factors in the accident. Example; if an accident occurred in a curve it might not be a contributing factor to the accident. However, if the curve camber was incorrect the curve can be considered as a pre-crash factor.

Reference

1 Accident Databases for Collisions with Roadside Infrastructure, Deliverable 1, European Community, R&TD-Project, 5th Framework Programme "Growth", RISER Project GDR2/2001/50088/RISER/S07.15369, 2004

2 Standardisation of Accident and Injury Registration Systems, Final Report, Transport RTD Programme of the 4th Framework Programme, STAIRS Project RO-96-SC.204, 1999

GLOSSARY

The definitions on road and roadside terms as presented below are developed by the members in the RISER project. There can be differences to National and European definitions. The phrasing in the European Best Practice for Road Design is based on this glossary to be sure that the definitions are used the same way.

Arrester bed

Arrester beds are designed to stop vehicles that have lost braking ability on long downgrades. They are parallel ramps filled with smooth, coarse, free-draining gravel. They stop the vehicle by increasing the rolling resistance. Arrester beds are commonly built on an up grade to add the benefits of gravity to the rolling resistance.

Back slope (see ditch)

Slope associated with a ditch, opposite the road edge beyond the ditch bottom

Boulder

A large rounded mass of rock lying on the surface of the ground or embedded in the soil in the roadside, normally detached from its place of origin.

Break-away structure

A design feature which allows a device such as a sign, luminary, or traffic signal support to yield or separate upon impact. The release mechanism may be a slip plate, plastic hinges, fracture elements, or a combination of these.

Bridge abutment

A bridge abutment is the end of a wall (bridge, tunnel etc.), and is normally located in the roadside.

Bridge pier/pillar

A bridge pier is an upright structure, often a series of columns, which supports a bridge. It can be located in the central reserve or in the roadside.

Bridge parapet

A longitudinal barrier whose primary function is to prevent an errant vehicle from going over the side of the bridge structure. It can be either steel or concrete.

CCTV Masts

A mast on which a Closed Circuit Television camera is mounted for traffic surveillance

Carriageway

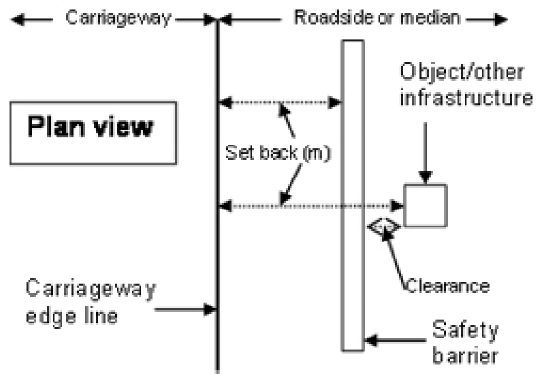
The part of the roadway constructed for use by vehicular traffic. Includes the travel lanes in between the edge line markings.

Central reserve

The portion of a divided roadway separating the travel lanes for traffic in opposite directions.

Clearance

Unobstructed horizontal dimension between the front side of safety barrier (closest edge to road) and the traffic face of the protected object (figure shows the plan view of road with definitions of set back and clearance measurements).



Clear/Safety zone

The total roadside border area, starting at the edge line of the carriageway, available for safe use by errant vehicles. This area may consist of a shoulder, a recoverable slope, a non-recoverable slope, and/or a clear run-out area. The desired width is dependent upon the traffic volumes, speeds and on the roadside geometry.

Contained vehicle

For example, a vehicle which comes in contact with a road restraint system and does not pass beyond the limits of the safety system.

Containment level

Description of the standard of protection offered to vehicles by a road restraint system. In other words, the Containment Performance Class Requirement that the object has been manufactured to (EN 1317).

Crash cushion

Energy absorbing system that prevents an errant vehicle from impacting fixed object hazards by gradually decelerating the vehicle to a safe stop or by redirecting the vehicle away from the hazard.

Culvert

A structure to channel a water course. Can be made of concrete, steel or plastic.

Culvert end

The end of the channel or conduit, normally a concrete, steel or plastic structure (figure illustrates a concrete culvert end which is hazardous).

Cut slope

Earth embankment created when a road is excavated through a hill, slopes up from the roadway.

Design Speed

A speed determined for the design of the physical features of a road that influence vehicle operation. It is the maximum safe speed that can be maintained over a specified section.

Distributed Hazards

Also known as 'continuous obstacles', distributed hazards are hazards which extend along a length of the roadside, such as embankments, slopes, ditches, rock face cuttings, retaining walls, safety barriers not meeting current standard, forest and closely spaced trees.

Ditch

Ditches are drainage features that run parallel to the road. Excavated ditches are distinguished by a fore slope (between the road and the ditch bottom) and a back slope (beyond the ditch bottom and extending above the ditch bottom).

Divided roadway

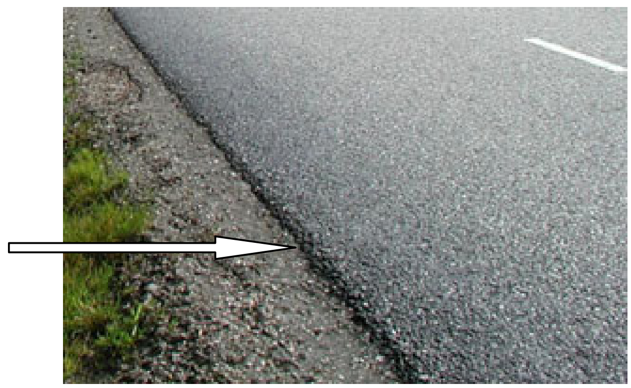
Roadway where the traffic is physically divided with a median and/or road restraint system. Number of travel lanes in each direction is not taken into account. See also dual carriageway.

Drainage gully

A structure to collect water running off the roadway.

Drop-off

The vertical thickness of the asphalt edge.



Dual carriageway

A divided roadway with two or more travel lanes in each direction and traffic is physically divided with a median and/or road restraint system. See also divided roadway.

Edge line

Road marking indicating where the carriageway ends and the roadside or median begins. If a shoulder or emergency lane is present, these are located in the roadside beyond the edge line.

Embankment

A general term for all sloping roadsides, including cut (upward) slopes and fill (downward) slopes (see cut and fill slope).

Encroachment

When the vehicle leaves the carriageway and enters the roadside.

Energy absorbing structures

Any type of structure which, when impacted by a vehicle, absorbs energy to reduce the speed of the vehicle and the severity of the impact.

Fill slope

Earth embankment created when extra material is packed to create the road bed, slopes down from the roadway.

Frangible

A structure readily or easily broken upon impact (see also break-away structure).

Fore slope (see ditch)

Associated with a ditch, the slope beside the roadbed before the ditch bottom

Guardrail

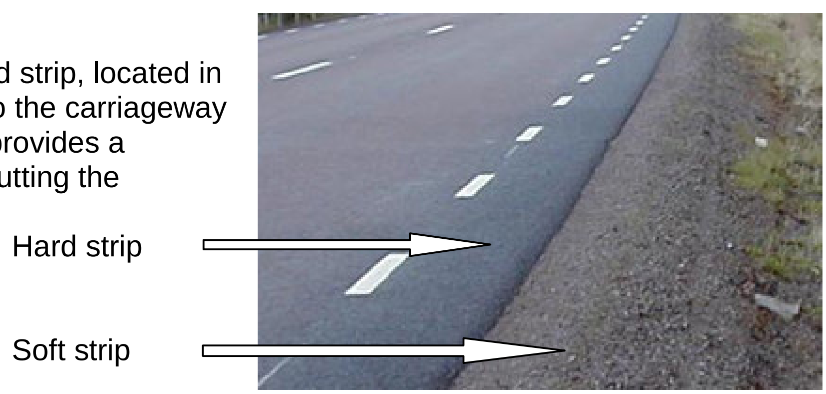
Another name for a post and beam safety barrier.

Hard/Paved shoulder

A hard shoulder is defined as being an asphalt or concrete surface immediately beyond the carriageway edge line. Shoulder pavement surface and condition as well as friction properties are intended to be as good as the road surface.

