IRDES

Forgiving Roadside Design Guide

Deliverable Nr 3

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Executive summary

In the recent years several projects have been conducted to produce guidelines to design forgiving roadsides worldwide and several national standards have been produced but different approaches are often proposed. The final results of Trans-National Research Projects, aimed at identifying harmonised solutions, are often extremely scientific but not practical and result in a lack of applicability.

Based on the results of WP1 and WP2 and together with an additional literature review, this WP of IRDES produced a practical guideline that, thanks to the contribution of ANAS and to the interaction with Road Administrations and Operators (through the Webinars that have been organized and through the synergy with the TG on Road safety of CEDR), can be applied in practice in road safety design projects. The different proposed interventions are linked to the potential effectiveness estimated and defined in WP2 and in other relevant literature in order to allow the user to perform cost-effectiveness evaluation before planning a specific treatment.

One of the issues has been the harmonisation of different existing standards or the identification of underlying reasons for different existing solutions for the same treatments in order to allow the user to select the optimal treatment and to properly assess its effectiveness.

The roadside features for which the IRDES design guideline has been developed are:

- Barrier terminals
- Shoulder rumble strips
- Forgiving support structures for road equipment
- Shoulder width.

Each feature is analysed in a separate section of the guideline providing:

- Introduction
- Design criteria;
- Assessment of effectiveness;
- Case studies/Examples;
- Key references.

Additional roadside features have been analysed in D1 (Annex 1) and in D2 (Annex 2). In the latter the potential safety effects of applying different treatments (hard shoulders, soft shoulders, crash barriers) in sharp bends have been analysed and a procedure to perform effectiveness evaluations on specific applications has been proposed.

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Abbreviations

Abbreviation	Definition
AADT	Annual average daily traffic
AASHTO	American Association of State and Highway Transportation Officials
ADT	Average Daily Traffic
CEDR	Conference of European Directors of Roads or Conférence Européenne des Directeurs des Routes
ERA-NET	European Research Area Network
IRDES	Improving Roadside Design to Forgive Human Errors
HSM	Highway Safety Manual
NCHRP	National Cooperative Highway Research Programme
PTW	Powered Two-Wheeler
RISER	Roadside Infrastructure for Safer European Roads
ROR	Run-off-road
RVS	Richtlinien und Vorschriften für das Straßenwesen
SVA	Single vehicle accident
TG	Technical Group
TRB	Transportation Research Board

1 Introduction

IRDES (Improving Roadside Design to Forgive Human Errors) is a research project of the cross-border funded joint research programme “ENR SRO1 – Safety at the Heart of Road Design”, which is a trans-national joint research programme that was initiated by “ERA-NET ROAD – Coordination and Implementation of Road Research in Europe” (ENR), a Coordination Action in the 6th Framework Programme of the EC. The funding partners of this cross-border funded Joint Research Programme are the National Road Administrations (NRA) of Austria, Belgium, Finland, Hungary, Germany, Ireland, Netherlands, Norway, Slovenia, Sweden and United Kingdom.

1.1 Motivation and goals

Each year 43,000 persons are fatally injured in Europe due to road accidents. The RISER project has shown that even though 10 percent of all accidents are single vehicle accidents (typically run-off-road (ROR) accidents) the rate of these events increases to 45 percent when only fatal accidents are considered [1]. One of the key issues of this high ROR fatality rate is to be found in the design of the roadsides that are often “unforgiving”. CEDR has identified the design of forgiving roads as one of the top priorities within the Strategic Work Plan. For this reason, a specific Team dealing with Forgiving Roadsides has been established within the Technical Group (TG) on Road Safety of CEDR.

A number of different studies have been conducted in recent years to design roadsides to forgive human errors, but there is still a need for:

- A practical and uniform guideline that allows the road designer to improve the forgivingness of the roadside
- A practical tool for assessing (in a quantitative manner) the effectiveness of applying a given roadside treatment

The aim of the IRDES project is to produce these two outputs with specific reference to a well identified set of roadside features.

1.2 Methodology

The project team of IRDES created the following work plan:

WP0: Coordination and Management

WP1: Collection and harmonization of studies and standards on roadside design

WP2: Assessment of Roadside Intervention Effectiveness

WP3: Production of a Roadside Design Guide

WP4: Pilot Project

WP5: Organization of Workshops and Round Tables

Based on the results of the WP1 and WP2, as well as taking into account the inputs gathered from the different potentially interested users of the roadside design guidelines during two Webinar workshops, organised within the IRDES project, a guideline has been developed to assist the user in designing properly selected roadside treatment and to evaluate its effectiveness in terms of potential crash reductions. To provide the user with the detailed information on the effectiveness assessment studies conducted in the IRDES WP2, the output of this WP is included in the guideline as an annex, as well as the result of the literature review (WP1) which covers a much wider variety of roadside features than the WP3 guideline itself.

The roadside features for which the IRDES design guideline has been developed are:

- Barrier terminals;
- Shoulder rumble strips;
- Forgiving support structures for road equipment;
- Shoulder width;

Each feature will be analysed in a separate section of the guideline.

Additional roadside features have been analysed in D1 (Annex 1) and in D2 (Annex 2). In the latter the potential safety effects of applying different treatments (hard shoulders, soft shoulders, crash barriers) in sharp bends have been analysed and a procedure to perform effectiveness evaluations on specific applications has been proposed.

1.3 Definition of roadside

According to the RISER project [1], a roadside is defined as the area beyond the edge line of the carriageway. There are different views in literature on which road elements are part of the roadside or not. In IRDES Project, the median is considered as roadside, since it defines the area between a divided roadway. Therefore, all elements located on the median are considered as roadside elements as well. Figure 1 depicts a roadway cross section (cut and embankment section) including some roadside elements. In this specific figure, the roadside can be seen as the area beyond the traffic lanes (or carriageway). The shoulders are thus part of the roadside, since the lane markings define the boundaries. The slopes, the clear zones (also called safety zones) or the tree are examples of roadside features that are discussed in detail in Annex 1.

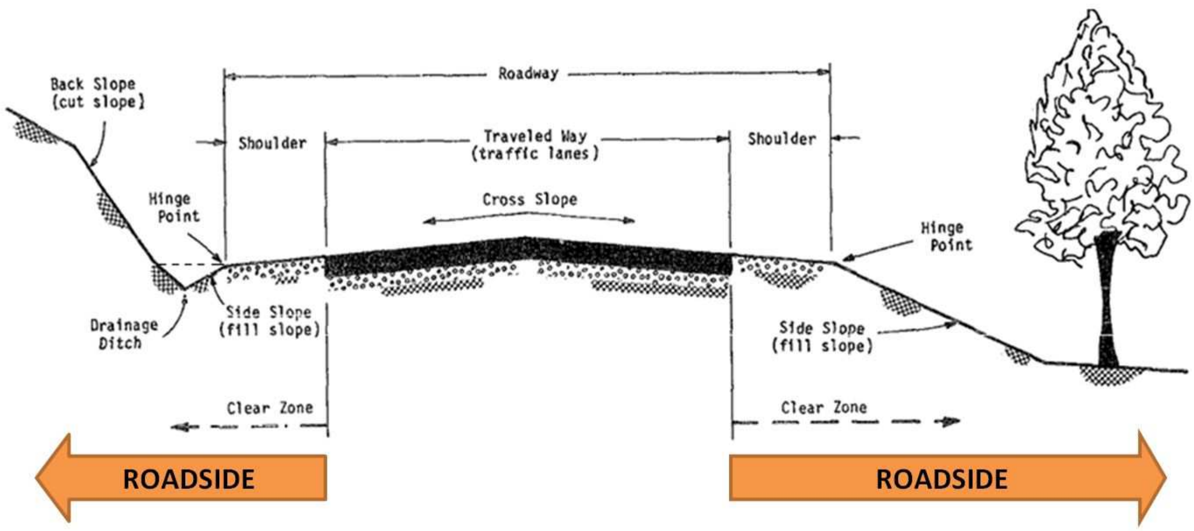


Figure 1: Roadway cross section with examples for roadsides with clear zones [2]

1.4 The IRDES Design Guideline within the framework or ERANET SRO1 Projects.

IRDES Project is one of the 5 projects funded within the ENR SRO1 programme "Safety at the Heart of Road Design" aimed at improving road safety by increasing the awareness and acceptance to implement joint road safety solutions following the concepts of **self-explaining roads** and **forgiving roadsides** taking human factors and human tolerance into consideration.

The IRDES project results should therefore be seen in combination with the results of the other 4 projects in order to define integrated safety programmes that aim at both having self explaining and forgiving roads and the interrelation between self-explaining roads and forgiving roadsides should be considered in the design process.

1.4.1 Research projects in ERANET SRO1 Programme

The main objectives of the other 4 projects in the ERANET SRO1 Programme are synthesized below.

ERASER (www.kfv.at/eraser**)**

ERASER aimed to bridge the gap between fundamental knowledge concerning self-explaining roads and the practical, hands-on knowledge that road authorities require to make their roads safer by applying the concept of self-explaining roads. The starting point was the relevant fundamental knowledge that exists on different approaches to self-explaining roads, which was compared and evaluated. Subsequently, it was demonstrated how to assess road users' ability to recognise specific categories of roads and understand their context. And finally, it was shown how to implement the results in the development of a decision support tool for road authorities. This tool is essentially a checklist road authorities can use to determine the extent to which their roads are self-explaining, but also contains information concerning design elements that can help to make roads more self-explaining.

SPACE (http://www.fehrl.org/space)

SPACE will identify solutions that offer the greatest potential safety gains through a state of the art review, international expert panel review, interactive visual tools and driving simulator experiment. This will lead to tools that can identify unsafe or non-explaining areas of the network and that are able to estimate the potential safety benefits of the road safety measure. These tools will register change in driving behaviour and also explain why changes occur. The developed tools will be used for evaluation of different measures aiming to find a self-explaining road. Other aims are to determine the speed adaption and situational awareness benefits of different self-explaining design measures. A comparison will be done of different approaches leading to recommended common strategies

RISMET (http://rismet.swov.nl)

The project aims at developing suitable road safety engineering evaluation tools that will support the aims of the "improvement of road safety through an increased awareness and acceptance to implement joint road safety solutions" based on the concepts of self explaining roads (SER) and with just consideration of human factors and tolerances. These evaluation tools allow the easy identification of both unsafe (from accidents or related indicators) and potentially unsafe (from design and other criteria) locations in a road network. With such evaluation tools estimates of potential benefits at the local and the network level can be calculated and potential effects on aspects such as driver behaviour can be estimated. Since evaluation tools rely on good quality data, RISMET aims at reviewing available data sources for effective road infrastructure safety management in EU-countries, linked to a quick scan and assessment of current practices.

EuRSI (http://na-srv-1dv.nuim.ie/eursi/)

The main goal of the European Road Safety Inspection (EuRSI) project was to investigate new approaches to identifying and explaining risk, within the context of a RSI, along rural road networks in Europe. This project focused on three main objectives: to explore and develop new approaches to mapping route corridor using LiDAR MMS technology, review risk assessment within the context of a RSI and finally build and test a prototype risk assessment toolset that could help road authorities highlight and understand risk along rural roadways. Some of the key outputs of this project include a better insight to the capabilities of LiDAR mapping technology, the short-comings of contemporary risk assessment methodologies and finally the need to link key dynamic and static road factors when identifying and explaining risk along roadway following a RSI.

More detailed information on the ERANET SRO1 programme can be found at http://www.eranetroad.org/index.php?option=com_content&view=article&id=74&Itemid=74.

1.4.2 Forgiving vs. self-explaining

Forgiving and self-explaining roads are two different concepts of road design, which aim at reducing the number of accidents on the whole road network. The project IRDES only deals with forgiving roadsides. However, the term “self-explaining” needs to be defined in order to differentiate it from the term “forgiving”.

According to [3], self-explaining roads are based on the idea that appropriate speed or driving behaviour can be induced by the road layout itself. They therefore reduce the need for speed limits or warning signs. It is generally known that multiple road signs in complex traffic situations can lead to an information overload and an increasing risk of driving errors. Herrstedt [4] writes that a safe infrastructure depends on a road-user-adapted design of different road elements such as markings, signs, geometry, equipment, lighting, road surface, management of traffic and speed, traffic laws etc. The idea behind self-explaining roads is to design the road according to an optimal combination of these road elements.

In synthesis: self-explaining roads aim at preventing driving errors, while forgiving roads minimize their consequences. The first priority of forgiving roadsides is to reduce the consequences of an accident caused by driving errors, vehicle malfunctions or bad roadway conditions. It must be focused on treatments to bring errant vehicles back onto the lane to reduce injury or fatal run-off-road accidents. If the vehicle still hits a road element, the second priority is to reduce the severity of the crash. In other words, the roadside should forgive the driver for their error by reducing the severity of run-off-road accidents (see Annex 1).

Forgiving roads depend on how the roadside is designed and equipped. But the roadside is also a component of the driver’s field of view which governs the driver’s behaviour and according to PIARC Human Factors Guidelines [5] a well designed field of view contributes to enhance road safety.

Therefore, well designed roadsides contribute to achieve both self explaining and forgiving roads.

The requirements to design forgiving roadsides which will be given in this document have to be combined with the requirements to design self explaining roads, which are the focus of the ERASER and SPACE ERANET projects. A comprehensive compatibility analysis is therefore necessary prior to finalize the design of the roadsides.

2 Barriers terminals

2.1 Introduction

Safety barriers are forgiving roadside treatments designed to shield hazardous obstacles and/or to prevent vehicles from running off the roadway. However, the ends or transitions between two different types of barriers can result in a hazardous roadside objects. Safety barrier ends are considered hazardous when the termination is not properly anchored or ramped down in the ground, or when it does not flare away from the carriageway [6]. The RISER database contains 41 accidents where barriers were the only obstacles involved. In 14 cases (i.e. 34.1 percent), the termination of the barrier was hit. Crashes with “unforgiving” safety barrier ends often result in a penetration of the passenger compartment.

This section of the IRDES forgiving Roadside Design Guide is aimed at providing practical guidelines on how to properly design a barrier terminal and how to evaluate the effectiveness of replacing unprotected terminals with crashworthy terminals.

2.2 Design criteria

2.2.1 Unprotected vs. Crashworthy terminals

An unprotected terminal (also called “exposed” terminal) is a barrier end termination aligned parallel (or close to parallel) to the travelled lane that is within the roadside clear zone (Figure 2) and that, in case of head-on impact, can stop the vehicle abruptly with barrier elements that can penetrate the vehicle itself or the vehicle can roll-over after impacting against the terminal (Figure 3). Crashworthy terminals are barriers end treatments that are aimed at either redirect the vehicle in the carriageway or safely decelerating the vehicle after the head-on impact with the terminals nose.

Figure 2: Unprotected (or “exposed”) terminals

Figure 3: Head on impact against an unprotected terminal [7]

2.2.2 Energy-absorbing vs. Non energy absorbing terminals

Crashworthy terminals can be designed to redirect vehicles back in the carriageway or to stop them immediately, so that they cannot pass through the barrier. The first type of terminals is called "flared" as the alignment of the terminal diverges from the alignment of the roadway edge (Figure 4). The second type is called "tangent" and the alignment of the terminal is parallel to the roadway edge (Figure 5).Tangent terminals are aimed at stopping the vehicle and have to be treated as energy-absorbing devices to be tested according to ENV 1317-4 (which will be superseded by EN1317-7 standard, as detailed in chapter 2.5.1). Flared terminals are usually not designed to dissipate significant amounts of the kinetic energy in a head-on crash and are therefore considered non-energy-absorbing devices even though there are limited products (mainly in the US market) that are flared and energy-absorbing.

Figure 4: Flared terminal [8]

Figure 5: Tangent terminal [1]

Tangent terminals may be installed with a 0.3 m to 0.6 m offset from the barrier aligment (over the entire terminal length) to minimize hits against the nose. Flared terminals generally require a 1.2 m offset although some designs have been successfully tested with offsets less than 0.9 m. Because the flared terminal is located further from the travelled way, head-on impacts are less likely and the vehicle is more likely redirected in the carriageway without sudden decelerations.

On the other hand in crash tests with non-energy-absorbing terminals unbraked vehicles have travelled more than 75 m behind and parallel to the guardrail installation or along the top of the barrier when struck head-on at high speeds.

Energy-absorbing terminals have demonstrated their ability to stop impacting vehicles in relatively short distances (usually 15 m or less depending on the type of terminal) in high-speed head-on impacts on the terminal nose but if they are tangent the probability of hitting the nose is higher than in the flared ones and the impact severity on the occupants can be extremely high when the vehicle hits the nose sliding with a yaw angle.

The decision to use either an energy-absorbing terminal or a non-energy-absorbing terminal should therefore be based on the likelihood of a near end-on impact and the nature of the recovery area immediately behind and beyond the terminal. When the barrier length-of-need (see chapter 2.2.5) is properly defined and guaranteed and the terminal is therefore placed in an area where there is no need for a safety barrier protection it is unlikely that a vehicle will reach the primary shielded object after an end-on impact regardless of the terminal type selected. Therefore if the terrain beyond the terminal and immediately behind the barrier is safely traversable a flared terminal should be preferred.

If, for local constraints, the proper length of need cannot be guaranteed or if the terrain beyond the terminal and immediately behind the barrier is not safely traversable, an energy-absorbing terminal is recommended.

Flared non-energy-absorbing terminals

The advantage using flared non-energy-absorbing terminals is that there are usually non-proprietary terminals that essentially can be installed as a termination of any W-beam steel barrier. The most commonly flared non-energy-absorbing terminals are the Eccentric Loader Terminal (ELT) and the Modified Eccentric Loader Terminal (MELT).

The ELT is a non-proprietary system that has a flared design with the end consisting of a fabricated steel lever nose inside a section of corrugated steel pipe (Figure 6).

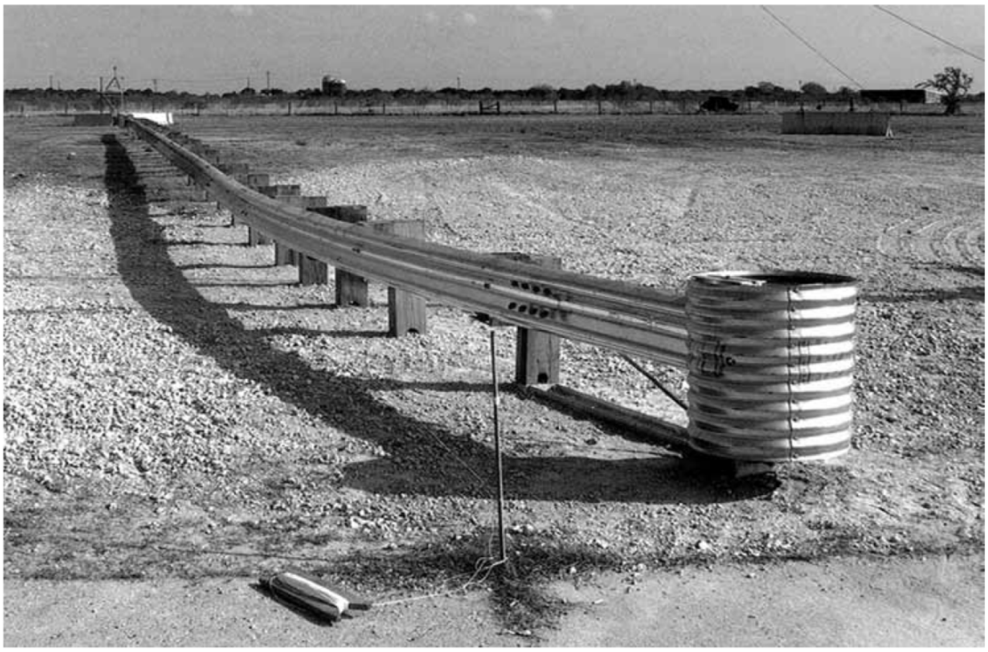


Figure 6: Eccentric Loader Terminal (ELT) non proprietary terminal [9]

The ELT is 11.4 m long and is designed with a curved flare that provides a 1.2 m offset in the end post. This curvature is critical for proper impact performance. The rail elements should be field-bent, while all posts should be wood. The length-of-need point which means the point after an errant vehicle should not gate the terminal (cfr. § 2.2.5) is located at 3.81 m from the end of the terminal.

The MELT is a modified version of the ELT and several design configurations are available worldwide with the name MELT or WAMELT or similar. The version described in the AASHTO Roadside Design Guide (Figure 7, [9]) has been tested to NCHRP Report 350 TL-2 for use on lower-speed roadways. This terminal is 11.4 m long and is designed with a parabolic flare that provides a 1.2-m offset to the end post and the length-of-need point is located at 3.8 m from the end of the terminal.

Several other MELT terminals, such as the MELT used in Oregon – USA [10] and the WAMELT used in Australia (Figure 8 , [11]) are tested in TL-3 at a test speed of 100 km/h and can therefore be considered as equivalent to a P3 terminal according to ENV1317-4 (see chapter 2.5.1) even though technically not tested according to the CEN standards.

Figure 7: Modified Eccentric Loader Terminal (MELT) non proprietary terminal for level TL-2 [9]

Drawing:

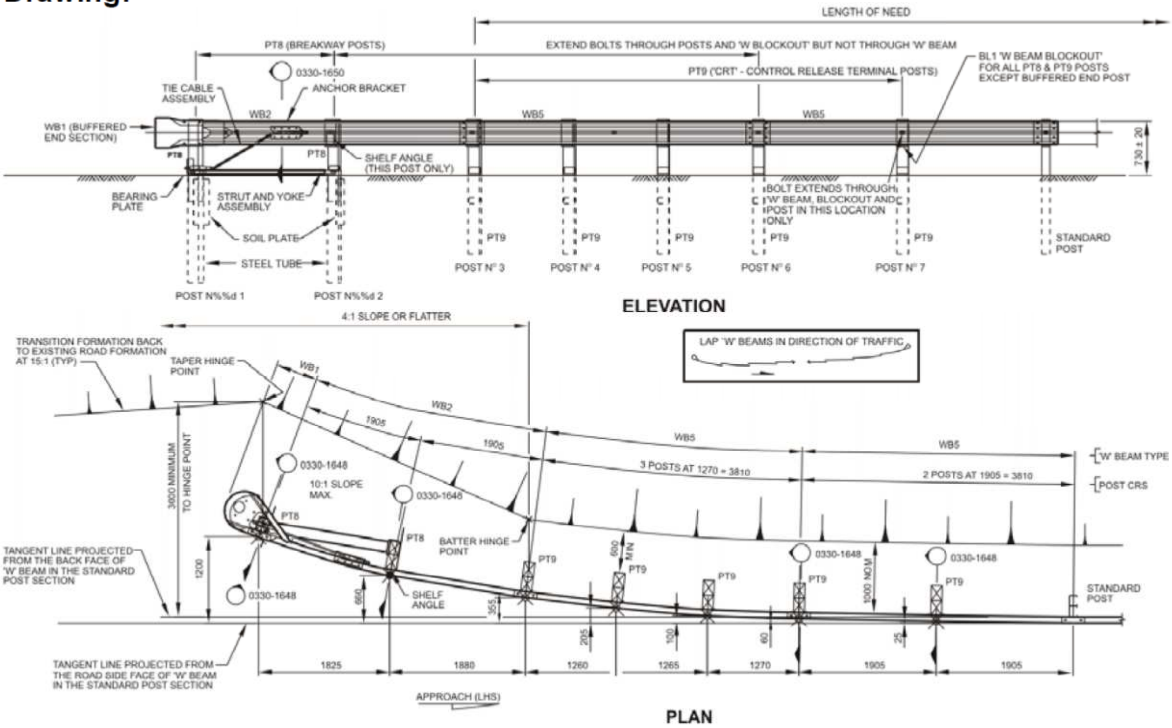


Figure 8: Australian Modified Eccentric Loader Terminal (WAMELT) non proprietary terminal for level TL-3 [11]

In several countries flared non-energy-absorbing terminals are accepted based on design criteria with no crash test requirements (as allowed also in the current draft of the prEN1317-7) but they are essentially based on a very similar approach as in the MELT terminals, as shown in the example of Figure 9, often applied in Italian motorways new barriers design. In other countries (such as in Germany) only devices tested according to ENV1317-4 are allowed.

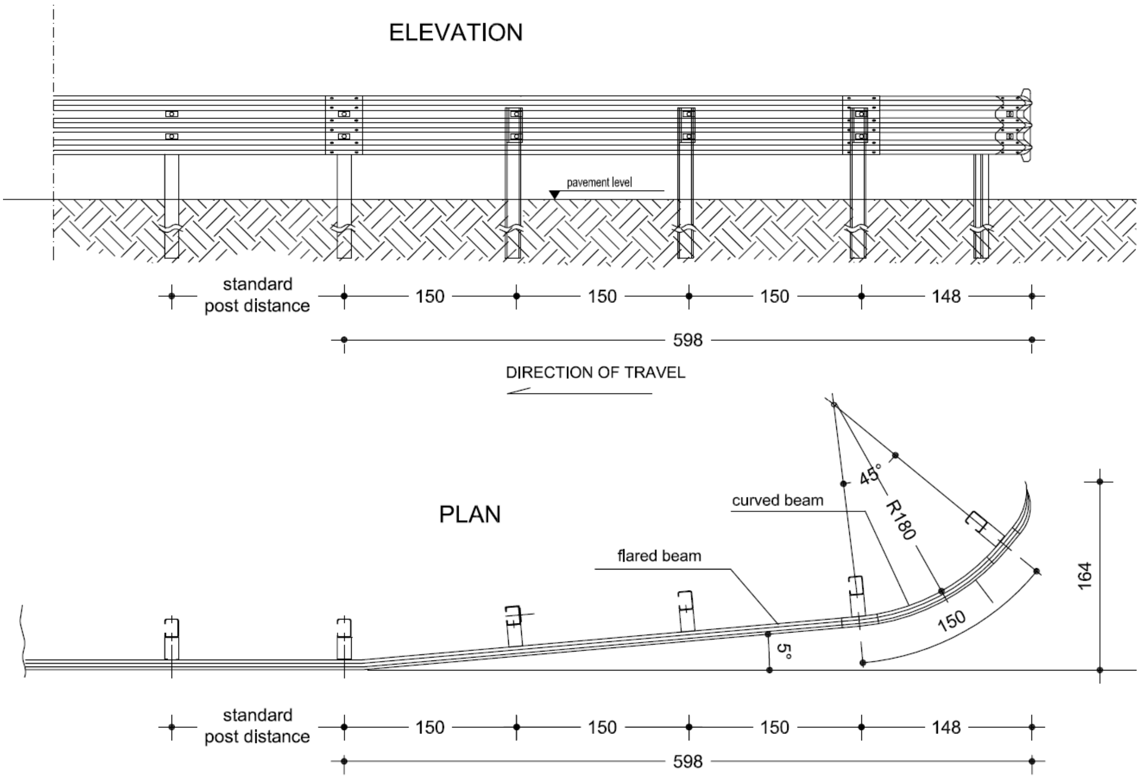


Figure 9: flared terminal in use in most of the new installations on Italian motorways

To evaluate the effectiveness type of this type of terminals an assessment of the crashworthiness by either a set of full scale crash test or by numerical simulations is strongly recommended.

Turn-down terminals (Figure 10, left) o flared-degraded terminals (Figure 10, right) which have been commonly used in the last years in several counties are now often replaced in new designs by flared terminals with no degradation as the longitudinal slide that arises from the degradation to the ground can lead to an overriding of the barrier. It should be noted anyhow that the different studies conducted on in service terminals were not able to show such effect based on the analysis of events occurred against turn-down terminals. Flared-degraded terminals, on the other hand, could work properly only if the degraded end buried in the ground if far enough from the travelled lane.

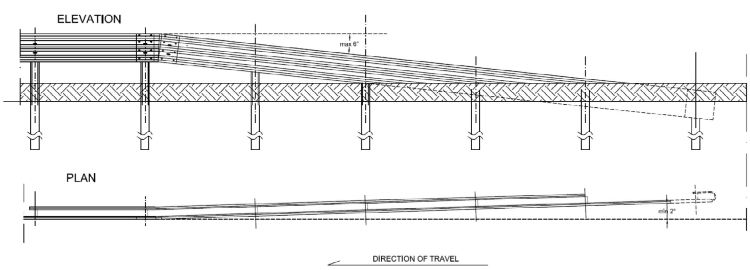



Figure 10: Turn-down terminal (left) and flared-degraded terminal (right)

In two lane roads terminals on both sides of the barrier should be crashworthy as a head-on impact could occur on both ends while in one way roads the leading edge of the barrier could be ended with simply degraded terminal (not flared) or even be left unprotected.

In Germany simply degraded terminals (not flared) are allowed on single direction two lane roads and have been tested according to ENV1317-2 in class P2U (12-m Regelabsenkung).

Tangent energy-absorbing terminals

Most of the energy-absorbing terminals are proprietary devices and, to be used in the EU, should be tested according to ENV1317-4 [12] (now) and EN1317-7 when this will be officially released and published by CEN (see chapter 2.5.1). One of the very few non-proprietary energy-absorbing terminal is the Midwest Guardrail System (MGS) Terminal (Figure 11) but this has been tested in the USA according to NCHRP350 standard and to be used in the EU should be tested according to the ENV1317-4.

Figure 11: Midwest non proprietary energy-absorption terminal

When using an energy-absorbing terminal in the EU, a performance class should be defined according to ENV 1317-4 as indicated in chapter 2.5.1. Some national standards provide indications of the minimum performance class to be applied as a function of the posted speed limit. In Table 1 the minimum performance classes required by the Italian Standard on Safety Barriers [13] are shown. These requirements could be used as guidelines where no national requirements are given.

Table 1. Energy-absorbing terminals: minimum performance classes according to ENV 1317-4 required by the Italian Standard [13]

Posted speed limit (V)	**Minimum performance class**
V ≥ 130 km/h	P3
90 km /h ≤ V < 130 km/h	P2
V < 90 km/h	P1

The German standard [14] requires that all the upstream (start) and downstream (end) terminals are all tested according to ENV1317-4 in class P2 specifying also that:

- For single carriageway bi-directional two lane roads (one lane per direction) P2A devices have to be used (with the “start” and “end” terminal acting in both directions of travel);
- For mono-directional two lane roads P2U devices have to be used (with the “start” and “end” terminal acting only in the direction of travel).

When using an energy-absorbing terminal it is essential to check that the terminal being considered is compatible with the barrier system. The terminals are tested according to ENV 1317-4 connected to a specific longitudinal barrier which can affect the overall behaviour of the terminal. In using the terminal with a different barrier the designer has to check it’s compatibility in order to have the same performance of the system on site.

2.2.3 Buried in backslope terminals

If the barrier termination is located in a section in cut a buried in backslope terminal could be adopted (Figure 12).

According to the AASHTO Roadside Design Guide [9] this system provides full shielding of the identified hazard, eliminates the possibility of any end-on impact with the terminal, and minimizes the likelihood of the vehicle passing behind the rail if designed according to the following criteria:

- The steepness of the slope that covers the end of the barrier should be nearly vertical, such as 1V:2H, in which the slope effectively becomes an extension of the barrier face and a motorist cannot physically get behind the terminal. The length-of-need begins at the point where the installation crosses the ditch bottom;
- If there is a foreslope between the carriageway and the backslope the buried-in-backslope design can still be applied if the foreslope is lower than 1V:4H. In these cases the height of the W-beam rail should be held constant in relation to the roadway shoulder elevation until the barrier crosses the ditch bottom. When the distance from the ground to the bottom of the W-beam exceeds approximately 460 mm a rail should be added below the W-beam to minimize the potential for wheel snag on the support posts.

When these conditions are not met a crashworthiness terminal, either energy-absorbing or non-energy-absorbing, should be installed.

Figure 12: Buried in backslope terminal [1]

2.2.4 Medians

Barriers terminations in medians are always extremely critical and should be avoided as much as possible by using, for instance, removable barriers in median getaways. If a barrier termination is needed (for instance where a single carriageway road is split in a dual carriageway with a barrier in the median) this should always be a tangent energy-absorbing terminal but it has to be designed specifically for medians and tested also for impacts in the rear side (position 5 kg B) according to ENV1317-4 [12]. This means that the device has to be classified for use in location “A” (ALL: to be hit both upstream and downstream) according to ENV1317-4. Terminals tested only for location “U” or “D” (see chapter 2.5.1) cannot be applied in medians. If possible the terminal should be symmetrical as lateral hits can occur on both sides.

In addition the terminal behaviour during the crash should not lead to having loose ends in the carriageway opposite to the direction of travel of the errant vehicle.

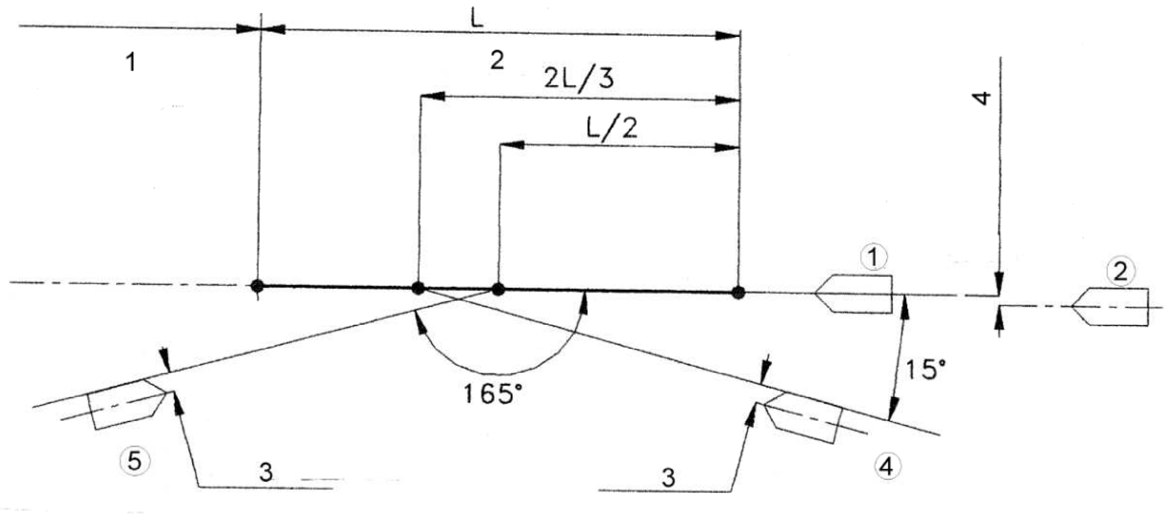


Figure 13: test position for tangent terminals according to ENV 1317-4 [12]

2.2.5 Length of need

For angled impacts of 15 degrees or higher at the first post, all W-beam terminals perform about the same and impacting vehicles will gate or pass through the terminal and travel behind and beyond it until they are stopped safely (Figure 14).

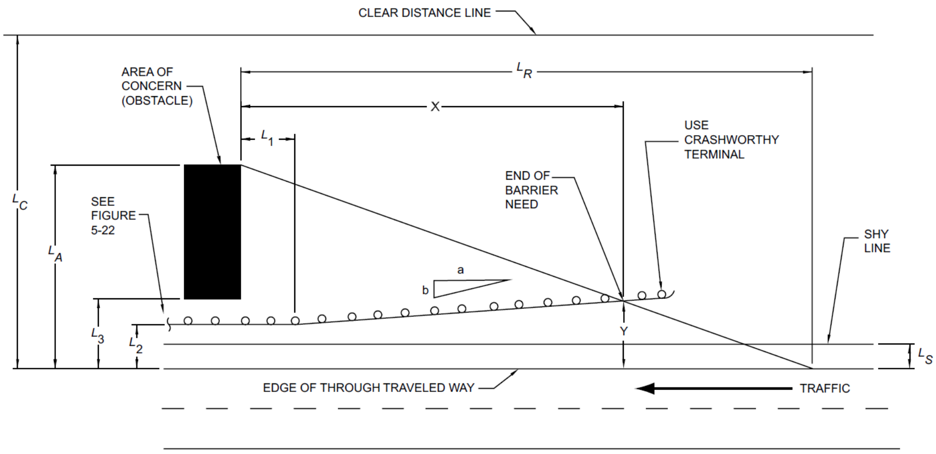
Figure 14: Result of a hit against the first few posts of a terminal [1]

For each terminal the “length of need” point, which means the point after which the longitudinal barrier can be considered capable of offering the full strength, has to be given by the manufactures. It should be noted anyhow that if the terminal is not designed to offer also “anchorage” to the barrier the length of need point could be downstream from the end of the terminal.

The location of the “length of need” point with respect to the first section that needs the barriers protection (either an obstacle or the beginning of a bridge or any other hazardous location) is a key issue in roadside design.

According to the AASHTO Roadside Design Guide the length of need can be determined as a function of the roadway design speed and of the average daily traffic (Fig. 15). According to the RISER Guidelines the length of need can be defined with reference to a vehicle running off the road with an angle α=5° (Fig. 16). This assumption leads to values similar to those of the AASHTO Roadside Design Guide for almost any obstacle offset for low speed (50-60 km/h) low volume roads (up to 5000 vehicles/day). For highly trafficked or high speed roads the 5° angle could lead to underestimate the proper length of need and a site specific evaluation is recommended.

The length of need as defined above is aimed only at avoiding the crash of a passenger car against the obstacle and might not be sufficient to provide the proper anchorage to the barrier when hit by a heavy vehicle.



Design Speed (km/h)	Runout Length (L_R) Given Traffic Volume (ADT), (m)			
	Over 10,000 veh/day	5,000 to 10,000 veh/day	1,000 to 5,000 veh/day	Under 1,000 veh/day
130	143	131	116	101
110	110	101	88	76
100	91	76	64	61
80	70	58	49	46
60	49	40	34	30
50	34	27	24	21

Figure 15: definition of the length of need (X) according to the AASHTO Roadside Design Guide [9]

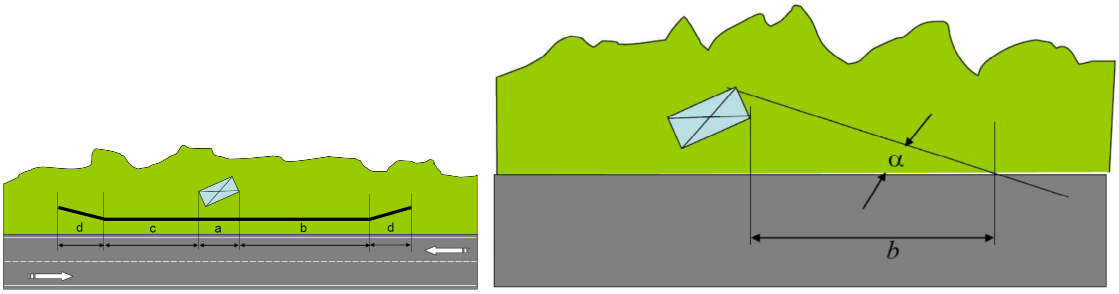


Figure 16: definition of the length of need (b) according to the RISER Guidelines [1]

2.2.6 Design of terminals in proximity of driveways

When a barrier termination is located in proximity of a driveway the usual terminal configuration might be not applicable and specific solutions have to be designed. The German standard “Guidelines for passive protection on roads by vehicle restraint systems (RPS), 2009 Edition” proposes a set of solutions for different configurations of driveways. The type of terminal (AEK) to be adopted will be different depending on the fact that an offset can be obtained (flared terminal) or not (tangent terminal) and depending on whether the terminal is on the main roadway or on the driveway.

If the barrier requires a lateral offset this should be achieved with a fare rate of 1:20 – up to 1:2 in exceptional cases. The barrier should then last at least 15 m parallel to the roadway prior to the start of the hazardous area for two lane roads and at least 10 m for single lane roads.