Hard strip

A typically narrow paved strip, located in the roadside adjacent to the carriageway edge line. A hard strip provides a surfaced strip that is abutting the carriageway.



Highway

Roadway is used instead because highway is often thought of as a motorway.

Horizontal alignment

The geometric description of the roadway within the horizontal plane.

Impact Angle

For a longitudinal barrier, it is the angle between a tangent to the face of the barrier and a tangent to the vehicle’s longitudinal axis at impact. For a crash cushion, it is the angle between the axis of symmetry of the crash cushion and a tangent to the vehicle’s longitudinal axis at impact.

Impact attenuators

A roadside (passive safety) device which helps to reduce the severity of a vehicle impact with a fixed object into a less severe collision. Impact attenuators decelerate a vehicle both by absorbing energy and by transferring energy to another medium. Impact attenuators include crash cushions and arrester beds.

Kerb (Curb)

A border or row of joined stones forming part of a gutter along the edge of a street. A unit intended to separate surfaces to provide physical delineation or containment. Often used as edges of road islands in intersections.

Length of Need

Total length of a longitudinal barrier needed to shield an area of concern.

Median

See Central reserve

Nearside

A term used when discussing right and left hand traffic infrastructure. The side of the roadway closest to the vehicle's travelled way (not median).

Non Paved surface

A surface type that is not asphalt or concrete (e.g. grass, gravel, soil...).

Non Paved roadside

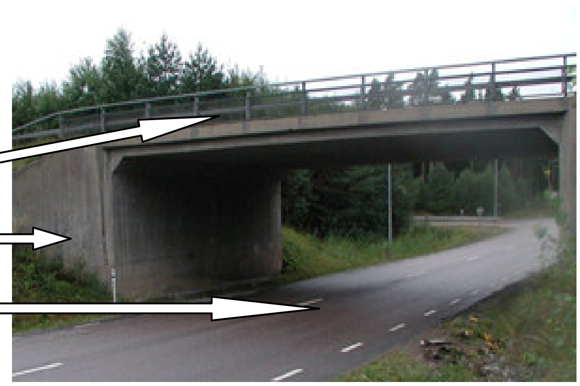
A roadside which contains very little or no paved surface immediately beyond the edge line.

Offside

A term used when discussing right and left hand traffic infrastructure. The side of the roadway closest to opposing traffic or a median.

Overpass

A structure including its approaches which allows one road to pass above another road (see also underpass).



Paved shoulder

See hard shoulder.

Pedestrian restraint system

Classified as a group under road restraint system. A system installed to provide guidance for pedestrians.

Point Hazard

Narrow item in the roadside that could be struck in a collision for example trees, bridge piers, lighting poles, utility poles, sign posts (figure illustrated a rigid utility pole).

Recovery zone

Zone beside the travel lanes that allows avoidance and recovery manoeuvres for errant vehicles.

Rebounded vehicle

A vehicle that has struck a road restraint system and then returns to the main carriageway.

Retaining wall

A wall that is built to resist lateral pressure (especially a wall built to support or prevent the advance of a mass of earth) (see figure for bridge abutment and overpass).

Road restraint system (RRS)

General name for all vehicle and pedestrian restraint systems used on the road.

Road Equipment

General name for structures related to the operation of the road and located in the roadside.

Road Furniture

See Road Equipment

Roadside

The area beyond the edge line of the carriageway. The area between a divided roadway (median or central reserve) may also be considered roadside.

Roadside Barrier

See safety barrier

Roadside hazards

Continuous or punctual, natural or artificial, fixed objects or structures endangering an errant vehicle leaving its normal path. The risks associated with these hazards include high decelerations to the vehicle occupants or vehicle rollovers.

Roadway

The paved area of the road including shoulders, for vehicular use.

Rock face cuttings

Rock face cuttings are created for roads constructed through hard rock outcroppings or hills.

Rumble strip (Shoulder rumble strips)

A thermoplastic or grooved transverse marking with slight vertical profile which is designed to provides audible and tactile warning by the use of the ribs. It is normally located between hard shoulders and nearside travel lanes of carriageway.

Safety barrier

The purpose of safety barriers is to provide a shield between hazardous roadside areas and vehicle traffic. Types of safety barriers include for example steel, concrete and cable safety barriers.

Safety zone

See Clear zone

Set-back

Lateral distance between the carriage edge line and an object in the roadside (see diagram for clearance).

Shoulder

The portion of the roadway contiguous with the travel lane, primarily for accommodation of stopped vehicles, emergency use, lateral support of the carriageway (see figure for rumble strip). On non motorways the shoulder can be used by pedestrians and bicycles.

Single carriageway

See undivided roadway

Slope

A general term used for embankments. It can also be used as a measure of the relative steepness of the terrain expressed as a ratio or percentage. Slopes may be categorized as negative (fore slopes) or positive (back slopes) and as parallel or cross slopes in relation to the direction of traffic.

Soft strip

A narrow strip of gravel surface found in the roadside beyond the roadway (normally beyond a hard strip/shoulder) (see figure for hard strip).

Termination (barrier)

The end treatment for a safety barrier, also known as a terminal. It can be energy absorbing structure or designed to protect the vehicle from going behind the barrier.

Travel/Traffic lane

The part of the roadway that is travelled on by motor vehicles. A carriageway can include one or more travel lanes.

Underpass

Opposite to overpass, the roadway passing under another roadway (see figure for overpass).

Undivided roadway

Roadway with no physical separation. Also known as single carriageway.

Vehicle restraint system

Classified as a group under road restraint system. A device used to prevent a vehicle from striking objects outside of its travelled lane. This includes for example safety barriers, crash cushions, etc.

Verge (grass)

Grass border in the roadside.

Vertical alignment
The geometric description of the roadway within the vertical plane.

APPENDIX A: HUMAN FACTORS CONSIDERATIONS

Introduction

It is obvious from the accident statistics that single-vehicle accidents are a significant component of annual road casualties, according to Collin (2000) 33.8% of all fatalities in the European Union in 1998 were the result of single-vehicle collisions. Run-off-the-road (ROR) accidents apparently occur because drivers fail to keep their vehicle on the road. The objective of good road design is to provide a roadway that enables drivers to recover safely in case a vehicle unintentionally crosses the carriageway edge-line. The reasons for unintentional roadside encroachments are various and may include drivers trying to avoid a vehicle, object or animal in their travel lane, inattentive driving due to distraction, fatigue, sleep, alcohol or drugs, unexpected effects of weather on pavement conditions, or travelling too fast through a curve etc. But also roadway design factors, such as traffic lanes that are too narrow given the road function and design speed, or substandard curves, inconsistent road design with unexpected transitions that surprise the driver, may contribute to the occurrence of ROR accidents. To include human factors it is a good start to look at the road(side) design from the ***driving task*** perspective and to be aware of typical ***driver characteristics*** before making the step to human factors issues related to roadside infrastructure.

The Driving Task

In the literature the task analysis for driving a car is well documented. A frequently used conceptual model of the driving task consists of three hierarchically ordered levels, ***navigation***, ***guidance*** and ***control*** (Allen et al., 1971). Tasks at the navigation level refer to the activities related to planning and executing a trip from origin to destination. The need for processing information only occurs occasionally, with intervals ranging from a few minutes to hours. The guidance level refers to tasks dealing with the interaction with both environment (roadway, traffic signs, traffic signals) and other road users. Activity is required rather frequently with intervals of a few seconds to a few minutes. At the control level the motion of the vehicle is controlled in longitudinal and lateral direction. Information has to be frequently processed, ranging from intermittent activities every few seconds to almost continuous control. Alexander and Lunenfeld (1986) visualised the relationship between the levels by a set of nested triangles (see Figure 1), hierarchically ordered from a low to a high level with an increasing ***complexity*** and from high to low with an increasing urgency (***primacy)***. For example, a flat tire or being suddenly confronted with a heavy wind gust will immediately interrupt activities at the navigation level and put all attention to the control level, since getting lost has less severe consequences than running off the road.

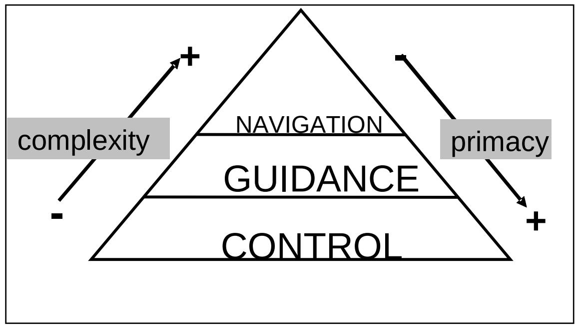


Figure 1 The three hierarchical levels of the driving task according to Alexander and Lunenfeld (1986).

At each level of the driving task the successive steps of information processing, i.e. perception, processing and decision-making, and action take place. Moreover, the way a driver performs these tasks strongly depends on the routine the driver has developed in task performance. Rasmussen (1985) distinguishes three levels of task performance: knowledge-based, rule-based, and skill-based. The highest level (knowledge-based) refers frequently to new situations (for example, finding the best route to a new destination) or situations that occur frequently in itself, but in which the driver still has little experience. The choice of behaviour depends on interpretation and deductive reasoning. When a situation occurs frequently, a rule develops, after some time, how to deal with that situation and recognising that situation leads to appropriate behaviour without a 'need' to understand exactly what is going on. Skill-based tasks are conducted automatically, incoming information automatically results in the right behaviour without any cognitive control. Theeuwes (1993) introduced a nice three-dimensional representation of the driving task as is given in Figure 2.

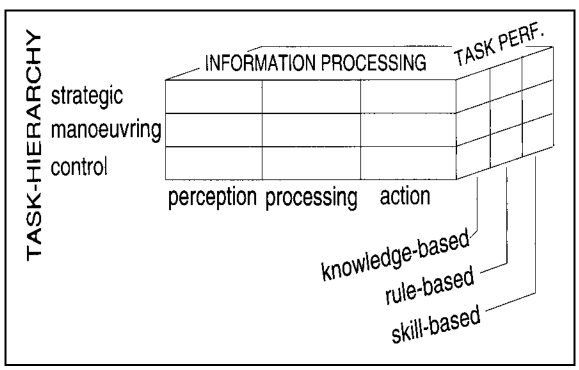


Figure 2 The driving task in three dimensions (Theeuwes, 1993).

Driver characteristics

It is obvious, in the road design, to include those driver characteristics that are relevant for the driving task such as for speed choice or lateral positioning. For example, if it were established that the 95th percentile of the distributions of standard deviations of lateral position is 0.25 m at design speed, it is easy to calculate the minimum lane width that would make an involuntary lane departure unlikely to occur (Janssen & van der Horst, 2000). But a complicating factor may be that drivers may display compensatory behaviour in case the resulting lane width is actually so comfortably to them that they start driving less carefully.

In the so-called funnel model, various human factors aspects are ordered from background factors of road users that determine how functions are performed resulting in certain road user behaviour, which in turn influences the total system performance, (see Figure 3). Demographic factors include individual differences such as gender, age, nationality, driving experience, impairment, physical, mental, visual capabilities, personality, etc. Temporary differences include fatigue, alcohol, drugs, motivation, attention, emotional state, etc. Road(side) design should take into account the way in which road users interact with the dynamic, and not only with the static environment (Van der Horst & Hagenzieker, 2002). Concepts such as ***expectancy*** and ***consistency*** should be central. In particular, transitions are inherently difficult (for example, from straight road to bend, from one road category to another with a different function, etc.). Three human factors aspects appear to be crucial in road safety:

- ***situation awareness***
  - including perception of relevant elements in the current situation, comprehension of the current situation, and projection of the future situation
- ***workload***
  - too much is bad and resulting in stress; too little is bad because of resulting in a low arousal level of the driver
- ***attention***
  - the stage preceding the actual processing by the senses.

As an example of the latter factor, in the USA recently, a large-scale study was completed, in which 100 car drivers were observed in great detail for a one-year period in their vehicle during driving to get more insight in the pre-crash phase of collisions, the so-called 100-car naturalistic study (Neale, Dingus, Klauer, Sudweeks & Goodman, 2005). In this study, 82 crashes were registered and 761 near-crashes (defined as a conflict situation requiring a rapid, severe evasive manoeuvre to avoid a crash).

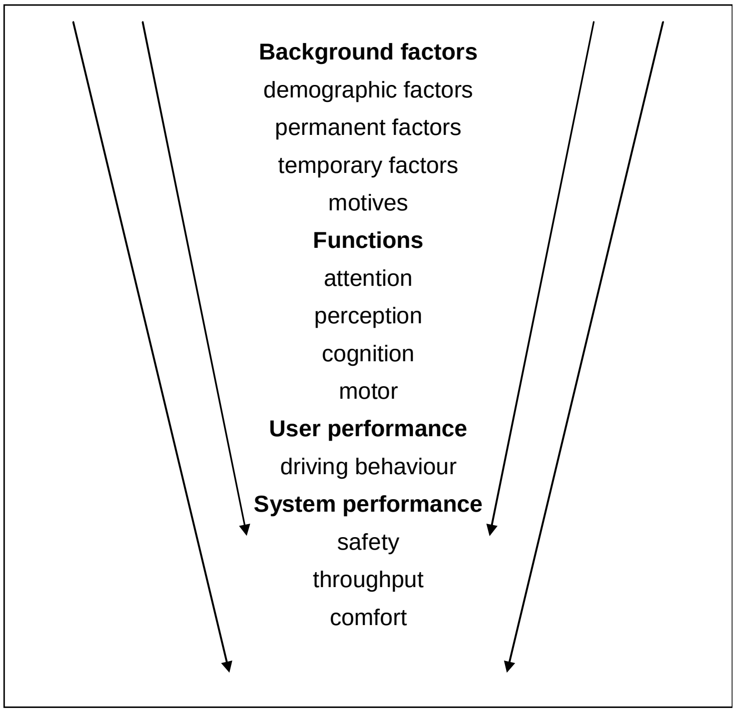


Figure 3 Ordering of (categories of) characteristics in 'funnel' model (Janssen & van der Horst, 2000)

Figure 4 gives an example of a categorisation of events in which the driver was attentive or inattentive. Driver inattention included ***secondary task engagement, fatigue***, ***driving-related inattention to the forward roadway*** and ***non-specific eye-glance away from the forward roadway***. These categories were extracted manually by data reductionists from video. It appeared that a majority of events (78% of the crashes and 65% of the near crashes) have driver inattention as a contributing factor. The sources of inattention that generally contributed to the highest percentages of events were wireless devices, internal distractions and passenger-related secondary tasks.

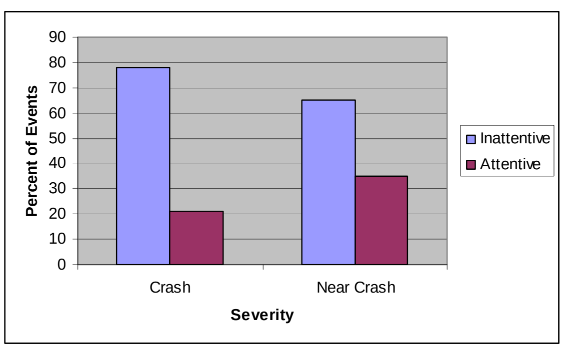


Figure 4 Percentage of crashes and near-crashes with inattention/distraction as a contributing factor (Neale, et al., 2005).

It is obvious that also other aspects of the driver such as his intentions, attitudes, emotions and subjective norms play a role in driver behaviour. One possible representation of this is given in Figure 5.

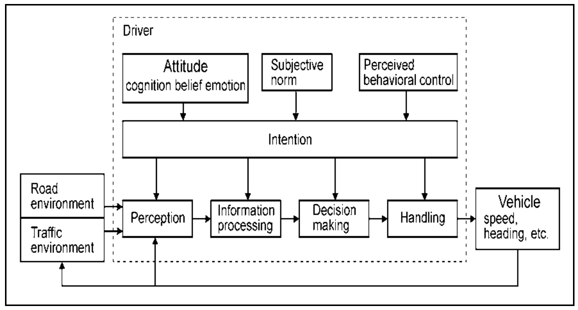


Figure 5 A driver behaviour model according to van der Horst (1998).