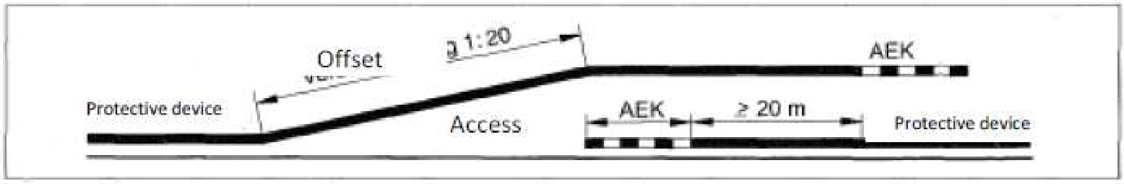


Fig. 10: Discontinuances of protective equipment for approaches

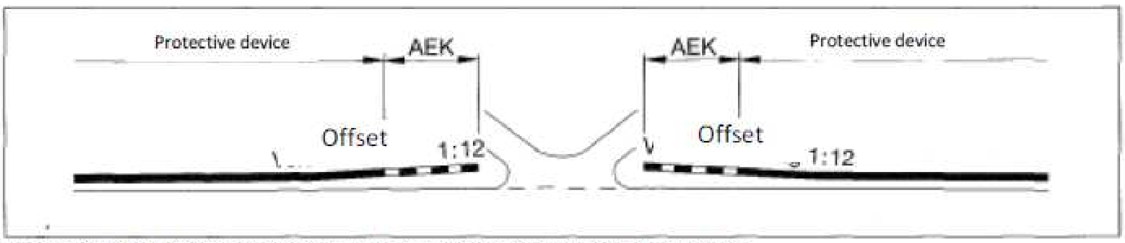


Fig. 11 a: Interruption of protective devices with start and end construction and with offsets

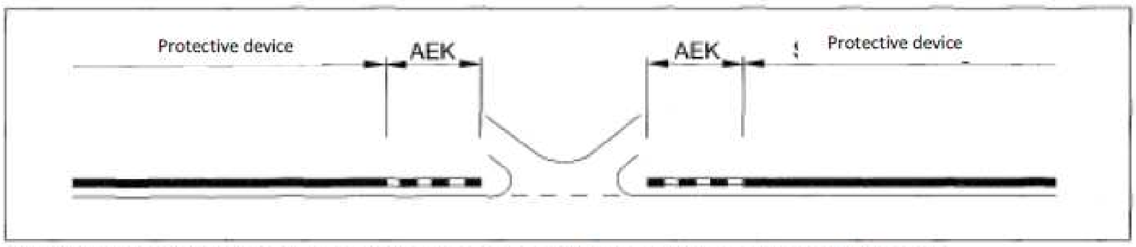


Fig. 11 b: Interruption of protective equipment with start and end construction in alignment of the protective device

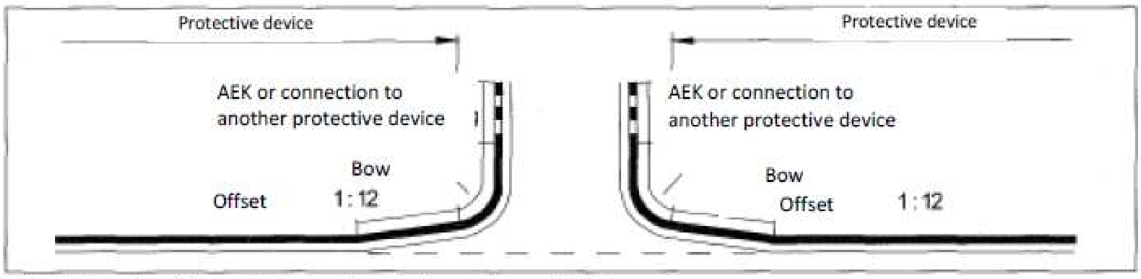


Fig. 11 c: Interruption of the protective equipment with curvature and offset

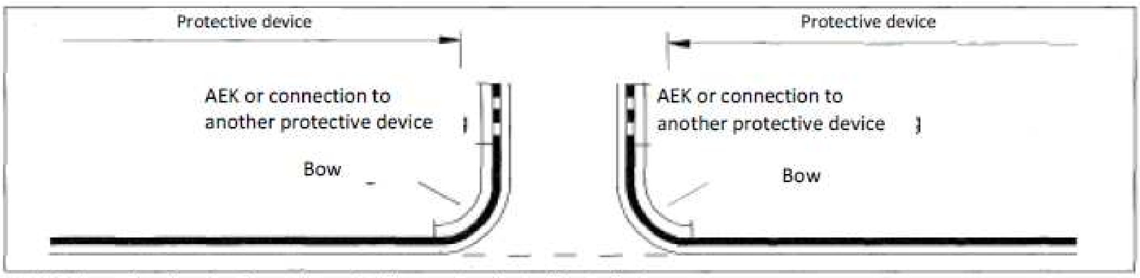


Fig. 11 d: Interruption of protective equipment with curvature, but without offset

Figure 17: terminals configuration in proximity of driveways according to German Guidelines [14]

2.3 Assessment of effectiveness

Even though road barriers terminations are commonly recognized as an important roadside safety hazard there is currently no quantitative manner to estimate the safety effects of removing them.

In the NCHRP Report 490 “In-service performance of safety barriers” several studies concerning barriers terminals have been analysed but it resulted that they are essentially devoted to understanding how the specific terminal is working and not at quantifying the effect of modifying the terminal configuration [16].

In the recently published “Highway Safety Manual” the Roadside Hazard Rating doesn’t account for the terminals configuration [17].

One of the reasons is that crashes against terminals are rare event and a typical “before/after” analysis cannot be performed in these cases.

In WP2 of the IRDES project a procedure for the determination of a CMF for the number of unprotected (or “exposed”) terminals has been developed and a CMF has been derived from the data collected on part of the secondary rural network of the Arezzo Province. The statistical analysis conducted on a typical secondary rural network in Italy showed a significant reduction of the number of fatal and injury crashes when the number of unprotected terminals is reduced and a Crash Modification Factor was derived as a function of the reduction in the number of unprotected terminals.

The equation relating the CMF with the number of unprotected terminals per km (UT) is given by:

$$CMF = e^{0.02381 \times UT}$$

The effect of changing the type of terminal from un unprotected to a flared or energy absorption one could not be established as this type of terminals are not yet installed in the analysed network.

It should be noted, anyhow, that the extensive in-service performance evaluation conduced in the USA [16] lead to the conclusion that the flared non-energy-absorbing terminals (in the specific case the MELT and the Breakaway Cable Terminal, BCT which is similar to the MELT with a cable added) perform well on site if installed correctly. Improper installation (inadequate offset, incorrect flare or other installation flaws) or lack of maintenance was found to be the primary reason for unsatisfactory results in some applications.

2.4 Case studies/Examples

Barrier terminals, both energy-absorbing and non-energy-absorbing are now a standard practice and not an experimental application. The NCHRP Report 490 “In-service performance of traffic barriers”, published in 2003 [16] presents a very interesting overview of the in-service performance of most of the devices available at that time.

In the AAHTO Roadside Design Guide Ed. 2010 [9] an extensive review of the terminal available in the US is presented but it should be noted that these terminals are not necessarily compliant with ENV1317-4 which is to be applied in the EU market. A similar inventory for the EU market is currently not available.

2.5 References

2.5.1 Standards

CEN standards

In November 2001 a European “prestandard” was published by CEN as ENV 1317-4 dealing with both terminals and transitions (Road restraint systems - Part 4: Performance classes, impact test acceptance criteria and test methods for terminals and transitions of safety barriers). This European Prestandard (ENV) was approved by CEN on 30 September 2001 as a prospective standard for provisional application. The period of validity of this ENV was limited initially to three years. After two years the members of CEN have been requested to submit their comments, particularly on the question whether the ENV can be converted into a European Standard.

Even though many national standards have referred to the ENV1317-4 for the use of terminals in public roads, this “prestandard” was not converted into a European Standard and has been removed from the list of published standard on the CEN catalogue.

Two new work items have been established to deal separately with Transitions and with terminals leading to the new draft standards prEN1317-4 (Road restraint systems - Part 4: Performance classes, impact test acceptance criteria and test methods for transitions of safety barriers and Removable Barrier Section) and pr-EN1317-7 (Road restraint systems - Part 7: Performance classes, impact test acceptance criteria and test methods for terminals of safety barriers).

As far as ENV 1317-4 has never been published as a European Standard this was not incorporated in the EN 1317-5 standard which is the basis for the CE marking of road restraint systems. Therefore, as of today the terminals cannot be marked CE, but several countries require that the energy-absorbing terminals to be installed on public road comply with ENV 1317-4 requirements.

ENV 1317-4 defines the tests required to classify a terminal in a given “performance class” (P1 to P4, as shown in Figure 18) but, as mentioned earlier, defines also different type of tests depending on whether the terminal is supposed to be installed:

- U (upstream) which is the typical application;
- D (downstream);
- A (all) which means that the terminal could be hit in both directions and this is typical of medians.

Performance class	Location		Tests: Approach	Approach reference	Vehicle mass (kg)	Velocity (km/h)	Test code [1)]
P1	A		head on nose 1/4 offset to roadside	2	900	80	TT 2.1.80
P2	A	U	head on nose 1/4 offset to roadside	2	900	80	TT 2.1.80
			side, 15° 2/3 *L*	4	1 300	80	TT 4.2.80
		D	side, 165° 1/2 *L*	5	900	80	TT 5.1.80
P3	A	U	head on nose 1/4 offset to roadside	2	900	100	TT 2.1.100
			head-on centre	1	1 300	100	TT 1.2.100
			side, 15° 2/3 *L*	4	1 300	100	TT 4.2.100
		D	side, 165° 1/2 *L*	5	900	100	TT 5.1.100
P4	A	U	head on nose 1/4 offset to roadside	2	900	100	TT 2.1.100
			head-on centre	1	1 500	110	TT 1.3.110
			side, 15° 2/3 *L*	4	1 500	110	TT 4.3.110
		D	side, 165° 1/2 *L*	5	900	100	TT 5.1.100

[1)] Test code notation is as follows:

TT	**1**	**2**	**100**
Test of Terminal	Approach	Test vehicle mass	Impact speed

NOTE 1 To avoid ambiguity, the numbering of the approach path in Table 1 and in Figure 3 is the same as in EN 1317-3; approach 3 is present in EN 1317-3 as test 3 for crash cushions, but it is not required for Terminals.

NOTE 2 The test with approach 5 is not run for a flared terminal when, at the relevant impact point, the angle (α) of the vehicle path to the traffic face of the terminal is less than 5 °.

Figure 18: terminals: vehicle impact test criteria and performance classes according to ENV 1317-4 [12]

Some national standards include provisions for terminals among which the following:

- Italian Standard [13]: D.M. 2367/2004 containing the “istruzioni tecniche per la progettazione, l’omologazione e l’impiego dei dispositivi di ritenuta nelle costruzioni stradali” (in Italian)
- German Standard Guidelines for passive protection on roads by vehicle restraint systems – RPS R1 [14]: (in English)
- Austrian Guidelines, RVS 05.02.31; Traffic control, Traffic guidance facilities, Vehicle restraint systems, Requirements and installation [15] (in German).

2.5.2 Design guidelines

There are several guidelines available for safety barriers and their terminations. Among the others the following could be mentioned:

- AASHTO Roadside Design Guide, Ed 2011, USA [9];
- Department of Infrastructure Energy and Resources: ROAD SAFETY BARRIERS DESIGN GUIDE Part B, Tasmania - Australia [8].

In addition several states worldwide provide drawing of non proprietary flared terminals:

- Oregon Department of Transportation (USA) [10];
- Missouri Department of Transportation (USA) [18];
- Mainroads West Australia [11].

3 Shoulder Rumble strips

3.1 Introduction

Rumble strips are road safety features used to alert road users straying off the road or drifting into the opposing lane of traffic both by causing a vibro-tactile and an audible warning. They are intended to reduce road accidents caused by drowsy or inattentive motorists and can be distinguished in shoulder, centreline or transverse rumble strips [19]. This report will be dealing only with shoulder rumble strips.

A shoulder rumble strip is a longitudinal design feature installed on a paved roadway shoulder near the outside edge of the travel lane (Figure 19). It is made of a series of indented or raised elements intended to alert inattentive drivers through vibration and sound that their vehicles have left the travel lane [20]. On divided highways, shoulder rumble strips are typically installed on the median side of the roadway as well as on the outside (right) shoulder.

Figure 19: shoulder rumble strips [23]

Even though the use of rumble strips has been proven to be a low cost and an extremely cost effective treatment there is still a limited use of this type of safety feature likely due to a lack of practical guidelines and to the perception of potential counter effects as noise issues, bicycle and motorcycle riding, maintenance issues. The section of the IRDES Roadside Design Guideline is aimed at providing practical guidelines on how to properly design shoulder rumble strips to avoid such counter effects and how to evaluate the effectiveness of implementing such an intervention to reduce run off road accidents.

3.2 Design criteria

3.2.1 Shoulder Rumble strips configuration

In terms of construction techniques there are 4 different rumble strip types commonly used: milled-in, rolled-in, formed, and raised. A short description of each rumble strip type is provided hereafter [24]:

- Milled-in (or “milled”): This design is made by cutting (or grinding) the pavement surface with carbide teeth;
- Rolled-in (or “rolled”): The rolled-in design is generally installed by using a steel wheel roller to which half sections of metal pipe or solid steel bars are welded. The compaction operation presses the shape of the pipe or bar into the hot asphalt shoulder surface;
- Formed: The formed rumble strip is added to a fresh concrete shoulder with a corrugated form which is pressed onto the surface just after the concrete placement and finishing operations;
- Raised: Raised rumble strip designs can be made from a wide variety of products and installed using several methods. The elements may consist of raised pavement markers, a marking tape affixed to the pavement surface, an extruded pavement marking material with raised portions throughout its length or an asphalt material placed as raised bars on the shoulder surface.

The most common shoulder rumble strips type are the milled and the rolled ones. The difference between the two types is not only the construction technique adopted to realize them but also the resulting cross section and therefore the effects on vehicle vibrations, as shown in Figure 20.

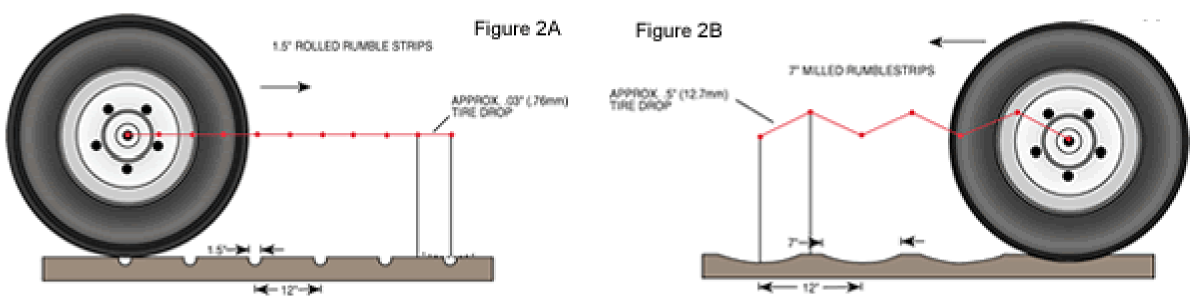


Figure 20: difference in cross section between rolled (left) and milled (right) shoulder rumble strips [23]

The key parameters in the layout design of the shoulder rumble strips are:

A	offset
B	length
C	width
D	depth
E	spacing
F	bicycle gap

as shown in Figure 21.

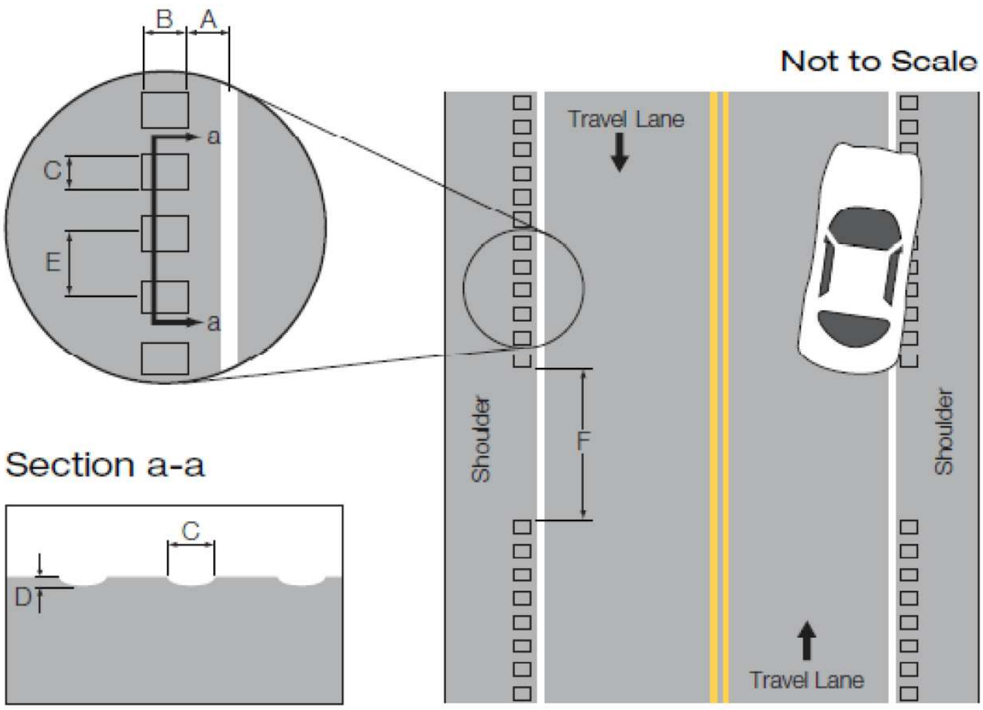


Figure 21: design parameters of shoulder rumble strips [20]

The “typical” rumble strip configuration is given by the values shown in Table 2.

Table 2. Typical milled and rolled rumble strip configurations ([20], [21], [22])

	PARAMETER	MILLED RUMBLE STRIPS	ROLLED RUMBLE STRIPS
A	offset	0-760 mm	0-760 mm
B	length	400 mm	400 mm
C	width	180 mm	40 mm
D	depth	13 mm	32 mm
E	spacing	305 mm	170 mm

The issue of bicycle gaps will be specifically addressed in chapter 3.2.2.

This same standard for milled rumble strips is adopted as a standard design for motorways in Germany [42] with no bicycle gaps except for the acceleration and exit lanes.

In NCHRP Report 641 [21] conclusive evidence was found that on rural freeways rumble strips placed closer to the edgeline are more effective in reducing single vehicle run off road severe crashes (fatal and injury crashes). For other roadway types similar results have not been found but, if no other constraints require to move the strips further in the shoulder, the best location is still as close as possible to the edgeline as this will widen the recovery zone after the strips and provide the larger possible width of the remaining shoulder for bicycle travel.

This type of design is extremely effective but quite “aggressive” leading to a high noise and vibration inside, and potentially outside, the vehicle and producing a considerable disturbance to cyclists.

In NCHRP Report 641 a different “less aggressive” configuration has been designed to reduce the incremental noise induced inside the vehicle from the 10-15 dBA associated to the “typical” configuration, to 6-12 dBA and to provide less disturbance to cyclists (Table 3).

Table 3. Milled rumble strip configuration designed to be less aggressive ([21])

PARAMETER		LESSE AGGRESSIVE MILLED RUMBLE STRIPS
A	offset	0-760 mm
B	length	152 mm
C	width	127 mm
D	depth	10 mm
E	spacing	280-305 mm

The lower spacing (280 mm) is recommended for non-freeway facilities with lower operating speeds, near 72 km/h, while the higher spacing (305 mm) is recommended for non-freeway facilities with higher operating speeds, near 88 km /h [41].

Due to the fact that this solution leads to a reduction in the internal noise a reduction in external noise is also likely to occur and this configuration could therefore be preferred in close proximity to residential areas.

3.2.2 Shoulder Rumble strips and bicycle riding

One of the major disadvantages of shoulder rumble strips is the negative effect that these can have on bicycle riding. This issue has been addressed by Moeur [40] and Torbic [41] leading to proposals for designing “bicycle friendly” rumble strips.

Moeur focused on the “bicycle gap” (F in Figure 21) in milled rumble strips. In this type of rumble strips the bicycle wheel completely drops in the grooves affecting considerably both comfort and handling and changing the design configuration of the strips has little or no effect. Reducing the groove depth to 10 mm has an effect but rather limited and not sufficient to allow cyclist to travel over the strips. Moeur suggested therefore that on rumble strips on “noncontrolled-access” highways include periodic gaps of 3.7 m in length, and that these gaps be placed at periodic intervals at a recommended spacing of 12.2 m or 18.3 m. This recommended spacing is not affected by the width of the strips for widths up to 300 mm. Including gaps in the rumble strips pattern would satisfy bicyclists’ need to cross the rumble strip pattern without causing them to enter the grooved area. In addition these are sufficiently long as to permit a typical bicyclist to cross without entering the grooved area, but not so long as to permit a vehicle tire at a typical run-off-road angle of departure to cross the gap without entering the grooved area.

It should be noted that, according to Moeur, rolled rumble strips do not affect cyclist handling as the wheel doesn’t drop in them (Figure 23) but, on the other hand, this solution is much less effective in terms of alerting errant drivers. This solution could therefore be considered in areas where considerable bicycle traffic is expected an shoulders are not wide enough to allow for the passage of the bicycles between the strips and the pavement edge.

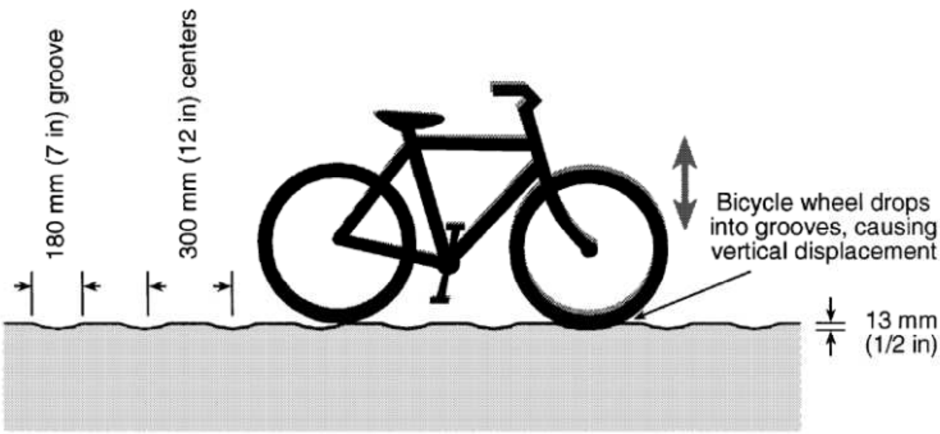


Figure 22: bicycle ride on “typical” milled shoulder rumble strips [40]

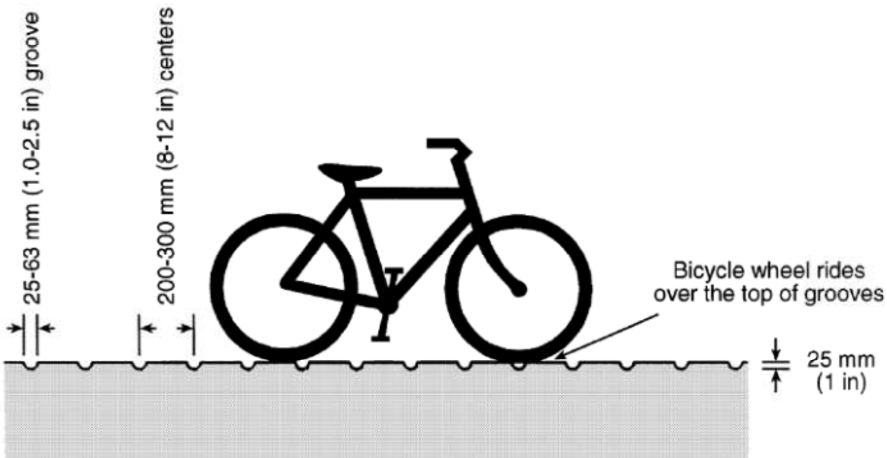


Figure 23: bicycle ride on rolled shoulder rumble strips [40]

Torbic [41] focused the study on the geometric parameters of the rumble strips (C, D, E in Figure 21) analysing different patterns by means of numerical simulation (Figure 24) and testing on site the most promising ones. This study lead to the definition of the "less-aggressive" configuration discussed in chapter 3.2.1 and shown in Table 3.

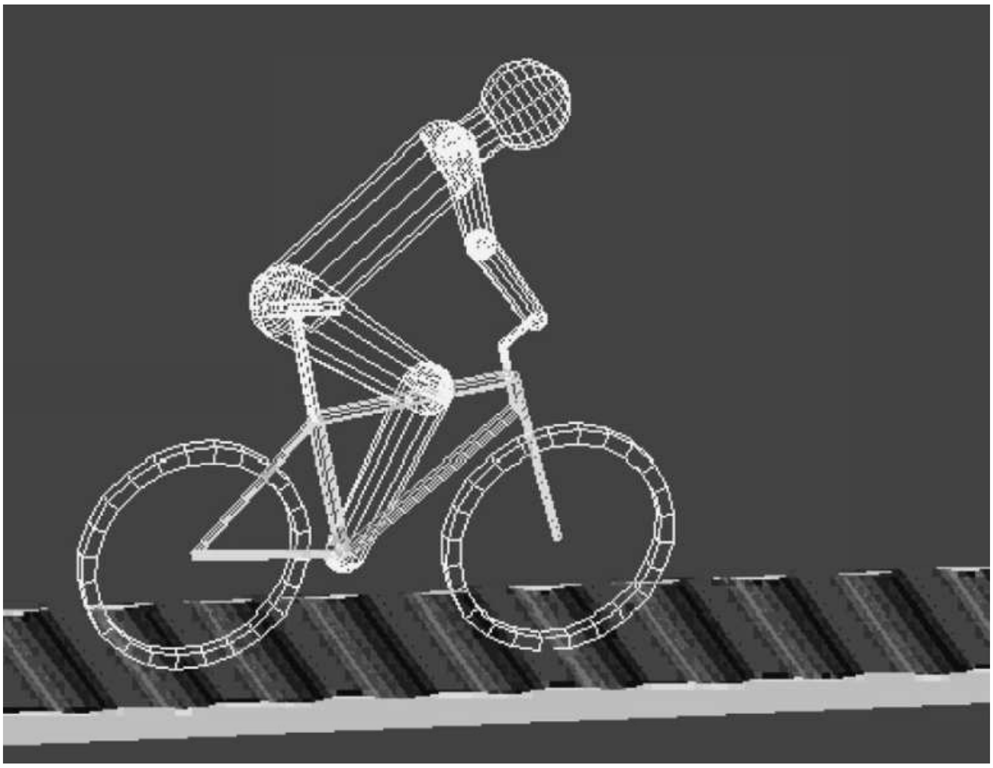


Figure 24: simulation of bicycle ride over milled shoulder rumble strips [41]

FHWA [20] recommends to consider possible "mitigations" to reduce the effect on bicycle riding if the strips are placed along bicycle routes or those with heavy bicycle traffic where less than 1.2 m pavement exists beyond the rumble strip. Mitigation measures include:

a. Use of edge line rumble strips rather than shoulder rumble strips, where it will allow additional shoulder area beyond the rumble strip that is usable to a bicyclist.
b. Periodic gaps of 3.0 to 3.6 feet between groups of the milled-in elements, spaced at 12.2 to 18.3 feet, throughout the length of the shoulder rumble strip;
c. Minor adjustments in design dimensions that have been shown to produce rumble strip designs more acceptable to bicyclists. The principal adjustments to the milled-in strip elements studied are decreased length transverse to the roadway (B), increased center-to-center spacing (E), reduced depth (D), and reduced width longitudinal to the roadway (C).

Mitigation measures "b" and "c" are the solutions proposed respectively by Moeur and Torbic, as described above.

3.2.3 Shoulder Rumble strips and motorcycle riding

Even though motorcycle riding in the shoulder is not allowed, a concern raised when dealing with milled rumble strips is the possible hazard for motorcycle riders.

In 2008 a specific study was conducted in Minnesota [43], where centreline rumble strips (which are much more likely to affect the motorcycle riders' safety than shoulder rumble strips) have been installed on rural highways since 1999, to look for possible detrimental effects on 2 and 3 wheeled cycles. Motorcycle accidents in rural highways where centreline rumble strips are installed were 29 with none showing rumble strips as a concurrent factor in the accident.

In addition to the accident analysis 40 hours of on site observations were made leading to the conclusion that there were no visible indications of rider correction or overcorrection and no obstacles to passing due to the rumble strips in the centreline. Controlled conditions on a closed circuit supported this observation through 32 riders in all types of cycles and experience levels from 0 to 41 years of street riding. Interviews confirmed that the riders had no difficulty or concern with the rumble strips.

In Alaska [44] the depth of the centreline rumble strips have been reduced to 3/8" (approximately 10 mm) in order to reduce the impact to motorcyclists and other users, while still providing warning to drivers. This type of configuration is consistent with the "less aggressive" design as described in chapter 3.2.1 suggesting that this configuration is to be preferred in areas where a high traffic of motorcycles is expected.

3.2.4 Noise issues

The noise disturbance to the nearby residents is often considered as a limiting factor for the practical applicability of rumbles strips. Even though shoulder rumble strips should not be traversed except when a driver leaves the roadway, rumble strip installations may still produce noise complaints where there are nearby residences, depending on the type of vehicles, the lane width and curvature, and the type of manoeuvres occurring on the road ([20]).

Mitigation measures may include:

- Increasing the offset (A), particularly through curves where off-tracking is prevalent or in corridors with high volumes of truck traffic.
- Removal of the rumbles in the vicinity of turn lanes or in spot locations such as a single house along a segment of roadway. The need to discontinue the use of rumbles in spot locations should not necessarily prevent their use along a segment or corridor.

According to Torbic [21] shoulder rumble strips should be interrupted 200 m prior to entering the residential area. In the proximity of residential areas or where the reduction of generated noise is an issue the "less aggressive" design configuration (see chapter 3.2.1) could be used as this results in less disturbance.

Kragh [25] analysed the effects on noise of the shape of the strip and concluded that rumble strips with sinusoidal shape leed to only 0.5 – 1 dB increase in noise level as compared to an old stone mastic asphalt (at 25 m from the road). The typical rumble strip with "cylinder-segment" indentations gives an increase of 2 – 3 dB. Rectangular indentations shows significantly higher noise levels (3 – 7 dB higher) than the rumble strips with a sinusoidal profile as well as significantly higher noise levels (2 – 5 dB higher) than the "cylinder segment" strip.

3.2.5 Maintenance of Shoulder Rumble strips

The CEDR Report "Best Practice for Cost-Effective Road Safety Infrastructure Investments" [19] defines Rumble strip as characterised by a low installation cost and requiring little or no maintenance. There is no noticeable degradation of pavement due to rumble strips and additionally, they are effective in snow and icy conditions and may act as a guide in inclement weather for truck drivers.

The 2011 Technical Advisory released by the US Federal Highway Administration [20] confirmed that the concerns of accelerated pavement deterioration due to installation of rumble strips appear of be unfounded. To reduce the pavement deterioration due to traffic travelling over them it is suggested to locate the rumble strips at least a few inches from joints. Where there are deterioration concerns, an asphalt fog seal can be placed over milled-in strips to preserve them from oxidation and moisture.

Recent experiences in Michigan has shown that shoulder preventative maintenance treatments, such chip seal on top of an existing rumble strip, has been shown to retain the basic shape of the ships, although losing some cross-section. However, stones from the chip seal enhance the noise and vibratory properties of the rumble. Micro-surface and ultra-thin hot-mix asphalt overlays fill in existing lines of rumble strips, but a fresh line of rumble strips can be cut into the overlay at the same location without significant delaminating caused by the underlying filled-in rumbles.

If an overlay has to be placed over a shoulder where rumbles strips have been either milled or rolled the surface has to be prepared prior to overlaying the shoulder. Based upon an observational study, it is recommended to prepare areas with rumble strips prior to overlayment either by either:

- milling, inlaying, and overlaying;
- simply milling and overlaying.

Other preparation approaches such as shim and overlay or simply overlay will likely result in some degree of reflection in the area of the former rumble strips ([21]).

3.2.6 Selection of sites where to install Shoulder Ships

According to the FHWA Technical Memorandum – ACTION: Consideration and implementation of proven safety countermeasures [35]: "*Rumble Strips or Rumble Stripes should be provided on all new rural freeways and on all new rural two-lane highways with travel speeds of 50 mph or greater. In addition, State 3R (Resurfacing, Restoration, Rehabilitation) and 4R (Resurfacing, Restoration, Rehabilitation, Reconstruction) policies should consider installation of continuous shoulder rumble strips on all rural freeways and on* *all rural two-lane highways with travel speeds of 50 mph or above (or as agreed to by the Division and the State) and/or a history of roadway departure crashes, where the remaining shoulder width beyond the rumble strip will be 4 feet or greater, paved or unpaved. Federal and local agencies and tribal governments administering highway projects using Federal funds should also be encouraged to adopt similar policies for providing rumble strips or rumble strips*".

NCHRP Report 641 [21] provided a detailed set of guidelines to establish where the shoulder rumble strips can effectively be placed:

- *Shoulder Width*: Minimum shoulder widths for rumble strip application range from 2 to 10 ft (0.6 to 3.0 m), with 4 ft (1.2 m) being the most common value. Minimum shoulder widths may differ by roadway type.
- *Lateral Clearance*: Minimum lateral clearances range from 2 to 7 ft (0.6 to 2.1 m), with 4 ft (1.2 m) and 6 ft (1.8 m) being the most common values. Some agencies may prefer to define the lateral clearance to be the distance from the outside (i.e., right) edge of the rumble strip to the outside edge of the shoulder, while others may measure the clearance to the nearest roadside object rather than the outside edge of the shoulder.
- *ADT (Average Daily Traffic)*: Minimum ADTs for rumble strip application range from 400 to 3,000 ADT, but in most cases fall between 1,500 and 3,000 ADT.
- *Bicycles*: Agencies address bicycle considerations in several ways, including: (a) not installing rumble strips on roads with significant bicycle traffic or if the roadway is a designated bicycle route, (b) adjusting the dimensions of the rumble strips, (c) adjusting the placement of the rumble strips, (d) adjusting the minimum shoulder width and/or lateral clearance requirements, and/or (e) providing gaps in periodic cycles. Guidance provided in the AASHTO Guide for the Development of Bicycle Facilities should also be considered.
- *Pavement Type*: Some agencies only install shoulder rumble strips on asphalt surfaces. The use non conventional asphalt pavements (such as porous wearing courses) should be investigated by means of trial sections .
- *Pavement Depth*: Minimum pavement depths range from 1 to 6 in. (25 to 152 mm).
- *Area Type*: Some agencies only install shoulder rumble strips in rural areas, primarily due to potential noise disturbance. The recommended distance from the residential area where rumble strips should be terminated is 200 m;
- *Speed Limit*: Minimum speed limits used by agencies ranged from 45 to 50 mph (72 to 80 km/h). Some agencies also adjust the rumble strip dimensions depending upon the speed limit.
- *Crash Frequencies/Rates*: Some agencies establish a threshold value, such as the statewide average for the given roadway type.

Shoulder rumble strips are typically interrupted in the following locations:

- Intersections, driveways, and turn lanes;
- Entrance and exit ramps;
- Structures (i.e., bridges);
- Areas where the lateral clearance drops below a specified value and/or areas where the lateral clearance is limited due to adjacent guardrail, curb, or other obstacles;

- Residential areas;
- Catch basins and drainage grates;
- Pavement joints;
- Median crossings.

Also in British Columbia (Australia, [26]) it is recommended not to use shoulder rumble strips in “urban areas” and a good indication of an urban highway section is given by:

- Speed Zone of 70 km/h or less in the vicinity of a settlement;
- Highway Section with curb-and-gutter or a sidewalk;
- The spacing between driveways and intersections is less than 150 metres.

3.3 Assessment of effectiveness

The first effectiveness evaluation studies on shoulder rumble strips are dated back in the early 90-ies. All these studies lead to the conclusion that this treatment extremely cost effective in reducing single vehicle run off road accidents on freeways.

- Wood [27], in 1994, reported a 70% reduction in single vehicle run off road accidents by implementing milled in rumble strips in the Pennsylvania Turnpike;
- Hickey [28], in 1997, updated Wood results on the effects of the shoulder rumble strips in the Pennsylvania Turnpike still confirming a reduction in single vehicle run off accidents by 60% over 53 test segments;
- Perillo [29], in 1998 reported a reduction in single vehicle run off road accidents up to 88% after the installation of milled in shoulder rumble strips in the New York Thruway.

It should be noted, anyhow, that the above mentioned studies are all very simple and straightforward comparisons between the accidents occurred before and after the rumble strip installation without a sound statistical interpretation of the data (so-called “naïve” before-after studies).

In 1999 Griffith conducted more rigorous study on rolled-in rumble strips ([30], [31]) associated to a “medium-high” level of predictive certainty by the NCHRP Project 17-25 [32], where the potential reduction in single vehicle run off road accidents was estimated in 14% considering all freeways (rural and urban) and 21% considering only rural freeways. Even though these expected reductions in accidents are much smaller than the ones estimated in the late 90-ies these are still extremely valid considering also the limited cost of the intervention. As noted in [32] these results are not applicable to other road classes (two-lane or multilane rural highways). Similar results have been obtained, again for freeway segments, by Carrasco [33] showing that the late 90-ies indications on the effectiveness of shoulder rumble strips on accident reduction were overestimated, still having an actual reduction of single vehicle run off accidents of 22%.

More recently Patel et al. [34] have analyzed the effect of this treatment on two lane rural roads and found out that there is still a considerable safety effect with a reduction in single vehicle run off road accident of 13%, when all accidents are considered and 18% when considering only injury accidents. It was noted, anyhow, that not all sites experience a crash reduction and the resulting standard deviation of the expected crash reduction is 8% for total accidents and 12% for injury accidents. This means that, considering a 95% confidence interval, the effectiveness in terms of crash reduction can range from 13-15.7% and 13+15.7% for all accidents and 18-23.5% and 18+23.5%. As it can be seen a “negative crash reduction” (which means a crash increase) can occur within the 95% confidence interval. According to Patel et al. an in depth study with a larger database should be conducted to find out the explanatory variables that lead to such a different performance in different sites (eg. road geometry, different type of accidents etc).

In 2008 the US FHWA issued the “Memorandum” (ACTION: Consideration and implementation of proven safety countermeasures [35]) stating that continuous shoulder rumble strips (CSRS) can be applied on many miles of rural roads in a cost-effective manner and that studies have documented the following crash reduction benefits:

- Overall crash reduction of 13% and injury reduction of 18% on rural two-lane highways.
- Overall crash reduction of 16% and injury reduction of 17% on rural multi-lane divided highways.
- Reduction in run-off-road crashes of 38% on freeways.

Combining the results from different studies (including [31] and [34]) in a manner consistent with the procedures for combining study results for incorporation in the Highway Safety Manual [36], Torbic [37] have recently recommended a set of CMF (in the study named AMF according to the previously used acronym) to be applied to Single Vehicle Run Off Road crashes (SVROR) to account for shoulder rumble strips on rural freeways and rural two lane roads, shown in Figure 25. A different CMF is given for total SVROR accidents and for fatal+injury) crashes only (SVROR FI).

Treatment	Roadway Type	Accident Type and Severity	AMF[a]	SE[b]
Shoulder rumble strips[c]	Rural freeways	SVROR	0.89	0.1
		SVROR FI	0.84	0.1
Shoulder rumble strips[d]	Rural two-lane roads	SVROR	0.85	0.1
		SVROR FI	0.71	0.1

[a]AMF = accident modification factor.
[b]SE = standard error of estimate.
[c]AMF and SE based on combined results for rolled SRS from Griffith (*4*) and for milled SRS from this research.
[d]AMF and SE based on combined results from Patel et al. (*5*) and this research.

Figure 25: Crash Modification Factors (AMF/CMF) for shoulder rumble strips recommended for inclusion in the Highway Safety Manual by Torbic et al. [37]

These values are statistically more reliable that the ones given in the FHWA memorandum ([35]) that seem overestimated. The values proposed by Torbic are therefore recommended for the evaluation of the effectiveness of shoulder rumble strips in Rural Freeways and Rural two-lane roads.

For urban freeways and multilane divided highways the analysis conducted by Torbic resulted to be statistically non significant as in previous studies. For multilane divided highways the values proposed by Carrasco [33] can be used as a best estimate of the effects of milled shoulder rumble strips: SVROR crashes are expected to be reduced by 22% and SVROR FI crashes by 51% but more statistically sound research is needed.

RISER Guidelines [1] highlight that according to a number of reports based upon in-depth investigations of accidents, the human factor (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. RISER's detailed data has shown that inappropriate speed or speeding is not the main factor of accidents. The type of accidents that could be positively affected by having shoulder rumble strips installed (Heavy workload, panic, internal or external distraction and above all fatigue) where a considerable amount (56 cases out of 189).

Another important effect of shoulder rumble strips is the reduction in the crash severity. The 2011 FHWA Technical Advisory [20] indicated that, in a study of 1,800 run-off-road freeway crashes, one state found that drift-off-road crashes (due to inattentive driving) resulted in death or serious injury at a rate 3 to 5 times that of other categories of run-off-road crashes.

In 2005 an extensive driving simulator study has been performed in Sweden [38] in order to investigate the effects on fatigue drivers of shoulder and centreline rumble strips on narrow roads (≤ 9 m). This study has shown that all the different type of rumble strips considered and all the different placements where effective in alerting the drivers and induced the correct averting action. Based on the responses of the drivers no risk was associated with more "aggressive" rumble strips.

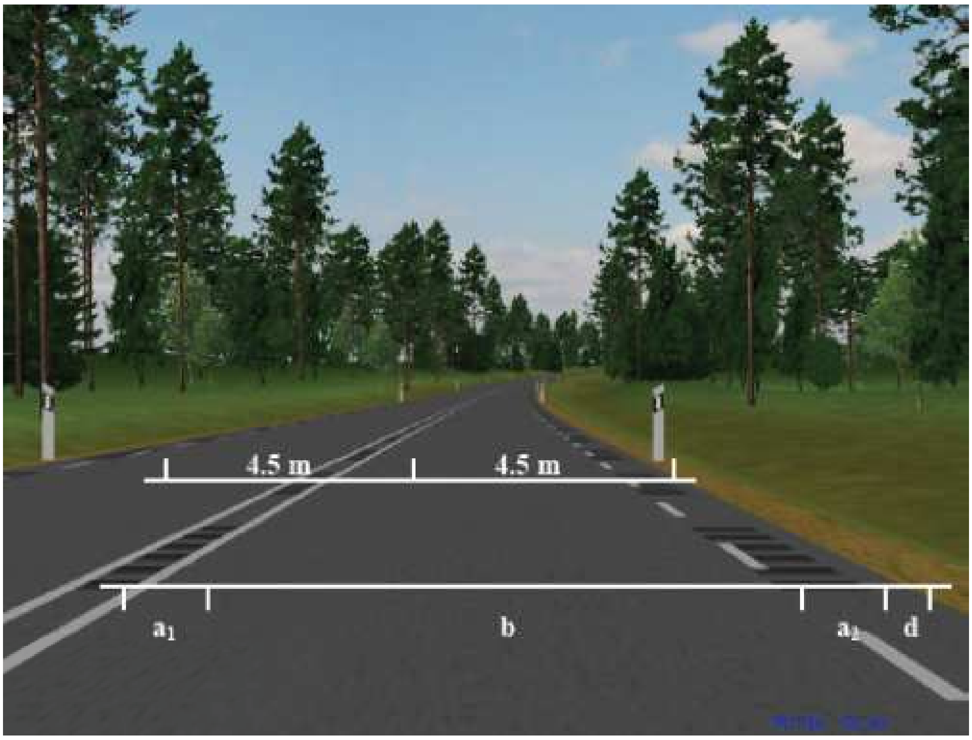


Figure 26: layout used for the simulator evaluation in [38].

Rumble strips are also identified as a potential safety intervention for single vehicle accidents by the PIARC Road Safety Manual [39] even though there is no specific quantification of the potential accident reduction that could be expected.

3.4 Case studies/Examples

Shoulder rumble strips represent a widely used technique worldwide even tough the applications in Europe are still limited compared to the US and Australia.

Sweden is one of the countries in Europe were milled shoulder rumble strips (also called “grooved” rumble strips) are extensively used on freeways and therefore within the IRDES Project (WP2) a specific study was conducted to evaluate the effectiveness of such treatments (see Annex 2 for a detailed description of the study). The configuration of the rumble strips is essentially the “typical” one described in chapter 3.2.1 with a bicycle gap of 2870 mm (Figure 27).

The results of the analyses conducted on 200 km of treated sections confirm that this type of intervention is definitely reducing crashes with an estimate of 27.3% reduction. Within a 95% confidence interval the potential effect was estimated between 8.6% and 45.7% which is still a quite large spread, meaning that the analysis should be enlarged to a wider dataset but, on the other hand, no “essential reversal effect” is found which means that, within a 95% confidence interval, the treatment will not give negative effects (increase) on crashes.

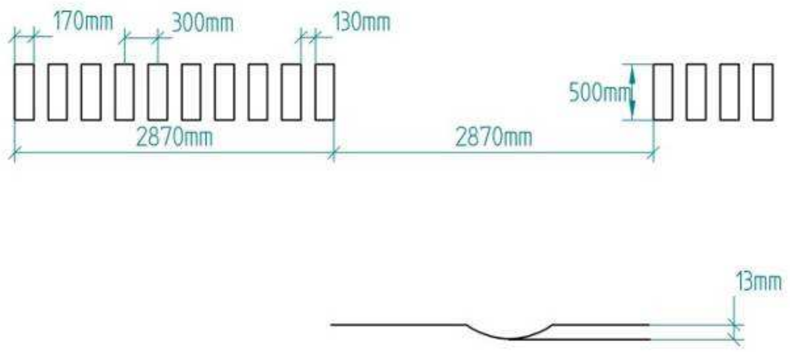


Figure 27. Configuration of the milled shoulder rumble strips in Sweden analysed in WP2 (Annex 2)

An extensive case study on the use of rumble strips in motorway has been conducted in Germany [42] showing that shoulder rumble strips have a positive effect on fatal crashes and crashes with severe personal injury (-15%) while injuries with light injuries or property damage only crashes increased (+6%). The conclusion of this study was that the primary effect of the rumble strips is not the reduction in the total number of crashes (that resulted in to be essentially stable with a -1% variation) but the reduction in the crash severity.

Another interesting result was that SVROR accident leaving the right edge of the road where reduced by a considerable 43% (-18% to -60% in a 95% confidence interval) but, on the other hand, an increase of crashes with the vehicle leaving the carriageway to the left due to overcorrection has been noticed.

Raised rumble strips have been recently applied in the Rome Beltway in Italy combined with coloured surfacing to prevent the use of the extra widening of the left shoulder that has been left for sight distance issues.

Figure 28. Raised rumble strips used in the left shoulder in the Rome Beltway.

3.5 References

The Federal Highway Administration (FHWA) has established a specific web site (http://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/) were several good references on shoulder rumble strips can be found.

No national design standard was found that can be considered as a reference. It should be mentioned, on the other hand, that the Austrian standard RVS 09.01.25 (tunnel safety in Austria) refers to rumble strips on edge marking as a treatment to improve safety beginning 100 m prior to the tunnel entrance.

4 Forgiving support structures for road equipment

4.1 Introduction

Single or point objects placed within the clear zone can represent an hazard for a vehicle that looses it's control and leaves the carriageway. Within the RISER Project [1] several studies have been reviewed showing that the collision with point objects represent a relevant percentage of crashes (e.g. 24% of fatal accident in Finland, 31% of fatal accidents in France and 42% of road deaths in Germany). They can be either natural or artificial, human-made structures made of different materials. In this section of the report guidance for designing safer support structures for road equipment will be provided including utility poles, sign and lighting posts support. Protection of natural obstacles such as trees is not addresses in this guideline.

Within the WP1 of IRDES an extensive literature review of the studies dealing with evaluating the potential effects on safety of obstacles was performed (see Annex 1). The RISER project showed that trees are the most dangerous roadside objects. Around 17 percent of all tree accidents recorded were fatal [1]. In the case studies of this investigation, where speed data were known, all fatal accidents involved impact speeds of 70 km/h or more. Structures such as signs, concrete walls, fences etc. are hit in 11 percent of all fatal single vehicle accidents (SVA). According to the RISER accident analysis, safety barriers appear to be the object most impacted in SVA. However, safety barrier SVA generally resulted in minor injuries. It should be noted anyhow that safety barriers themselves can pose a hazard if not properly designed and installed.

The study in [45] is based on the U.S. Department of Transportation's Fatality Analysis Reporting System (FARS) and shows the results of an analysis of fatal accidents caused by striking fixed objects. In total, 8,623 fatalities have been analysed. Figure 29 shows the distribution of fixed object crash deaths in 2008. It clearly depicts the high percentage of tree accident deaths (48 percent). Utility poles and traffic barriers were the next most frequent objects struck with hits against utility poles responsible for 12% of fatalities.

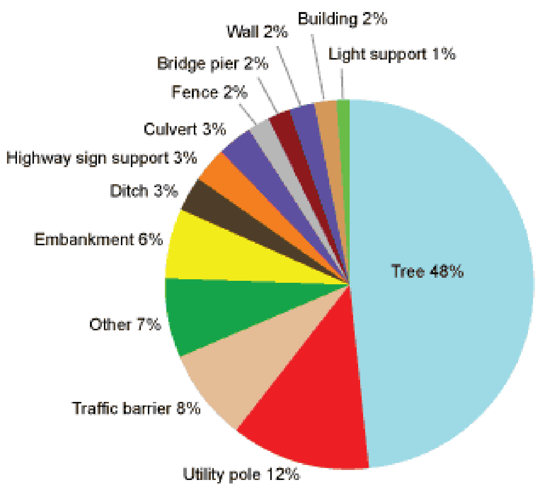


Figure 29: Percent distribution of fixed object crash deaths, based on 8,623 fatalities, 2008 [45]

In many crashes, the vehicle hits more than one roadside object. A study published by the Roads and Traffic Authority of New South Wales in Australia [46] examined the specific types of roadside objects that were hit by vehicles in second impacts. The analysis only contained fatal accidents and indicates again that trees are the most frequently struck roadside objects, followed by utility poles and embankments. Trees and utility poles have the highest percentage of objects hit in first as well as second impact (see Figure 30).

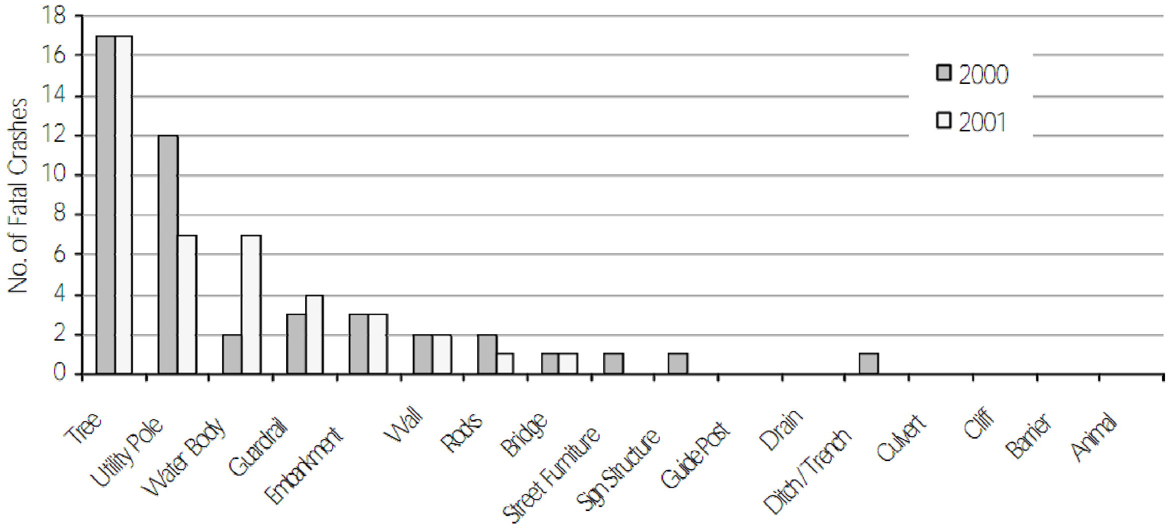


Figure 30: Roadside objects hit in second impact, based on 1,029 fatal accidents, NSW 2000 & 2001 [46]

Because of the structural strength of the utility poles and other support structures, combined with the small contact area between the vehicle and these structures, these crashes tend to be severe (Figure 31) as shown also in Figure 32 where almost 40% of the crashes with poles resulted to be fatal or with some level of injury [48].

Figure 31: Collision with a lighting column – 2 fatalities [47]

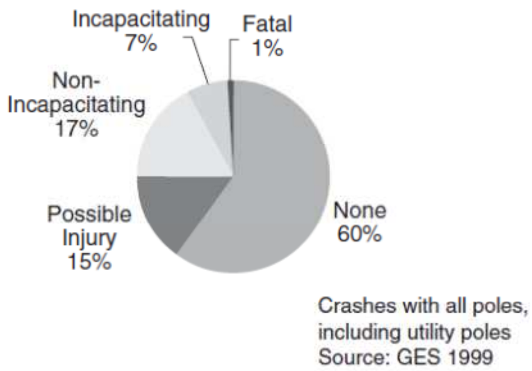


Figure 32: severity distribution of accidents against poles [48]

4.2 Design criteria

It is frequent to hear, amongst designers and road managers, that obstacles in the roadside NEED to be protected with safety barriers. This is a simplistic approach that should be overcome to reach a forgiving roadsides design approach as placing a barrier (with its length of need and its terminals) is not necessarily the most "forgiving" solution and it can be extremely costly as compared to the achieved benefits. As shown in the RISER Projects [1] the section of the proper protection to be considered when an obstacle is located in the vicinity of the roadway devies complete process where the placement of a safety barrier (hazard protection) is only the very last option (Figure 33).

Once the specific obstacle is identified as a potential problem the distance between the obstacle and the carriageway has to be compared with the clear zone (called "safety zone" in Figure 33) required for the specific road configuration, design speed and traffic. If the obstacle is outside the clear zone this is not considered an hazard. The criteria for defining the clear zone are addressed on Annex 1.

If the object is located within the safety zone this could be an hazard or not depending on several factors.

Generally speaking an object in the clear zone can be considered an hazard if one or more of the following events occur [2]:

- The vehicle is abruptly stopped.
- The passenger compartment is penetrated by some external object.
- The vehicle becomes unstable due to roadside elements.

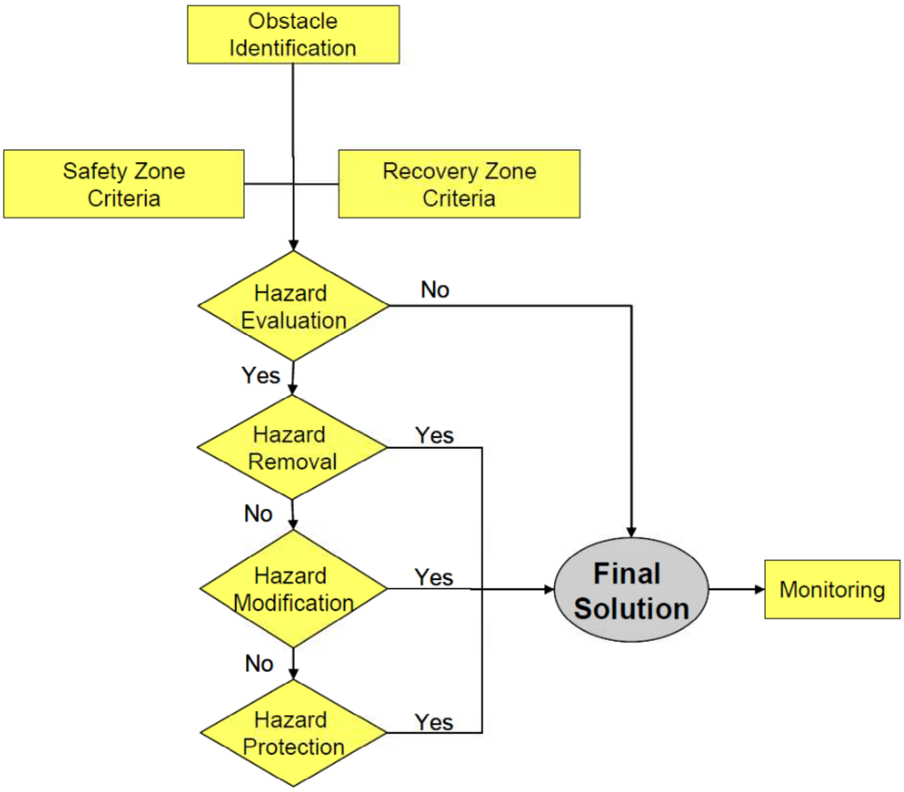


Figure 33: procedure for handling lateral obstacle according to [48]

According to both RISER [1] and SETRA [47] Guidelines an obstacle is not to be considered an hazard if it has been positively tested according to EN12767 standard “Passive safety of support structures for road equipment – Requirements, classification and test methods” [49].

For all other obstacles the following criteria can be found in the literature:

- According to [51] an obstacle is to be considered an hazard if has a diameter or thickness greater than 100 mm;
- According to RISER Guidelines [1] obstacles are considered hazard or not depending on the combination of diameter and impact speed, as shown in Figure 34;
- According to SETRA Guidelines [47] obstacles are considered an hazard if the resistant moment at the base exceeds 5.7 kN*m.

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.

Figure 34: definition of hazards for single point obstacle in the clear zone according to [48]

According to all the European Guidelines and standards on handling lateral obstacles (including RISER and SETRA guidelines but also Danish Standards [52], and almost all of the national standards that have adopted EN12767[1]) the support is not considered an "hazard" if it has been positively tested according to EN12767 standard. It should be noted, on the other hand, that the EN12767 standard considers three categories of passive safety support structures:

- high energy absorbing (HE);
- low energy absorbing (LE);
- non-energy absorbing (NE).

Energy absorbing support structures slow the vehicle considerably and thus the risk of secondary accidents with structures, trees, pedestrians and other road users can be reduced while Non-energy absorbing support structures permit the vehicle to continue after the impact with a limited reduction in speed. Non-energy absorbing support structures may provide a lower primary injury risk than energy absorbing support structures.

In addition EN12767 defines 4 levels of occupant safety based on the values of Acceleration Severity Index (ASI) and Theoretical Head Impact Velocity (THIV) calculated for tests at different speeds. Levels 1, 2 and 3 provide increasing levels of safety in that order by reducing impact severity. For these levels two tests are required:

- test at 35 km/h to ensure satisfactory functioning of the support structure at low speed.
- test at the class impact speed (50, 70 and 100) as given in the table shown in Figure 35.

Level 4 comprises very safe support structures classified by means of a simplified test at the class impact speed.

[1] It should be noted that some EU countries, such as Italy, have not yet adopted EN12767 as a mandatory standard for acceptance of road equipment support structures.

To control road user or vehicle occupant risk the test item or detached elements, fragments or other major debris from the test item shall not penetrate the occupant compartment. The windscreen may be fractured but shall not be penetrated. The vehicle shall remain upright for not less than 12 m beyond the impact point with a roll angle less than 45 º and a pitch angle less than 45 º.

All the tests use a light vehicle to verify that impact severity levels are satisfactorily attained and compatible with safety for occupants of a light vehicle.

Energy absorption categories	Occupant safety level	Speeds			
		Mandatory low speed impact test 35 km/h		Speed class impact tests 50 km/h, 70 km/h and 100 km/h	
		Maximum values		Maximum values	
		ASI	THIV km/h	ASI	THIV km/h
HE	1	1,0	27	1,4	44
HE	2	1,0	27	1,2	33
HE	3	1,0	27	1,0	27
LE	1	1,0	27	1,4	44
LE	2	1,0	27	1,2	33
LE	3	1,0	27	1,0	27
NE	1	1,0	27	1,2	33
NE	2	1,0	27	1,0	27
NE	3	0,6	11	0,6	11
NE	4	No requirement	No requirement	See 5.6	

Figure 35: passively safe support structures performance classes according to EN12767 [49]

This means that the structures tested according to EN12767 are not all equivalent and criteria need to be given to select the proper performance class.

EN12767 itself states that different occupant safety levels and the energy absorption categories will enable national and local road authorities to specify the performance level of an item of road equipment support structures in terms of the effect on occupants of a vehicle impacting with the structure. Factors to be taken into consideration include:

- perceived injury accident risk and probable cost benefit;
- type of road and its geometrical layout;
- typical vehicle speeds at the location;
- presence of other structures, trees and pedestrians;
- presence of vehicle restraint systems.

Guidelines for selecting the most appropriate performance class of support structures according to EN12767 are given mostly in northern European countries (Norway, Finland [53], [54]) where this type of roadside supports have been in place for several years.

In UK a specific National Annex to EN12767 [50] has recently been issued to provide guidelines for the implementation of "passively safe" support structures in the UK. A synthesis of this National Annex is provided in a very comprehensive technical report issued by TRL in 2008 [55]. The guidelines for the selection of the most appropriate performance class according to EN 12767 in different situations are given in Figure 36.

Situation	**Location**	**Type of support structure**		
		Lighting column	Sign or signal support	Non-harmful support structures
Non-built up all-purpose roads and motorways with speed limits > 40 mph	Generally in verges of motorways, dual carriageways and single carriageway roads	100:NE:1-3	100:NE:1-3	100:NE:4
	With significant volume of non-motorised users	100:LE:1-3 or 100:HE:1-3	100:LE:1-3	100:NE:4
	Where major risk of items falling on other carriageways	100:LE:1-3 or 100:HE:1-3	100:LE:1-3	100:NE:4 or 70:NE:4
Built up roads and other roads with speed limits ≤40 mph	All locations	70:LE:1-3 or 70:HE:1-3	70:LE:1-3	100:NE:4 or 70:NE:4

Figure 36: guidance for the selection of passively safe support structures performance classes according to EN12767 given by UK National Annex [55]

The UK National Annex also gives advice regarding:

- Roof deformation;
- Structural requirements;
- Traffic signpost spacing and recommendations;
- Sign plate recommendations;
- Gantry sign supports;
- Foundations;
- Underground electrical connections.

In terms of construction techniques there are several strategies to make poles or posts "forgiving" and compliant with EN12767 (see Annex 1):

- *Material use*: The most obvious way to increase the energy-absorbance is to use materials with low stiffness. Wooden poles or posts should therefore be avoided. A good compromise between energy-absorbance and safety are poles made of fibreglass that absorb the energy on its entire length. The pole cracks without having a predetermined breaking point;
- *Splicing*: Incorrect practices of predetermined breaking points can result in vehicle snagging and flying parts. In order to achieve a safe breakaway, splices should be kept close to the ground. According to [2], multiple splices should be avoided. An example is given in Figure 37.

Figure 37: Breakaway/spliced pole (left) and slip base (right) [56]

- *Slip-base poles*: A characteristic of slip base poles is that, when impacted at normal operating traffic speeds, they are generally dislodged from their original position (see Figure 38). It enables the pole to slip at the base and fall if a collision occurs.

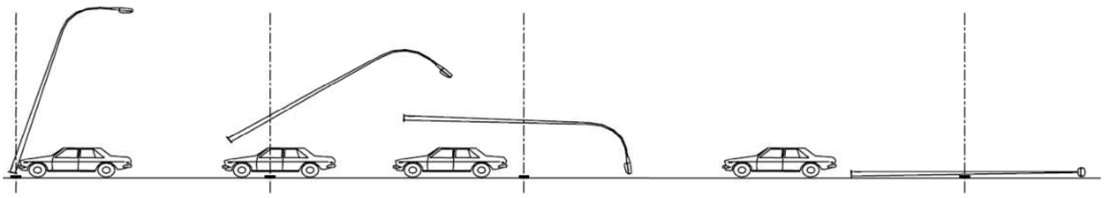


Figure 38: Vehicle impacting on a slip base pole [56]

- *Breakaway transformer base*: A transformer base, commonly made of cast aluminium, is bolted to a concrete foundation. The bottom flange of the pole is bolted to the top of the transformer base. The aluminium is heat-treated to make it “frangible,” so that the pole can break away from the base when struck by a vehicle.
- *Breakaway connectors*: When breakaway poles are used, the electrical conductors must also be breakaway. This is accomplished by using special pull-apart fuse holders (breakaway connectors). In the case of breakaway poles, the neutral must also have this breakaway connector but should be unfused. Breakaway connectors are fused or unfused connectors in the base of poles.

4.3 Assessment of effectiveness

Even though this type of structures have been in place for several years in several countries including most of the northern European counties (Norway, Finland, Sweden) and Iceland, sound statistical analyses of the effectiveness of using “passively safe” support structures in reducing the severity of crashes were not found.

In a passive safety support producers site ([57]) reference to 170 accidents involving EN12767 tested structures is given but no details are provided of the consequences of such events. The pictures shown in the web page (Figure 39) highlight the performance of the support structures when hit by a passenger car. The structure results stable with the passenger car going through it, potentially with minor damage.

Figure 39: “passively safe” sign support after being hit by a passenger car [57]

According to [48] field data from Massachusetts (five crashes) indicate that in the limited applications, there have been no serious injuries from crashes involving a specific type of passively safe utility pole while Texas reported one crash involving this type of utility pole. This crash did not involve a serious injury, although erosion had reduced the pole's effectiveness.

A risk assessment of the potential effect of using passively safe lighting columns and signposts has been performed in [55] by combining the likelihood of occurrence of different events that can lead to passenger injuries. Figure 40 shows the results obtained in terms of risk assessment for different lighting columns options on rural single lane carriageway roads where the conventional solution is compared with the traditional solution of protecting the column with a safety barriers and with the option of using a “passively safe” column. The risk associated with the use of “passively safe” o “forgiving” lighting columns resulted almost 8 times lower than the risk associated to conventional unprotected columns. The solution of protecting the column with a safety barrier is still 2 times higher than the risk associated by “passively safe” columns. Similar conclusions were derived for lighting columns on rural dual carriageways and for signposts on both single carriageway and dual carriageway rural roads.

Option	Risk (number of equivalent fatalities per year) on rural single carriageway					
	Errant vehicle occupants	Other road users				All road users
		Hit by falling column	Run into fallen column or debris	Shunt collision	Lane change collision	
Unprotected conventional lighting column 2.5m from edge of carriageway	0.0146	-	-	-	-	0.0243
Conventional column 2.5m from edge of carriageway with safety barrier protection	0.0036	-	-	-	-	0.0058
Passively safe column 2.5m from edge of carriageway	0.0017	0.000087	0.00013	0.000075	0.00017	0.0032

Figure 40: risk assessment for different lighting columns options on rural single lane carriageway roads [55]

4.4 Case studies/Examples

Forgiving or “passively safe” support structures are widely used in Europe and worldwide and therefore several different applications can be found.

In the web site http://www.ukroads.org/passivesafety/ a collection of “crash friendly” products in use in the UK is given.

4.5 References

4.5.1 Design guidelines and standards

When dealing with the issue of lighting, signs and support structures in the roadsides the following guidelines could be considered as a reference:

- Annex 1 to this report (for the definition of clear zones);
- SETRA “Guidelines – Handling lateral obstacles on main roads in open country” [47]
- The UK national Annex to EN12767 [50];
- Texas Department of Transportation highway illumination manual [58];
- The AASHTO Roadside Design Guide [9].

Any “passively safe” or “forgiving” support to be installed in Europe should be tested according to EN12767 standard [49], even in those countries where this standard has not yet adopted as mandatory for the approval of road equipment support.

5 Shoulder width

5.1 Introduction

The width of the outer shoulder (right for most of the European countries) is commonly recognised as an important roadside safety feature as it increases the recovery zone that allows an errant driver to correct it's trajectory without running off the road.

According to PIARC Road Safety Manual [59] on rural roads the shoulders should be clear of obstacles and stabilized in order to facilitate recovery of encroaching vehicles.

According to the SafetyNet report on Roads [60] the implementation of a shoulder (especially paved) or an emergency lane contribute to improve road safety on rural roads.

On the other hand too wide shoulders can lead not only to limited effects but also to counter-effects with an increase in accidents. The SafetyNet report indicates that this could occur when emergency lanes are wider than 3.00 m.

5.2 Design criteria

5.2.1 Outer shoulder width

Each country has its own design criteria for defining the proper outer shoulder width for different road types and it is therefore inappropriate to define a "recommended" design criteria as this might result in conflict with national standards that typically provide also additional requirements. As an example in Austria, France, Italy and Sweden the minimum outer shoulder widths required for different type of newly constructed rural roads are shown in Table 4. Very similar requirements are given for motorways with speed limits of 130 km/h (2.5 - 3.00 m) while for secondary roads with speed limits of 80 to km/h there is much more variability from the range 1.5-2.0 m used for conventional rural secondary roads in Austria, France and Italy, to 0.5 m used in Sweden for rural roads with no bicycles, 0.75-1.5 used for mountain road in France and 1.0 m used for local roads in Italy.

Table 4. outer shoulder width requirements in Austria, France, Italy, Sweden

	Road type	**Speed Limit (km/h)**	**Standard outer shoulder width (m)**	**Shoulder type**
Austria [61]	Motorway	130	2.50 - 3.00	Paved
	Motorway (special cases)	130	3.50 - 4.00	Paved
	Rural Road	100	1.50 - 2.00	Paved
France [47]	Motorway – Normal Traffic	130 (110)	2.50 - 3.00	Paved
	Motorway – Moderate Traffic	130 (110)	2.00	Shoulder coated over 1 m min
	Expressway	90	2.00 - 2.50	Shoulder coated
	Multifunction road – interurban main	90 (110)	2.00	Shoulder stabilised and preferably coated
	Multifunction road – single carriageway 2 lanes	90	2.00 (1.75)	Shoulder stabilised and preferably coated
	Multifunction road – mountain roads	90	0.75 to 1.50	Shoulder stabilised and preferably coated
Italy [62]	Motorway	130	2.50-3.00	Paved
	Divided Highway	110	1.75	Paved
	Secondary Rural Road	90	1.25-1.50	Paved
	Local Rural Road	90	1.00	Paved
Sweden [63]	Motorway	110	2.00	Paved
	Divided single carriageway (2+1) [No bicyclists]	100	0.50-0.75	Paved
	Divided single carriageway (2+1) [With bicyclists]	100	0.75-1.00	Paved
	Single carriageway [No bicyclist]	80	0.5	Paved
	Single carriageway [With Bicyclists]	80	0.75	Paved

5.2.2 Paved versus unpaved

Generally speaking paved shoulders are to be preferred to unpaved shoulders as these allow for a better control of an errant vehicle. According to Zegeer ([64], quoted in [59]) paving shoulders can lead to a 5% accident reduction. The results of the evaluation conducted in WP2 of the IRDES Project (see Annex 2) on high risk curves lead to the same conclusion that paved shoulders are a more effective treatment as compared to non paved shoulders.

In addition most of the national standards require, for new roads, paved outer shoulders.

It should be considered, on the other hand, that wide paved shoulders can induce wrong behaviours in the drivers, such as speeding due to the perception of reduced risk and using the shoulders as travel or passing lanes. One option to have wide paved shoulders limiting the visual negative effects could be to adopt a different colour for the outer part of the shoulder (Figure 41 and Figure 28, the latter referred to median shoulders).

Figure 41: use of different colours to reduce the drivers safety perception related to having wide shoulders [47]

5.3 Assessment of effectiveness

Several studies have shown that the outer shoulder width is a very important parameter in rural roads crash estimation for secondary rural roads and highways.

In the RIPCORD-ISEREST Project [65] a summary of the findings on the effects of shoulder width on secondary rural roads (single carriageway) can be found. The effects of widening the shoulders can be quite variable from one study to another but all of them are consistent in the indication that there is a positive effect for shoulder widths up to 3.00 m. In the same report several Safety Performance Functions are given and almost all of them include shoulder width as a variable in the model.

Since the publication of the Highway Safety Manual [17] in 2010 this has been considered the key reference for the definition of outer shoulder width on rural single carriageway two lane roads and multilane rural highways. The Crash Modification Factor (CMF) for shoulder width on rural two lane single carriageway roads, is given in Figure 42. This CMF applies only to a subset of the total crashes (single vehicle run-off-road crashes, multiple vehicle head on, opposite direction sideswipe, same direction sideswipe).

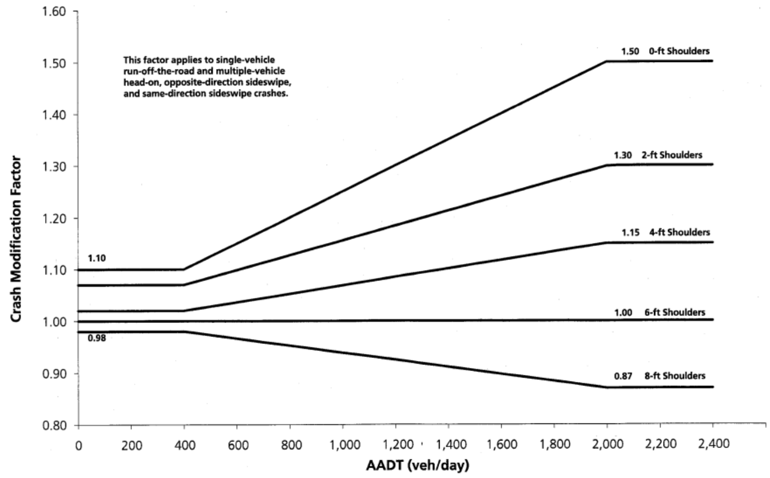


Figure 42: CMF for shoulder width effect on rural two lane single carriageway roads according to the HSM [17]

The effect of outer shoulder width in multilane undivided and divided highways is shown in Figure 43 and in Figure 44.

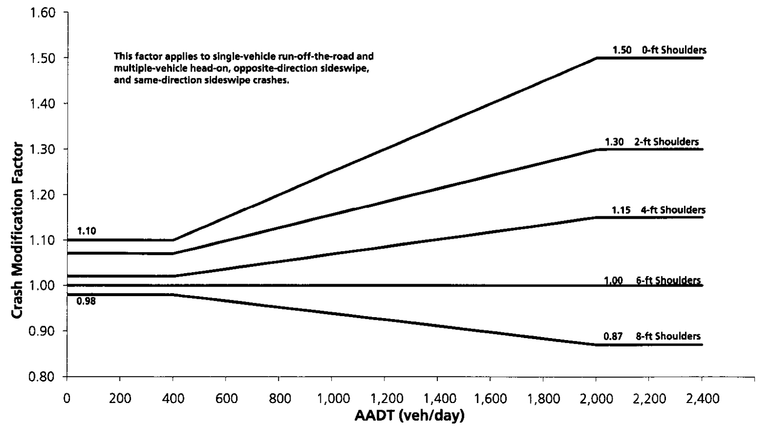


Figure 43: CMF for shoulder width effect on rural multilane undivided highways according to the HSM [17]

Average Shoulder Width (ft)				
0	**2**	**4**	**6**	**8 or more**
1.18	1.13	1.09	1.04	1.00

Note: This CMF applies to paved shoulders only.

Figure 44: CMF for shoulder width effect on rural multilane divided highways according to the HSM [17]

For motorways, which are not included in the current edition of the HSM, there are currently no consolidated CMF models to account for a variation in shoulder width and the effect of this factor should therefore be derived from the application of Safety Performance Functions having the shoulder width as one of the independent variables.

Two different studies have been selected for this type of roads:

- For open air sections the work recently published by Park [66] contains a summary of the most recent models develop for motorways. Out of the 4 models shown only 1 includes the outer shoulder width as an independent variable for rural lane models. The results of the analysis conducted by Park on Texas database confirmed that outer shoulder width is not a key variable for this type of roads but it should be noted that in 228 out of 256 pairs considered for the analysis the outer shoulder width was above 3.00 m. This results confirms that for shoulder widths larger than 3.00 m no significant benefit is achieved;
- In tunnels shoulder are often narrower than 3.00 m and the confined environment can affect the driver's behaviour and therefore the effect of outer shoulders could be more relevant. The Swiss Council for Accident Prevention [67] proposed the following model specifically developed for tunnels:

$$N = e^{\{-19{,}51+[0{,}77\cdot\ln(A)]+(-0{,}59\cdot B)+[1{,}61\cdot\ln(C)]+[0{,}12\cdot\ln(D)]+[-0{,}82\cdot\ln(E)]\}}$$

  where:

  N is the number if expected accidents;

  A is the tunnel length;

  B is the number of tubes (2 or 1);

  C is the ADT (Average Daily Traffic);

  D is the percentage of Heavy goods vehicles;

  E is the shoulder+sidewalk width (in metres).

A recent work conducted in Italy has shown that this model can be applied very well also for tunnels other than the ones used for the model development with a calibration coefficient of 0.93 required to apply the model on the Italian network [68].

As indicated earlier the effect of enlarging the outer shoulder width in rural roads is clearly positive for narrow shoulders while for larger shoulders this can be more questionable or even negative. It is therefore recommended that the CMF and predictive function given above are used for estimating the effects of having shoulder width below the national standards. For enlarging the shoulders above the national standards a specific risk assessment should be conducted and additional interventions to prevent the use of the extra width of the shoulder should be considered (such as using different colours as shown above).

5.4 Case studies/Examples

Within the IRDES Project 3 case studies have been conducted that related directly or indirectly to the evaluation of the effectiveness of changing the shoulder width and the type of shoulder (paved/unpaved).

In the experiment conducted in France (see Annex 2, chapter 3) the combined effect of lane width and shoulder width has been investigated (Figure 45). At the time of completion of the IRDES project the results of the experiment were not available yet and conclusion cannot be drawn. Yet this is a very important topic as section enlargement is often not achievable in existing roads and defining the optimal combination of lane width and shoulder width could lead to a safer road section. This same issue was recently addressed in a FHWA funded study specifically focusing on the safety evaluation of lane and shoulder width combinations [69].

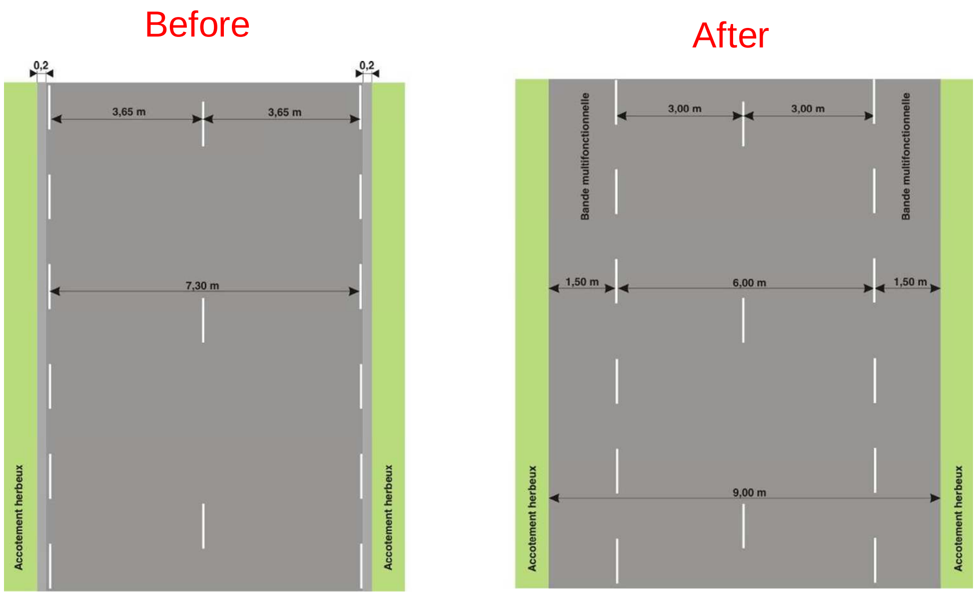


Figure 45: before/after configuration for the IRDES WP2 analysis of the combined effect of shoulder and lane width (Annex 2)

The experiment conducted in Austria (see Annex 2, chapter 6) was aimed at identifying the potential effectiveness of different type of treatments (including increasing the length of the shoulder, either paved or unpaved) in high risk bends. The example in Figure 46 shows that having a hard shoulder in the outer shoulder is the most effective treatment and that this is also more effective than placing a safety barrier.

Scenario (Number)	MAIS	Effectiveness
No forgiving roadside (1)	6	0%
Soft Shoulder (2)	2	70%
Hard Shoulder (3,4,5)	0	100%
Tree (6)	6	0%
Safety Barrier (7)	1	90%

Figure 46: Example of results from the analysis of the effectiveness of having soft (unpaved) and hard (paved) in high risk bend (Annex 2)

In the accident analysis conducted in Italy (see Annex 2, chapter 4) a safety performance function was developed for the rural single carriageway, two lanes roads and the shoulder width resulted as one of the most significant parameters affecting crash estimates.

6 Conclusion and recommendations

This guideline provided practical guidance for the use of:

- Barrier terminals
- Shoulder rumble strips
- Forgiving support structures for road equipment
- Shoulder width

and the criteria for assessing the effectiveness of this type of interventions on different type of roads.

The key issues can be summarized as follows:

Barriers terminals

Safety barrier ends are considered hazardous when the termination is not properly anchored or ramped down in the ground, or when it does not flare away from the carriageway and crashes with “unforgiving” safety barrier ends often result in a penetration of the passenger compartment and severe consequences.

Crashworthy terminals can be either flared or parallel, energy-absorbing or non-energy absorbing but in the latter case they have to be properly designed and flared to avoid front hits on the nose of the terminal. In some countries only devices tested according to ENV1317-4 are allowed.

The decision to use either an energy-absorbing terminal or a non-energy-absorbing terminal should therefore be based on the likelihood of a near end-on impact and the nature of the recovery area immediately behind and beyond the terminal. When the barrier length-of-need (see chapter 2.2.5) is properly defined and guaranteed and the terminal is therefore placed in an area where there is no need for a safety barrier protection it is unlikely that a vehicle will reach the primary shielded object after an end-on impact regardless of the terminal type selected. Therefore if the terrain beyond the terminal and immediately behind the barrier is safely traversable a flared terminal should be preferred.

If, for local constraints, the proper length of need cannot be guaranteed or if the terrain beyond the terminal and immediately behind the barrier is not safely traversable, an energy-absorbing terminal is recommended.

Turn-down terminals o flared-degraded terminals which have been commonly used in the last years in several counties are now often replaced in several countries in new designs by flared terminals with no degradation as the longitudinal slide that arises from the degradation to the ground can lead to an overriding of the barrier.

Additional issues to be considered in the terminals design, that are addressed in chapter 2, are:

- The definition of the “length of need”;
- The configuration of the terminals in the backfills;
- The configuration of the terminals in the medians;
- The configuration of the terminals adjacent to driveways.

In terms of effectiveness there are no before-after studies available but in WP2 of the IRDES projects a CMF to account for the number of unprotected terminals has been developed and could be used as a reference.

Shoulder rumble strips

Shoulder rumble strips have been proven to be a low cost and extremely effective treatment in reducing single vehicle run off road (SVROR) crashes and their severity.

For rural freeways the Crash Modification Factor (CMF) for the use of milled rumble strips has been estimated combining different studies in:

- 0.89 (which means potential reduction of crashes of 11%) for SVROR crashes, with a standard error of 0.1;
- 0.84 (which means potential reduction of crashes of 16%) for SVROR fatal and injury crashes, with a standard error of 0.1.