Also in the road traffic, road users, inevitably, will make errors and human errors are causing most of the accidents. Reason (1990) distinguishes ***slips and lapses*** (the plan is adequate but there is minor failure in execution), ***errors*** (misapplication of a rule or failure to apply a correct rule), and ***violations*** (deliberate deviations from rules). It is obvious that all type of errors may apply for roadside accidents, and as indicated in the introduction the roadside should be made forgiving for road users that do not properly conduct their task of speed choice and lateral positioning and end up aside of the road. The first step, of course, should be that the road and traffic situation do not surprise the driver and meets his expectancies as much as possible and drivers do not run off the road. But in case they do, try to reduce the consequences both for themselves as for other road users.

Human factors issues related to roadside infrastructure

This section gives an overview of a literature review on the interaction between roadside elements and driver behaviour, of the accident causation issues identified in the RISER detailed database and a selection of some human factors case examples. Moreover, it summarises the results of a detailed human factors road scene analysis of ten selected accident sites, and details the results of a driving simulator study conducted at TNO to investigate the influence of different roadside features including trees, barriers, signs, and emergency lanes on speed choice and vehicle lateral placement.

Literature review interaction roadside elements and driver behaviour

In the context of RISER a literature review was conducted to identify effects that roadside elements have on the lane keeping task (the ***guidance*** concept of road and roadside infrastructure directing driver's path), and to learn why drivers sometimes fail in performing this task (Janssen, de Ridder & Brouwer, 2004). Moreover, speed, or rather, speeding, plays a significant role in the occurrence of ROR accidents. In many instances drivers lose control of their vehicle because the speed chosen is not appropriate in a given situation. In general it can be said that if a driver can increase speed without increasing perceived risk difficulty (or perceived risk) he, or she, will do so. Safety interventions that make the driving task easier (such as straightening out a curve) may be consumed by increases in speed. It also explains why it is important to inform a driver about the road environment and its task difficulty for the driver to be able to adapt driving behaviour accordingly (referring to 'no surprises' and design roads and road environments that meet drivers' expectancies, Self-Explaining Roads). At higher speeds drivers tend to show a more selective (narrow) visual search pattern, as they do in case of high workload. A special case is that of so-called ***behavioural adaptation*** after roadside hazards have been treated. It deserves specific mention because this is often raised as an issue of concern when treatment is being considered. For example, we may take away the risk of colliding with trees only to observe that drivers now move closer to the edge of the road and thereby increase their risk of leaving the lane after all. A Finnish study by Kallberg (1993) indicated that reflector posts on narrow, curvy, and hilly roads can significantly increase driving speeds and consequently increase the number of accidents in darkness. Reflector posts may increase visual guidance and help the driver see the road alignment ahead, but may have an adverse effect on safety due to increases in driving speeds.

Out of a total of 144 papers reviewed, 61 relevant papers were selected that dealt with the driver-roadside interaction in one way or another. There are not that many studies that have actually looked into driver behaviour, or that – at least – present some ideas about the role of driving behaviour in the chain of events leading to a ROR accident. Most countermeasures that are presently under discussion in the literature are directly infrastructure-based. It is surprising that only once or twice the potential of advanced in-vehicle devices, such as Lane Departure Warning systems, is mentioned as a remedy to ROR accidents. It should be noted that the relevance of driver behavioural studies is as high to these systems as it is to the more classical approaches, as these supports can only be designed adequately if it is known what behaviour they should deal with (i.e., prevent or correct).

RISER Detailed database

A review of over 200 detailed cases was conducted. The retrospective nature of this review meant that all the relevant details for RISER may not have been collected at the time of original collection. In a general sense it appears that the lateral positioning and speed of the vehicle were two of the primary factors leading to the reviewed crashes. This is observed in the vehicle motions prior to the crash where over 50 % of the cases involved some sort of lateral motion of the vehicle. Following this; speed, fatigue, and alcohol were risk factors that were attributed to the driver in several cases. Effective means of controlling the vehicle position in the lane is difficult to determine from the available accident data. Controlling driver fatigue and speed is also difficult to achieve using the static roadside elements. For more details, the reader is referred to RISER Deliverable D04 (de Ridder, Thomson & van der Horst, 2005).

Human Factors Case Examples

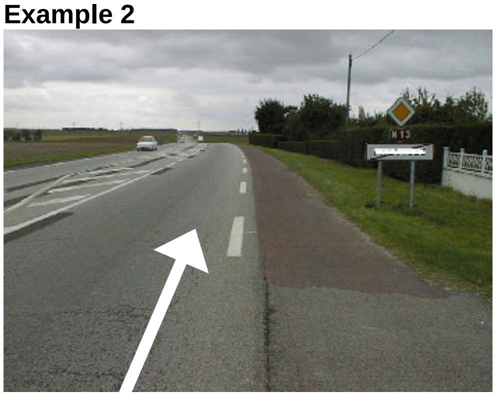
This section outlines ten cases examples from the RISER detailed database which show how the layout of a road can possibly lead to the onset of a road side collision occurring. These cases were chosen because they were considered to have more relevant human factors issues related to the highway than other cases in the database.

Example 1

The non-motorway road consisted of two lanes in each direction, separated by a grass central reservation with some shrubs. At the accident location, the two lanes in the car's direction of travel are being filtered down to one lane. White painted lines reduce the number of lanes in order to prevent vehicles from overtaking at intersections. At the time of the accident, it was daylight, it was raining and the road was wet. For an unknown reason, the driver of the car braked too hard and the vehicle ran onto the nearside verge. The driver steered back onto the carriageway, but went too far and had to steer towards the nearside again. The car slid off the road to the nearside, hit an embankment and rolled over. The driver, who was belted, suffered slight injuries.

Human factors issues related to the highway - The driver was reported as being tired, so concentration levels may have been low. However, the fact that 2 lanes were merging into one just before the accident location may have been an issue, particularly if there was inadequate signage to warn of the lane merging. Also, it appears from the photographs that nearside edge of the road is very uneven, which may have made it more difficult for the driver to regain control of the vehicle once it left the road.

Example 2



The accident occurred at night on a single carriageway road, which had no street lighting. It was raining and the road surface was wet. The car was travelling at 90 km/h through a left hand bend, when the driver thought that they saw a vehicle coming towards them. The driver steered right and braked to avoid it. The car was actually parked on the grass verge on the right hand side of the road. When the driver realised this, they drove off the right hand side of the road and lost control of the car. The vehicle struck a fence and then a telegraph pole situated just after the grass verge. The driver was not wearing a seatbelt and was not injured, despite impacting the windscreen. The passenger was belted and was slightly injured.

Human factors issues related to the highway - It appears from the accident information that the main reason for the vehicle leaving the road was the driver being confused about the 'actions' of the parked car. The presence of the vehicle at the point where the road bended to the left, plus the lack of road lighting and lack of visual cues on the road (e.g. reflective signs or road markings), all would have contributed to the confusion of the driver and resulted in the steering and braking manoeuvres carried out by the driver. If the layout of the road had been more self-explaining, the driver might have realised that avoidance manoeuvres were not necessary and the run-off could have been avoided.

Example 3

The accident occurred during daylight on a single carriageway road. The weather and road surface were dry. The road had been recently resurfaced and there was loose gravel. There was a temporary speed limit of 70 km/h. The novice driver panicked in the traffic situation (thought there was not enough room to pass an oncoming car), braked and skidded on the gravel. The vehicle hit a raised section on the nearside then the driver steered hard to the left. The car rotated 180° and then rolled over in a ditch (drainage gully) on offside. The road was straight at site of accident but there were bends on approach (left bend). The occupants were not injured.