For rural two lane roads the Crash Modification Factor (CMF) for the use of milled rumble strips has been estimated combining different studies in:

- 0.85 (which means potential reduction of crashes of 15%) for SVROR crashes, with a standard error of 0.1;
- 0.71 (which means potential reduction of crashes of 29%) for SVROR fatal and injury crashes, with a standard error of 0.1.

Given the very low standard errors these results can be considered extremely reliable in estimating the potential effect of milled shoulder rumble strips on these type of roads.

For urban freeways and multilane divided highways the analysis data available do not yet allow for a statistically sound evaluation of the effectiveness but a best estimate of the effects of rolled shoulder rumble strips and milled shoulder rumble strips is given by the following:

- Rolled shoulder rumble strips on urban freeways are expected to reduce SVROR crashes by 18% and SVROR fatal and injury crashes by 13%;
- Milled shoulder rumble strips on rural multilane divided highways are expected to reduce SVROR crashes by 22% and SVROR fatal and injury crashes by 51%.

Different design configurations have been proposed for milled rumble strips:

- a “more aggressive” (and more effective) configuration that, can cause higher disturbance to bicycle drivers and to residents in the surrounding. This type of configuration is recommended when there are no residents in the vicinity of the road and when either a 1.2 m remaining shoulder is available or very limited or no bicycle traffic is expected;
- a “less aggressive” configuration that is more “bicycle friendly” and reduces the noise disturbance in the surrounding.

Rumble strips on “noncontrolled-access” highways should include periodic gaps of 3.7 m in length placed at periodic intervals of 12.2 m or 18.3 m to satisfy bicyclists’ need to cross the rumble strip pattern without causing them to enter the grooved area. This recommended length is sufficiently long as to permit a typical bicyclist to cross without entering the grooved area, but not so long as to permit a vehicle tire at a typical run-off-road angle of departure to cross the gap without entering the grooved area.

Shoulder rumble strips should not be placed closer than 200 m to an urban area where, if needed, rolled rumble strips could be considered as these produce less noise and do not affect bicycle handling.

Forgiving support structures for road equipment

This section of the guideline addressed the issue of identifying potential hazards in the roadside and defining the most appropriate solutions for making the hazard caused by support structures more forgiving. It is frequent to hear, amongst designers and road managers, that obstacles in the roadside NEED to be protected with safety barriers. This is a simplistic approach that should be overcome to reach a forgiving roadsides design approach as placing a barrier (with its length of need and its terminals) is not necessarily the most “forgiving” solution and it can be extremely costly as compared to the achieved benefits.

In this Guideline the procedure developed in the RISER Projects has been proposed and implemented. This requires to identify if the obstacle can be considered and hazard which means if it is within the clear zone clear zone and if it has structural characteristics that can lead to injuries to an errant vehicle impacting against the obstacle. Criteria for identifying the potential hazards are given in chapter 4.2.

Support structures that have been tested according to EN12767 standard are considered to be passively safety but different performance classes are given in the standard and guidelines for selecting the most appropriate performance class in different situations are given in chapter 4.2.

Even though this type of structures have been in place for several years in several countries including most of the northern European counties (Norway, Finland, Sweden) and Iceland, sound statistical analyses of the effectiveness of using “passively safe” support structures in reducing the severity of crashes were not found. On the other hand several studies can be found that indicated that crashes against these type of structures rarely lead to severe consequences.

A risk assessment of the potential effect of using passively safe lighting columns and signposts has been performed in the UK by combining the likelihood of occurrence of different events that can lead to passenger injuries. The risk associated with the use of “passively safe” o “forgiving” lighting columns resulted almost 8 times lower than the risk associated to conventional unprotected columns. The solution of protecting the column with a safety barrier is still 2 times higher than the risk associated by “passively safe” columns.

Shoulder width

The width of the outer shoulder (right for most of the European countries) is commonly recognised as an important roadside safety feature as it increases the recovery zone that allows an errant driver to correct it’s trajectory without running off the road but the effect of enlarging the outer shoulder width in rural roads is clearly positive for narrow shoulders while for larger shoulders this can be more questionable or even negative. It is therefore recommended that the CMF and predictive functions given in chapter 4.3 are used for estimating the effects of having shoulder width below the national standards. For enlarging the shoulders above the national standards a specific risk assessment should be conducted and additional interventions to prevent the use of the extra width of the shoulder should be considered (such as using different colours).

For rural single carriageway two lane roads and for multilane divided and undivided highways consolidated CMF functions can be found in the recently published Highway Safety Manual while for motorways in open air the effect of the shoulder width is often not found as these road type have usually an outer shoulder width of 2.50-3.0 m that has been shown to be the value above which no effect can be seen in crash reduction. For motorways in tunnels, where shoulder are often more narrow and the confinement affects the drivers behaviour, a specific Safety Performance Function is given to estimate the effect of having a reduced shoulder width.

Given the fact the national standards usually set the criteria for defining the minimum or standard outer shoulder width a “uniform” value was not proposed but the requirements given for rural roads in Austria, France, Italy and Sweden have been compared showing that the these are very similar for Motorways with speed limits of 130 km/h (2.50-3.00 m) while being more variable in the secondary road network with a speed limit of 80 to 100 km/h.

Glossary

Arrester bed
An area of land adjacent to the roadway filled with a particular material to decelerate and stop errant vehicles; generally located on long steep descending gradients.

Back slope (see ditch)
A slope associated with a ditch, located opposite the roadway edge, beyond the bottom of the ditch.

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 support
A sign, traffic signal or luminaire support designed to yield or break when struck by a vehicle.

Abutment
The end support of a bridge deck or tunnel, usually retaining an embankment.

Vehicle parapet (on bridges)
A longitudinal safety barrier whose primary function is to prevent an errant vehicle from going over the side of the bridge structure. It can be constructed from either steel or concrete.

CCTV Masts
A mast on which a closed circuit television camera is mounted for the purpose of traffic surveillance.

Carriageway
The definition of the 'carriageway' differs slightly amongst countries. The edge of the carriageway is delineated by either the "edge line" or, if no edge line is present, the edge of the paved area.

Central reserve
An area separating the carriageways of a dual carriageway road.

Clearance
The unobstructed horizontal dimension between the front side of safety barrier(closest edge to road) and the traffic face of the.

Clear/Safety zone
The area, starting at the edge of the carriageway, that is clear of hazards. This area may consist of none or any combination of the following: a 'hard strip', 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
A vehicle which comes in contact with a road restraint system and does not pass beyond the limits of the safety system.

Containment level
The 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 and tested to (EN 1317).

Crash cushion
A road vehicle energy absorption device (road restraint system) installed in front of a rigid object to contain and redirect an impacting vehicle ("redirective crash cushion") or to contain and capture it ("non-redirective crash cushion").

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.

Cut slope
The earth embankment created when a road is excavated through a hill, which slopes upwards from the level of the roadway.

Design speed
The speed which determines the layout of a new road in plan, being the speed for which the road is designed, taking into account anticipated vehicle speed on the road.

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 central reserve 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 protruding above the ground level at the edge of the paved surface.

Dual carriageway
A divided roadway with two or more travel lanes in each direction, where traffic is physically divided with a central reserve and/or road restraint system. See also ‘divided roadway’.

Edge line
Road markings that can be positioned either on the carriageway surface itself at the edge of the carriageway, or on the ‘hard strip’ (if present) next to the carriageway.

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

Encroachment
A term used to describe the situation when the vehicle leaves the carriageway and enters the roadside area.

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
An earth embankment created when extra material is packed to create the road bed, typically sloping downwards from the roadway.

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

Fore slope (see ditch)
The fore slope is a part of the ditch, and refers to the slope beside the roadway, before the ditch bottom.

Forgiving roadside
A forgiving roadside mitigates the consequence of the “run-off” type accidents and aims to reduce the number of fatalities and serious injuries from these events.

Guardrail
A guardrail is another name for a metal post and rail safety barrier.

Hard/Paved shoulder
An asphalt or concrete surface on the nearside of the carriageway. If a ‘hard strip’ is present, the hard shoulder is immediately adjacent to it, but otherwise, the shoulder is immediately adjacent to the carriageway. Shoulder pavement surface and condition as well as friction properties are intended to be as good as that on the carriageway.

Hard strip
A strip, usually not more than 1 metre wide, immediately adjacent to and abutting the nearside of the outer travel lanes of a roadway. It is constructed using the same material as the carriageway itself, and its main purposes are to provide a surface for the edge lines, and to provide lateral support for the structure of the travel lanes.

Highway
A highway is a road for long-distance traffic. Therefore, it could refer to either a motorway or a rural road.

Horizontal alignment
The projection of a road - particularly its centre line - on a horizontal plane.

Impact angle
For a longitudinal safety 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. 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 unit intended to separate areas of different surfacings and to provide physical delineation or containment.

Lane line
On carriageways with more than one travel lane, the road marking between the travel lanes is called the 'lane line'.

Limited severity zone
An area beyond the recovery zone that is free of obstacles in order to minimize severity in case of a vehicle run-off.

Length of need
The total length of a longitudinal safety barrier needed to shield an area of concern.

Median
See 'central reserve'.

Motorways
A dual carriageway road intended solely for motorized vehicles, and provides no access to any buildings or properties. On the motorways itself, only grade separated junctions are allowed at entrances and exits.

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, surface dressing or concrete (e.g. grass, gravel, soil, etc).

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 (or an obstacle).

Paved shoulder
See ‘hard shoulder’.

Pedestrian restraint system
A system installed to provide guidance for pedestrians, and classified as a group of restraint systems under ‘road restraint systems’.

Pier
An intermediate support for a bridge.

Point Hazard
A narrow item on the roadside that could be struck in a collision, including trees, bridge piers, lighting poles, utility poles, and sign posts.

Recovery zone
A 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, particularly a wall built to support or prevent the advance of a mass of earth.

Road restraint system (RRS)
The general name for all vehicle and pedestrian restraint systems used on the road (EN 1317).

Road equipment
The 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 roadway.

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

Roadway
The roadway includes the carriageway and, if present, the hard strips and shoulders.

Rock face cuttings
A rock face cutting is created for roads constructed through hard, rocky outcrops or hills.

Rumble strip (Shoulder rumble strips)
A thermoplastic or milled transverse marking with a low vertical profile, designed to provide an audible and/or tactile warning to the road user. Rumble strips are normally located on hard shoulders and the nearside travel lanes of the carriageway. They are intended to reduce the consequences of, or to prevent run-off road events.

Rural roads
All roads located outside urban areas, not including motorways.

Safety barrier
A road vehicle restraint system installed alongside or on the central reserve of roads.

Safety zone
See ’clear zone’.

Self-explaining road
Roads designed according to the design concept of self-explaining roads. The concept is based on the idea that roads with certain design elements or equipment can be easily interpreted and understood by road users. This delivers a safety benefit as road users have a clear understanding of the nature of the road they are travelling on, and will therefore expect certain road and traffic conditions and can adapt their driving behaviour accordingly. (Ripcord-Iserest, Report D3, 2008).

Set-back
Lateral distance between the way and an object in the roadside for clearance).

Shoulder
The part of the roadway between the carriageway (or the hard strip, if present) and the verge. Shoulders can be paved (see ‘hard shoulder’) or unpaved (see ‘soft shoulder’).
Note: the shoulder may be used for emergency stops in some countries; in these countries it comprises the hard shoulder for emergency use in the case of a road with separate carriageways.

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/Unpaved shoulder
A soft shoulder is defined as being a gravel surface immediately adjacent to the carriageway or hard strip (if present). In some countries it is used as an alternative for hard shoulders.

Soft strip
A narrow strip of gravel surface located in the roadside, beyond the roadway (normally beyond a hard strip/shoulder).

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.

Transition
A vehicle restraint system that connects two safety barriers of different designs and/or performance levels.

Travel/Traffic lane
The part of the roadway/carriageway that is travelled on by vehicles.

Treatment
A specific strategy to improve the safety of a roadside feature or hazard.

Underpass
A structure (including its approaches) which allows one road or footpath to pass under another road (or an obstacle).

Underrider
A motorcyclist protection system installed on a road restraint system, with the purpose to reduce the severity of a PTW rider impact against the road restraint system.

Undivided roadway
A roadway with no physical separation, also known as single carriageway.

Unpaved shoulder
See ‘soft shoulder’.

Vehicle 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. These are classified as a group of restraint systems under ‘road restraint systems’.

Verge
An unpaved level strip adjacent to the shoulder. The main purpose of the verge is drainage, and in some instances can be lightly vegetated. Additionally, road equipment such as safety barriers and traffic signs are typically located on the verge.

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

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Annex 1
State of the art report on existing treatments for the design of forgiving roadsides

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Executive summary

Analyses of fatal road accidents in the European Union show that 45 percent are single vehicle accidents. These accidents are primarily classified as run-off-road accidents, where the vehicle leaves the road and enters the roadside. A roadside is called unforgiving, if hazardous objects such as trees are placed in an inappropriate distance to the road so that the risk of severe accidents is increased.

The European road directors declared the implementation of forgiving roadsides as one of the most promising short-term measures to increase road safety. The purpose of this concept is to avoid crashes of errant vehicles or to minimize crash consequences.

The goal of work package one of the IRDES project is to collect and harmonize common standards and guidelines for roadside treatments. Initially, this deliverable introduces typical roadside hazards, which are the basis for appropriate counter-measures. The main part of this report comprises results and findings of relevant literature, guidelines and standards dealing with roadside treatments.

Summarizing the literature study, three categories of treatments are proposed:

1. The removing or relocation of potentially dangerous roadside objects
2. The modification of roadside objects or design
3. The shielding of roadside objects

These three categories determine the main structure of the report. The first category mainly comprises recommendations for so-called safety zones. These are obstacle-free areas beyond the travel lane in order to avoid collisions. Additionally, these zones assist drivers to perform easy recovery manoeuvres. Especially for road planning, an appropriate safety zone should be considered.

If hazardous obstacles cannot be removed or relocated, they need to be modified. Crashworthy structures or breakaway devices are common examples for modifications. Moreover, the design of slopes and ditches are relevant factors for a safe road.

In many cases, removing or modifying hazardous objects is not possible or economically advisable. Isolating or shielding the drivers from the respective objects helps to minimize the severity of a crash. Safety barriers and attenuators at bridge abutments are good examples for this kind of treatment.

The output of this deliverable is a harmonized collection of state-of-the-art treatments to make roadsides forgiving. In further work packages of IRDES, the effectiveness of the treatments will be assessed by several methods. The final outcome of the IRDES project is a practical guideline for forgiving roadside design in Europe, referring to the results and findings of this report.

List of Figures

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Abbreviations

Abbreviation	Definition
AADT	Annual average daily traffic
AASHTO	American Association of State and Highway Transportation Officials
ADT	Average Daily Traffic
CEDR	Conference of European Directors of Roads or Conférence Européenne des Directeurs des Routes
ERA-NET	European Research Area Network
IRDES	Improving Roadside Design to Forgive Human Errors
NCHRP	National Cooperative Highway Research Programme
PTW	Powered Two-Wheeler
RISER	Roadside Infrastructure for Safer European Roads
ROR	Run-off-road
RVS	Richtlinien und Vorschriften für das Straßenwesen
SVA	Single vehicle accident
TG	Technical Group
TRB	Transportation Research Board

1 Introduction

IRDES (Improving Roadside Design to Forgive Human Errors) is a research project of the cross-border funded joint research programme “ENR SRO1 – Safety at the Heart of Road Design”, which is a trans-national joint research programme that was initiated by “ERA-NET ROAD – Coordination and Implementation of Road Research in Europe” (ENR), a Coordination Action in the 6th Framework Programme of the EC. The funding partners of this cross-border funded Joint Research Programme are the National Road Administrations (NRA) of Austria, Belgium, Finland, Hungary, Germany, Ireland, Netherlands, Norway, Slovenia, Sweden and United Kingdom.

1.1 Motivation and goals

Each year 43,000 persons are fatally injured in Europe due to road accidents. The RISER project has shown that even though 10 percent of all accidents are single vehicle accidents (typically run-off-road (ROR) accidents) the rate of these events increases to 45 percent when only fatal accidents are considered (see [A.2]). One of the key issues of this high ROR fatality rate is to be found in the design of the roadsides that are often “unforgiving”. CEDR has identified the design of forgiving roads as one of the top priorities within the Strategic Work Plan. For this reason, a specific Team dealing with Forgiving Roadsides has been established within the Technical Group (TG) on Road Safety of CEDR.

A number of different studies have been conducted in recent years to design roadsides to forgive human errors, but there is still a need for:

- A practical and uniform guideline that allows the road designer to improve the forgivingness of the roadside
- A practical tool for assessing (in a quantitative manner) the effectiveness of applying a given roadside treatment

The aim of the IRDES project is to produce these two outputs with specific reference to a well identified set of roadside features. The goals of this report are to summarize state-of-the-art treatments to make roadsides forgiving, as well as to harmonize currently applied standards and guidelines.

A non-goal of this deliverable is to assess the effectiveness of the presented treatments. This topic is part of another work package of IRDES, where tools and methods to evaluate treatments are analysed.

1.2 Methodology

The project team of IRDES created the following work plan:

WP0: Coordination and Management

WP1: Collection and harmonization of studies and standards on roadside design

WP2: Assessment of Roadside Intervention Effectiveness

WP3: Production of a Roadside Design Guide

WP4: Pilot Project

WP5: Organization of Workshops and Round Tables

This deliverable presents the results and findings of Work Package 1, which include a collection of relevant literature, position papers, guidelines and project summaries regarding roadside design. The goal is to harmonise this literature under consideration of existing national and international standards. Therefore, all project partners provided the authors of this deliverable with information gathered about their national standards, as well as with relevant scientific documents. An expert workshop has not been carried out in the scope of this work package.

This report aims to harmonize common approaches for roadside treatments that are carried out throughout the world. By doing so, the basis is provided to develop a practical and uniform guideline for effective roadside treatments in WP3 of the IRDES project. After reviewing relevant literature, the following categories of treatments to improve roadside safety were worked out:

1. Removing and relocating obstacles
2. Modifying roadside elements
3. Shielding obstacles

These three categories are based on the works of Waugh [A.1] and the U.S. Department of Transportation [B.17] and define the structure of this deliverable (see Chapter 3.1 to Chapter 3.3). The idea of a fourth category called "Delineating road obstacles" is suggested in the Roadside Design Guide of AASHTO [B.1] and mentioned in [B.17]. It means that the driver's awareness of hazards should be increased when other treatments are not possible.

Existing roadsides can be improved and new roadsides can be safely constructed[1] by following a number of prioritised measures:

First, fixed objects that may be hazardous should be eliminated from the roadside. This provides a safety zone for the drivers to regain control over their vehicle, return to the travel lane or stop. Safety zones (sometimes called clear zones) are described in Chapter 3.1.1. Especially in the planning phase of a new road, safety zones should be considered. If fixed obstacles cannot be removed completely, it should be tried to relocate them. The further away an obstacle is located from the travel lane, the smaller the chance to hit it.

The second treatment category should be considered if the obstacle can neither be removed nor relocated. In this case, the structures of the objects should be modified in order to make it breakaway or energy absorbing, or even traversable like culvert ends.

In some cases, hazardous roadsides cannot be improved by applying the previous treatments. Isolating or shielding the drivers from the respective objects helps to minimize the severity of a crash. Safety barriers and bridge abutments are good examples for this kind of treatment. When no other measure can be made to work, hazardous roadside objects should be delineated and lane markings should be improved in order to limit the likelihood of runoff road accidents and obstacle hits.

These three categories can be seen as top-level treatment types that will be subdivided into several single treatments. They are explained in subchapters, containing references to existing standards, guidelines or research papers.

1.3 Definition of roadside

According to the RISER project [A.2], a roadside is defined as the area beyond the edge line of the carriageway. There are different views in literature on which road elements are part of the roadside or not. In this report, the median is considered as roadside, since it defines the area between a divided roadway. Therefore, all elements located on the median are considered as roadside elements as well. Figure 1 depicts a roadway cross section (cut and embankment section) including some roadside elements. In this specific figure, the roadside can be seen as the area beyond the traffic lanes (or carriageway). The shoulders are thus part of the roadside, since the lane markings define the boundaries. The slopes, the clear zones (also called safety zones) or the tree are examples for roadside features that will be described in the following chapters in detail.

[1] These improvements for new roadside should also be applied to existing roads, whenever possible.

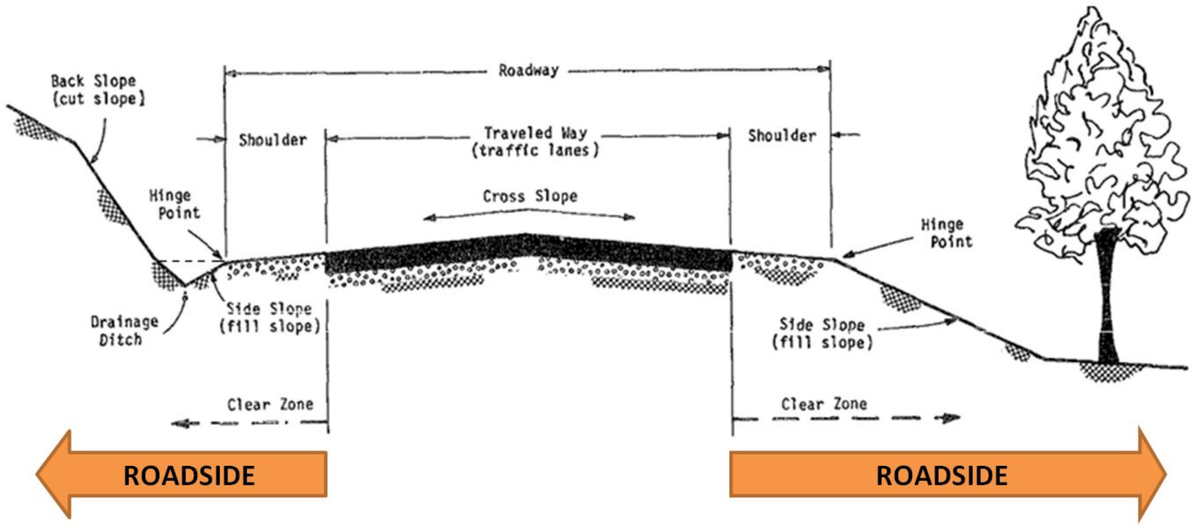


Figure 1: Roadway cross section with examples for roadsides with clear zones [B.17]

1.4 Forgiving vs. self-explaining

Forgiving and self-explaining roads are two different concepts of road design, which aim at reducing the number of accidents on the whole road network. The project IRDES and therefore this report only deals with forgiving roadsides. However, the term “self-explaining” needs to be defined in order to differentiate it from the term “forgiving”.

According to [A.5], self-explaining roads are based on the idea that appropriate speed or driving behaviour can be induced by the road layout itself. They therefore reduce the need for speed limits or warning signs. It is generally known that multiple road signs in complex traffic situations can lead to an information overload and an increasing risk of driving errors. Herrstedt [A.6] writes that a safe infrastructure depends on a road-user-adapted design of different road elements such as markings, signs, geometry, equipment, lighting, road surface, management of traffic and speed, traffic laws etc. The idea behind self-explaining roads is to design the road according to an optimal combination of these road elements.

In short, it can be said that self-explaining roads aim at preventing driving errors, while forgiving roads minimize their consequences. The first priority of forgiving roadsides is to reduce the consequences of an accident caused by driving errors, vehicle malfunctions or bad roadway conditions. It must be focused on treatments to bring errant vehicles back onto the lane to reduce injury or fatal run-off-accidents. If the vehicle still hits a road element, the second priority is to reduce the severity of the crash. In other words, the roadside should forgive the driver for their error by reducing the severity of run-off-road accidents.

2 Roadside hazards

The forgiving roadside concept emerged in the mid 1960s to account for the fact that vehicles can run off the roadway. The reasons for vehicles to leave the roadway have been grouped into [B.1] the following:

- Driver operation such as inattention, fatigue, influence of alcohol or drugs, evasion manoeuvres, excessive speed etc.
- Roadway conditions such as poor alignment, poor visibility, reduced pavement friction, inadequate drainage, substandard signing, marking or delineation etc.
- Vehicle malfunctions such as steering and braking failures, tire blowouts etc.

The main factors that affect the severity of a run-off-road accident are the layout and type of objects within the roadside. A main objective of designing forgiving roadsides is to provide clear zones, which is not always possible. Some roadsides have potential hazards for the drivers close to the carriageway. Often the placement of certain objects such as lighting poles, traffic signs or bridge barriers cannot be avoided. Other objects such as embankments, slopes or ditches affect roadside safety and should be treated in an effective manner. As stated in [B.17], a roadside object is considered hazardous when one or more of the following events occur:

- The vehicle is abruptly stopped.
- The passenger compartment is penetrated by some external object.
- The vehicle becomes unstable due to roadside elements.

In [B.2], a roadside hazard is any non-breakaway or non-traversable roadside feature that is greater than 100 mm in diameter or thickness. The RISER project showed that trees are the most dangerous roadside objects. Around 17 percent of all tree accidents recorded were fatal [A.2]. In the case studies of this investigation, where speed data were known, all fatal accidents involved impact speeds of 70 km/h or more. Structures such as signs, concrete walls, fences etc. are hit in 11 percent of all fatal single vehicle accidents (SVA). According to the RISER accident analysis, safety barriers appear to be the object most impacted in SVA. However, safety barrier SVA generally resulted in minor injuries. It should be noted anyhow that safety barriers themselves can pose a hazard if not properly designed and installed.

The study in [C.1] is based on the U.S. Department of Transportation's Fatality Analysis Reporting System (FARS) and shows the results of an analysis of fatal accidents caused by striking fixed objects. In total, 8,623 fatalities have been analysed. Figure 2 shows the distribution of fixed object crash deaths in 2008. It clearly depicts the high percentage of tree accident deaths (48 percent). Utility poles and traffic barriers were the next most frequent objects struck.

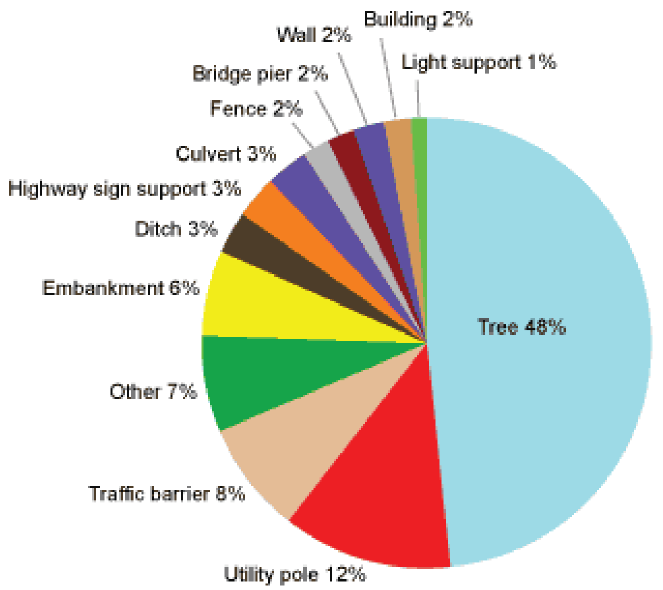


Figure 2: Percent distribution of fixed object crash deaths, based on 8,623 fatalities, 2008 [C.1]

In many crashes, the vehicle hits more than one roadside object. A study published by the Roads and Traffic Authority of New South Wales in Australia [A.7] examined the specific types of roadside objects that were hit by vehicles in second impacts. The analysis only contained fatal accidents and indicates again that trees are the most frequently struck roadside objects, followed by utility poles and embankments. Trees and utility poles have the highest percentage of objects hit in first as well as second impact (see Figure 3). An interesting result of the study is the fact that water bodies only contribute in secondary object hit fatalities.

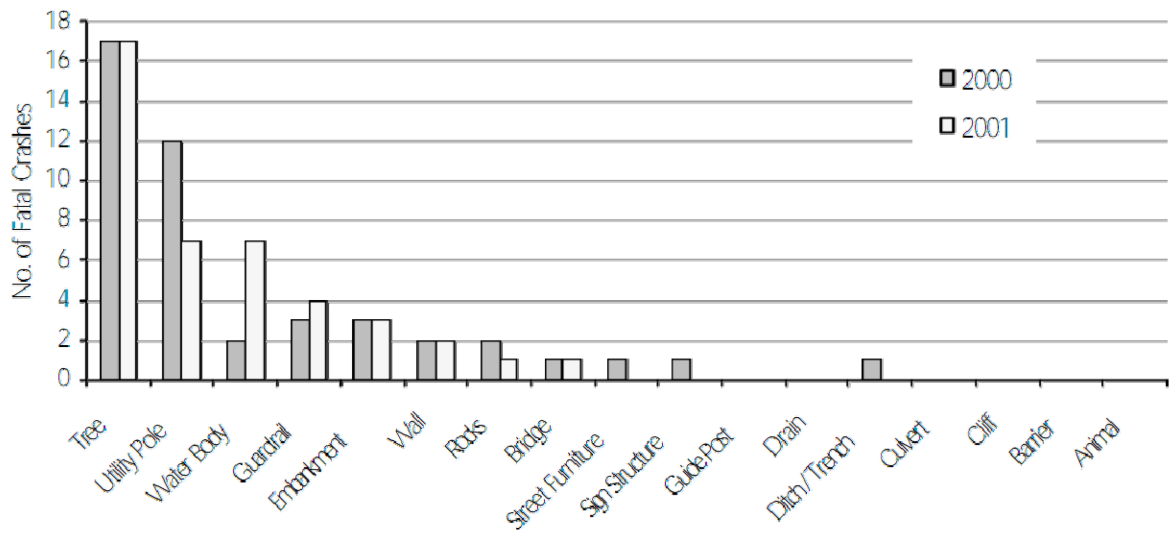


Figure 3: Roadside objects hit in second impact, based on 1,029 fatal accidents, NSW 2000 & 2001 [A.7]

This chapter deals with roadside hazards and gives an overview about a high number of exemplary objects. Treatments to improve hazardous roadside elements are presented in Chapter 3.1 to Chapter 3.3. The works in [B.17] and [A.2] present similar categorisations of hazardous obstacles. In this report, they are harmonised as follows:

1. Single fixed obstacles
2. Continuous obstacles
3. Dynamic roadside hazards

2.1 Single fixed obstacles

According to several studies, single or point objects make up the highest number of potential hazards along the roadside. According to [B.5], point hazards are defined as permanent installations of limited length. They can be natural or artificial, human-made structures made of different materials. Of course, large rigid structures such as bridge abutments cause the most severe accidents, since they do not provide sufficient energy absorbance. On the following pages, different examples of single obstacles as well as their degree of hazardousness are explained.

2.1.1 Trees and other vegetation

Accident analyses in [A.7] and [C.1] proved that tree crashes claim a high number of fatally injured victims. Compared to other roadside obstacles, trees or other rigid vegetations seem to be most hazardous. According to the RISER project, trees become particularly dangerous when the diameter exceeds 20 cm (see [A.2]) – in France it is 10 cm. The impact speed is considered dangerous if higher than 40 km/h. According to a study in [A.8], the injury severity for tree collisions is much higher than in all accidents recorded (see Figure 4).

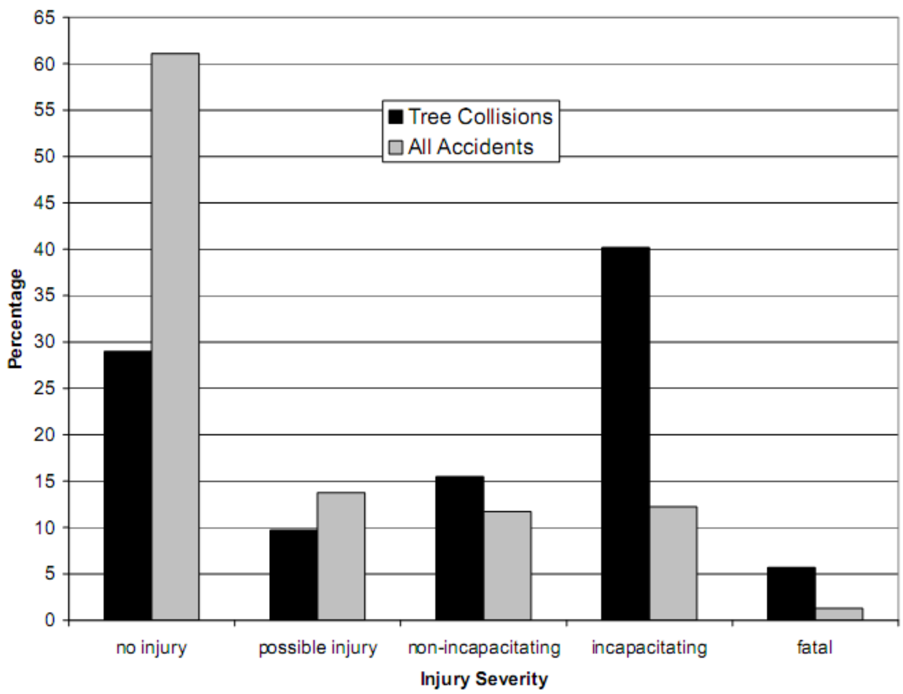


Figure 4: Relative frequency of injury severity for tree collisions and all accidents (in percent), based on 1,830 tree accidents [A.8]

A guide from the NCHRP [B.3] contains an interesting analysis of the relation between the average distance of trees to the travel lane and tree accidents. It shows that shorter distances result in more accidents. The example pictures in Figure 5 show trees that are located too close to the road without delineation or shielding. In the right picture, the tree was the second impacted object, after the vehicle hit the kerb.

Figure 5: Examples for hazardous trees located on the roadside (Source: [B.6], [C.6])

However, one should also consider a tree as an aesthetic roadside design element, as Bratton and Wolf did in [A.8]. Simply removing trees can be an emotional community issue. There are research gaps on how trees can be effectively incorporated into a safe roadside design that promotes community values and environmental amenities. Guidelines for a safe and aesthetic design of urban roadside treatments have been worked out in [B.4].

2.1.2 Utility poles

Utility poles typically carry power or telephone overhead cables. The poles are often made of rigid wood or concrete and can therefore be called “unforgiving”, since the energy absorbance ability is minimal. Two examples for hazardous utility poles located on the roadside are depicted in Figure 6. In both pictures, the poles are located within one meter of the road and are not shielded.

Figure 6: Two examples for hazardous utility poles (Source: [C.4])

Figure 2 shows that utility poles are the second most hazardous roadside obstacles regarding fatal accidents. One primary finding of a study by Mak and Mason [A.9] was that pole accidents are mostly urban problems with approximately 37 pole accidents per 100 miles of highway (~161 km) as compared to 5.2 for rural roads. They also found that pole accidents in rural areas have higher impact severities than urban pole accidents. Of course, the impact severity depends on the driving speed, which is generally higher on rural roads.

2.1.3 Sign and lighting posts and supports

Other than utility poles, the structures described here carry lights or traffic and warning signs. Mostly, they must be located close to the roadway and cannot be removed or relocated. They are hazardous if they are non-breakaway during impacts. The results in [C.1] show that sign and light supports cover four percent of the fixed object crash fatalities. The literature regarding in-depth analyses of crashes with pole facilities is limited.

In the RISER project, guidelines throughout Europe have been collected which define a minimum diameter of different types of posts and supports beyond which they are no longer considered safe. Further information can be found in [A.3]. Figure 7 shows two examples of hazardous poles on the roadside.

Figure 7: Examples for hazardous sign poles (Source: [A.3])

2.1.4 Abutments and tunnel entrances

Abutments, overpasses, bridge piers and walls at tunnel entrances are mostly made of rigid concrete and are considered extremely hazardous. According to RISER [A.3], such objects are dangerous, if the diameter of a pier is greater than 1 metre, if they are too close to the roadway or if they are unshielded. Often, the entrance to a tunnel is constructed in a way that does not allow a vehicle to slide along the structure. However, walls and bridge piers have a relatively small percentage of crash fatalities compared to other fixed objects (see Figure 2). Examples for a hazardous bridge abutment as well as an overpass are depicted in Figure 8.

Figure 8: Examples for a hazardous bridge abutment (left) and overpass (right) (Source: [A.2])

2.1.5 Safety barrier terminals and transitions

Safety barriers are forgiving roadside treatments to shield hazardous obstacles and/or to prevent vehicles from running off the roadway. However, the ends or transitions between two different types of rails can be hazardous roadside objects. Safety barrier ends are considered hazardous when the termination is not properly anchored or ramped down in the ground, or when it does not flare away from the carriageway [A.3]. The RISER database contains 41 accidents where barriers were the only obstacles involved. In 14 cases (i.e. 34.1 percent), the termination of the barrier was hit. Crashes with “unforgiving” safety barrier ends often result in a penetration of the passenger compartment.

The most common transition section occurs between bridge rail ends and approach barriers. In these cases in particular, the transitions may cause high decelerations and are therefore “unforgiving”. Figure 9 depicts two examples for dangerous safety barrier terminations. In the right picture, a transition between bridge rail and roadway guardrail is missing. Both ends have no proper end treatment.

Figure 9: Examples for hazardous safety barrier terminations

2.1.6 Rocks and boulders

Single rocks and boulders are dangerous obstacles when located too close to the roadway. Exposed outcrops mainly occur on roads constructed in a rocky environment, where the provision of a safety zone is expensive. A further hazard resulting from rock cuts on the roadside are fragments that can fall down from steep slopes onto the roadway. See Figure 10 for examples of such roadside hazards.

Figure 10: Examples for hazardous boulders (left) and rocks (right) on the roadside (Source: [A.2] and [A.3])

2.1.7 Drainage features

In case a vehicle runs off the road, drainage features like culverts or culvert ends are hazardous roadside obstacles. They are commonly used to channel a water course and are made of concrete, steel or plastic. According to [C.1], three percent of all fixed object crash deaths are caused by culverts. The examples in Figure 11 depict hazardous drainage structures. As seen in the left picture, these features are often made of rigid material, which cannot absorb the impact energy.

Figure 11: Examples for hazardous drainage features (Source: [A.2])

2.1.8 Other single fixed obstacles

Besides the obstacles mentioned above, other roadside objects may be hazardous for drivers. Single rigid structures like masonry road markings, hydrants, unshielded houses, artwork, etc. are common roadside features that must be treated in an effective manner. In the last decade, many roundabouts were subject to an artistic redesign to let the middle appear more attractive. Some of these artworks are extremely hazardous due to "unforgiving" construction and protruding parts. Especially motorcyclists can be seriously injured or killed when hitting such an artwork.

2.2 Continuous hazards

Continuous hazards are distributed objects that are of considerable length, making it unpractical to remove or relocate them. On the following pages, several examples of continuous hazards and their impact on roadside safety are presented.

2.2.1 Embankments and slopes

An embankment is a man-made ridge of earth or stone that carries a road or railway. The term comprises all kinds of sloping roadsides including cut and fill slopes (see Figure 12). A cut slope is the face of an excavated bank required to lower the natural ground line to the desired road profile. In contrast to that, a fill slope is the face of an embankment required to raise the desired road profile above the natural ground line[2]. How hazardous a slope is depends on its height or depth, its steepness and distance to the roadway. A detailed analysis of standards in different countries defining the thresholds for those parameters has been performed in the RISER project [A.3].

[2] Definitions taken from the Ministry of Forests of Government of British Columbia

Figure 12: Examples for hazardous cut (left) and fill slopes (right) (Source: [A.2])

According to [C.1], embankments are hit in 6 percent of all fixed object crash deaths. The risk of a vehicle rollover is high when hitting an embankment, especially when it is a steep slope. The study also showed that nearly a third of all fatal embankment accidents are caused by rollover. This is the highest percentage of all objects included in the analysis.

2.2.2 Ditches

Ditches are defined as drainage features created to channel water, which mostly run parallel to the roadway. They are formed by the sideslope and backslope planes. Roadside designers must ensure that ditches are wide enough to provide adequate drainage and snow storage capacity. According to [B.2], a ditch deeper than 1 metre and with a sideslope steeper than 4:1 is considered hazardous and should be treated in an effective manner.

Figure 13: Examples for hazardous roadside ditches (Source: [B.8])

The graphic in Figure 2 shows that 3 percent of all fixed object crash fatalities are caused by run-offs in ditches. The literature on injury severity of ditch accidents is limited.

2.2.3 Road restraint systems

After trees and utility poles, road restraint systems (e.g. steel safety barriers, cable barriers, etc.) are the third most dangerous roadside obstacles [C.1]. Although mostly barrier terminations are hit, the rails themselves can be considered roadside hazards as well. The goals of a barrier are to prevent a vehicle from running off the road, as well as to protect vulnerable road users from traffic. Median barriers are commonly used to separate traffic in different directions and with high differential speeds.

Safety barriers should be constructed in a way to smoothly redirect impacting vehicles at a low departure angle [B.2]. However, accident studies have shown that redirected vehicles often interact with other vehicles, which results in severe accidents. Furthermore, some barriers are made of rigid or semi-rigid material to prevent run-offs at bridges or other dangerous roadsides. Some countries consider cable barriers as a hazardous roadside obstacle, especially from motorcyclists. Much research has been done in this area and there is little or no evidence that cable barriers / wire rope safety barriers are any more dangerous to motorcyclists than the normal metal Armco barriers-it is the poles that hold up the wire rope safety barrier and the Armco barrier which are the problem for motorcyclists. When a motorcyclist falls off their bike they are usually sent sliding along the road and the poles are their main concern. On the contrary, wire rope safety barrier is a lot more forgiving than either concrete barrier or metal Armco barriers - it will deflect and absorb the energy of the impact, while still containing the vehicle. As such it should not be considered any more of a hazard than any other safety barriers (see Figure 14).

Figure 14: Examples of collisions with safety barriers (Source: [A.10], [C.2])

2.2.4 Kerbs

In many urban environments, roadway shoulders are not practicable as a roadside treatment. Instead, kerbs are commonly used to prevent run-off-accidents. A kerb is typically the edge between a sidewalk and a roadway and consists of concrete, asphalt or a line of kerbstones. One purpose is to prevent motorists from driving onto the roadside, while the other purpose is to ensure an efficient drainage of the roadway. It should be noted that kerbs – like road restraint systems – are a treatment to improve roadside safety, but can simultaneously prove a hazard for motorists. A summary of studied safety aspects of kerbs in [B.4] includes the finding that kerbs do not have the ability to redirect vehicles upon impact. The most significant factor influencing a vehicle's trajectory is kerb height. Improper kerb design may lead to an impact with a second obstacle such as other vehicles or can cause vaulting of the vehicle.

2.2.5 Permanent water bodies

The term permanent water body describes rivers, lakes, canals or small ponds that are located on the roadside. When a vehicle enters the water body, the main hazard, which is the risk of drowning, arises.

2.2.6 Other continuous obstacles

During the creation of this report, a discussion arose whether forests should be included as continuous obstacles or not. The RISER guidelines distinguish between trees and a line of trees, since the treatments to improve them may differ. A whole line of trees, often planted for aesthetic reasons, is not as practical to remove or relocate as a single tree. Thus, they must be shielded using safety barriers.

Other distributed hazards could be unshielded pipelines or rigid structures like continuous walls. Rock outcrops may be considered continuous as well.

2.3 Dynamic roadside hazards

In [B.4], the term dynamic roadside features can be found, which include

- bicycle facilities,
- pedestrian facilities and
- parking.

In contrast to the hazards presented in Chapter 2.1 and 2.2, dynamic hazards are not fixed but moving. Dynamic roadside features are more prevalent in urban environments, which are generally more complex than rural roadsides. The literature regarding the relationship between dynamic roadside elements and roadside safety is limited. On the one hand, bicycle lanes or sidewalks provide an additional clear zone for drivers. On the other hand, bicycle hardware such as racks may be potential hazards for drivers. However, the risk concerns the pedestrians using the sidewalk rather than the drivers of vehicles. This leads to a different approach of roadside treatments, since the persons moving on the roadside must be protected. A study of the FHWA [A.10] determined that 11 percent of all pedestrian-vehicle-crashes recorded occurred at roadside locations such as sidewalks or parking lots.

In many urban environments, on-street parking is necessary and requires approximately 2.4 metres from the roadside. This results in a reduction of the travel lane width, as well as limited possibilities for clear zones. The risk of accidents caused by vehicles attempting to pull in or out of a parking space may rise, and sight distances are shortened. There is a need for treatments to ensure proper sight distances and safe separation of the travel lane and parking lots.

3 Treatments to make roadsides forgiving

In the previous chapter, a high number of potential hazards were described which affect roadside safety. This chapter deals with treatments for those hazards, considering three types of strategies to improve roadside safety:

1. Removing and relocating obstacles (see Chapter 3.1)
2. Modifying roadside elements (see Chapter 3.2)
3. Shielding obstacles (see Chapter 3.3)

In literature, delineation is often mentioned as treatment if all of the three measures above are unfeasible. Delineating can help a driver to avoid hitting roadside hazards. However, this measure is not included as a separate chapter, because it belongs to the strategies for self-explaining and not for forgiving roads.

Based on the proposed four steps for the treatment of roadside hazards written in [B.5], the following procedure was worked out for this report:

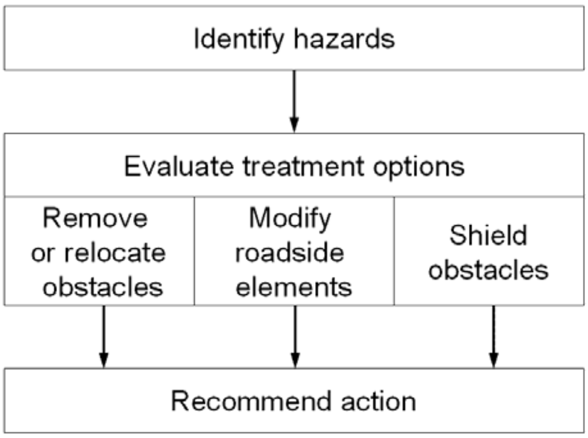


Figure 15: Procedure for forgiving roadside treatments

The three steps in Figure 15 can be applied either on existing roads or in the planning phase for new roads. Potential hazards must also be considered during planning, and the treatment may primarily be to provide a safety zone (often called clear zone) on the roadside. On existing roads, the identification of hazards can be established by road safety inspections or using accident histories. Moreover, hazards are identified by considering traffic volumes and speeds, road geometry, surface properties and the expected severity of crashes.

Another approach presented in [B.2] includes an additional step before the hazard identification: Determine desirable clear zone. Based on data such as design speed, slope information, curvature, topography or non-removable road furniture, the clear zone requirements are identified. The desirable clear zone width is the basis for the removing or relocation of obstacles. In this report, the step to determine safety zone requirements is included in the first category of treatments and will be explained in Chapter 3.1.1.

Several treatment options, which are the main concern of this report, are typically evaluated in a quantitative and qualitative assessment procedure. The assessment of treatments as well as their effectiveness will be dealt with in work package 2 of the IRDES project and are not described in this deliverable. The evaluation phase may result in a number of options, from which a treatment can be chosen. The outcome is one or more recommended actions, based on a prioritisation of the treatments.

3.1 Removing and relocating obstacles

3.1.1 The safety zone concept

The most obvious roadside improvement can be accomplished by providing a so-called safety zone, i.e. providing an obstacle-free area with a flat and gently graded ground. Removing hazardous roadside features provides motorists with room and condition to regain control over their vehicle in case of a run-off. Objects that cannot be eliminated should be relocated outside the safety zone. The safety zone can be divided into two areas: the recovery zone (shoulders) and the limited severity zone (see Figure 16).

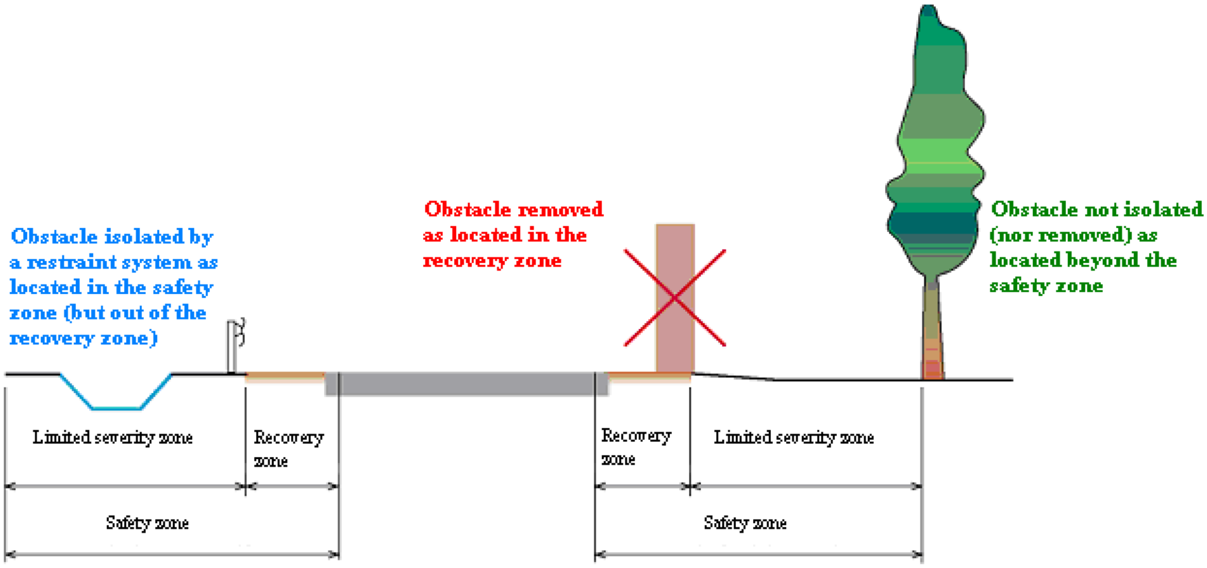


Figure 16: Safety zone definition, as depicted in [B.9]

Many national definitions do not distinguish between these two types of zones, only mentioning the need for a safety zone that may consist of a shoulder, a recoverable slope, a non-recoverable slope, as well as a clear run-out area. However, the two concepts are handled in separate chapters in this report.

The width of safety zones varies throughout the world depending on the underlying policy and practicability. Within the project RISER, the national dimensions for a safety zone of seven different European countries have been determined. Common criteria for the dimensioning are:

- Design speed
- Side slope gradients
- Road type
- Traffic flow/volume
- Horizontal alignment (straight or curved roads)
- Driving lane width
- Percentage of heavy-vehicles
- Evaluation of personal and third party risks

A detailed table of the dimensions depending on different parameters can be found in [A.3]. Generally, the higher the design speed, the wider the safety zone should be. The same relation is valid for curve radii. In [B.5], it is mentioned that safety zones also depend on traffic volumes. The widths dependent on speed limits, as defined in five different countries, are depicted in the diagram in Figure 17. In Sweden [B.16], a “good” safety zone lies between 3 and 14 meters, depending on curve radius and design speed. The width for safety zones on inner curves is generally lower than on outer curves. A study from Australia indicates that the desirable safety zone for straight high-trafficked roads with 100 km/h zones is 9 metres wide [B.5].

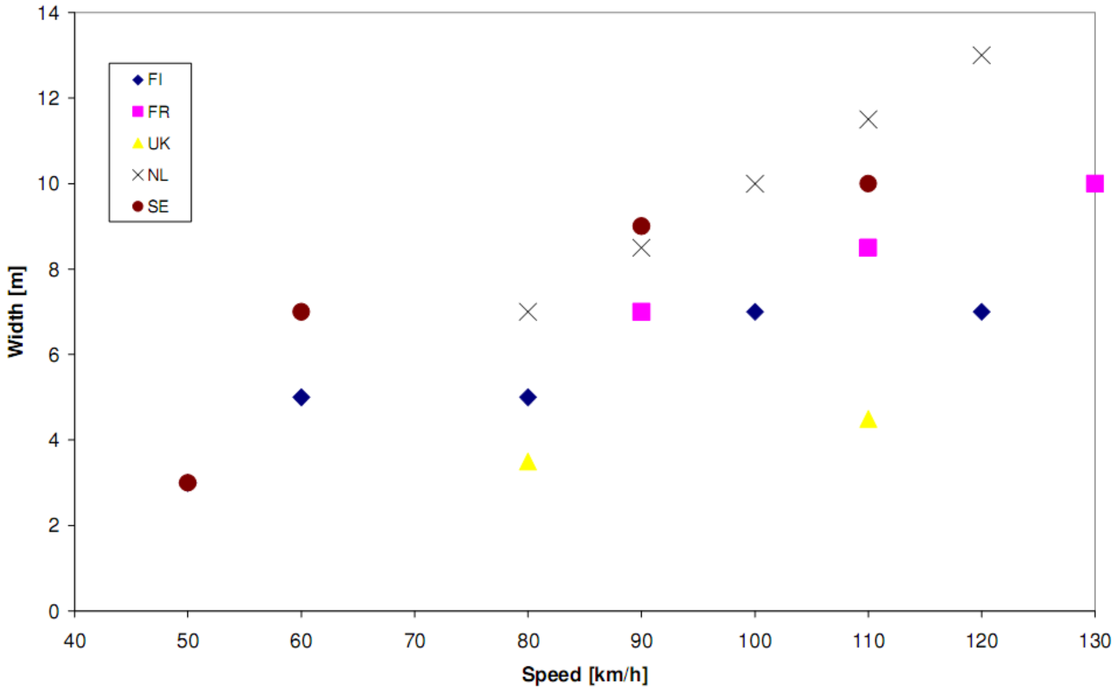


Figure 17: Safety zone widths as a function of speed limit for different countries [A.3]

The AASHTO Roadside Design Guidelines include a calculation method for clear zone widths, which is the most used worldwide. It is a function of the posted speed, side slope, and traffic volume. For further information see [B.1].

The government of Western Australia proposes a method, where the width of an appropriate safety zone (clear zone) is determined in three steps [B.5]:

1. Determine the desirable clear zone width (CZ) for a straight road based on the 85th percentile speed and the one-way traffic volume (see Figure 18). In general, the higher the speed and the AADT, the higher the zone width.
2. Multiply the CZ by an adjustment factor F_c, which is a function of operating speed and curve radius (see Figure 19). This factor increases with higher speeds and lower curve radii.
3. Compute a value called effective clear zone width (ECZ) that depends on the roadside slope gradients (see Figure 20). W_B is the batter width, W_1 is the width from the edge of the traffic lane to the beginning of the slope and W_2 is the width from toe of batter.

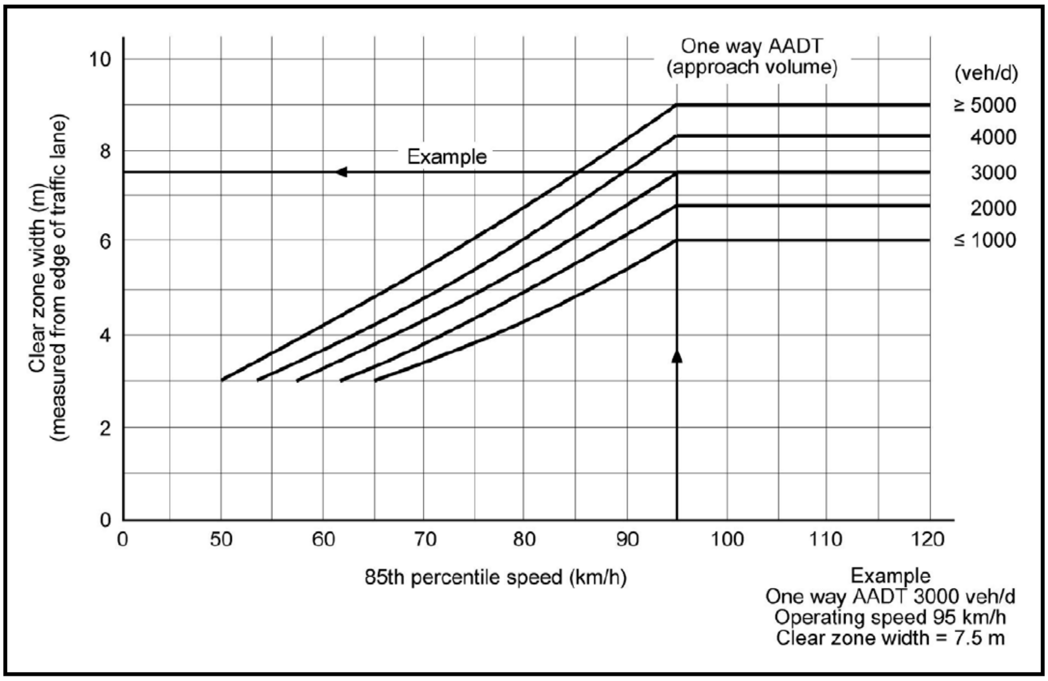


Figure 18: Clear zone distances based on 85th percentile speed and AADT [B.5]

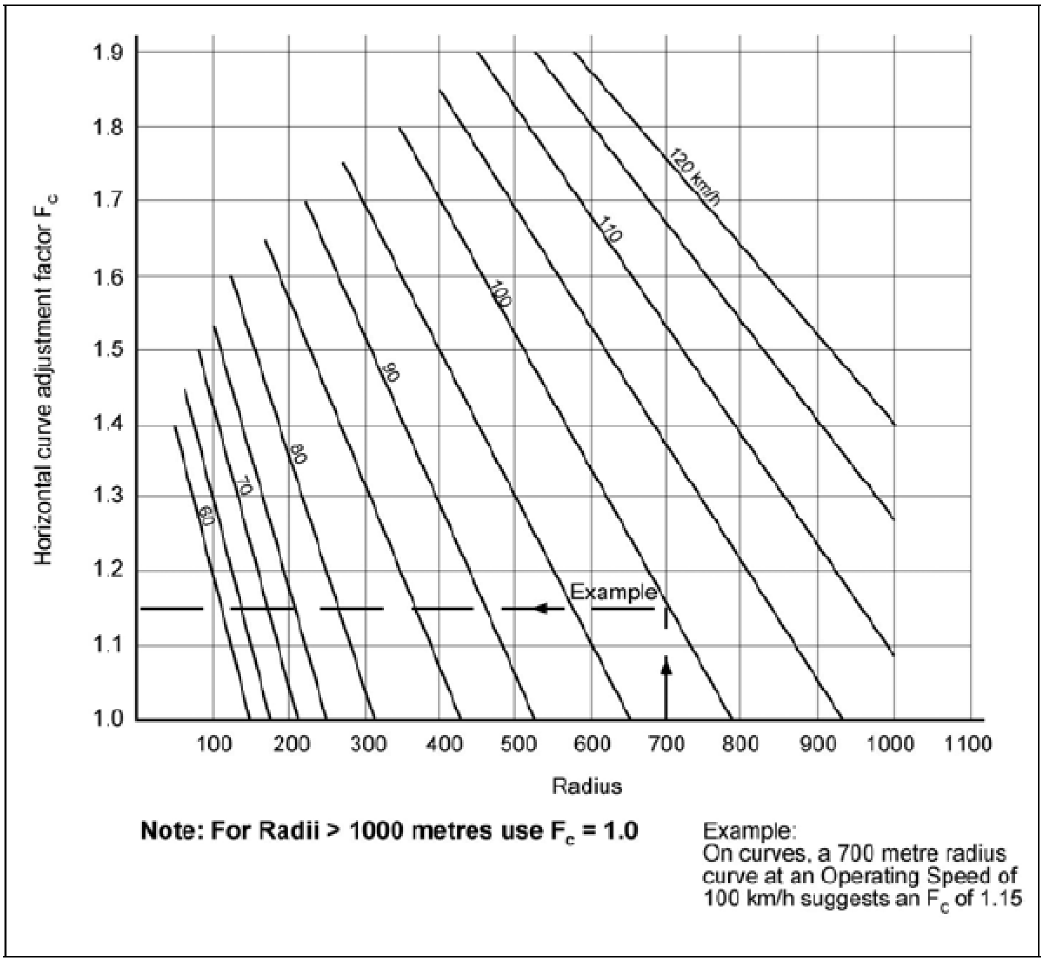


Figure 19: Curve adjustment factors to multiply with the clear zone width [B.5]

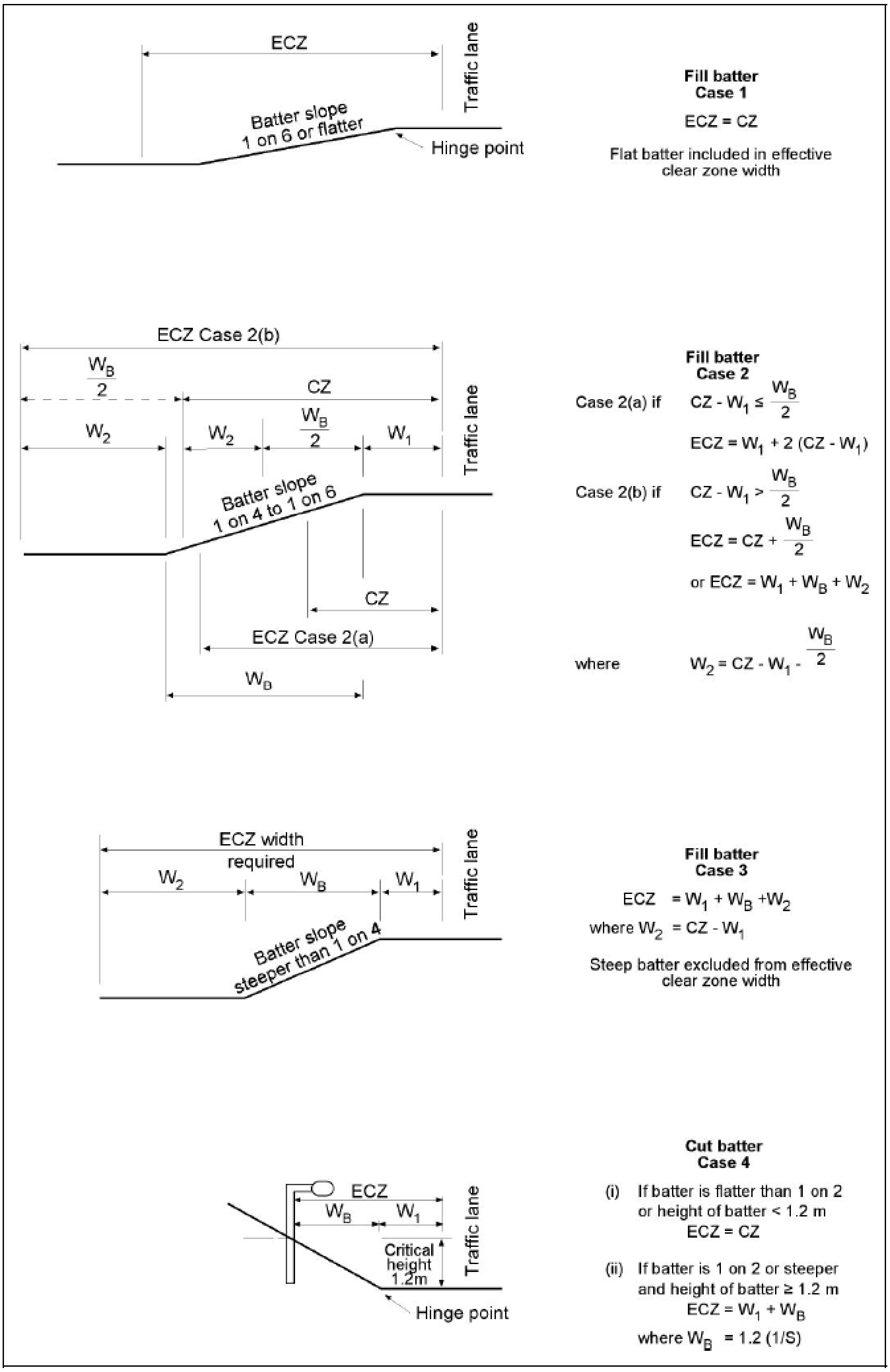


Figure 20: Calculation of the ECZ based on roadside slope [B.5]

3.1.1.1 Recovery area

According to [B.9], a recovery area is a side strip next to the pavement and is available for road users to perform easy recovery manoeuvres. It must be free of any obstacles so that drivers can return to the travel lane or can stop if necessary. The recovery zone is commonly defined as a hard or soft shoulder lane located immediately beyond the carriageway edge line. In Germany, the recovery zone is defined as a roadside shoulder area for emergency rescue services [A.3]. However, mostly it is not considered as a separate issue, but included in the total safety zone. Providing a recovery zone can comprise the following treatments:

- Hard shoulder construction
- Soft shoulder construction
- Enhancement of existing shoulders
- Median shoulders

A hard shoulder is a paved surface immediately beyond the carriageway edge line. The skid resistance of the surface should be as good as the carriageway surface in order to avoid skidding accidents. Hard shoulders are commonly used to provide emergency lanes, parking lanes, bicycle or pedestrian lanes. Several studies have proven the positive effect of hard shoulders on road safety. According to studies of Elvik and Vaa [A.12], rural roads with hard shoulders have an accident rate reduction of about 5 to 10 percent compared to rural roads without shoulders. An additional advantage of shoulders is the improved sight distances in curves.

Figure 21: Examples of a hard (left) and soft shoulder (right) (Source: [A.4])

Examples for shoulders are given in Figure 21. In contrast to hard shoulders, soft shoulders are unpaved areas beyond the paved carriageway e.g. in Austria [B.21], the width of unpaved shoulders depends on the travel lane width and lies between 0.25 and 0.5 metres. High drop-offs from paved to unpaved surfaces should be avoided, since they can be hazards in case of a run-off. However, this approach is not valid for roads with high level of traffic, where unpaved shoulders are not allowed. Other elements must be considered such as road geometry, space available, allocation of shoulder, traffic composition, etc.

The dimensions of shoulders have been heavily discussed among road engineers and safety experts. Instead of solely considering shoulder width as a safety aspect, the interdependencies between number of lanes and lane width need to be analysed. Wider shoulders may encourage higher driving speeds. For countries where the recovery zone is clearly stated as a separate issue, the widths vary between 0.25 and 4 metres, depending on the road type, travel lane width or design speed. Generally, the higher the design speed of the road, the wider the recovery zone. Based on the intended usage of the recovery zone, the widths are recommended between 1 to 1.5 metres for the recovery of errant vehicles and 3 to 4 metres for emergency lanes.

3.1.1.2 Limited severity zone

Some guidelines distinguish between the recovery area and the rest of the safety zone. The so-called limited severity zone does no longer attempt to prevent vehicles from leaving the road, but to minimize the severity in case of a run-off. It is defined as the area beyond the recovery zone, but is still part of the safety zone.

Figure 22: Broad limited severity zone, but narrow recovery area [B.9]

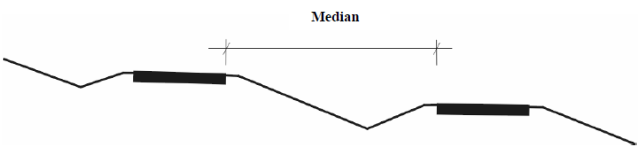
Any hazardous obstacle should be removed from this zone. This includes the removal of any single hazards such as poles, light supports or trees, as well as continuous hazards such as walls. Since the limited severity zone is not explicitly mentioned in most guidelines and standards, dimensions are not always provided. In some countries, the side slope gradient is taken into account for the zone width.

3.1.1.3 Median shoulders

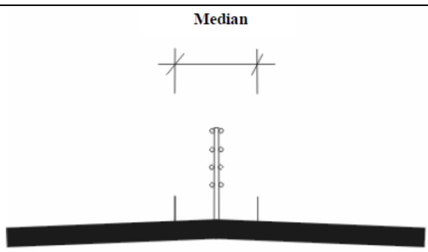
The median, also called central reserve, separates travel lanes for traffic in opposite directions. In most documents, it is not considered as part of the roadside, but as a separate issue. It is mentioned in this report though, because a median can reduce run-off-road accidents or minimize their severity. An additional benefit of medians includes the provision of recovery areas for errant vehicles and emergency stopping. In urban areas, medians are commonly used for pedestrian refuge and traffic control device placement. They can also be planted to improve the visual environment. Past research studies have found three safety trends regarding medians [A.14]:

1. Crashes between opposing vehicles are reduced with medians.
2. Median-related crashes decrease as the median width increases beyond 30 feet (9.1 metres). Up to 30 feet, the crashes increase as the median width increases.
3. The effect of median widths on total crashes is questionable.

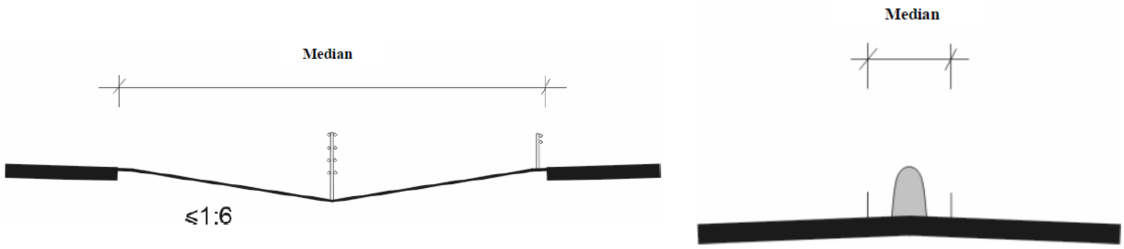
The recommended widths vary from country to country because they depend on the available space, as well as the intended use of the median. According to a Swedish Standard [B.16], medians can be divided into several types:



a) Median designed as slope, without barrier



b) Median between 1.5 and 2.5 metres with barrier



c) Median width >2.5 metres with barrier

d) Median between 1.5 and 2.5 metres with rigid barrier

Figure 23: Different types of medians [B.16]

When the median is designed as a slope (upper left picture in Figure 23a), the width can vary, but should be wide enough to separate both carriageways horizontally and in profile. A safety zone should be considered or barriers installed in order to prevent collisions with obstacles.

Figure 23b and Figure 23d depict medians with barriers between 1.5 and 2.5 metres. The two roadways have a common alignment, and the median between is typically paved.

Figure 23c shows a median greater than 2.5 metres with a barrier. The surface can be soft or paved and the slope gradient should not be steeper than 1:4.

A special type of median is a tunnel wall that separates two carriageways. The tunnel wall needs to fulfil the requirements on safety zones and barriers.

3.1.2 Arrester beds in lane diverge areas

Arrester beds in lane diverge areas are treatments for vehicles that have lost their braking ability. They are able to slow down and stop a vehicle going off the road without an impact against a crash cushion and are often used on roads with long downgrades e.g. in mountainous areas. They are also called emergency escape ramps or runaway truck lanes, because they are mainly designed to accommodate large trucks to prevent roadside accidents. The principal factor for the need of an arrester bed is determined by runaway accident experience. The ramps are often built before a critical change in the curvature of the road, or before a place that may require the vehicle to stop, such as an intersection in a populated area. The surface of the arrester bed is made of a specific material that increases rolling resistance and allows the vehicle to decelerate. Common arrester beds are composed of a layer of granular material of suitable aggregate size, shaped with geometry specifically designed to favour the sinking of vehicle wheels. Examples are given in Figure 24.

Figure 24: Examples for arrester beds [C.3]

There is a lack of specific guidelines dealing with the design or requirements of arrester beds. Typically, accident statistics, the relation between operation speed and road gradients or curvature are relevant for the construction of the ramp. To design an arrester bed, a detailed analysis is needed. Length will vary depending on speed and grade. The AASHTO developed a policy on geometric design of highways and streets, including design principles for escape ramps [B.24]. The length required by the ramp can be calculated using the equations in Figure 25.

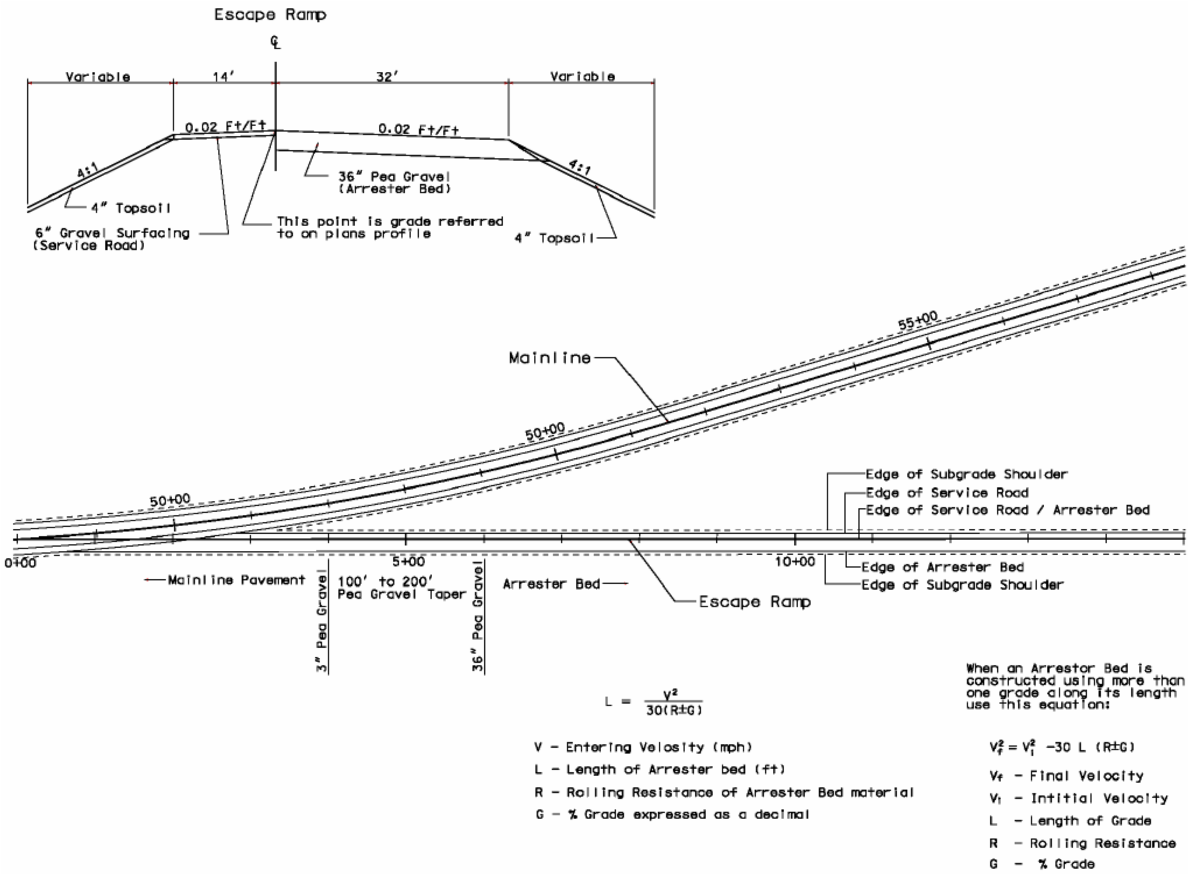


Figure 25: Escape ramp layout [B.24]

3.1.3 Safe plantation

Following the principle of safety zones, hazardous plants or trees should be removed from the specified roadside area. However, grass, weeds, brush and tree limbs can obscure or limit a driver's view of traffic control devices, approaching vehicles, wildlife and livestock, and pedestrians and bicycles. Even if hazardous plants have been removed from the roadside, the growth of plants and mature trees can lead to new roadside obstacles. Controlling vegetation therefore helps to reduce crashes and injuries. Road operators are encouraged to develop roadside vegetation management programs to eliminate or minimize vegetation. The FHWA of the U.S. Department of Transportation published a guideline for vegetation control, which includes several treatments such as regular mowing, cutting or the use of herbicides (see [B.6]). The NCHRP published a guide to eliminate tree crashes or to reduce the harm that results from a collision [B.3]. One major objective of this guideline is to prevent trees from growing in hazardous locations.

3.2 Modifying roadside elements

In some cases, hazardous obstacles cannot be removed from the roadside safety zone. Single and continuous hazards need to be modified in order to minimize injury or property damage at a crash. They must be improved by making them breakaway or crashworthy. The following chapters show different treatments to make non-removable objects more forgiving.

3.2.1 Breakaway devices

Since the 1980s, road authorities have installed collapsible lighting columns to increase roadside safety. The advantage is a smaller likelihood of impact damage and injury, while the disadvantage is the falling pole that can be a hazard to surrounding traffic, pedestrians or property. Non-breakaway poles are still used if pedestrian traffic is high, overhead electric lines are close or if the pole is mounted atop a concrete traffic barrier. However, breakaway poles are preferred in most roadside areas. There are several strategies to make poles or posts “forgiving”. This can be achieved by the following modifications:

- *Material use*: The most obvious way to increase the energy-absorbance is to use materials with low stiffness. Wooden poles or posts should therefore be avoided. A good compromise between energy-absorbance and safety are poles made of fibreglass that absorb the energy on its entire length. The pole cracks without having a predetermined breaking point.
- *Splicing*: Incorrect practices of predetermined breaking points can result in vehicle snagging and flying parts. In order to achieve a safe breakaway, splices should be kept close to the ground. According to [B.17], multiple splices should be avoided. An example is given in Figure 26.

Figure 26: Breakaway/spliced pole (left) and slip base (right) [C.4]

- *Slip-base poles*: A characteristic of slip base poles is that, when impacted at normal operating traffic speeds, they are generally dislodged from their original position (see Figure 27). It enables the pole to slip at the base and fall if a collision occurs.

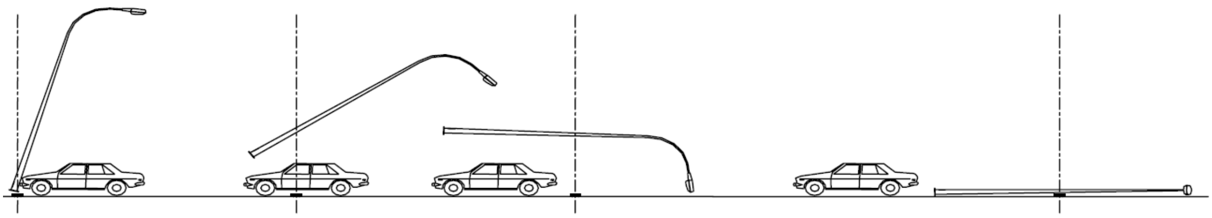


Figure 27: Vehicle impacting on a slip base pole [C.4]

- *Breakaway transformer base*: A transformer base, commonly made of cast aluminium, is bolted to a concrete foundation. The bottom flange of the pole is bolted to the top of the transformer base. The aluminium is heat-treated to make it "frangible," so that the pole can break away from the base when struck by a vehicle.
- *Breakaway connectors*: When breakaway poles are used, the electrical conductors must also be breakaway. This is accomplished by using special pull-apart fuse holders (breakaway connectors). In the case of breakaway poles, the neutral must also have this breakaway connector but should be unfused. Breakaway connectors are fused or unfused connectors in the base of poles.

The Texas Department of Transportation published a highway illumination manual (see [C.5]) that includes specific guidelines for the placement and use of breakaway devices. According to the manual, the falling area must be considered in the placement of breakaway poles. To prevent secondary accidents due to falling poles, they should be placed so that a sufficient falling area is ensured.

3.2.2 Ditch and slope treatments

Ditches are used as drainage features on roadsides. They usually consist of a foreslope, a ditch bottom with or without drainage features and a backslope. If ditches are considered hazardous, they need to be modified to increase safety. Based on the shape of the ditch, several treatments are state of the art:

- *Buried drainage*: Removing is imposed when the ditch is useless. Usually, drainage is necessary and thus cannot be removed. An effective treatment is to fill the ditch with draining materials after fitting a collector. This eliminates any hazardous sideslopes from the safety zone.
- *Modify slope ratio*: If a ditch cannot be removed, the slopes should be kept as shallow as possible. In general, the steeper the foreslope or backslope, the higher the risk for drivers of errant vehicles. So-called recoverable sideslopes permit the driver to regain control over the vehicle. Recoverable slopes have a slope ratio of 4:1 or flatter. For higher traffic volumes, sideslopes should be designed with a 6:1 ratio. Although the influence of backslopes is generally less than that of foreslopes, a ratio of 3:1 or flatter is recommended [B.2]. Examples for safe ditches are depicted in Figure 28.
- *Bottom modifications*: Ditch bottoms can either be sloped or flat. Thomson and Valtonen [A.17] investigated the behaviour of errant vehicles in V-shaped ditches. They proved that rounding the bottom prevents vehicles from a rollover. As a conclusion, they recommend a rounded bottom ditch with a foreslope of 4:1 and backslope 2:1.Ditches must be designed wide enough to provide adequate drainage and snow storage capacity. For reasons of safety, the width of the bottom should be at least 1 metre. In [B.2], a minimum width of 1.2 metres is preferred. Very shallow and wide ditch bottoms may require additional buried drainage.
- *Cover ditches*: Another common treatment is to cover the ditch with gutters or any other drainage system. This is particularly recommended at roadsides where a deep ditch is needed. Examples are given in Figure 29.
- *Modify masonry structures in ditches*: Ditches often include drainage features such as culverts, kerbs or control dams, which are made of rigid, non-energy-absorbent material. These structures need to be made crashworthy by modifying their shape.
- *Isolate most dangerous ditches*: Isolating ditches means to shield them from errant vehicles. The space required for an adequate road restraint system must be taken into account. This type of treatment is discussed in Chapter 3.3.
- *False cutting*: It is a shape of road embankment which is able to create a ground division between road section and external environment so that the roadside appears to drivers like a cutting, such as a linear artificial hill. This kind of artificial hill can also prevent the road to be seen from an external point of view.