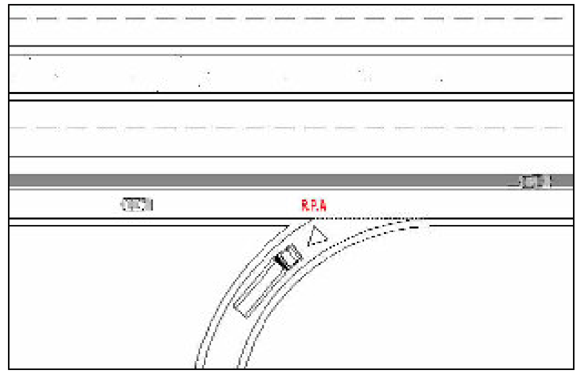
Human factors issues related to the highway - From the photographs, it appears that the road was being redeveloped at the time of the accident. The newly resurfaced road was covered in loose gravel, which was probably reducing the visibility of the centre line markings and therefore, there were very few visual clues of the road ahead to assist the driver. Therefore, the lack of visual clues led to the driver thinking the road was too narrow to pass the oncoming car.

Example 4

The accident happened on the exit slip road of a motorway during daylight hours. The weather and road surface were dry. The driver of the vehicle was driving too fast for the road (100 km/h, the recommended speed was 60 km/h), and the car left the road to the offside on the slip road. The car fell into the embankment and rolled over. Both occupants suffered minor injuries.

Human factors issues related to the highway - Although the main reason for the accident occurring was the vehicle's inappropriately high speed, it is possible that the layout of the road caused the driver to think the bend of the road was less severe than it actually was. Also, there appears to be no visual clues to warn drivers of the approaching bend in the road, such as chevron signs, either on the approach or at the start of the bend.

Example 5

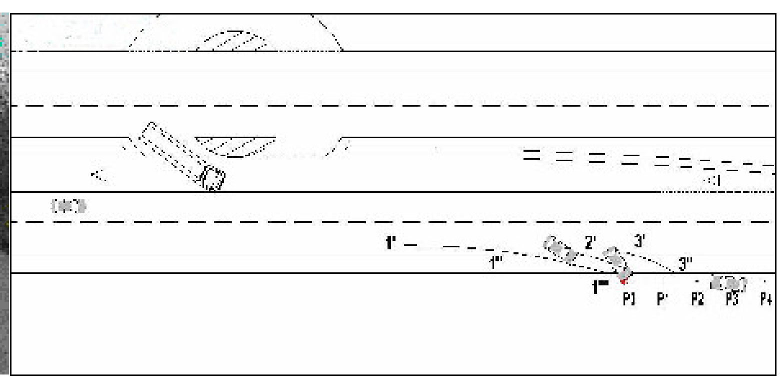


The accident occurred on an entry slip road of a non-motorway dual carriageway. The collision occurred at dawn, it was raining and the road was wet. The car ran off the road to avoid an impact with a truck that was entering the road from a side road. This avoidance manoeuvre resulted in the car impacting a lamp post. The car driver was not wearing a seat belt and was slightly injured.

Human factors issues related to the highway

- The truck did not obey a sign that established that vehicles from right must give preference to the other vehicles. It is possible that the truck driver misinterpreted the layout of the road. From looking at the photographs, there is only one small 'give way' sign at the road junction, which may have been missed by the truck driver, who would have been at a more elevated position in the truck cab. Also, the road markings at the junction location are worn away, so may have also been missed by the truck driver. Therefore, the poor signage and markings, in addition to the weather conditions, would have made it less obvious to the driver of the truck that they were approaching a junction where they would have to give way to oncoming traffic.

Example 6



The accident occurred on a non-motorway dual carriageway road. It was daylight and the weather and road conditions were dry. The car driver had to steer right suddenly to avoid collision with a truck entering the road from offside. The car left the road to the nearside, hit a barrier termination and travelled along the top of the barrier (rotated 180^{o})

for 10.8 m until it came to a stop on the barrier. The driver, who was belted, suffered slight injuries.

Human factors issues related to the highway - The layout of the road, which allows vehicles to enter the carriageway from the opposite side of the road through a gap in the central safety barrier, does not allow much room for larger vehicles, such as trucks, to negotiate the turn into the central refuge lane before entering the main carriageway, as shown in the diagram. This may have given the impression to the car driver that the truck was moving into the same lane they were travelling in. Also, it may not have been obvious to the driver of the truck that they had to give way to traffic already on the main carriageway, as there are very few signs at the junction to instruct drivers.

Example 7

The accident occurred on a motorway. It was dark but the road was lit by street lighting. The weather and road conditions were dry. The car driver steered back onto the main motorway from the exit slip road at the last minute, over-steered, struck the central reservation barrier and rebounded back into the main carriageway. The after impact distance was 15 m. The occupants of the vehicle were all belted and the front seat passenger suffered slight injuries (all others were not injured).

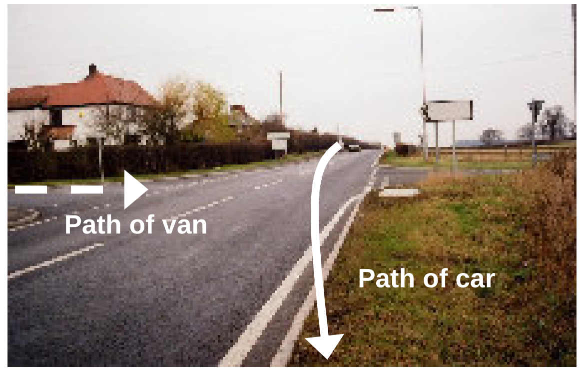
Human factors issues related to the highway - The human factors issues in this accident are not clear, as it is not known why the driver of the vehicle attempted to re-join the main carriageway at the last minute. However, it may have been a result of poor signage or a misleading road layout that led to the driver possibly taking the wrong exit off the motorway. But there is no information or photographs about the approach to the accident to know whether the signage or road layout was adequate or not.

Example 8

The accident occurred on a motorway. It was dark but the road was lit by street lighting. The weather and road conditions were dry at the time of the accident. The car impacts a safety barrier end while trying to enter the exit slip road. The occupants of the vehicle were all belted and the rear seat passenger suffered slight injuries (all others were not injured).

Human factors issues related to the highway - Similar to Example 7, the human factors issues in this accident are not clear. From the photographs, the condition of the road and the road markings appear poor. Therefore, there would be little to help guide the driver along the correct drive line , especially at night. As with Example 7, there are no photographs of the approach to the site of the accident, so it is not possible to determine the level of visibility of the road leading to the impact site or to ascertain how adequate the signage was.

Example 9 (left hand traffic)



The accident occurred on a single carriageway road (100 km/h speed limit). It was daylight, the weather was dry, but the road surface was icy. The driver of the car swerves to avoid the van which pulls out of a side road. It leaves the road to the nearside and collides with a fence followed by a telegraph pole. The driver, who was belted, suffered slight injuries.

Human factors issues related to the highway - On the approach to the accident site, the view of the road ahead is restricted by the uphill gradient of the road (not shown in photographs). Therefore, the driver of the car would not have seen the van pull out from the side road until it was quite close. Also, the driver of the van would not have seen the oncoming car until it was quite close, but by then, the van driver would have already started to pull out. On the approach to the junction, the only signs to warn the car driver of the approaching road junction were at the top of the incline.

Example 10 (left hand traffic)

The accident occurred on a single carriageway road. It was daylight, it was raining and there was oil/diesel on the road. The car approaches the roundabout junction, skids and leaves the carriageway ahead, colliding with a multiple posted chevron sign which is mounted on the roundabout. A post from the chevron sign penetrates the windscreen. Both the driver and the front seat passenger were belted and suffered slight injuries.

Human factors issues related to the highway - On approach to the roundabout, there is a bend to the left just before arriving at the roundabout, which cannot be seen easily by the driver on the approach. The rain may also have obscured the driver's view of this even more. There are also no advance warnings to the driver to slow down before the bend. National speed limit (100 km/h) signs are present right up to the junction itself. So there are very few visual cues to instruct the driver to slow down before the start of the bend.