In 2009 a Finish report on full-scale crash tests and simulations of ditches and slopes has been published. [A.18]

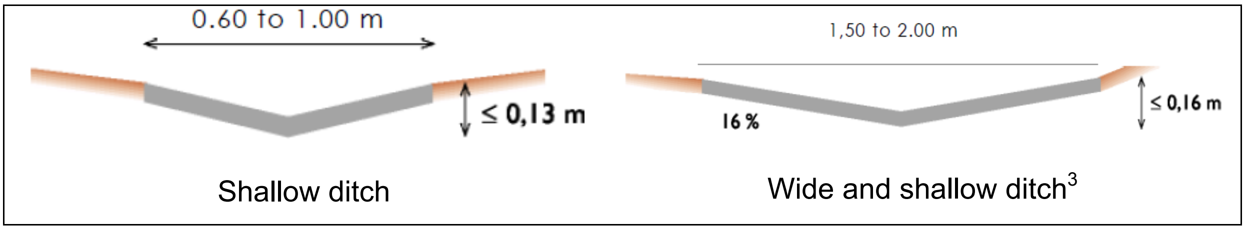


Figure 28: Examples for safe ditch design[B.9]

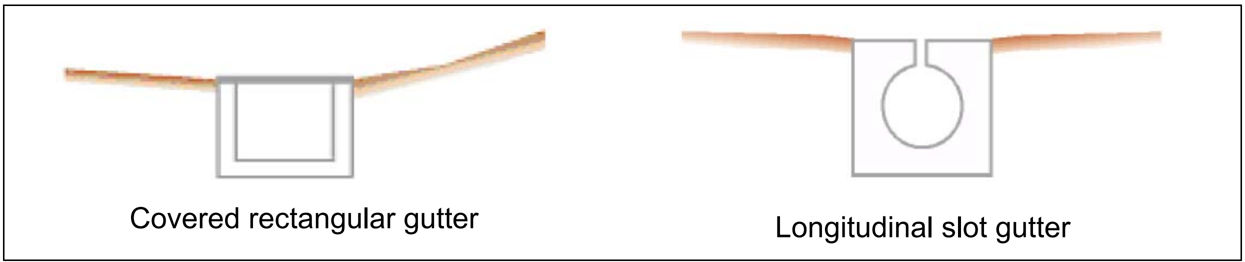


Figure 29: Examples for covering ditches [B.9]

3.2.3 Crashworthy masonry structures

Masonry structures such as parapets, culverts or kerbs can often be found on roadsides, especially at ditches or bridges. They generally have a minimal energy-absorbance and are thus very hazardous obstacles for errant vehicles. If they cannot be removed from the safety zone, these structure need to be modified in an appropriate manner. Other masonry structures such as bridge piers, walls or buildings, which cannot be removed or relocated, should be shielded with a road restraint system. Isolating or shielding the obstacles – which is the most appropriate strategy - is subject of Chapter 3.3. This chapter deals with treatments to modify masonry structures to make them crashworthy.

If a vehicle runs off the road into a ditch, culvert ends can be hazardous obstacles. If they cannot be removed, safer designs need to be considered. A common treatment for culvert ends is bevelling (see Figure 30).

Figure 30: Bevelled culvert end (left) and chamfered parapet (right) (Sources: [A.2], [B.9])

Short parapets, mostly found at bridges to protect errant vehicles from running off the slope, are hazardous due to their rigidness. If possible, they should be removed or replaced by a lighter barrier. However, in some cases modifying the structure of the parapets is a cheap and easy treatment. When the parapet is too short to protect errant vehicles, it should be

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[3] In literature, the slope gradient is specified in different ways. Either ratios (e.g. 4:1, 1:4) or percentages are common.

extended to an adequate length. The ends of a parapet can be chamfered to minimize the aggressiveness in case of a collision (see Figure 30). Ideally, the ends have an offset to the outside. This kind of treatment can be applied to any other masonry structure that cannot be removed from the safety zone.

In this report, kerbs are also categorized as masonry structures. They serve as drainage control, pavement edge or walkway delineation. As mentioned in [B.9], kerbs are not considered as obstacles if their height does not exceed 20 cm. However, hitting a vertical kerb may cause an errant vehicle to mount or launch. Therefore, special design treatments of kerbs increase roadside safety. The Transportation Research Board published guidelines dealing with kerb and kerb-barrier installations [B.28]. When kerbs must be used on high-speed roads, the shortest possible kerb height and flattest slope should be used to minimize the risk of tripping the vehicle in a nontracking collision. The shape of the kerbs is a safety-relevant feature that depends on the operating speed of the roadway. Vertical kerbs should be used at low-speed roads, since they may cause vehicle roll-overs at high impact speeds. Sloping kerbs are configured such that a vehicle can safely ride over the kerb. They prevent vehicles from being redirected back into the traffic stream and are therefore the recommended option on highways and high-speed roads.

Figure 31: Vertical kerb (left) and sloping kerb (right)

Often, kerbs are used in combination with road restraint systems. In the scope of this report, kerb-barrier combinations have also been researched. The state of the art is presented in Chapter 3.3.6.

3.2.4 Shoulder modifications

Shoulder treatments that promote safe recovery include shoulder widening, shoulder paving, and the reduction of pavement edgedrops. Shoulders may not always be flush with the roadway surface. Such shoulder edgedrops can be caused by soil erosion next to the pavement, rutting by frequent tyre wear or from repaving, where material is added to the lane but not to the adjacent shoulder. This hazard needs to be treated by bevelling the edges or by levelling the pavements. It is common to slope the edge with an angle of 45 degrees [B.4].

If the skid resistance of a paved shoulder is insufficient, treatments to increase surface friction should be applied. Moreover, any other hazardous surface damages such as potholes or cracks need to be eliminated from the shoulder.

3.2.5 Modification of retaining walls and rock cuts

According to [B.9], a wall is acceptable in the safety zone when it meets the following conditions:

- longitudinal to the road or virtually (offset < 1/40th);
- no protrusion nor edge likely to block a vehicle, or better: smooth;
- heights over 70 cm;

- sufficiently sturdy to withstand an impact.

If a hazardous wall or continuous rock cannot be removed from the safety zone, its extremities need to be treated or isolated if possible. Rough walls or rocks must let the vehicle slide in case of an impact. Therefore, its surface is typically smoothed and cavities between protrusions are filled with masonry. Examples for wall treatments are depicted in Figure 32.

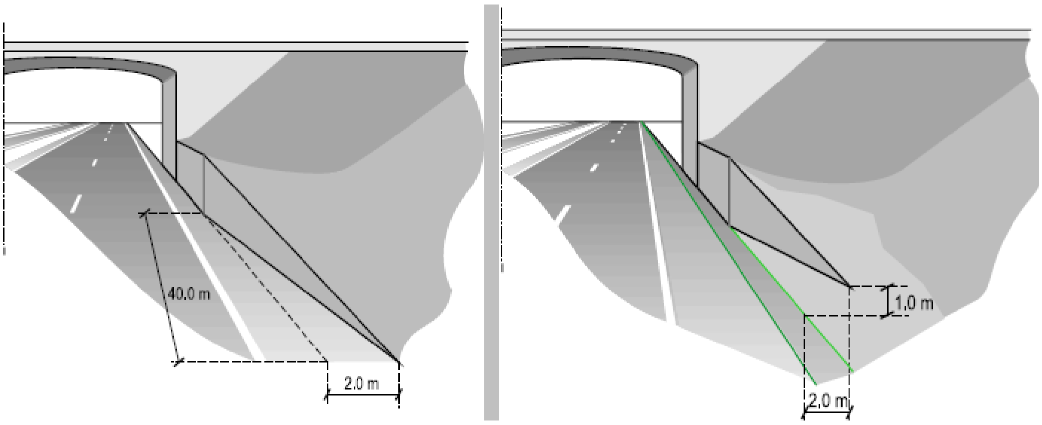

Figure 32: Example of end design of a retaining wall close to the carriageway[B.16]

3.2.6 Safety barrier terminals

Safety barriers belong to the group of road restraint systems and are explained in more detail Chapter 3.3, which deals with shielding measures for hazardous objects and locations. In some cases, modification of existing safety barrier terminals is necessary. First of all, two different types of terminals exist, which differ in their purpose. Terminals can be used to redirect vehicles back onto their original track or to stop them immediately, so that they cannot pass through the barrier [A.2]. Depending on the situation, one or the other type can be useful. If the terminals are aimed at stopping the vehicle these have to be treated as energy absorbing devices and have to be tested according to ENV 1317-4 (which will be superseded by the new EN1317-4 standard, as detailed in Appendix)

Especially when terminals appear as hazards, as explained in Chapter 3.3, countermeasures are necessary. For rigid barriers (see Chapter 3.3.1) the most probable way to modify the terminal is to make it semi-rigid (see Chapter 3.3.2). This causes the vehicle to crash into a deformable barrier first, which guides the vehicle onto the rigid one. The problem with this installation is the transition between the two barrier types, which will be handled in Chapter 3.2.7. The second option is to build them breakaway, so that for impacts the terminal breaks and swings back behind the barrier [B.22]. Also a deflection from the traffic lane towards the roadside is an appropriate measure, as can be seen in Figure 33.

Figure 33: Deflecting breakaway safety barrier terminal [B.22]

Another possibility to handle hazardous safety barrier terminals is to shield them separately by crash cushions, which will be handled in Chapter 3.3.6.

3.2.7 Safety barrier transitions

The transition between two safety barriers has to ensure that vehicles slide along the barrier in a smooth way, without any interruption. All necessary information about safety barriers and its types can be found in Chapter 3.3.

Especially between semi-rigid (see Chapter 3.3.2) and rigid barriers (see Chapter 3.3.1), the transition has to be stiff enough to ensure a change without snagging onto the rigid barrier [B.22]. This transition is depicted in Figure 34.

Figure 34: Transition between semi-rigid and rigid barrier [B.22]

The transition between a flexible barrier (see Chapter 3.3.3) and a semi-rigid barrier is commonly constructed by overlapping the flexible one in front. This leads vehicles to slide onto the semi-rigid barrier in a smooth way. The same installation can be used when flexible and rigid barriers are connected.

3.3 Shielding obstacles

In many cases removing or modifying hazardous objects is not possible or economically advisable. To prevent collisions of vehicles with these objects, the third option is to shield them by using road restraint systems (RRS). The hazardous object is fully protected, so that deviating vehicles crash into the RRS, which alleviate the consequences of the impact. These systems can appear as hazardous objects themselves, but the severity of occurring accidents should still be less than without RRS. They are divided into vehicle- and pedestrian-restraint systems as depicted in Figure 35.

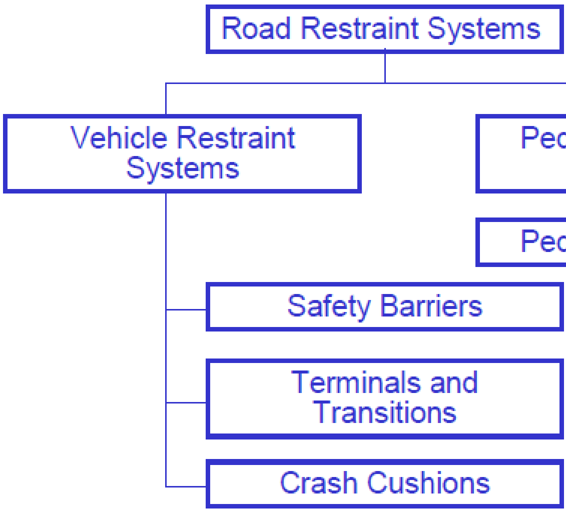

Figure 35: Classification of road restraint systems [A.13]

The most important group of RRS are safety barriers. They prevent errant vehicles from leaving the traffic lane and therefore minimize the probability to collide with a hazardous object. They can be installed either at the roadside or at the median. The purpose of RRS is to protect drivers and passengers of errant vehicles, as well as to prevent collision with opposing traffic. Moreover, pedestrians and cyclists are protected from getting onto the road or falling off a dip or into water. Besides the restrain function, another purpose is the redirection of vehicles onto their original path so that they can more easily continue their movement. The effectiveness of RRS is evaluated according to the following criteria:

- Containment level of RRS
- Impact severity
- Deformation or operating width

Safety barriers have to prevent vehicles from passing through, implying over- and underriding, while the severity of crashes should be reduced. This can be achieved by constructing the barrier deformable or moveable. Therefore safety barriers are divided according to their deflection level in following three main groups, which will be handled later on in detail.

- Rigid
- Semi- rigid
- Flexible

The criteria of deformation state that traffic barriers should also be intact after an impact and possible debris do not cause damages to vehicle occupants. Detailed requirements of RRS are regulated in the European Norm (EN) 1317. They are subdivided into following eight parts:

- Part 1: Terminology and general criteria for test methods [B.24]
- Part 2: Performance classes, impact test acceptance criteria and test methods for safety barriers [B.25]
- Part 3: Performance classes, impact test acceptance criteria and test methods for crash cushions [B.32]
- Part 4: Performance classes, impact test acceptance criteria and test methods for transitions of safety barriers (draft) – *spread "old" Part 4* [B.26]
- Part 5: Product requirements and evaluation of conformity for vehicle restraint Systems [B.27]
- Part 6: Pedestrian restraint system – Pedestrian Parapet [B.23]
- Part 7: Performance classes, impact test acceptance criteria and test methods for terminals of safety barriers (draft) – *spread "old" Part 4* [B.28]
- Part 8: Motorcycle road restraint systems which reduce the impact severity of motorcyclist collision with safety barriers (draft) [B.31]

More detailed information about each part can be seen in Appendix A. The EN 1317 is a tool to support the road planners with a standardized comparison of various RRS. It does not give advice on which RRS to take in specific situations. This is handled in guidelines like the RISER document [A.2].

The use of safety barriers and other restraint systems is usually subject to national regulations and standards. An example of a national standard (Italy) is summarized in Appendix.

3.3.1 Rigid barriers

Rigid barriers are commonly made out of concrete. Rigid barriers retain their shape and position when hit by a vehicle, leading to heavy impacts. They provide a high containment level without any deflection under impact. The advantage, on the other hand, is the small space consumption, since it does not deflect at all. This is especially of interest for median installations where the barrier is close to the traffic lane, as Figure 36 (left) shows.

Figure 36: Examples of rigid median barriers [B.22]

Typical applications are motorways with high speed, where total restraint is required. They show the best performance in terms of containment, with the disadvantage of higher injury risk.

3.3.2 Semi-rigid barriers

Semi-rigid barriers are the most common alternative to rigid barriers, since they usually cause less severe accidents. They are typically made out of steel. Semi-rigid barriers have two main functions. On the one hand, they prevent errant vehicles from passing through. On the other hand, they absorb the energy of the impact by deformation. This leads to less severe accidents and a better performance in terms of redirection. However, subsequent collisions with other vehicles or obstacles may occur due to redirection. The most commonly used type of semi-rigid barrier is the W-beam, which can be seen in Figure 37. Concrete modular barriers which can be deformed when hit by a vehicle are also considered as semi-rigid barriers.

Figure 37: A typical installation of a median W-beam [B.22]

3.3.3 Flexible barriers

Typical examples for flexible barriers are cable barriers and safety fences. Flexible barriers cause the least damage to vehicles, and pose the smallest risk of injury to vehicle occupants, compared to all other barrier types. The main disadvantage of flexible barriers is that they require more space behind them, since they can deflect by up to three metres. Also the slope in the area of deflection should be flat enough to ensure a secure redirection performance. Like semi-rigid ones, flexible barriers may cause crashes where a vehicle is deflected from a barrier, but subsequently collides with another vehicle or obstacle.

3.3.4 Temporary safety barriers

Temporary barriers are mainly used to shield construction sites from traffic and therefore have a limited lifetime. They are made out of steel, concrete and nowadays more often plastic polymers. One of the main differences between temporary and permanent barriers is the anchorage. Temporary barriers have to be placed individually, since working sites are only on restricted areas and only for restricted time periods. Hence they cannot be integrated in the road infrastructure as permanent barriers, which leads to the second difference that they do not offer the same level of protection. However, safety at working sites is mainly determined by other factors. On the one hand, the speed at these locations is lower (e.g. through speed limits), so that the impacts on barriers are initially lower. On the other hand, usually one or more lanes are closed, which leads to more careful driving behaviour.

Figure 38: Common temporary safety barriers (Sources: [B.22], [C.7])

3.3.5 Underriders

Steel safety barriers increase the likelihood of motorcyclists being injured or even killed. The problem is that motorcycles have no crush zone to reduce the impact of the vehicle on the barrier and that the rider usually fall off the bike during the accident. Typically, collisions with the posts of barriers are a main factor for injuries, when the rider slides into the restraint system. Other risk sources are the upper and lower edges, as well as too low a mounting height.

Another problem is that motorcyclists can slide through the barrier and crash into a hazardous object behind (e.g. tree, steep slope). Safety treatments are so-called underriders, which are mounted at the bottom of the barrier and prevent the motorcyclist from passing through the barrier, as well as appearing as shielding for posts and edges [B.20].

Figure 39: Example of underriders leading to a continuous shape (Source: [B.20])

Any underrider applied to a safety barrier will modify its behaviour. Under special circumstances, they could decrease the overall safety outcome of the protection system. Any barrier with an underrider will therefore have to be tested according to EN1317-8 (when available) or to national standard (as in Italy, Spain etc).

3.3.6 Kerb-barrier combinations

In the scope of this report, guidelines for the use of kerbs in conjunction with barriers as well as research papers dealing with safety of kerb-barrier combinations have been investigated. Generally, it is not desirable to use barriers alongside kerbs. Instead of installing barriers, safety zones free of any roadside obstacles are recommended. If concerns about drainage make them essential for proper highway maintenance, inadequate design of the kerb-barrier combination can result in overriding or underriding barriers. The following properties as well as their interdependencies need to be considered for improving roadside safety:

- Kerb height
- Kerb shape or slope
- Offset distance from kerb to barrier
- Barrier type
- Barrier height

According to [B.28], the roadside designer should consider a maximal kerb height of 100 mm when using barriers alongside. The kerb slope should be 1:3 (vertical : horizontal) or flatter. Barriers installed behind kerbs should not be located closer than 2.5 metres for any operating speed in excess of 60 km/h. This minimal distance is needed to allow the vehicle suspension to return to its pre-departure state, where impacts with the barrier should proceed successfully without vaulting it. However, in some European countries (e.g. Austria), it is common to place the kerb under the barrier, i.e. the kerb is flush with the face of the barrier. Figure 40 depicts a design chart for kerb-barrier combinations. Most roadside design guidelines do not recommend using rigid barriers in combination with kerbs.

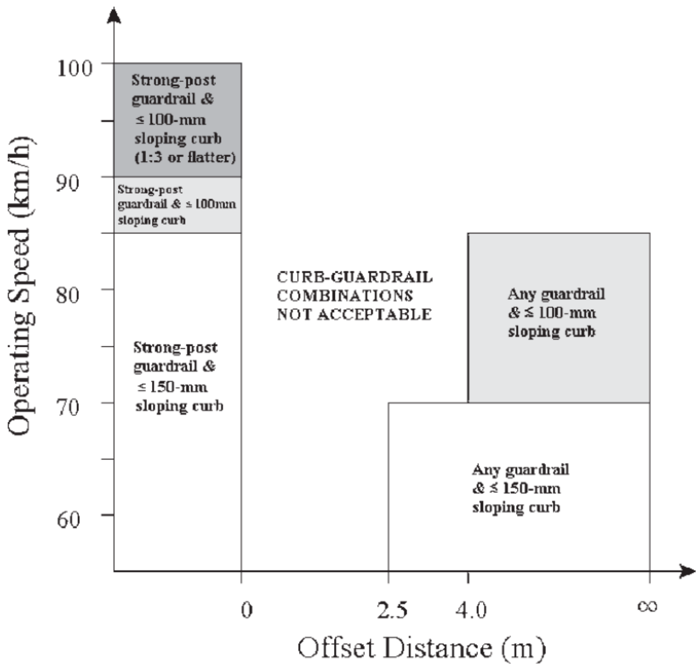

Figure 40: Kerb-barrier combinations by operating speed and offset distance [B.28]

3.3.7 Impact attenuators

Impact attenuators or crash cushions are restraint systems which are used to reduce the consequences of crashes with point obstacles. The protection of terminals and transitions can also be handled with this measure. They are typically protected in all directions, so that they can be better customised than barriers. In any case they should only be used if safety barriers are not possible at all or an appropriate installation cannot be reached.

Crash cushions can be distinguished by the absorption method used as follows:

- Multiple plastic boxes, made heavier by internal bags filled with salt, water or foam and connected with steel cables
- Sack devices, made from synthetic fibre sacks containing cylindrical sink elements, filled with expanded clay, linked together and leaning against lightened steel cusp
- Valved tubes, protected by sliding steel blades and connected with steel cables

Examples of common impact attenuators are depicted in Figure 41.

Figure 41: Examples of crash cushions (Sources: [A.3] and [C.4])

Several factors should be considered in the placement of impact attenuators. The attenuator should be placed on a level surface or on a slope no greater than 5 percent. The surface should be paved, bituminous or concrete without any kerbs in the surrounding of the attenuator. The orientation angle depends on the design speed or the alignment of the road.

4 Conclusion and recommendations

The first work package of the IRDES project deals with a collection and harmonization of current standards and studies regarding roadside design and forgiving roadsides. This deliverable comprises state-of-the-art treatments and strategies to make roadsides more forgiving. The goals of this report are to summarize existing treatments and to harmonize currently applied standards and guidelines. Three groups of treatments are discussed: Removing or relocating obstacles from the roadside, modifying roadside elements and shielding obstacles.

As a conclusion, it must be stated that removing obstacles is the primary strategy in most countries. Providing a so-called safety zone with a certain width allows drivers to regain control over their errant vehicle and to return to the travel lane or stop. Especially in the planning phase of a new road, safety zones should be considered. They should be free of obstacles with a flat and gently graded ground. Road operators are also encouraged to develop roadside vegetation management programs to eliminate or minimize vegetation. It is recommended to consider the safety zone width as a function of the posted speed, side slope, and traffic volume. However, some guidelines also include curve radii in their calculations. The AASHTO Roadside Design Guidelines introduce a calculation method for clear zone widths, which is the most used worldwide. It provides a useful basis for developing a uniform and practical guideline concerning forgiving roadside design, which is handled in WP3 of IRDES. Shoulders are named as recovery areas in this report. There exist several national standards regarding shoulder widths and their surface properties. A lack of standards concerning the so-called limited severity zone (the area beyond the shoulder) has been found.

If hazardous obstacles cannot be removed from the roadside safety zone, they need to be modified in order to minimize injury or property damage at a crash. Poles or supports are commonly made break-away and masonry structures (e.g. walls, curbs or buildings) are made crashworthy. There exist a high number of specifications to make obstacles more forgiving. In many national standard documents, certain side slope treatments are mentioned. In general, the steeper the slope, the higher is the risk for drivers of errant vehicles. Slopes should thus be kept as shallow as possible. For higher traffic volumes, side slopes should be designed with a 6:1 ratio. Ditches must be designed wide enough to provide adequate drainage and snow storage capacity. For reasons of safety, the width of the bottom should be at least one metre. Drainage features such as culvert ends or control dams need to be made crashworthy by modifying their shape. As there exist numerous different regulations for slope ratio and ditch characteristics, they should be harmonized with respect to proper drainage as well as its forgiving nature. Shoulder treatments that promote safe recovery include shoulder widening, shoulder paving as well as the reduction of pavement edge drops. If the skid resistance of a paved shoulder is insufficient, treatments to increase surface friction should be applied. Moreover, any other hazardous surface damages such as potholes or cracks need to be eliminated from the shoulder.

To prevent collisions of vehicles with obstacles, the third option is to shield them by using road restraint systems (RSS). In this deliverable, restraint systems are divided into safety barriers and impact attenuators. Safety barriers have to prevent vehicles from passing through, implying over- and underriding, while the severity of crashes should be reduced. This can be achieved by constructing the barrier deformable or moveable. Therefore, safety barriers are divided according to their deflection level in most guidelines and standards. Detailed requirements of RRS are regulated in the European Norm (EN) 1317. However, it does not give advice on which RRS to take in specific situations. This is handled in specific guidelines such as the RISER documents. Future uniform European guidelines should also include recommendations for kerb-barrier combinations as well as safe motorcycle restraint systems. Standards concerning these topics are currently under development. Impact attenuators or crash cushions (e.g. plastic boxes filled with sand or water) are restraint systems, which are used to reduce the consequences of crashes with point obstacles. The protection of terminals and transitions can also be handled with this measure. In some cases, modification of existing safety barrier terminals is necessary. If the terminals are aimed at stopping the vehicle these have to be treated as energy absorbing devices and have to be tested according to ENV 1317-4. In most reviewed guidelines, a deflection from the traffic lane towards the roadside is an appropriate measure to make terminals forgiving. The transition between two safety barriers has to ensure that vehicles slide along the barrier in a smooth way, without any interruption. It also has to be stiff enough to ensure a change.

The results of the literature review carried out in the scope of this report will be the basis for the development of a uniform and practical European guideline for roadside design. Moreover, the guideline is based on an assessment of the effectiveness of different treatments, which is part of work package 2 within IRDES.

The large number of possible treatments to make a road forgiving shows the large potential of those systems for increasing road safety. A harmonization helps road operators and authorities in their decisions to plan safe roads. Common road planning procedures together with Road Safety Audit or Road Safety Inspections on existing roads, have to include the specific view on forgiving roadsides.

Glossary

Arrester bed
An area of land adjacent to the roadway filled with a particular material to decelerate and stop errant vehicles; generally located on long steep descending gradients.

Back slope (see ditch)
A slope associated with a ditch, located opposite the roadway edge, beyond the bottom of the ditch.

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 support
A sign, traffic signal or luminaire support designed to yield or break when struck by a vehicle.

Abutment
The end support of a bridge deck or tunnel, usually retaining an embankment.

Vehicle parapet (on bridges)
A longitudinal safety barrier whose primary function is to prevent an errant vehicle from going over the side of the bridge structure. It can be constructed from either steel or concrete.

CCTV Masts
A mast on which a closed circuit television camera is mounted for the purpose of traffic surveillance.

Carriageway
The definition of the ‘carriageway’ differs slightly amongst countries. The edge of the carriageway is delineated by either the “edge line” or, if no edge line is present, the edge of the paved area.

Central reserve
An area separating the carriageways of a dual carriageway road.

Clearance
The unobstructed horizontal dimension between the front side of safety barrier(closest edge to road) and the traffic face of the.

Clear/Safety zone
The area, starting at the edge of the carriageway, that is clear of hazards. This area may consist of none or any combination of the following: a ‘hard strip’, 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
A vehicle which comes in contact with a road restraint system and does not pass beyond the limits of the safety system.

Containment level
The 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 and tested to (EN 1317).

Crash cushion
A road vehicle energy absorption device (road restraint system) installed in front of a rigid object to contain and redirect an impacting vehicle ("redirective crash cushion") or to contain and capture it ("non-redirective crash cushion").

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.

Cut slope
The earth embankment created when a road is excavated through a hill, which slopes upwards from the level of the roadway.

Design speed
The speed which determines the layout of a new road in plan, being the speed for which the road is designed, taking into account anticipated vehicle speed on the road.

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 central reserve 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 protruding above the ground level at the edge of the paved surface.

Dual carriageway
A divided roadway with two or more travel lanes in each direction, where traffic is physically divided with a central reserve and/or road restraint system. See also ‘divided roadway’.

Edge line
Road markings that can be positioned either on the carriageway surface itself at the edge of the carriageway, or on the ‘hard strip’ (if present) next to the carriageway.

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

Encroachment
A term used to describe the situation when the vehicle leaves the carriageway and enters the roadside area.

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
An earth embankment created when extra material is packed to create the road bed, typically sloping downwards from the roadway.

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

Fore slope (see ditch)
The fore slope is a part of the ditch, and refers to the slope beside the roadway, before the ditch bottom.

Forgiving roadside
A forgiving roadside mitigates the consequence of the “run-off” type accidents and aims to reduce the number of fatalities and serious injuries from these events.

Guardrail
A guardrail is another name for a metal post and rail safety barrier.

Hard/Paved shoulder
An asphalt or concrete surface on the nearside of the carriageway. If a ‘hard strip’ is present, the hard shoulder is immediately adjacent to it, but otherwise, the shoulder is immediately adjacent to the carriageway. Shoulder pavement surface and condition as well as friction properties are intended to be as good as that on the carriageway.

Hard strip
A strip, usually not more than 1 metre wide, immediately adjacent to and abutting the nearside of the outer travel lanes of a roadway. It is constructed using the same material as the carriageway itself, and its main purposes are to provide a surface for the edge lines, and to provide lateral support for the structure of the travel lanes.

Highway
A highway is a road for long-distance traffic. Therefore, it could refer to either a motorway or a rural road.

Horizontal alignment
The projection of a road - particularly its centre line - on a horizontal plane.

Impact angle
For a longitudinal safety 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. 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 unit intended to separate areas of different surfacings and to provide physical delineation or containment.

Lane line
On carriageways with more than one travel lane, the road marking between the travel lanes is called the 'lane line'.

Limited severity zone
An area beyond the recovery zone that is free of obstacles in order to minimize severity in case of a vehicle run-off.

Length of need
The total length of a longitudinal safety barrier needed to shield an area of concern.

Median
See 'central reserve'.

Motorways
A dual carriageway road intended solely for motorized vehicles, and provides no access to any buildings or properties. On the motorways itself, only grade separated junctions are allowed at entrances and exits.

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, surface dressing or concrete (e.g. grass, gravel, soil, etc).

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 (or an obstacle).

Paved shoulder
See 'hard shoulder'.

Pedestrian restraint system
A system installed to provide guidance for pedestrians, and classified as a group of restraint systems under 'road restraint systems'.

Pier
An intermediate support for a bridge.

Point Hazard
A narrow item on the roadside that could be struck in a collision, including trees, bridge piers, lighting poles, utility poles, and sign posts.

Recovery zone
A 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, particularly a wall built to support or prevent the advance of a mass of earth.

Road restraint system (RRS)
The general name for all vehicle and pedestrian restraint systems used on the road (EN 1317).

Road equipment
The 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 roadway.

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

Roadway
The roadway includes the carriageway and, if present, the hard strips and shoulders.

Rock face cuttings
A rock face cutting is created for roads constructed through hard, rocky outcrops or hills.

Rumble strip (Shoulder rumble strips)
A thermoplastic or milled transverse marking with a low vertical profile, designed to provide an audible and/or tactile warning to the road user. Rumble strips are normally located on hard shoulders and the nearside travel lanes of the carriageway. They are intended to reduce the consequences of, or to prevent run-off road events.

Rural roads
All roads located outside urban areas, not including motorways.

Safety barrier
A road vehicle restraint system installed alongside or on the central reserve of roads.

Safety zone
See ’clear zone’.

Self-explaining road
Roads designed according to the design concept of self-explaining roads. The concept is based on the idea that roads with certain design elements or equipment can be easily interpreted and understood by road users. This delivers a safety benefit as road users have a clear understanding of the nature of the road they are travelling on, and will therefore expect certain road and traffic conditions and can adapt their driving behaviour accordingly. (Ripcord-Iserest, Report D3, 2008).

Set-back
Lateral distance between the way and an object in the roadside for clearance).

Shoulder
The part of the roadway between the carriageway (or the hard strip, if present) and the verge. Shoulders can be paved (see 'hard shoulder') or unpaved (see 'soft shoulder').
Note: the shoulder may be used for emergency stops in some countries; in these countries it comprises the hard shoulder for emergency use in the case of a road with separate carriageways.

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/Unpaved shoulder
A soft shoulder is defined as being a gravel surface immediately adjacent to the carriageway or hard strip (if present). In some countries it is used as an alternative for hard shoulders.

Soft strip
A narrow strip of gravel surface located in the roadside, beyond the roadway (normally beyond a hard strip/shoulder).

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.

Transition
A vehicle restraint system that connects two safety barriers of different designs and/or performance levels.

Travel/Traffic lane
The part of the roadway/carriageway that is travelled on by vehicles.

Treatment
A specific strategy to improve the safety of a roadside feature or hazard.

Underpass
A structure (including its approaches) which allows one road or footpath to pass under another road (or an obstacle).

Underrider
A motorcyclist protection system installed on a road restraint system, with the purpose to reduce the severity of a PTW rider impact against the road restraint system.

Undivided roadway
A roadway with no physical separation, also known as single carriageway.

Unpaved shoulder
See ‘soft shoulder’.

Vehicle 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. These are classified as a group of restraint systems under ‘road restraint systems’.

Verge
An unpaved level strip adjacent to the shoulder. The main purpose of the verge is drainage, and in some instances can be lightly vegetated. Additionally, road equipment such as safety barriers and traffic signs are typically located on the verge.

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

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Appendix

Summaries of EN documents (EN 1317 parts 1 to 8 and EN 12767)

The European Standard **EN 1317** consists of the 8 parts (some are under preparation).

- EN 1317-1, *Road restraint systems - Part 1: Terminology and general criteria for test methods*;
- EN 1317-2, *Road restraint systems - Part 2: Performance classes, impact test acceptance criteria and test methods for safety barriers including vehicle parapets*;
- EN 1317-3, *Road restraint systems - Part 3: Performance classes, impact test acceptance criteria and test methods for crash cushions*;
- ENV 1317-4, *Road restraint systems — Part 4: Performance classes, impact test acceptance criteria and test methods for terminals and transitions of safety barriers*;
- prEN 1317-4, *Road restraint systems − Part 4: Performance classes, impact test acceptance criteria and test methods for transitions of safety barriers* (under preparation: this document will supersede ENV 1317-4 for the clauses concerning transitions)*;*
- EN 1317-5, *Road restraint systems − Part 5: Product requirements and evaluation of conformity for vehicle restraint systems*;
- prEN 1317-6, *Road restraint systems − Pedestrian restraint systems — Part 6: Pedestrian Parapet* (under preparation);
- prEN 1317-7, *Road restraint systems − Part 7: Performance classes, impact test acceptance criteria and test methods for terminals of safety barriers* (under preparation: this document will supersede ENV 1317-4 for the clauses concerning terminals);
- prEN 1317-8, *Road restraint systems - Part 8: Motorcycle road restraint systems which reduce the impact severity of motorcyclist collisions with safety barriers* (under preparation).

EN12767
Passive Safety of support structures for road equipment – Requirements and test methods

EN1317-1

Introduction:
In order to improve and maintain highway safety, the design of safer roads requires, on certain sections of road and at particular locations, the installation of road restraint systems to restrain vehicles and pedestrians from entering dangerous zones or areas. The road restraint systems designated in this standard are designed to specify performance levels of containment and to redirect errant vehicles and to provide guidance for pedestrians or other road users.
The standard identifies impact test tolerances and vehicle performance criteria that need to be met to gain approval. The design specification, for road restraint systems entered in the test report, should identify the on-road site conditions under which the road restraint system should be installed.

The performance range of restraint systems, designated in this standard, enables National and Local Authorities to recognize and specify the performance class to be deployed. The range of possible vehicular impact scenarios in an on-road road restraint system is extremely large in terms of speed, approach angle, vehicle type, vehicle attitude, and other vehicle and road conditions. Consequently the actual on-road impacts which occur may vary considerably from the specific standard test conditions. However, adequate implementation of the standard should identify the characteristics, in a candidate safety road restraint system that is likely to achieve maximum safety and reject those features which are unacceptable.

Manufacturers may wish to modify their products following the test and clause n. 5.2, 6.2.1.5 and Annex A in EN 1317-5: 2006 set out the procedure to be followed.
Manufacturers may wish to place their products in Families, as system type tested products, and clauses 4.7 in EN 1317-2: 2010, 5.5 in EN 1317-3: 2010 and in ENV 1317-4: 2002 set out the procedure to be followed.
The modifications included in this part of the standard are not a change of test criteria, in the sense of the Annex ZA.3 of Part 5.

Scope:

This standard contains provisions for the measurement of performance under impact and impact severity levels and includes:

- Test site data
- Definitions for road restraint systems; other parts of the standard may add to these
- Vehicle specifications including loading requirements for vehicles used in the impact tests
- Instrumentation for the vehicles
- Calculation procedures and methods of recording crash impact data including impact severity levels
- VCDI mandated measurements (VCDI is not a mandated requirement)
- Informative Annexes

<u>EN1317-2</u>

Introduction:
This standard includes improved impact test procedures and allows for the introduction of Families of Products and a Part 2 report template.

In order to improve safety the design of roads may require the installation of safety barriers including parapets which are intended to contain and redirect errant vehicles safely for the benefit of the occupants and other road users on sections of road and at particular locations defined by the National or Local Authorities.
In this standard, several levels of performance are given for the three main criteria relating to the restraint of a road vehicle:

- the containment level;
- the impact severity levels;
- the deformation as expressed by the working width.

The different performance levels of safety barriers including parapets will enable National and Local Authorities to specify the performance class of the system to be deployed. Factors to be taken into consideration include the class or type road, its location, geometrical layout, the existence of a vulnerable structure, potentially hazardous area or object adjacent to the road.

The description of a safety barrier including parapet system conforming to this Standard

incorporates the relevant classes and performance levels of the product.
To ensure satisfactory product design it is imperative to consider the requirements of this standard and the references in clause 2, together with the requirements of EN 1317-1: 2010. Quality of manufacture, installation and durability must fulfil the requirements of EN 1317-5:2006.

Manufacturers may wish to modify their products following the ITT and clause nos. 5.2, 6.2.1.5 and Annex A in EN 1317-5:2006 set out the procedure to be followed. The modifications included in this part of the standard are not a change of test criteria, in the sense of the Annex ZA.3 of Part 5.

Scope:
This European standard shall be read in conjunction with EN 1317-1. These two standards support EN 1317-5.
This standard specifies requirements for:

- Impact performance of safety barriers and vehicle parapets
- Classes of containment and impact severity levels

EN1317-3

Introduction:
Based on safety considerations, the design of roads may require the installation of crash cushions at certain locations. These are designed to reduce the severity of vehicle impact with a more resistive object.

One objective of this standard is to lead to the harmonisation of current national standards and/or regulations for crash cushions and to categorize them into performance classes.

The standard specifies the levels of performance, required of crash cushions, for the restraint and/or redirection of impacting vehicles. The impact severity of vehicles in collision with crash cushions is rated by the indices Theoretical Head Impact Velocity (THIV), and Acceleration Severity Index (ASI) (see EN 1317-1).

The different performance levels will enable national and local authorities to specify the performance class of crash cushions. The type or class of road, its location, its geometrical layout, the existence of a vulnerable structure or potentially hazardous area adjacent to the road are factors to be taken into consideration.

Attention is drawn to the fact that the acceptance of a crash cushion will require the successful completion of a series of tests (see Table 1, 2, 3, etc.).

This European Standard is a supporting standard to EN 1317-5, which shall be read in conjunction with EN1317-1. Manufacturers may wish to modify their products following the ITT, and clause numbers 5.2, 6.2.1.5 and Annex A in EN1317-5 set out the procedure to be followed.

The modifications included in this part of the standard are not a change of test criteria, in the sense of the Annex ZA.3 of Part 5.

Scope:
This European Standard specifies requirements for the performance of crash cushions from vehicle impacts. It specifies performance classes and acceptance criteria for impact tests.

ENV1317-4

This is a preliminary standard which was aimed at specifying test methods for terminals and transitions. This standard has been discharged and will be replaced by EN 1317-4 for transitions and EN1317-7 for terminals. Until the new EN1317-4 and EN1317-7 will be published ENV1317-4 is commonly used for testing energy absorbing terminals.

prEN1317-4

Introduction:
In order to improve safety the design of roads may require the installation of safety barriers including parapets which are intended to contain and redirect errant vehicles safely for the benefit of the occupants and other road users on sections of road and at particular locations defined by the National or Local Authorities. Problems may also arise in the connection between two different safety barriers having consistent difference in design and/or in stiffness. Transitions are required to provide a smooth and safe change from one barrier to the other.

This standard specifies the direction of impact, and the methods for determining the critical impact points, for the testing of transitions.
Methods for designing transitions without specific crash tests are also included in the standard as well as criteria to apply tested transitions to different products without the need for repeating the crash tests.

Scope:
This European Standard is a supporting standard to EN1317-5 and shall also be read in conjunction with EN1317-1.

This Part completes Part 2 of the standard because it specifies performance for transitions, considered as the linkage between safety barriers of different types.

This Standard also defines acceptance criteria for impact tests and test methods.

EN1317-5

Introduction:
This document is a product standard for vehicle restraint systems placed on the market.

This document is designed for use in conjunction with Parts 1, 2, 3, prEN 1317-6 or ENV 1317-4. To ensure the full performance of road restraint systems in use, their production and installation is intended to be controlled in accordance with this document.

Scope:
This standard includes requirements for the evaluation of conformity of the following road restraint systems produced:

- safety barriers;
- crash cushions;
- terminals (will be effective when ENV 1317-4 becomes an EN);
- transitions (will be effective when ENV 1317-4 becomes an EN);
- Vehicle / Pedestrian Parapets (only for the vehicle restraint function)

Pedestrian parapet requirements are not covered in this standard.

Requirements for the evaluation of durability with respect to weathering are included in this standard.

Requirements for other forms of durability (e.g. Marine environment, sand abrasion) are not included.

Temporary barriers are not within the scope of this standard.

prEN1317-6

Introduction:
The safety considerations of pedestrians using road bridges and footbridges and similar structures that require the installation of special road restraint systems: pedestrian parapets.

Pedestrian parapets are provided and designed to restrain and to guide pedestrians and other non-vehicle road users including cyclists and equestrians.