Summary:

The ten case examples outlined in this section have a very limited amount of information about the possible reasons why the vehicle ran off the road, including the roadway issues that may have contributed to the initial run-off. However, from what is known about these cases, it is possible that all ten cases have involved at least one of three types of issues related to the layout of the road:

- Road markings (markings missing, poor quality or faded)
- Signage (signs missing, location of signs)
- Road geometry (bends, inclination)

For the majority of cases in the RISER detailed database, there is not enough information prior to the initial run-off to know exactly why the vehicles had a run-off in the first place. Due to a lack of available information with respect to road layout it is difficult to draw any conclusions whether the run-offs were directly associated to the road layout or not.

One third of the cases (69 of 211) in the database had no causation information at all. In 19 % of the cases, the driver exceeded the legal alcohol limit, in 15 % the driver was fatigued, in 9 % the driver was not driving appropriately for the road surface conditions, in 6 % the driver was not concentrating because of internal distractions, 5 % of the vehicles had serious defects and 4 % of the drivers were attempting to avoid other vehicles/objects on the road. Some cases have more than one of these causation factors.

By comparing levels of alcohol impairment to those in the statistical database, it can be seen that the proportion of alcohol impairment cases in the detailed database is higher (19 %) than it is in the statistical database (9 %). However, the sample of cases in the detailed database is not totally random (e.g. high bias towards fatal cases), which is one possible reason for the larger proportion in the detailed database.

The data show the importance of retrieving more thorough accident causation data concerning the road and roadside to be able to use accident data in the road(side) design process.

Detailed Road Scene Analyses

Detailed Road Scene Analyses (RSA) were conducted by two human factors experts at a selection of ten accident sites in the Netherlands, to provide more in-depth information in relation to the interaction of the driver with the road design and roadside infrastructure. For five out of the ten sites, the RSA did not reveal a specific reason based on the road layout why the crash with a tree or roadside infrastructure had occurred. Two locations showed a mismatch between the road design and road category and the speed limit posted (the road layout invites the road user to drive faster than the speed limit). At one location a multitude of curves might be appealing to the frequent user (especially motor cyclists) and invite to race. Two accidents occurred in a work zone area with confusing road markings. At two locations it appeared that, once a road user had made an error and found him/herself behind a hazard protection device such as a poorly visible barrier or an interrupted guardrail, the collision with the hazard was almost inevitable.

The driving simulator study

Given the limited data in the database of accidents collected in the RISER project, a driving simulator study was developed to investigate two of the main factors leading to crashes – lateral position and speed of the vehicle. The driving simulator study observed the influence of different roadside features including trees, barriers, signs, and emergency lanes on speed choice and vehicle lateral placement. Different constructions of the man made objects were investigated as well as the lateral positioning of the different objects.

For the conditions on the motorway, where different types of safety barriers were introduced, it can be concluded that there was no effect on speed or on lateral position dependent on the type of safety barrier that was introduced. Overall no guidance of any type was found. The presence or absence of an emergency lane did have an influence on driving behaviour. When an emergency lane was absent, drivers tended to choose a position on the road that was further away from the right side marking. How far away the driver chose to drive from the right side marking when an emergency lane was absent depended on the type of safety barrier. When the standard 0.75 m high Dutch concrete barrier was introduced (this is the lowest safety barrier of all safety barriers introduced) and when the 0.9 m high concrete barrier was introduced (the second lowest of all safety barriers) in combination with an emergency lane, drivers drove closer to the edge markings than in other conditions. However, when the emergency lane was absent, they moved further away from the right side edge markings in these conditions than in other conditions, compared to the situation with an emergency lane. It could be the case that familiarity in the condition with an emergency lane plays a role.

Another conclusion based on these results and the results on the rural road is that when an obstacle is introduced, drivers tend to temporarily move away from that obstacle and choose a position in the lane further away from the edge line. This effect was also found in earlier field studies when introducing a sound barrier or entering a tunnel entrance (Blaauw, & van der Horst, 1982; Bakker, & van der Horst, 1985; de Vos, Hoekstra, Pieterse, 1998; Martens & Kaptein, 1997, 1998). The effect was not found in the curve sections on the motorway.

In the conditions with the curves on the motorway, the results revealed that when drivers see a particular treatment for the second time, they tend to be less impressed by it and, as in this case, drive faster through the curve and closer towards the right edge marking than the first time. Also, when a new treatment (like the stripes) is introduced, speed goes down. However, based on the previous finding, this effect might be temporary.

On the rural road, drivers did change their speed when trees or safety barriers were introduced, dependent on how close they were positioned to the road. When they were 4.5 m away or more, no effects on speed were found, whereas when they were positioned 2 m away or less, speeds were reduced.

For the lateral position a different picture occurred. When trees were introduced in combination with a safety barrier, drivers tended to choose a position away from the safety barrier and trees. However, when trees were introduced solely, no effects on the lateral position chosen were found. In fact, the position chosen in these two conditions was the same as in the condition with the trees at 30 m away from the roadside. One has to question therefore whether drivers understand the risks of trees alongside the road and whether that might be an underlying reason of the many incidents and accidents with trees. Trees along the road do not seem to influence driving behaviour that much and are not considered to be a serious hazard by road users. This is in line with the real life studies reported in France, (CETE 2000 & 2002) where the removal of trees closer than 2 m from the carriageway edge line had no influence on travel speeds. One important result from the French study was that after the trees have been removed, the average number of injury accidents decreased by 50 %, and the number of fatal accidents reduced by 75 %. It is important to realize that the current guidelines recommend that no obstacles should be in the safety zone which is at least 4.5 m from the carriageway edge line for 80 km/h roads in most European countries surveyed, and, if so, should therefore be removed or protected.

Human Factors recommendations relevant for road(side) design and redesign

Based upon the analyses as presented in the previous sections, we make the following recommendations relevant for road(side) design and redesign:

- Make the road and roadside design such that they meet drivers' expectancies by applying the concept of Self-Explaining Roads and road categorisation based upon the road function.
- Inform the driver about transitions in road function and road layout in a timely manner. Do not surprise the driver.
- Drivers make errors, either at the strategic or manoeuvring level (from the human factors case examples it appears that often the initial event is trying to avoid other road users in the interaction between road users), or are driving too fast relative to the situation with consequences at the control level, or there is a lack of an early action (inattention, distraction, fatigue, etc.). With respect to the latter, one can consider installing shoulder rumble strips or edge line profile markings to warn the driver that he/she is starting to exceed the lane. These measures appear to reduce the number of lane departures (van der Horst, de

Vos & Folles, 1997), but also may result in behavioural adaptation effects such as increased driving speeds during wet-road conditions.

- Trees along the road do not seem to influence driving behaviour that much and are apparently not considered as a serious hazard by vehicle drivers. With respect to roadside safety, therefore, trees require special attention.
- Make the roadside forgivable. Since drivers make errors and inadvertently exceed their lane, the likelihood of a collision or a rollover should be minimised and the severity of crashes that occur reduced.
- Be aware of behavioural adaptation effects. Make a shoulder such that people are able to correct their manoeuvre without inviting them to drive on it without problems (for example by providing discomfort without losing vehicle control), or provide sufficient visual guidance but not more than that to avoid increases in speed (Finnish example of reflector posts (Kallberg, 1993)).

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APPENDIX B: FORTHCOMING UK STANDARDS[1]

Passive Safety

The current Advice Note (TA89/04) states that any sign posts larger than 90 mm diameter require protection or the use of passively safe posts. Passive signs can be used in the verge, at roundabouts, at repeat collision sites, and at nosings or splitters to avoid the need for ramped ends of safety fence.

Passive posts should not be used in central reserves on gantry signs. The new Advice Note, TA 89/05 (release late November 2005) will allow lighting columns and traffic signal poles to be placed on passively safe posts, and provide some relaxation and further guidance on the use and positioning of passively safe posts.

IRRRS and Risk Assessment

The Interim Requirement for Road Restraint Systems (IRRRS) was introduced in 2002 and updated in 2004. The standard requires the use of protection where the object is located within 4.5 m of the carriageway, objects include trees with a diameter of more than 300 mm. Other issues of importance include a review of embankment height and slope, the closure of gaps in safety fence less than 50 m long, protection of lighting columns, provision of safety fence termination systems including crash cushions, and passively safe posts (see above).

From 2007 the Highways Agency is seeking to replace its current proscriptive siting criteria for impact protection, with a new risk assessment based criteria. This aims to:

- make risks and risk assessment more transparent in the Standard,
- enable designers to carry out site specific risk based design,
- minimize the need for approval of Departures from Standard by the Overseeing Organisation.

It is intended that the risk will be presented in terms of accidents per year/100km and determined by the probability of the vehicle leaving the road, the probability of the errant vehicle reaching the hazard, and the probability of injury if the hazard is reached.

If the hazard is reached, what is the likely consequence (without barrier) on the vehicle occupants and on third parties? If the risk is considered too high, can the object be moved, become passively safe, or risk reduced by using a vehicle restraint system? Designers will be provided with a database system to help them calculate the risks in each scenario.

[1] Trunk roads and motorways with a speed limit of 50 mph or more

APPENDIX C: THE ROLLOVER ACCIDENT FOR PASSENGER CARS

The rollover accident

A rollover, which is a very complex and individual event, is divided into 4 phases (Gugler et al, 2003):

1. Pre-roll phase
2. Point of no return
3. First phase of roll
4. Rolling phase

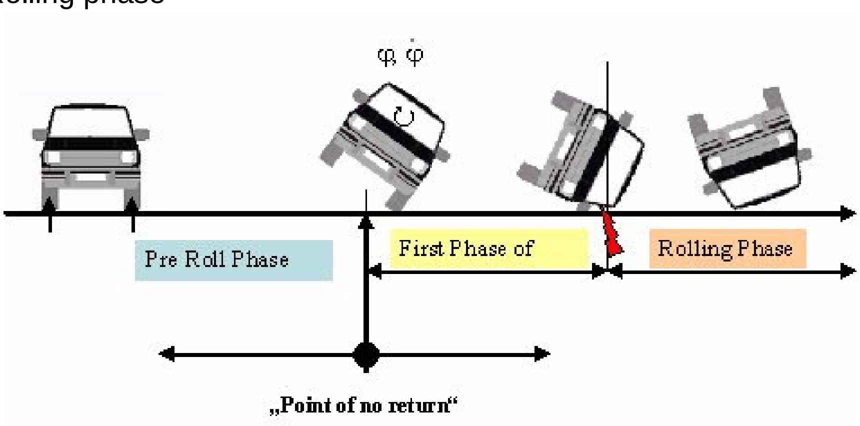
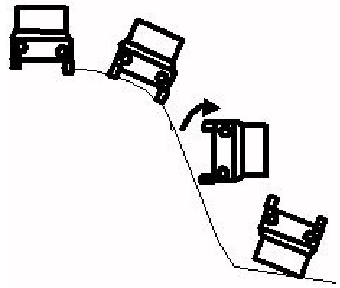


Figure 1 The Four Phases in a Rollover

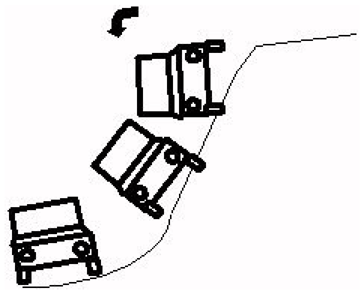
- **Pre-roll phase:** The pre-roll phase is when the vehicle is coming into a destabilized driving mode till the “point of no return” where a rollover cannot be avoided. In this phase active safety systems can be used to stabilize the vehicle and avoid exceeding the “point of no return”. The closer the vehicle comes to the “point of no return” the vehicle passive safety systems can also be activated in this phase. If possible, a severity estimation of the impending rollover should be done.
- **Point of no return:** Is a short time interval when the rollover cannot be avoided and passive safety systems have to be activated to reduce the risk of injuries to the occupants.
- **First phase of roll:** The first phase of roll starts from the “point of no return” and covers approximately the first 90 degrees of the roll angle. It ends with the first impact of the vehicle structure to the ground. The vehicle can always be in contact with the ground or loose the contact (flying phase).
- **Rolling phase:** The rolling phase is the phase from the end of the first phase of roll until the vehicle's rest position. The most important parameter for this phase is the number of rolls.

Classification of Rollovers

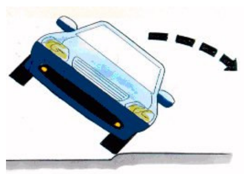
The scenarios, presented below, are based on a modification of the NHTSA-Classification (Asic, 2002) for rollover in Europe.



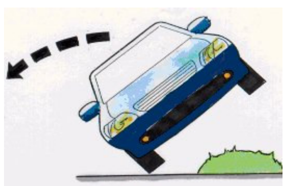
Fall-Over - Rolls downward due to negative slope



Flip-Over - Rolls downward due to positive slope

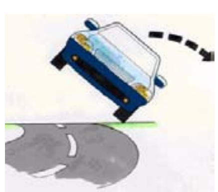


Trip-over - when the lateral motion of the vehicle is suddenly slowed or stopped inducing a rollover. The opposing force may be produced by a curb, pot-holes, or pavement dug into vehicle wheels.

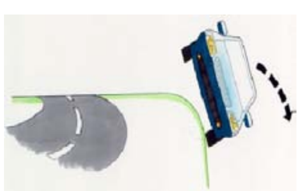


Flip-over - when vehicle is rotated along its longitudinal axis by a ramp-like object such as a turned down guardrail or the back slope of a ditch. The vehicle may be in yaw when it comes in contact with a ramp-like object.

Bounce-over - When a vehicle rebounds off a fixed object and overturns as a consequence. The rollover must occur in close proximity to the object from which it is deflected.



Turn-over - when centrifugal forces from a sharp turn or vehicle rotation are resisted by normal surface friction (most common for vehicle with higher COG.). The surface includes pavement surface and gravel, grass and dirt. There is no furrowing or gouging at the point of impact.
Note that if rotation and/or surface friction causes a trip, then the rollover is classified as a turn-over.



Fall-over - When the surface on which the vehicle is traversing slopes downward in the direction of movement of the vehicle cog. such that the cog. becomes outboard of its wheels.

Climb-over – when the vehicle climbs up and over a fixed object (e.g. guardrail, barrier) that is high enough to lift the vehicle completely off the ground. The vehicle must roll in the opposite side from which it approached the object.

Collision with another vehicle - When an impact with another vehicle causes the rollover. The rollover must be the immediate result of the impact between the vehicles. For example, this could occur at an intersection where a vehicle is struck in the side and the momentum of the struck vehicle results in a rollover.

End-over-end - When a vehicle rolls primarily around its lateral axis.

The Categories of Rollovers on the Road and in the Roadside Area (Case Study Based Analysis) (Gugler et al, 2003)

Kinematic parameters like angle and roll rate were investigated in addition to tire forces and velocity for the accidents collected in the Rollover project. The following categories has shown to be relevant in Europe see Figure 2 for distribution

1 Impact induced rollovers
   1.1 $\Delta v > 30$ km/h
   1.2 $\Delta v < 30$ km/h
2 Ramp-like object induced rollovers
3 Skidding & Yawing
   3.1 Trip induced rollover
   3.2 Turning and rollover
4 Others

The different scenarios focus on causes for the inducement for the roll. It has to be stated that also the roll trajectory is influenced by the road infrastructure. The car can hit any objects off the road which intrudes and/or deforms the passenger compartment or lead to high acceleration influencing the occupant movement. Different analysis showed that the contact of the occupant to a vehicle part during its intrusion is critical for severe injuries (e.g. head is in contact with roof when the roof is intruded by an impact of the roof with the ground).

Because the rollover event is a high complex and individual event the focus is set to the causes of rollover to avoid the roll (before the "point of no return") rather than the rolling phase.