Aspects included in the standard are:
- Safety in use for pedestrians and other highway users (excluding motor vehicles),
- The safety considerations of pedestrians using road bridges and footbridges and similar structures
- Analysis and test methods,
- Durability,
- Evaluation of the Conformity.

Scope:
This European Standard EN 1317-6 specifies geometrical and technical requirements and defines the requirements for design and manufacture of pedestrian parapets on bridges carrying a road or cycle path or footpath/bridleway or on top of retaining walls and other similar elevated structures.

This European Standard does not cover the requirements for:
- Vehicle restraint systems or pedestrian restraint systems in residential, commercial or industrial buildings and within their perimeter,
- Non rigid rails ie rope, cables,
- Transparency,
- Risks relating to the climbing of children.

This European Standard covers pedestrian parapets placed on the market as kits.

NOTE 1: The authorities for railways, rivers and canals can have additional special requirements.
NOTE 2: The above requirements for pedestrian restraint systems are normally defined in National Regulations or referenced in the project specification (or documentation).

prEN1317-7

Introduction:
The design purpose of safety barriers installed on roads is to contain errant vehicles that either leave the carriageway or are likely to encroach into the path of oncoming vehicles. EN 1317-2 deals with the impact performance of a safety barrier to which a terminal may be attached.

Terminals, which are defined as the beginning and/or end treatment of a safety barrier, are required to have specified impact performances without introducing additional hazards for passenger cars.

The description of a terminal conforming to this Standard incorporates the relevant classes and performance levels of the product.

Manufacturers may wish to modify their products or use them with different barriers following the ITT and clauses 5.2, 6.2.1.5 and Annex A of EN1317-5:2008 set out the procedure to be followed.

Scope
This European Standard is a supporting standard to EN1317-5 and shall also be read in conjunction with EN1317-1.

This Part completes Part 2 of the standard because it specifies performance for terminals, considered as the end treatment of a safety barrier.

This Standard also defines acceptance criteria for impact tests and test methods.

prEN1317-8

Introduction:
In order to improve safety the design of roads may require the installation of road restraint systems, which are intended to contain and redirect errant vehicles safely for the benefit of the occupants and other road users, or pedestrian parapets designed to restrain and to guide pedestrians and other road users not using vehicles, on sections of road and at particular locations defined by the national or local authorities.

Part 2 of this standard contains performance classes, impact test acceptance criteria and test methods for barriers. Whereas the aforementioned part covers the performance of these systems with respect to cars and heavy vehicles, this part of the standard addresses the safety of the riders of powered two-wheeled vehicles impacting the barrier having fallen from their vehicle.
As powered two-wheeler riders may impact a barrier directly (in which case no protection is offered by the vehicle) special attention is given to these vulnerable road-users. In order to minimise the consequences to a rider of such an impact, it may be necessary to fit a barrier with a specific PTW rider protection system. Alternatively, a barrier might specifically incorporate characteristics limiting the consequences of a PTW rider impact.

Rider protection systems may be continuous (including barriers specifically designed with the safety of PTW riders in mind) or discontinuous. A discontinuous system is one which offers rider protection in specific localised areas judged to be of higher risk. The most common example of a discontinuous system is one fitted locally to the posts of a post and rail type guardrail - adding nothing between the posts.

The purpose of this part of the standard is to define the terminology specific to it, to describe procedures for the initial type-testing of rider protection systems and to provide performance classes and acceptance criteria for them.

Accident statistics from several European countries have shown that riders are injured when impacting barriers either whilst still on their vehicles or having fallen and then sliding along the road surface. Whilst different statistical sources show one or the other of these configurations to be predominant, all known studies show both to constitute a major proportion of rider to barrier impact accidents. Some studies showing the sliding configuration to be predominant have led to the development and use of test procedures in some European countries, evaluating systems with respect to the sliding configuration. At the time of writing, a number of such protection systems were already on the European market. It is for this reason that it was decided to address the issue of sliding riders initially, in order to bring about the adoption of a European standard in as timely a manner as possible. However, the rider on vehicle configuration should also be considered as soon as possible for a subsequent revision of this part of the standard.

Scope:
This part of the European standard shall be read in conjunction with EN 1317 parts 1 and 2. These parts of the standard all support EN1317-5.

This part of the standard specifies requirements for the impact performance of PTW rider protection systems to be fitted to barriers or for the rider protection aspect of a barrier itself. It excludes the assessment of the vehicle restraint capabilities of barriers and the risk that they represent to the occupants of impacting cars. The performance of impacting vehicles must be assessed according to EN 1317 parts 1 and 2.

This part of the standard defines performance classes taking into account rider speed classes, impact severity and the working width of the system with respect to rider impacts.

For systems designed to be added to a standard barrier, the test results are valid only when the system is fitted to the model of barrier used in the tests. EN 1317-5 describes how it may be determined whether other barrier models are sufficiently similar to the barrier tested to allow their use in conjunction with the tested system without the need for additional testing. Guidelines for making this judgement are given in Annex G.

EN 12767

The severities of accidents for vehicle occupants are affected by the performance of support structures for items of road equipment under impact. Based on safety considerations, these can be made in such a way that they detach or yield under vehicle impact.

This European Standard provides a common basis for testing of vehicle impacts with items of road equipment support.

This European standard considers three categories of passive safety support structures:

- high energy absorbing (HE);
- low energy absorbing (LE);
- non-energy absorbing (NE).

Energy absorbing support structures slow the vehicle considerably and thus the risk of secondary accidents with structures, trees, pedestrians and other road users can be reduced.

Non-energy absorbing support structures permit the vehicle to continue after the impact with a limited reduction in speed. Non-energy absorbing support structures may provide a lower primary injury risk than energy absorbing support structures.

In this European Standard, several levels of performance are given using the two main criteria related to the performance under impact of each of the three energy absorbing categories of support structure. Support structures with no performance requirements for passive safety are class 0.

There are four levels of occupant safety:
Levels 1, 2 and 3 provide increasing levels of safety in that order by reducing impact severity. For these levels two tests are required:

- test at 35 km/h to ensure satisfactory functioning of the support structure at low speed.
- test at the class impact speed (50, 70 and 100) as given in Table 1.

Level 4 comprises very safe support structures classified by means of a simplified test at the class impact speed.

All the tests use a light vehicle to verify that impact severity levels are satisfactorily attained and compatible with safety for occupants of a light vehicle.

The different occupant safety levels and the energy absorption categories will enable national and local road authorities to specify the performance level of an item of road equipment support structures in terms of the effect on occupants of a vehicle impacting with the structure. Factors to be taken into consideration include:

- perceived injury accident risk and probable cost benefit;
- type of road and its geometrical layout;
- typical vehicle speeds at the location;
- presence of other structures, trees and pedestrians;
- presence of vehicle restraint systems.

Example for a national standard in Italy

Since 1992 a mandatory standard is in place in Italy to provide instruction for the design, construction and use of safety barriers and other road restraint systems (the Ministry Decree 223/1992).

The most recent update of the Italian national standard is the Ministry Decree 2367/2004 issued on the 21th of June of 2004. This decree has adopted in the EN 1317 standards for testing barriers to be used on public roads in Italy.

The Italian national regulation defines the minimum containment level of safety barriers to be used for different type of roads and different locations on the road section as defined in the following table:

Type of road	Type of traffic	Traffic barrier	Edging barrier	Bridge barrier
Motorways (A) and primary rural roads (B)	I	H2	H1	H2
	II	H3	H2	H3
	III	H3-H4	H2-H3	H4
Secondary rural Roads (C) and Urban arterials (D)	I	H1	N2	H2
	II	H2	H1	H2
	III	H2	H2	H3
urban distribution roads (E) and local roads (F)	I	N1	N1	H2
	II	H1	N2	H2
	III	H2	H1	H2

Type of traffic is defined according to the following table:

Type of traffic	Average annual daily traffic	% vehicles with mass >3.5 t
I	≤1000	Any
I	> 1000	≤ 5
II	> 1000	5 < n ≤15
III	> 1000	> 15

The areas to protect with safety barriers and other road restraint systems must include, at least:

- the margins of all open-air structures such as bridges, viaducts, underpasses and roadway support walls, independently from their longitudinal extension and their height from the ground; the protection must be extended for a suitable distance beyond the longitudinal development of the structure until it reaches points (both before and after the structure) from which the risk of severe consequences deriving from the exiting of vehicles from the roadway can be reasonably excluded;

- the median for divided carriageways. According the Italian Ministry Decree 5 November 2001 for the design of new roads a median has to be protected if the width of the median deducted the width of the left shoulders is less then 12m;

- road edges in sections with embankments with an height over the ground greater than or equal to 1 m and slopes greater than or equal to 2/3. For embankments lower than 1 m and for higher embankments with slope less than 2/3, the need for safety barriers depends on the combination of the slope and its height, considering situations of possible danger downstream of the slope (the presence of buildings, railway lines, dangerous material deposits or similar);

- fixed obstacles (frontal or lateral) that could endanger road users upon impact, for example bridge piers, emerging rocks, drainage systems that cannot be crossed, trees, street lighting and non frangible sign supports, waterways, etc, and other structures such as public or private buildings, schools, hospitals, etc. which would be endangered by an errant. These obstacles and buildings must be protected if it is not possible or convenient to relocate them and if they are at distance from the roadway edge shorter than a safety distance; this distance is not given in the national standard and it has to be defined by the designer considering, for example, the following parameters: design speed, traffic volume, road radius of curvature, embankment slope, obstacle type.

According to the Italian standard the safety barriers terminals can be either designed to avoid frontal hits with the barrier or energy absorbing devices tested according to ENV1317-4.

An UNI technical specification (UNI TR 11370 "Dispositivi stradali di sicurezza per motociclisti - Classi di prestazioni, modalità di prova e criteri di accettazione") has recently been published (July 2010) for testing safet barriers and underriders for motorcycle impacts.

Annex 2
Guide for the assessment of treatment effectiveness

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Executive summary

IRDES (Improving Roadside Design to Forgive Human Errors) is a research project of the cross-border funded research programme “ENR SRO1 – Safety at the Heart of Road Design”. Each year around 35,000 persons are fatally injured in Europe due to road accidents. The fatality rate in single vehicle run-of-road accident is around 45%. One of the key issues of this high ROR fatality rate is to be found in the design of the roadsides that are often “unforgiving”.

The aim of this deliverable is to presents the results of Work Package 2, which include four studies on different approaches to analyse the effectiveness of identified treatments which are variation of shoulder width; removal of barrier terminals; implementation of grooved rumble strips and treatments in curves. The report focuses on the methodologies rather than on the result of the studies.

To assess the effectiveness of shoulder width extension a tool designed to analyse vehicle speeds and trajectories was evaluated. The tool, named OT (Observatory of Trajectories), enables to measure vehicle movements. Due to delays in the modifications of the road, only measurement before the modifications could be conducted and analysed. Some issues regarding the amount of data collected were found and modifications to the method are needed.

In the study assessing the safety effects of removing unprotected barriers terminals on secondary rural roads the development of a Crash Modification Factor was derived. The method is based on cross sectional analysis of part of the Arezzo Prince road network in Italy. The procedure proposed could be applied to the evaluation of different roadside features.

To assess the effectiveness of the implementation of grooved rumble strips on dual carriageways comparisons between treated and non-treated roads were evaluated by statistical methods. Accident data including all severities in single vehicle accidents from several years with and without treatment was used in the analysis. The results showed that the estimated treatment effect is a 27.2% reduction of the accident intensity rate for single vehicle accidents.

The assessment of the effectiveness of treatments in curves was evaluated by using Vehicle-Infrastructure-Interaction Simulations (VIIS) based on measured road infrastructure parameters. Case studies of two accident spots in curves were selected and simulated with different safety treatments and parameter values (sensitivity analyses).

List of Figures

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Abbreviations

Abbreviation	Definition
AADT	Annual average daily traffic
AASHTO	American Association of State and Highway Transportation Officials
ADT	Average Daily Traffic
AIS	Abbreviated Injury Scale
ASI	Acceleration Severity Index
CEDR	Conference of European Directors of Roads or Conférence Européenne des Directeurs des Routes
EES	Energy Equivalent Speed
ERA-NET	European Research Area Network
HIC	Head Injury Criterion
HSM	Highway Safety Manual
IRDES	Improving Roadside Design to Forgive Human Errors
MAIS	Maximum Abbreviated Injury Scale
NCHRP	National Cooperative Highway Research Programme
OT	Observatory of Trajectories
PTW	Powered Two-Wheeler
RISER	Roadside Infrastructure for Safer European Roads
ROR	Run-off-road
RVS	Richtlinien und Vorschriften für das Straßenwesen
SAVe	System of Analysis of Vehicles
SVA	Single vehicle accident
TG	Technical Group
TRB	Transportation Research Board

1 Introduction

IRDES (Improving Roadside Design to Forgive Human Errors) is a research project of the cross-border funded research programme “ENR SRO1 – Safety at the Heart of Road Design”, which is a trans-national joint research programme that was initiated by “ERA-NET ROAD – Coordination and Implementation of Road Research in Europe” (ENR), a Coordination Action in the 6th Framework Programme of the EC. The funding partners of this research programme are the National Road Administrations (NRA) of Austria, Belgium, Finland, Hungary, Germany, Ireland, Netherlands, Norway, Slovenia, Sweden and United Kingdom.

Each year around 35,000 persons are fatally injured in Europe due to road accidents. The RISER project has shown that even though 10 percent of all accidents are single vehicle accidents (typically run-off-road (ROR) accidents) the rate of these events increases to 45 percent considering only fatal accidents (see [1]). One of the key issues of this high ROR fatality rate is to be found in the design of the roadsides that are often “unforgiving”. CEDR has identified the design of forgiving roads as one of the top priorities within the Strategic Work Plan. For this reason, a specific Team dealing with Forgiving Roadsides has been established within the Technical Group (TG) on Road Safety of CEDR.

1.1 Aim of the IRDES project

The aim of the IRDES project is to:

- Deliver a report which summarise the state-of-the-art treatments to make roadsides forgiving, as well as to harmonise currently applied standards and guidelines.
- Conduct and present the results from a survey, circulated among European Road Administrations, concerning the safety interventions used to improve roadside design and their estimated effectiveness.
- Deliver a report for assessing (in a quantitative manner) the effectiveness of applying a given roadside treatment (identified in the project).
- Deliver a practical and uniform guideline that allows the road designer to improve the forgivingness of the roadside.
- Arrange and report on two workshops including stakeholders to discuss the outcome of the project.

1.2 Aim of this deliverable (D2)

The aim of this deliverable is to presents the results of Work Package 2, which include four studies on different approaches to analyse the effectiveness of identified treatments. The treatments identified by the project are:

- Variation of shoulder width
- Removal of barrier terminals
- Rumble strip (grooved rumble strip in the shoulder, outside the edge line i.e. no painted lines)
- Treatments in curves (using vehicle-infrastructure-interaction simulation)

2 IRDES nomenclature

2.1 Definition of road side

According to the RISER project [1], a roadside is defined as the area beyond the edge line of the carriageway. There are different views in literature on which road elements are part of the roadside or not. In this report, the median is considered as roadside, since it defines the area between a divided roadway. Therefore, all elements located on the median are considered as roadside elements as well. Figure 1 depicts a roadway cross section (cut and embankment section) including some roadside elements. In this specific figure, the roadside can be seen as the area beyond the driving lanes (or carriageway). The shoulders are thus part of the roadside, since the lane markings define the boundaries.

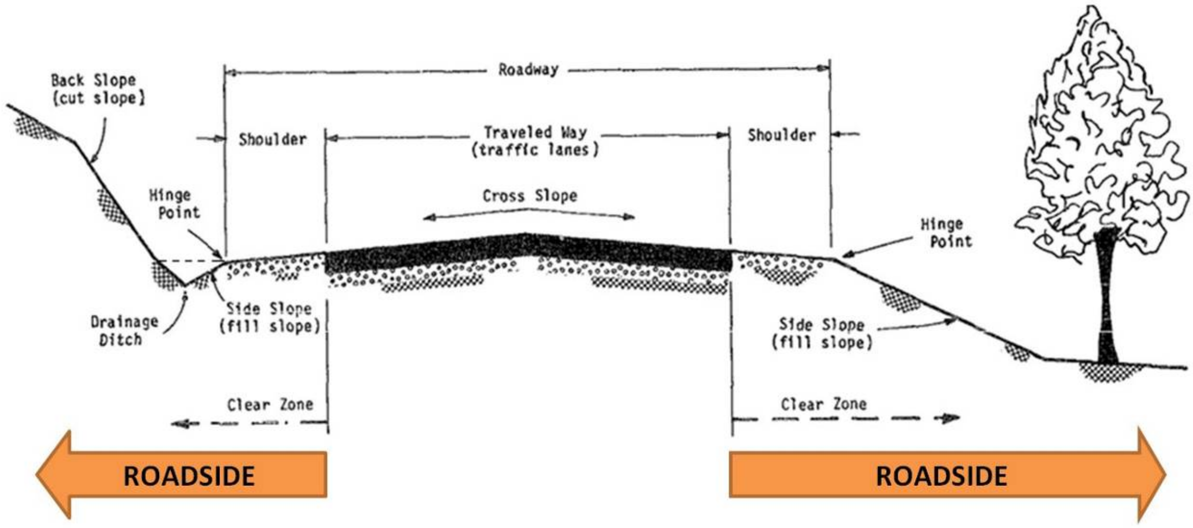


Figure 1. Roadway cross section with examples for roadsides with clear zones [2].

2.2 Forgiving vs. self-explaining roads

Forgiving and self-explaining roads are two different concepts of road design, which aim at reducing the number of accidents on the whole road network. The project IRDES and therefore this report only deals with forgiving roadsides. However, the term "self-explaining" needs to be defined in order to differentiate it from the term "forgiving".

According to [3], self-explaining roads are based on the idea that appropriate speed or driving behaviour can be induced by the road layout itself. They therefore reduce the need for speed limits or warning signs. It is generally known that multiple road signs in complex traffic situations can lead to an information overload and an increasing risk of driving errors. Herrstedt [4] writes that a safe infrastructure depends on a road-user-adapted design of different road elements such as markings, signs, geometry, equipment, lighting, road surface, management of traffic and speed, traffic laws etc. The idea behind self-explaining roads is to design the road according to an optimal combination of these road elements.

In short, self-explaining roads aim at preventing driving errors, while forgiving roads minimize their consequences. The first priority of forgiving roadsides is to reduce the consequences of an accident caused by contributing factors in the human, vehicle or road domain. It must be focused on treatments to bring errant vehicles back onto the lane to reduce injury or fatal run-off-accidents. If the vehicle still collides with a road element, the second priority is to reduce the severity of the crash.

3 Effectiveness of shoulder width extension

3.1 Introduction

In the framework of the IRDES project, a tool designed to analyse vehicle speeds and trajectories was evaluated. This tool, named OT (Observatory of Trajectories), enables to measure vehicle movements.

In order to test the tool, the technical research centre CETE NC identified an interesting road where shoulders are planned to be improved, in terms of broader width. The modifications to be assessed (before/after) consist in managing the road area by reducing the lane width and widen the paved shoulders at the same time. The results of the experiment should not only allow assessing the efficiency of the OT tool, but it should also provide information on the effects of the new design on driving behaviours.

3.2 Methodology

3.2.1 Measurement data unit

Vehicle type

The OT tool enables to segregate different road users. Even if it cannot measure powered two-wheelers, it can identify distinguish between cars and trucks. Thus, this tool is able to define some driving characteristics according to the road users.

Lateral position (from central road marking)

The lateral positioning of the vehicle is given in metres. The result represents the difference between the lateral centre of the measured vehicle and the centre of the carriageway. It has to be noticed that the lateral positioning of vehicles is analysed on a distance from 20 to 25 metres. It is possible to determine an average positioning over these 20-25 metres.

Speed

As for lateral positioning, speed is measured on a distance from 20 to 25 metres. It is given in metres per second [m/s].

Accurate datation

The data collection system allows combining several types of sensors, depending on the site to be studied. In order to « merge » all the data provided by the different sensors, it is necessary to set the same time basis.

In the present study, the two sensors that are used are a scanning laser range finder and radar. The time difference between these two sensors is estimated by a few milliseconds, which is acceptable for further data processing.

Binary information about the interaction with meeting vehicles

Among the first objectives defined in the protocol, there is the assessment of the influence of meeting vehicles on the opposite lane.

Through speed and lateral positioning measurements, the OT can differentiate between situations when vehicles are approached by another vehicle in the opposite lane or not.

3.2.2 Aggregate data

Average speed and lateral position on the measurement field of view for every type of vehicle by each hour of each day

The OT store speed and lateral positioning of each vehicle on a distance of about 25 metres on several positions of the trajectory. The average speed and average lateral positioning of each vehicle on the trajectory is calculated, as well as the maximum speed of each vehicle on the trajectory. The observation is carried out on a straight line and therefore the average speed and maximum speed do not differ much.

Identification of “free” vehicles (time space greater than 5 s between two vehicles)

In the present study, only free light vehicles are measured. A vehicle is « free » when its trajectory is not troubled with preceding vehicles. A vehicle is free when it can reach the desired speed because the nearest vehicle is too far to constrain it. The first interest of this discrimination is to enable behaviour analysis in relation with road infrastructure and external conditions independent from traffic values. The criterion used is the Inter Vehicle Time (TIV). The threshold selected to qualify free vehicles is 5 seconds.

Identification of vehicles crossing the central road marking

Previously explained, the OT enables to calculate average lateral position from central road marking, and if the vehicle cross the median line. These results are analysed in order to assess the impact of the trajectories when approaching vehicles are in the opposite lane.

Identification of vehicles which speed is 20km/h above posted speed limit

In addition to the parameters described above, we calculate the percentage of vehicles which are over legal speed and also the percentage of vehicles which are 20 km/h over posted speed.

3.2.3 Description of the OT measurement systems

The OT is composed of two tools: a multi-sensor acquisition tool and data processing software to follow moving objects.

Acquisition tool

For this study the acquisition tool included a scanning laser range finder and radar. A data acquisition centre automatically recorded 30s of data every 1.5 minute.

Software

The software called SAVe (System of Analysis of Vehicles) provides several algorithms to follow moving objects in video cameras and range finders.

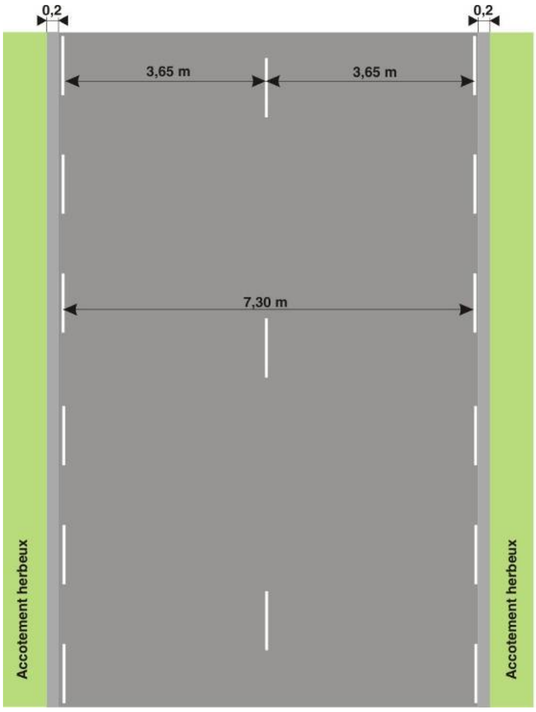
In special zones which can be defined in the road scenery measurements, the software calculates for every image the most probable position of each moving object.

3.2.4 A roadside improvement analysis

Description of the design

The selected design consists in managing the road space by both reducing the lane width and providing wider paved shoulders (see Figure 2 and Figure 3).

Before



After

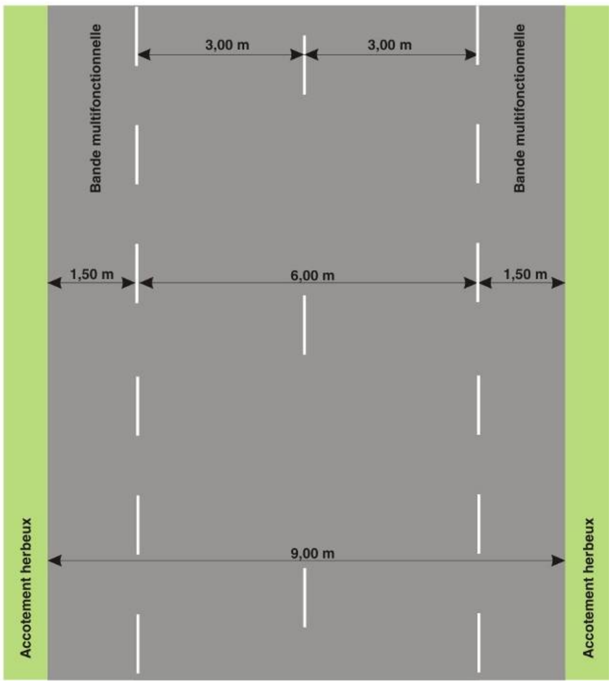


Figure 2. Before situation;
- 7,30 m-wide carriageway
- 0,20 m-wide hard strip

Figure 3. After situation;
- Lane width is reduced from 3,60 to 3m
- Usable roadway enlarged on both sides
- Provision of 1,50m-wide paved shoulders

In order to know the effects that could be expected from this new design, a literature review has been carried to find the impacts on accident rate, speeds and lateral positioning [5]...[12].

The literature review shows that reorganising spaces with the provision of wider paved shoulders is a complex phenomenon and does not permit to conclude on the effectiveness of a reduced lane width and wider paved shoulders. Most of the studies are limited to the effect of a reduced lane width, or a wider shoulder, but not both.

Nevertheless, it is possible to assume some elements about this design:

- **Slight decrease in the accident rate** after the implementation of the design
- **No significant effects on speeds**
- **Observed effect on lateral positioning**, moving more towards the centre of the lane during daylight.

Description of the study site

The design takes place in the South-East of Caen on the Departmental Road RD16, between Saint-Pierre-sur-Dives and Crève coeur-sur-Auge, on a 9 km road segment. The construction period was February to June 2011.

The tool was installed on the straight line and on the shoulder of the lane opposite the vehicles observed (see Figure 4).

Figure 4. Installation of the OT tool

3.3 Results of the roadside design changes

3.3.1 Results before works

Measurements before the road works were carried out in May 2010, for one week

Among the analysed vehicles (3415 on the straight line), it has been necessary to remove several measures, in particular these where there were doubts on the measurement quality.

In addition, vehicles which were not free (following another vehicle) have been removed from the analysis because their speed and lateral positioning could have influenced by the preceding vehicles.

Some recordings in the before situation were made for 30 seconds every 1.5 minute, it has been necessary to remove the first vehicle of each sequence of 30 seconds, in order to be sure it was not a vehicle troubled by others.

The exploitable sample consists of 260 vehicles of which 231 light vehicles (cars) and 29 heavy goods vehicles (trucks).

Results about speed:

Results about speed on the straight line are shown in Figure 5. The posted speed limit is 90 km/h on the studied road segment.

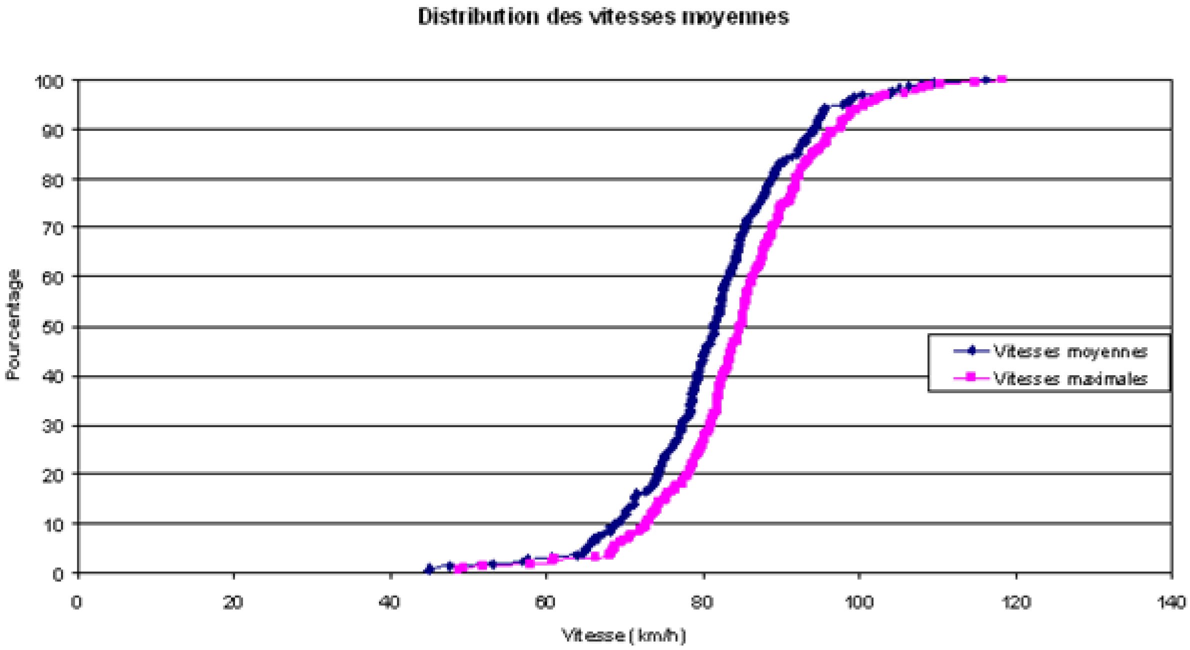


Figure 5. Measured average speed distribution. In blue line, the mean speed distribution and in pink line, the maximum speed distribution

The document shows that the V15 (with regard to average speeds) is of 92 km/h, whereas the V15 (with regard to maximum speeds) is of 94 km/h.

In this stage, it is difficult to interpret the data before the after situation has been analysed.

In the frame of speed analysis, the situation where another vehicle was approaching in the opposite lane could not be analysed because of too few situations were recorded (nine). This point should be improved in the after situation.

Further analysis of the speed function separated in day-time and night-time periods could not be performed due to low number of vehicles during night. The problem with low number of vehicles during night is neither due to sensor field of view nor visibility but due to low traffic volume. Again, the optimisation of the tool in the after period should enable to get this data.

Results about lateral positioning:

Readings of the lateral positioning of vehicles is shown in the Figure 6.The vehicle positioning is given in metres. It represents the difference between the lateral centre of the measured car and the centre of the median road marking. Each point, shown in the graph, is the representation of the average deviation of vehicles on the whole trajectories on 20-25 metres.

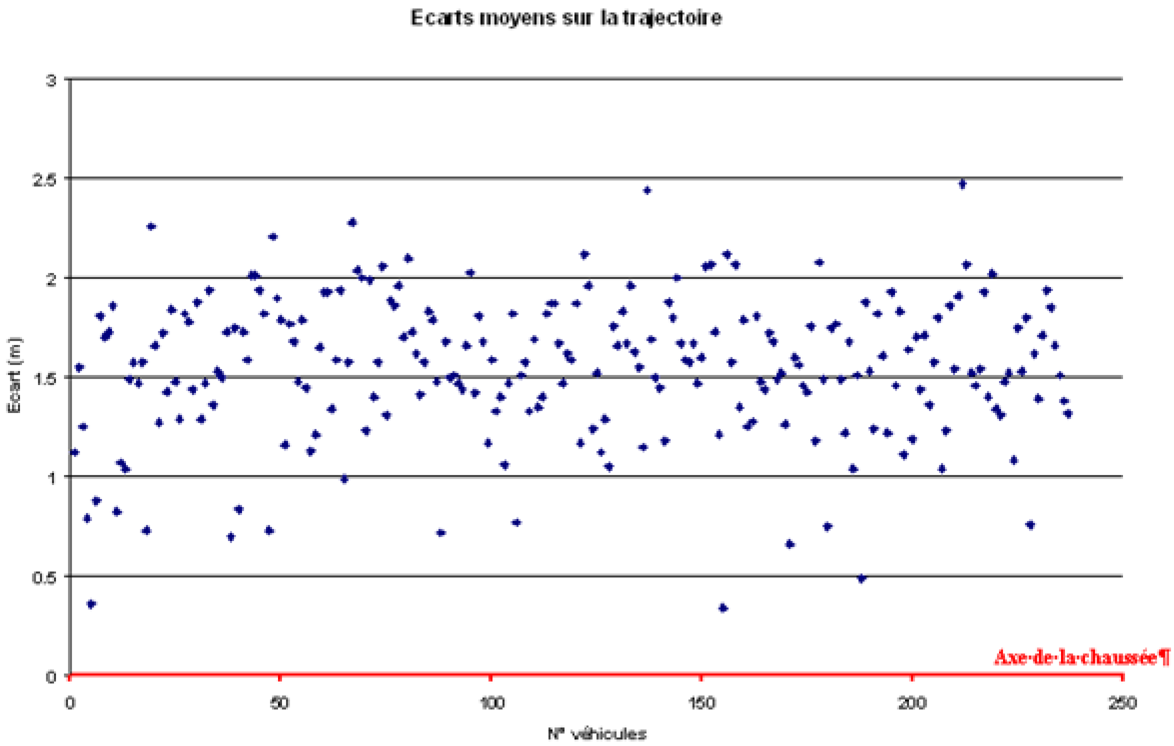


Figure 6. Lateral positioning from axial road markings

In general, the lateral centre of the vehicle is in a range of 1 to 2 metres from the central road marking, in particular in the range 1.5 to 2 metres.

Given that the average width of a vehicle (distance between external parts of tyres) is 1.80 metres (example of Renault Mégane), most of the vehicles travel at a distance between 0.5 to 1 metre from the edge of the central road marking.

The analyses show that there are 15 measures out of 260 (5.7%) where the vehicle crossed the median line, due to an (normal) overtaking manoeuvre on a straight road section.

Similar to the speed analysis, it was not possible to segregate lateral positioning by day and by night, because of the low number of vehicles registered by night.

3.3.2 Results after works

Due to delays in the modifications of the road the after analysis has not been performed.

Conclusion of the evaluation

Before the publication of the after situation results, it is however possible to draw some conclusion about this experiment in the before situation:

- the number of measured vehicles is insufficient. Due to the low number of measurements of free vehicles, it was not possible to analyse all parameters as required (e.g. the situation where another vehicle was approaching in the opposite lane). The system can calculate the width and the length of each vehicle so the lateral position is the distance between the left part of the vehicle and the median marking.
- the percentage of removed data are higher for trucks than for cars.

- the use of the OT tool enabled to get reliable data as far as speed and lateral positioning are concerned.

To improve the second analysis, the four experience feedbacks are:

- Increase the recording time to have more free vehicles tracked (2 minutes instead of 30 seconds).
- Measurement of the central marking in the rangefinder referential to improve accurate calibration.
- Use of 2 rangefinders at 2 different heights. One for the car measurement and the other for the heavy goods vehicle because their wheels are bigger.
- Need two weeks of recordings to be sure to have enough information.

4 Safety effects of removing unprotected barriers terminals on secondary rural roads

4.1 Introduction

Road barriers terminations, usually called “terminals”, are commonly recognized as an important roadside safety hazard but currently there is no quantitative manner to estimate the safety effects of removing them.

In the NCHRP Report 4090 “In-service performance of safety barriers” several studies concerning barriers terminals have been analysed but it resulted that they are essentially devoted are understanding how the specific terminal is working and not at quantifying the effect of modifying the terminal configuration [13].

In the recently published “Highway Safety Manual” the Roadside Hazard Rating doesn’t account for the terminals configuration [14].

One of the reasons is that crashes against terminals are rare event and a typical “before/after” analysis cannot be performed in these cases.

The aim of this part of the project was the development of a Crash Modification Factor for the effect of having unprotected Terminals on secondary rural roads based on the cross sectional analysis of part of the Arezzo Prince road network in Italy. It should be noted that the procedure proposed could be applied also to the evaluation of different roadside features.

4.2 Methodology

4.2.1 The procedure implemented

To evaluate the effect of a given road feature two different approaches are typically used:

- The development of a Safety Performance Functions (SPF) which allows directly to compare two alternative road configurations which differ only in terms of the given configuration. The limitation of this approach is that it should be applied only to networks with characteristics comparable with those of the network used for developing the SPF applied. In addition a Safety Performance Function can combine the effect of different variables which are not independent leading to wrong assumptions on the effect of the given variable;
- To overcome this problem a new approach has been developed by Harwood et al. [15] and has been adopted in the recently published Highway Safety Manual [14]. This approach includes a “base” model (that is a SPF base on a limited number of variables, typically length and traffic, that allows for the estimation of the expected number of crashes in “standard” or “base” conditions) and one or more multiplying factors called “Crash Modification Factors” (CMFs) that account for the effect of differences between the analysed section and the “base” conditions. The basic form of the safety prediction model, in this case, is:

$$E[N] = E[N]_b \times CMF_1 \times CMF_2 \times \cdots\cdots\cdots \times CMF_n$$

With:

E[N] = expected crash frequency, crashes/yr;
$E[N]_b$ = expected base crash frequency, crashes/yr; and

CMF_i = crash modification factor for the generic feature *i* (*i* = 1, 2, ..., *n*).

Each CMF represents the ratio N_w/N_{w_o} where, N_w represents the number of crashes expected in segment *with* one or more specified geometric design elements or traffic control devices, and $N_{w/o}$ represents the expected number of crashes that would be experienced *without* the specified feature. A CMF can be a constant or a function that represents the change in safety following a specific change in the design or operation of a segment.

The direct evaluation of a CMF for a given features requires either:

- To implement a specific intervention in a given section aimed at modifying the analysed treatment;
- To compare two sections that have all the same attributes with the only exception of the analysed feature.

In most databases, as in the one analysed in the IRDES project, the only way to have sections with identical attributes is to make them extremely small but this leads to have often sections with no accidents, as shown earlier. If longer sections are considered there are usually relatively few pairs of sections, if any, that have all identical attributes with the exception that the analysed one. And this is true also for the number of unprotected terminals, which is the aim of this investigation.

To overcome the aforementioned limitation a procedure has been proposed by Bonneson and Pratt [16] that uses a multivariate regression model to estimate the expected crash frequency for one segment of each pair, as may be influenced by its attributes. This estimate is then refined using the empirical Bayes (EB) technique developed by Hauer [17] to include information about the reported crash frequency for the segment. The segment for which the expected crash frequency is estimated is referred to as the “before” segment.

The second segment of each pair is considered to be the “after” segment. Its reported crash frequency is compared with the Empirical-Bayes (EB) estimate for the “before” segment during CMF calibration. The CMF is therefore given by:

$$CMF_i = \frac{E[N]_2}{E[N]_1}$$

Where 1 and 2 are the segments that have all the attributes equal with the only exception of the one for which the CMF is estimated. This type of procedure solves the problem of comparing sections with “zero” crashes but still needs to have sections with the same attributes.

In the IRDES project this procedure has been slightly adjusted to account for the fact that two sections of the pair are not “identical” in terms of attributes but also in terms of length and therefore there might be a difference even in other features and not only in the analysed one and these difference could lead to a wrong estimation of the CMF. In this case the CMF equation becomes:

$$CMF_i = \frac{E[N]_2}{E[N]_1} \times \frac{N_{p\_1}(\mathrm{var}\, i = base)}{N_{p\_2}(\mathrm{var}\, i = base)}$$

Where $N_{p\_1}(\mathrm{var}\ i = \mathrm{base})$ and $N_{p\_2}(\mathrm{var}\ i = \mathrm{base})$ are the number of crashes predicted for the two sections by using the safety performance function with the specific feature to be analysed set to the base value instead than to the specific value registered in the section. In the specific case of the estimation of the effect of unprotected terminals this would mean no unprotected terminals in both sections.

This modification also accounts for the difference in length between the two sections in the pair as this will affect in the same manner both the $E[N]_i$ and the N_{p-i} values:

$$CMF_i = \frac{\frac{E[N]_2}{L_2}}{\frac{E[N]_1}{L_1}} \times \frac{\frac{N_{p-1}(\text{var}\, i = base)}{L_1}}{\frac{N_{p-2}(\text{var}\, i = base)}{L_2}} = \frac{E[N]_2}{E[N]_1} \times \frac{N_{p-1}(\text{var}\, i = base)}{N_{p-2}(\text{var}\, i = base)}$$

To allow for the development of the CMF prediction model a number of activities have to be conducted that can be summarized as follows:

- Step 1: Identification of the sections to be analysed;
- Step 2: Survey of the roadside features;
- Step 3: Segmentation and Identification of homogeneous section;
- Step 4: Accident Data Collection;
- Step 5: Accident analysis (development of the safety performance function and estimation of the unprotected terminals CMF).

Each step will be described in details in the following sections.