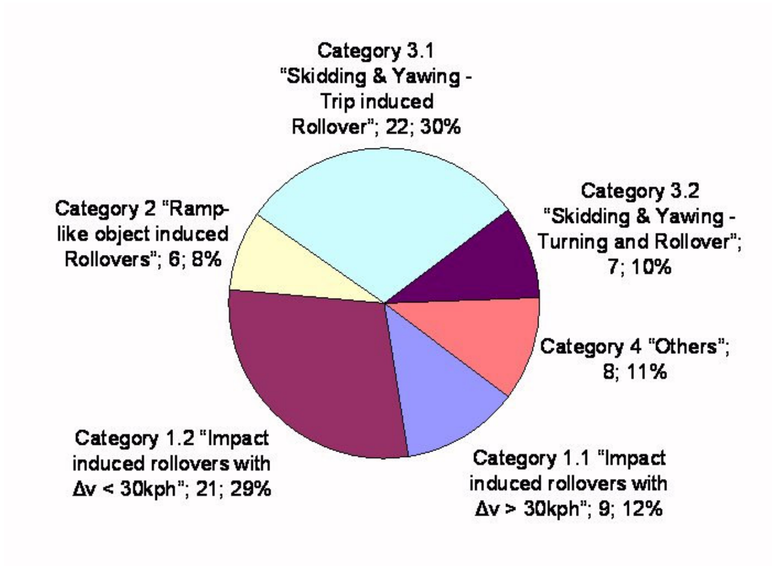


Figure 2 Distribution of Rollover Scenarios (Gugler et. al, 2003)

Category 1.1 "Impact induced rollovers with Δv > 30 km/h"

The change in vehicle velocity due to an impact is caused by:

- an obstacle which is part of the road like curbs, drain cover etc.
- an obstacle which is part of the landscape like rocks, trees etc.
- another vehicle.

Regarding injuries to occupants the inducing impact itself is assumed to be more severe than the rollover caused by the impact.

Category 1.2 "Impact induced rollovers with Δv < 30 km/h"

The causes for this scenario are the same as for category 1.1. After analysing the accidents it can be assumed that the severe event is the rolling phase itself and not the inducing impact (Δv < 30 km/h). Therefore each roadside infrastructure influencing the intrusion or deceleration ("hard contacts") is critical as well as the condition of the vehicle itself (roof strength).

Category 2 "Ramp-like object induced rollovers"

The following mechanisms can cause an accident in this category:

- The vehicle is launched of an object acting like a ramp (e.g. safety barrier termination with ramped end, concrete element, cut slopes) or be induced by the overrun of another vehicle (hood of the vehicle is acting like a ramp). These are so called active ramps because both the geometry and the velocity of the vehicle are inducing the rollover.
- The vehicle is driving on an embankment and the rollover is induced by the high gradient (often downward). This is a so called passive ramp because the rollover is induced by the geometry of the vehicle (wheel base, centre of gravity) and the gravity.

Category 3.1 "Trip induced rollover"

In this category, which is the most common type, the rollover is induced by tripping of the vehicle. The tripping is caused by increasing lateral forces due to increasing of friction which can be caused by the tyres grabbing into soft soil (e.g. embankments) or contact of the rim with the road surface (defect tyre).

Category 3.2 "Vehicle dynamic induced rollover"

When a vehicle comes into unstable driving mode caused by the driving manoeuvre the rollover is induced by the vehicle dynamics. The causes for this type or rollover are:

- Driving manoeuvre like the elk test leads to oscillations of the vehicle. The driving manoeuvre can be caused by the course of the road in combination with speeding (e.g. driving to fast into a round about) or an evasive driving manoeuvre (e.g. evasive a obstacle on the road).
- The suspension of the vehicle does not damp the oscillations.

Category 4 "Others"

This category summarises all events which cannot be related to the abovementioned categories. These are events like falling down by crashing through a guardrail or a jumping down an embankment etc. A big contributor to this category is the geometrical properties of the road.

References

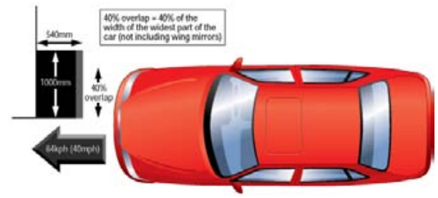
Gugler, J. et al: Rollover scenarios for Europe, Task 2.4 report, Graz University of Technology, European Community – R&TD-Project – 5th Framework-Programme "Growth" – Project "Rollover" G3RD-CT-2002-00802; 2003

Asic, S.: Field Conditions Definitions - NASS-CDS Classification, Presentation, Delphi, 2002, European Community – R&TD-Project – 5th Framework-Programme "Growth" – Project "Rollover" G3RD-CT-2002-00802; 2002

APPENDIX D: VEHICLE AND ROAD RESTRAINT SYSTEM CRASH TEST INFORMATION

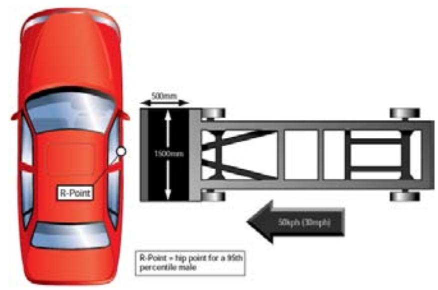
FRONT
European New Car Assessment Program (EuroNCAP)

Since 1997 frontal impact against deformable barrier (40 % overlap) with 64 kph



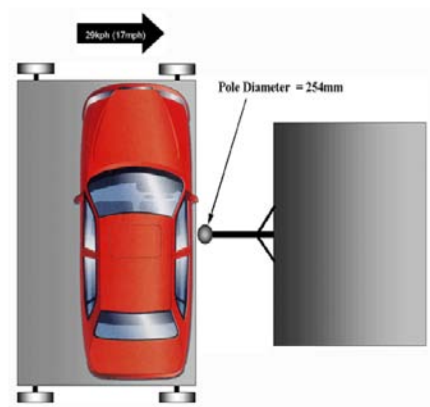
SIDE
European New Car Assessment Program (EuroNCAP)

since 1999 side impact, right angle with 50 kph



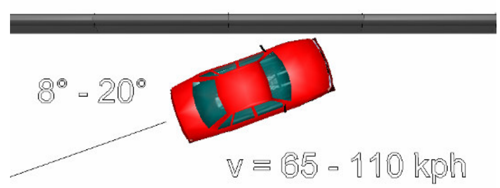
POLE
European New Car Assessment Program (EuroNCAP)

Sideways at 29 kph into a rigid pole (diameter 254 mm).



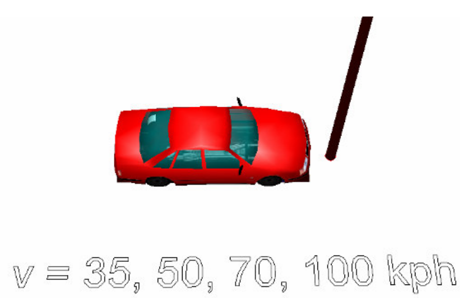
EN 1317
Road restraint systems

7 vehicle classes, impact velocity between 65 and 110 kph; impact angle between 8 and 20°



EN 12767
Passive safety of support structures for road equipment

impact velocity 35, 50 ,70 and 100 kph; Definition of 3 energy absorbing level



Frontal impact test

The frontal impact test simulates a collision with another structure that overlaps 40% of the car's bonnet on the driver's side. The structure is made out of a deformable mesh with a stiffness representative of a car bonnet, and impacts the vehicle at 40mph. The purpose of this test is to simulate a partially offset collision between the tested vehicle and an oncoming vehicle and this type of collision accounts for a large percentage of all car crashes on the road. It is therefore important that a car's ability to withstand this type of impact is tested.

Side impact test

The side impact test represents another important simulation of an accident that commonly occurs in the real world. A deformable crash barrier, approximately the width of the bonnet of a car, is impacted into the side of the tested vehicle.

For side and frontal test the possible impact velocity at the end of the clear zone is acceptable under the presumption that the hit object dissipates energy, otherwise the loads for the occupants can not be compared to the crash tests.

Pole test

A pole test is a representation of what would happen if the vehicle impacted with a thin pole (e.g. a road sign or tree). The main difference between the pole test and the other tests is that due to the pole being much thinner, the energy of the collision concentrated in a much smaller area and the crush depth measured on the vehicle is greater than in other tests. Without appropriate airbags and car designs, the type of accident that this represents can result in a severe injury.