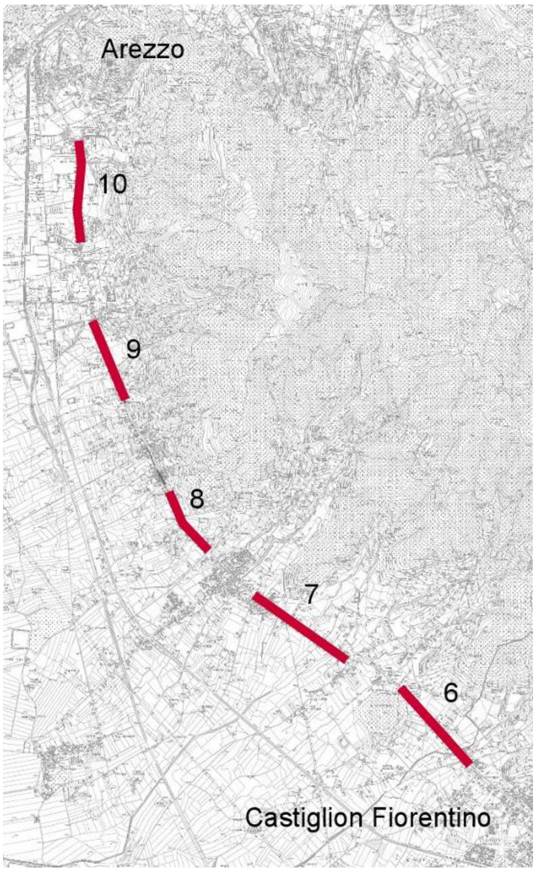
4.2.2 Identification of the sections to be analysed

The road network used for the analysis is a typical rural provincial network with a single carriageway with 2 lanes bidirectional managed by the Arezzo Province. The overall length of the network considered for the analysis is 90 km 50% of which are within urban areas or mountain roads and have been therefore excluded from the analysis. Within the timeframe of the IRDES project only part of this length could be covered by the fully roadside survey for a total length of 24 km divided in 7 consecutive stretches as shown in Table 1 and in Figure 7.

Out of the 24 km surveyed 3 km had to be excluded from the accident analysis as during the observation period (2001-2008) major infrastructural interventions have been conducted in the analysed sections. The final dataset is therefore referred to 21 km of secondary single carriageway rural roads.

Table 1. Provincial road stretches analysed

Stretch number	*From*	*To*	*Municipalities interested*	*Stretch length (km)*
T1	Catiglion Fiorentino	Vitiano	Castiglion Fiorentino Arezzo	1.0
T2	Ghetto	Rigutino	Arezzo	0.8
T3	Rigutino	Policiano	Arezzo	0.6
T4	Policiano	Il Matto	Arezzo	1.8
T5	Il Matto	Olmo	Arezzo	1.4
T6	Case Nuove di Ceciliano	Subbiano	Arezzo Capolona Subbiano	10.3
T7	Subbiano	Rassina	Subbiano Castel Focognano	8.2
			TOTAL	24.1



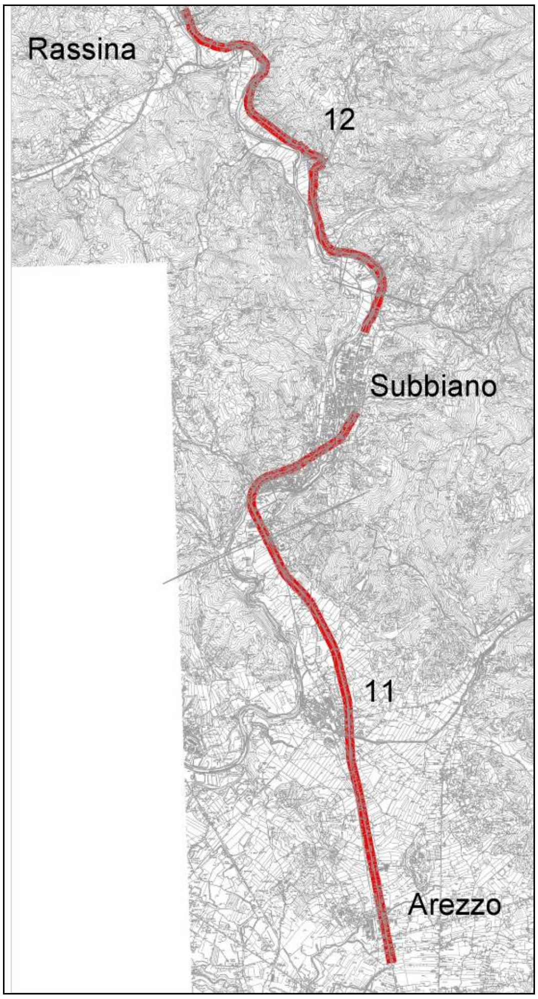


Figure 7. Provincial road stretches analysed South of Arezzo (left) and North of Arezzo (right)

4.2.3 Survey of the roadside features

As far as the official road inventory of the Arezzo Province doesn't contain information regarding the roadside configuration, the first step of the analysis has been to establish a procedure for the classification of the roadside features and the actual survey on part of the provincial road network.

The roadside feature that have been identified as potentially relevant for the safety assessment are listed in Table 2 while in Annex A the full survey check list has been included.

Table 2. Roadside features surveyed on site

Roadside element	*Required measure*
Shoulders	Width/Type
Banks	Width
Safety barriers	Type /Length
Safety barrier terminals	Type
Ditch	Width
Driveways	Type
Obstacles	Type – distance from horizontal marking
Lay-bys	Type - Width – Length

The survey of the different roadside features has been extended to any object within a range of 7 metres from the horizontal marking.

The linear features (shoulders, banks and ditches) are measured at constant intervals and at every section where they change in a visible manner (Figure 8). The safety barriers and the terminals are classified according to the coding given in the survey check list shown in Annex A. The terminals are recorded only if they are exposed to the traffic of the analysed road segment (Figure 9, left) which means that if the barriers bends in the driveway and the terminal is on the driveway this will not be included (Figure 9, right).

As far as in the analysed network there are no flared terminals or absorbing terminals tested according to ENV 1317-4 [18] this are not included in the check list coding. If these type of terminals are present a new coding have to be added for each type.

Lay-bys are areas parallel to the carriageway limited in longitudinal extension where the vehicle can stop without disturbing the traffic on the roadway and can be either paved or unpaved (Figure 10).

In addition to the specific roadside features the locations of the gas stations (Figure 11) and of the driveways have been identified as these are relevant variables for accident analysis. In Italian rural roads Gas Stations have a direct access from the main roadway and drivers pull in and out increasing the conflict points as in an intersection and the accidents tend to increase.



Figure 8. Survey of linear features


Figure 9. Type "a" barrier terminal (left) and barrier curved in the driveway that is not considered as un "unprotected" terminal (right).


Figure 10. Different type of lay-bys (unpaved, left – paved, right).

Figure 11. Gas station.

4.2.4 Segmentation and Identification of homogeneous section

One of the key issues in any accident analysis it the road segmentation aimed at identifying sections which can be considered “homogenous” with respect to the different variables analysed.

In defining when a section can be considered as “homogenous” the following parameters have been considered:

1) Horizontal layout (linear or transition/bend);
2) Roadside configuration: *embankment, cut, at grade, bridge or tunnel*;
3) Shoulder width;
4) Lane width;
5) Bank width;
6) Ditch width.

with a minimum length of 100 m.

The variation in the longitudinal grade has not been considered as a variable for road segmentation as this information was not available and couldn’t be collected directly on site.

An additional element required to identify homogeneous section is the location of intersections. Before and after the intersection are considered as two different locations. Minor intersections with very limited traffic on the secondary road are considered as driveways and do not change the homogenous section.

As far as several variables are continuous the following classifications have been adopted to identify where a variable can be considered as “constant” within a section.

Shoulder width

a. 0 cm – 60 cm
b. 61 cm – 120 cm
c. 121 cm – 180 cm
d. 181 cm – 240 cm

Embankment width

a. 0 cm – 60 cm
b. 61 cm – 120 cm
c. 121 cm – 180 cm
d. 181 cm – 240 cm

Ditch width

a. 0 cm – 60 cm
b. 61 cm – 120 cm
c. 121 cm – 180 cm
d. 181 cm – 240 cm
e. 241 cm – 300 cm

The direct application of the procedure lead to 235 sections within the 24.1 km, 173 of which turned had a length below the minimum of 100 m. This length is already shorter than the minimum assumed by the Highway Safety Manual [14] for the same type of application (0.1 mile = 160 m) and further reduction in length was not considered as acceptable. In addition a considerable amount of sections (145 of 235) resulted in "zero" accidents over the analysis period and this would lead to statistical problems in developing the accident prediction model.

Different segmentation procedures have then been considered:

A. Considering as triggering variables only the ones considered by the HSM which are the shoulder width, the lane width, the horizontal layout and the overall roadside configuration defined by means of the Roadside Hazard Rating (RHR) considered by the HSM as the only parameter characterising the roadside ;

B. Considering sections approximately 1 km centred on the kilometre post. The actual section length varies between 0.5 and 1.4 km due to the fact that the sections had to be trimmed in entering an urban area and at any intersection.

Figure 12 shows the two different segmentation procedures applied at the same road stretch.

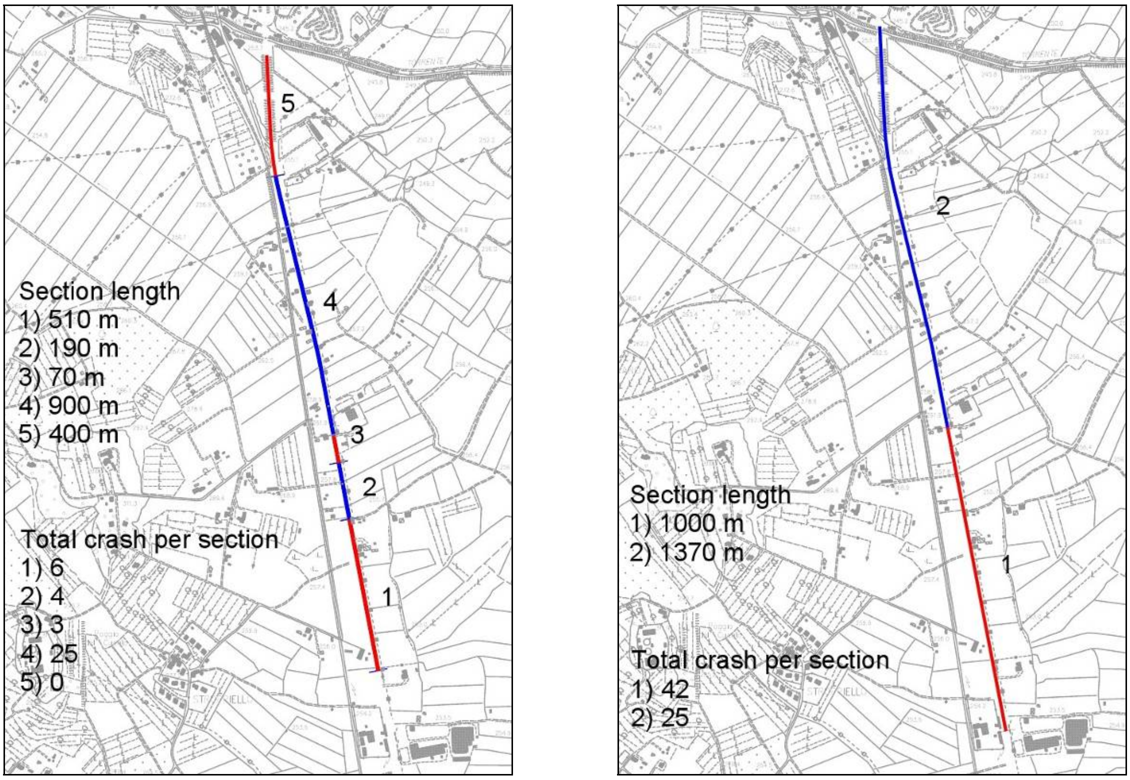


Figure 12. Segmentation by procedure A (left) and B (right).

The application of the procedure "A" lead to the analysed road network resulted in 50 sections with only 14 having a length of less than 100 m and with an average length of 280 m. In this case 28% of the sections still have "zero" accidents in the period of observation (2001-2008). In addition the localization of the accident was often given at the kilometre post and not at the metre (see § 4.2.5) which lead to excluding from the analysis 32% of the accident data.

The second procedure resulted in 23 sections, all longer than 100 m, with an average length of 790 m and with no section characterized by "zero" accidents.

In each section all the observed variables have be coded according to the following criteria:

OD = Object Density (number of obstacles/km)

AD = Average Obstacle Distance (m)

DD = Driveways Density (number of driveways/km)

UT = number of Unprotected barrier Terminals/km

LAY = number of Laybays/km

SW = Weighted Average of the Shoulder Width (m)

BG = Weighted Average of the Bank or Gutter width (m)

LW = Weighted Average of the Lane Width (m)

CURV = Average Curvature (m^{-1})

GS = binary variable (0-1) indicating if there is a gas station in the section

The traffic volume of the different road stretches, in terms of Annual Average Daily Traffic averaged over the period of observation, has also been obtained by the road administration and each section is therefore characterized also with this parameter.

For the parameters that are not constant in the “type B” segmentation procedure a weighted average has been applied considering the length as the weight for each “subsection” where the parameters remain constant.

4.2.5 Accident Data Collection

Accident data have been provided directly from the Arezzo Province and list all the events occurred on the S.R. 71 in the years 2001-2008. Two databases are available: the internal Province database and the database of the Integrated Regional Road Safety System (SIRSS).

In analyzing the data the following problems occurred:

1) A relevant part of the data in the SIRSS database doesn’t have the location of the accident on the road;
2) When the location is given this is given rounded to the nearest kilometre post, in accordance with the standard adopted by the Italian National Statistic Institute (ISTAT). This means that these set of data cannot be used to allocate the data in the type “a” segmentation (short but more homogeneous sections). The Province database, on the other hand, as a much more accurate accident location rounded at the metre. It should be noted, anyhow, that even in this case, a concentration of accidents seems to occur at the rounded kilometre distance which likely means that often the accident report doesn’t actually locate the accident but provides the nearest kilometre milepost.

Given the problems with the accident location listed above it was decided to conduct the accident analysis:

- With the type “b” segmentation;
- Combining the two accident databases to locate as many events as possible.

Given the fact that roadside safety features affect more the severity of the event than the occurrence it was decided to limit the analysis to injury and fatal accident (excluding the property damage only events which are also extremely underreported).

Consistently with the model proposed by the Highway Safety Manual for the Roadside Design CMF(see [14], chapter 10, eq. 10-20) the analysis has been developed for the total roadway segment crashes. In future developments of the research when more data will be available the development of models referred only to run-off-road crashes will be investigated.

Table 3. Fatal and injury accident records related to the period 2001-2008 for the type "b" sections

SEC	*CRASH*	*L (km)*	*AADT*
2_6_1	14	1.100	15193
2_7_1	14	0.740	15193
2_8_1	9	0.620	15193
2_9_1	24	1.300	15193
2_10_1	23	0.840	15193
2_11_1	21	0.500	14654
2_11_2	40	1.000	14654
2_11_3	24	1.370	14654
2_11_4	9	1.130	14654
2_11_5	3	0.640	14654
2_11_6	11	0.940	14654
2_11_7	3	0.430	14654
2_11_8	2	0.220	14654
2_11_9	3	0.500	14654
2_11_10	9	0.510	14654
2_12_1	8	0.500	8825
2_12_2	11	1.000	8825
2_12_3	5	1.000	8825
2_12_4	13	1.150	8825
2_12_5	10	0.800	8354
2_12_6	3	0.500	8354
2_12_7	6	0.800	8354
2_12_8	7	0.600	8354
TOTAL	272	18.190	-

4.2.6 Accident analysis

Development of a safety performance function for secondary rural roads

The safety performance function (SPF) used for accident model predictions usually is defined by:

$$Y = EXPO \times e^{(a_1 + a_2 \times v_2 \times ... \times a_n v_n)}$$

Where:

Y	is the dependent variable: Number of fatal+injury crashes occurred in the section in the 8 years of observation;
EXPO	is the total exposition given by 365 x 8 x L x AADT
L	is the section length in km
AADT	is the Annual Average Daily Traffic
$v_2 \ldots v_n$	are the independent variables considered for the study which are OD, AD, DD, UT, LAY, SW, BG, LW, CURV, GS as described in § 4.2.4.
$a_2 \ldots a_n$	are the model coefficients.

Amongst the different variables two groups have been identified, the *key variables* and the *supplemental variables*:

- The *key variables* are the Length (L) and the Traffic (AADT) as well as the input variable for which the CMF has to be developed (in the specific case the number of unprotected terminals, UT). These variables are kept in the model regardless of whether they are found to be statistically significant;
- The *supplemental variables* are the addition variables derived from the detailed survey that will be included in the model if they result to be statistically significant.

For the identification of the optimal relation between crashes (Y) and the traffic volume (AADT) both the linear and non linear solutions have been investigated. The linear solution has been adopted (consistently with the HSM model for rural two lane roads[1]) as the exponent of the non linear solution turned out to be very close to 1.

To identify the variables statistically significant for the model and to calibrate the SPF to the actual data the Generalized Linear Model (GLZ) tools of the “Statistica” software has been applied with a Poisson distribution of the dependent variable. This tool enables to model user defined functions and to evaluate the statistical significance of the different variables implemented in the model.

Given the rather limited number of datapoints available as compared to the number of variables investigated the following procedure has been applied to verify if the model tends to overfit the data lacking of prediction capabilities.

The evaluation of the statistically significant variables has been performed considering all the 23 datapoints. Out of the full dataset a subset of approximately 80% (19 data) has been extracted randomly to form the calibration dataset. These data are then used for the calibration of the multivariate regression model the variables of which have been defined in the previous stage. The remaining 4 data are used to test the prediction capabilities on the model (validation dataset).

[1] See [14], chapter 10, eq. 10-6

For the identification of the statistically significant variables the model as in eq. 1 has been calibrated by means of the Non Linear Estimation tool considering all the variables. For each calibration parameter the *p-value* is given by Statistica allowing for the identification of the statistically significant variables. The *p-value* is the probability of obtaining a test statistic at least as extreme as the one that was actually observed, assuming that the null hypothesis is true. In the development of the model the null hypothesis is rejected, and the result is said to be statistically significant, when the p-value is less than 0.05. The higher the *p-value* the less significant is the parameter.

With an iterative process the less significant variable *supplementary variable* is excluded from the analysis to the point where all the calibration parameters in the model, excluding those referred to the *key variables* result to be statistically significant. As it can for the summary results shown in Table 4 all the *supplementary variables* parameters (in the grey cells) result in a very low *p-value* (always below 0.03 and mostly below 0.01). The variable UT is left in the model independently of its significance as it is considered a *key variable*.

Table 4. Statistical significance of the selected variables

*CRASH=EXPO*exp(a1+a2*OD+a3*AD+a4*UT+a5*SW+a16*LW+a7*GS)*	
	P
Intercept	0.000229
OD	0.000000
AD	0.003956
UT	0.316004
SW	0.027129
LW	0.000262
GS	0.008344

Once the variables are identified the model is then calibrated based on the *calibration dataset* (containing 19 data points) and the results are shown in Table 5 while in Table 6 the goodness of fit statistics are shown. The Pearson χ^2 statistic for the model is 10.38 and the degree of freedom are 12 (=number of cases-number of variables=19-7). The $\chi^2_{0.05,12}$ is equal to 21 and therefore the actual χ^2 is significantly less meaning that the hypothesis that the model fits the data cannot be rejected. The goodness of fit statistics also show that both the Deviance/degrees of freedom and the Pearson χ^2/degrees of freedom result slightly less than 1 (0.7) meaning that there is no over-dispersion in the data distribution.

The Statistica Observed vs. Predicted plot of the calibration effort is presented in Figure 13 showing that the model fits extremely well the data over all the range of application. The residuals plot presented in Figure 14 shows that the residuals are evenly distributed with respect to the “zero” and among the whole range of predicted values.

Table 5. Calibration of the multivariate model for the SPF

*CRASH=EXPO*exp(a1+a2*OD+a3*AD+a4*UT+a5*SW+a16*LW+a7*GS)*	
	Estimate (a1 .... a7)
Intercept	8.89908
OD	-0.03037
AD	0.61177
UT	0.02381
SW	-1.02801
LW	-2.87574
GS	0.46892

Table 6. Goodness of fit of the SPF

*CRASH=EXPO*exp(a1+a2*OD+a3*AD+a4*UT+a5*SW+a16*LW+a7*GS)*			
	Df	*Stat.*	*Stat/Degree of freedom*
Deviance	12	8.27186	0.689322
Scaled Deviance	12	8.27186	0.689322
Pearson Chi²	12	8.42864	0.702386
Scaled P. Chi²	12	8.42864	0.702386
Loglikelihood		-4.51799	

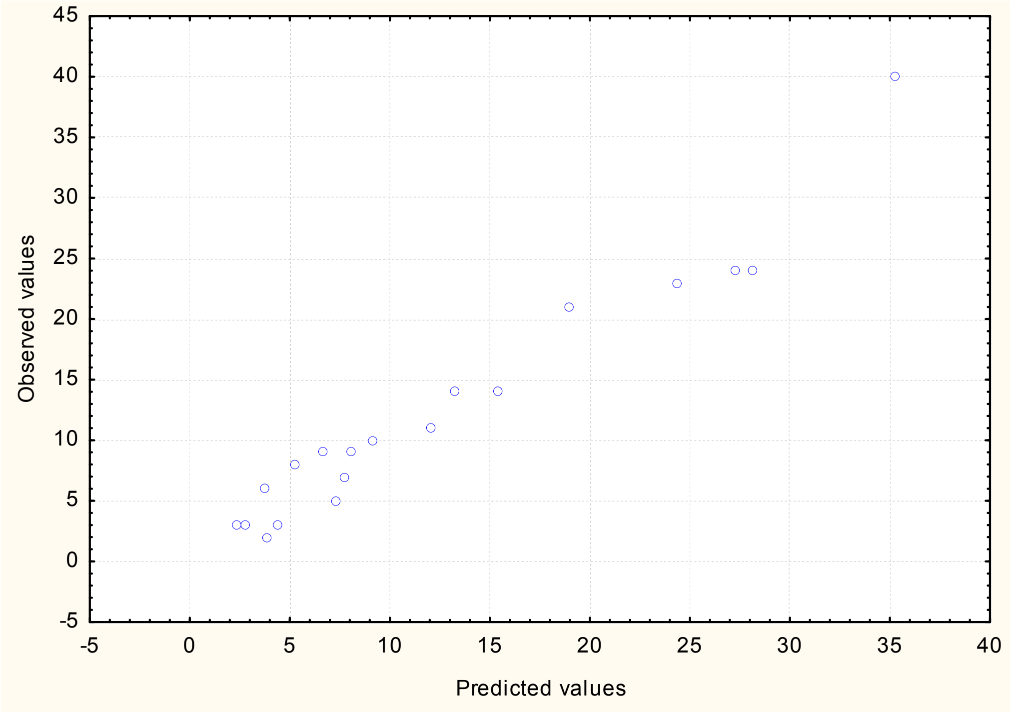


Figure 13. Observed vs. predicted plot or the calibration effort

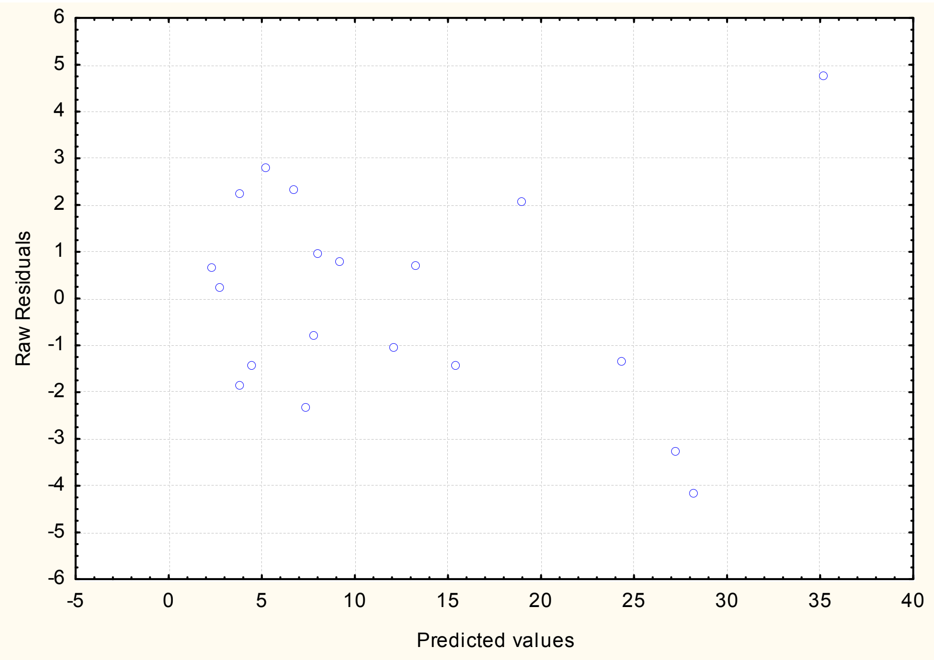


Figure 14. Residual vs. predicted plot or the calibration effort

The model parameters show a “counterintuitive” effect for the variables OD (obstacle density) and AD (average distance of obstacles). In the first case the number of predicted crashes reduces with increasing the OD while in the second case an increase in AD will lead to an increase in the number of predicted crashes.

This is due to the fact that the different variables OD and AD, even though statistically significant in the model, are not independent from the other variables and especially the shoulder width (SW) and the lane width (LW). As an example in Figure 15 clearly shows that the sections with a lower number of obstacles are also the sections with wider lane widths (which correctly would result in lower SPF predicted crashes). If the section with a specific combination of OD and LW is analysed the prediction is quite accurate but the SPF should not be used to derive a CMF for OD alone.

A very important variable in model resulted to be the presence of a gas station (GS) which is usually not considered in single carriageway rural roads. This is likely due to the fact that in Italian rural roads gas stations have a direct access on the roadway with extremely short diverge/merge lanes and left turns are allowed for vehicles pulling out of the gas station.

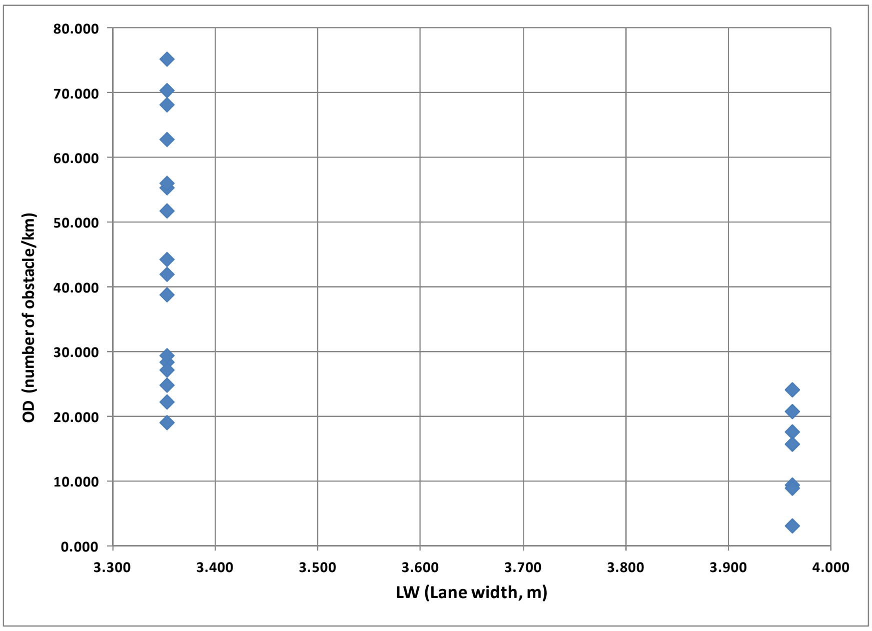


Figure 15. Number of obstacles per km vs. lane width

To test the prediction capabilities of the SPF proposed the 4 sections not used for the calibration has been analyzed with the model and the predicted values compared with the observed ones, as sown in Figure 16 where the annual crashes are plotted instead than the total crashes in 8 years. As it can be seen there is no bias in the model when used to analyze the validation data set and therefore the model can be used also to predict accidents for other roads than the one analysed. Given the small set of data used for the analysis the application leads to reliable estimations only for roads having parameters comparable with those used for the calibration of the model (see Table 7).

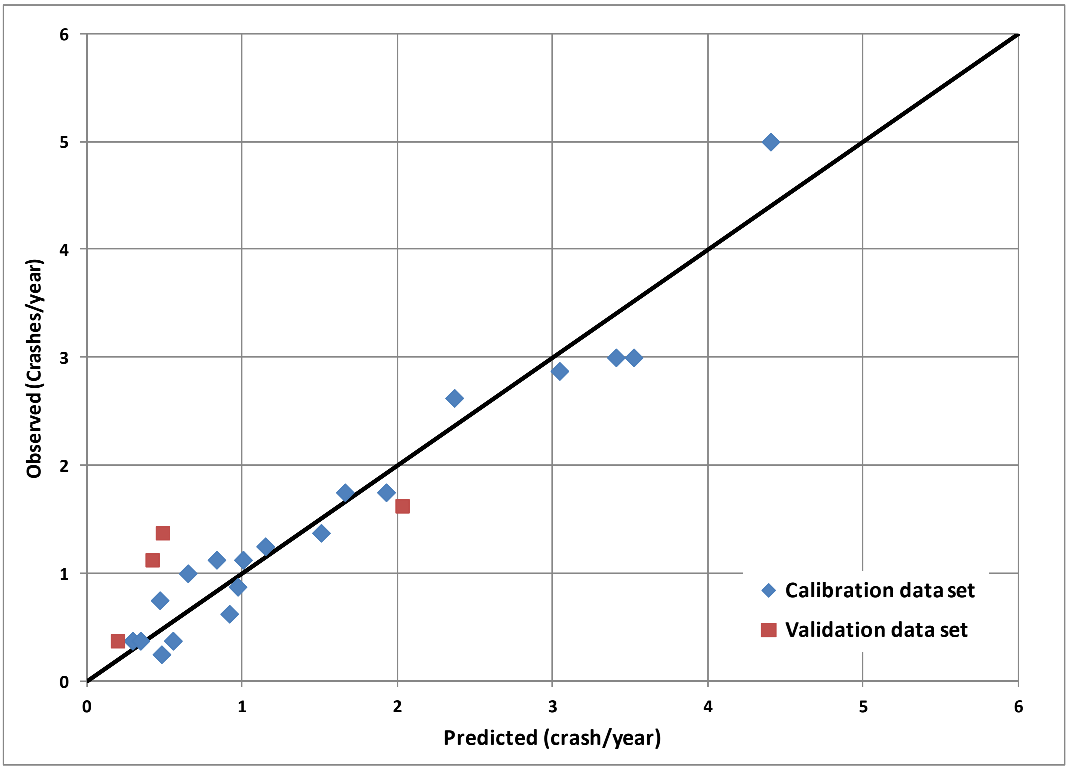


Figure 16. Observed vs. predicted annual crashes for the calibration and validation dataset

4.2.7 Estimation of the unprotected terminals CMF

As indicated in § 4.2 the CMF for the effect of having unprotected terminals in a section will be calculated by means of the following equation:

$$CMF_i = \frac{E[N]_2}{E[N]_1} \times \frac{N_{p\_1}(\text{var}\, i = base)}{N_{p\_2}(\text{var}\, i = base)}$$

Where:

$E[N]_1$ and $E[N]_2$ are the expected crash frequencies (in crashes/yr) for the two sections of a "pair";

$N_{p\_1}(\text{var } i = \text{base})$ and $N_{p\_2}(\text{var } i = \text{base})$ are the number of crashes predicted by means of the SPF for the same two sections with *var i* = UT set to 0.

The first issue is the identification of the "pairs" which have been extracted from the database based on the following criteria:

- The AADT has to be the same in the two sections;
- The lane width has to be the same in the two sections;
- The two sections in the pair have a different number of unprotected terminals per km (UT);
- The value of $N_{p\_1}(\text{UT} = 0)/L_j$ rounded to the integer should be similar in the two sections. The only pair where the two values differ for more than 1 crash/km is pair

"2" where the two sections have 33 and 35 crashes per km predicted by the model with UT=0;

- The two sections should be adjacent (if possible) to limit the possible environmental differences not quantified by the SPF.

Out of the 23 sections 6 pairs have been identified as shown in Table 7.

Table 7. Identification of the PAIRS for the unprotected terminals (UT) CMF definition

SEC	CRASH	OD	AD	UT	SW	LW	L	AADT	GS	$N_{p\_j}(UT=0)/Li$	PAIR
2_6_1	**14**	**70.515**	**3.053**	**7.273**	**0.300**	**3.353**	**1.100**	**15193**	**0**	**12**	**1**
2_7_1	**14**	**68.313**	**2.513**	**13.514**	**0.403**	**3.353**	**0.740**	**15193**	**1**	**13**	**1**
2_8_1	9	75.360	2.893	9.677	0.373	3.353	0.620	15193	0	9	
2_9_1	24	51.916	2.682	10.000	0.300	3.353	1.300	15193	0	17	
2_10_1	23	55.492	3.006	4.762	0.407	3.353	0.840	15193	1	26	
2_11_1	**21**	**28.545**	**2.702**	**6.0000**	**0.300**	**3.353**	**0.500**	**14654**	**0**	**33**	**2**
2_11_2	**40**	**42.125**	**2.796**	**0.0000**	**0.342**	**3.353**	**1.000**	**14654**	**1**	**35**	**2**
2_11_3	24	56.190	2.746	2.1898	0.471	3.353	1.370	14654	1	20	
2_11_4	**9**	**17.780**	**2.977**	**3.5398**	**1.494**	**3.962**	**1.130**	**14654**	**0**	**3**	**3**
2_11_5	**3**	**15.885**	**3.308**	**3.1250**	**1.533**	**3.962**	**0.640**	**14654**	**0**	**3**	**3**
2_11_6	11	9.574	3.656	0.0000	1.737	3.962	0.940	14654	0	4	
2_11_7	3	20.930	3.056	0.0000	1.161	3.962	0.430	14654	0	4	
2_11_8	2	9.091	2.700	27.2727	0.414	3.962	0.220	14654	0	9	
2_11_9	**3**	**24.286**	**2.905**	**8.0000**	**0.762**	**3.962**	**0.500**	**14654**	**0**	**5**	**4**
2_11_10	**9**	**3.268**	**2.300**	**41.1765**	**0.770**	**3.962**	**0.510**	**14654**	**0**	**6**	**4**
2_12_1	8	38.966	1.912	9.998	0.378	3.353	0.500	8825	0	8	
2_12_2	**11**	**27.333**	**1.646**	**21.995**	**0.697**	**3.353**	**1.000**	**8825**	**0**	**7**	**5**
2_12_3	**5**	**44.420**	**1.769**	**8.998**	**0.448**	**3.353**	**1.000**	**8825**	**0**	**6**	**5**
2_12_4	13	29.565	2.583	13.041	0.828	3.353	1.150	8825	0	10	
2_12_5	**10**	**22.404**	**1.398**	**14.997**	**0.527**	**3.353**	**0.800**	**8354**	**0**	**8**	**6**
2_12_6	**3**	**19.222**	**1.367**	**4.000**	**0.600**	**3.353**	**0.500**	**8354**	**0**	**8**	**6**
2_12_7	6	62.962	1.582	18.746	0.396	3.353	0.800	8354	0	3	
2_12_8	7	25.000	1.692	14.997	0.509	3.353	0.600	8354	0	9	

The estimated number of counts for each of the two segments of a pair is determined by means of the Empirical-Bayes method as:

$$E[N]_j = w_j \times N_{p\_j} + (1 - w_j) \times N_{o\_j}$$

Where

N_{p_j} is the number of crashes predicted by means of the SPF for the segment j for the entire analysis period (in the specific case 2001-2008);

N_{o_j} is the number of crashes in the segment j in the analysis period (in the specific case 2001-2008);

w_j is the Empirical-Bayes weight for segment j given by:

$$w_j = \frac{1}{1 + k \times N_{p\_j}}$$

Where k is the overdispersion parameter of the SPF function which can be either a constant value or, according to Hauer [19], preferably a function of the section length. This latter formulation has been adopted also in the Highway Safety Manual that, for the specific base SPF proposed for rural single carriageway two lane roads, defines the over-dispersion as:

$$k_j = \frac{0.236}{L_j(miles)} = \frac{0.3776}{L_j(km)}$$

In the specific case of the analysis based on the Arezzo Province the SPF didn't exhibit any overdispersion leading to a value of w_j = 1 and $E[N]_j = N_{p\_j}$. The $CMF_{2/1}$ value calculated for each pair is listed in Table 8, with section "2" being the section with the lowest number of unprotected terminals per km (UT) that represents the "after" condition.

The values of $CMF_{2/1}$ obtained are the crash modification factors that relates a section with UT_2 number of unprotected terminals to a section with UT_1 number of unprotected terminals and not with the base condition with UT=0.

The general form of the CMF for unprotected terminals should be in the form of:

$$CMF = e^{\beta \times UT}$$

so that the number of crashes in a given section could be estimated as:

$$N = N_b \times CMF$$

being N_b the number if crashes estimated in the base conditions with UT=0.

For each value of $CMF_{1/2}$ the corresponding value of CMF_2 (relating the section 2 of the pair to an ideal base condition with UT=0) has therefore to be calculated as:

$$\beta = \frac{\ln(CMF_{2/1})}{UT_2 - UT_1}$$

$$CMF_2 = e^{\frac{\ln(CMF_{2/1})}{UT_2 - UT_1} \times UT_2}$$

The correlation between CMF and UT as been obtained assuming:

- CMF=1 for UT=0;
- An exponential relation between CMF and UT.

The results of this final analysis are shown in Figure 17 and the equation relating the CMF with the reduction in the number of unprotected terminals per km is given by:

$$CMF = e^{0.02381 \times UT}$$

In the specific application developed for the Arezzo Province network the SPF didn't show any overdispersion and therefore the "β" of the CMF is the coefficient of UT in the SPF function. This is a very peculiar result and therefore the general formulation of the procedure has been described in this section in order to allow the user to develop the same CMF for different dataset which might more likely result in an over-dispersed SPF.

Table 8. CMF values for each of the 6 analysed pairs

SEC	*CRASH (N_{o_j})*	*UT*	*L*	*PAIR*	*N_{p_j}(UT=0)*	*N_{p_j}*	*$CMF_{2/1}$*
2_6_1	14	7.273	1.100	1	13.0	15.4	0.862
2_7_1	14	13.514	0.740		9.6	13.3	
2_11_1	21	6.0000	0.500	2	16.4	18.9	0.867
2_11_2	40	0.0000	1.000		35.2	35.2	
2_11_4	9	3.5398	1.130	3	3.1	3.4	0.990
2_11_5	3	3.1250	0.640		2.2	2.4	
2_11_9	3	8.0000	0.500	5	2.3	2.8	0.454
2_11_10	9	41.1765	0.510		3	8.0	
2_12_2	11	21.995	1.000	6	7.1	12.1	0.734
2_12_3	5	8.998	1.000		5.9	7.3	
2_12_5	10	14.997	0.800	7	6.4	9.2	0.770
2_12_6	3	4.000	0.500		4	4.4	

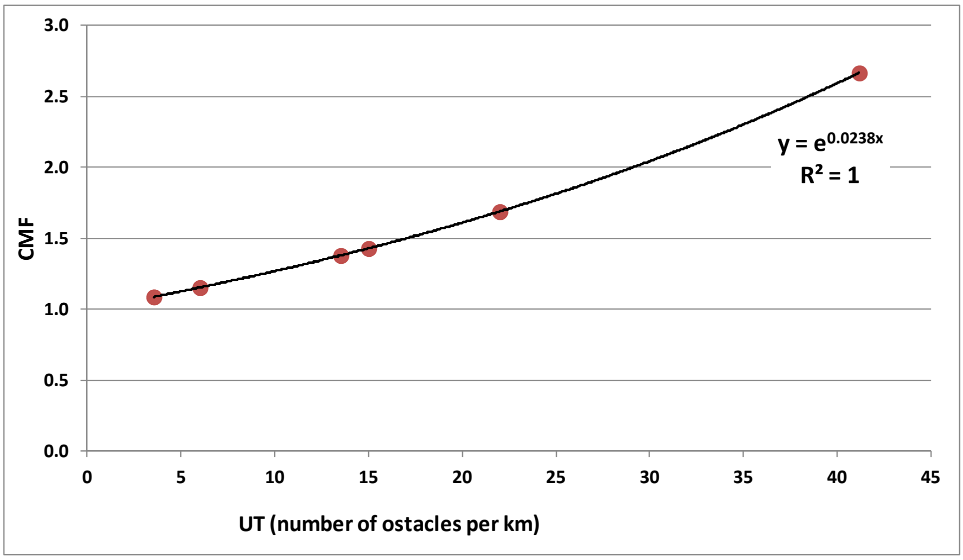


Figure 17. CMF Vs. number of unprotected terminals per km (UT)

4.3 Conclusions

The statistical analysis conducted on a typical secondary rural network in Italy shows a significant reduction of the number fatal and injury crashes when the number of unprotected terminals is reduced and a Crash Modification Factor was derived as a function of the reduction in the number of unprotected terminals.

The equation relating the CMF with the number of unprotected terminals per km is given by:

$$CMF = e^{0.02381 \times UT}$$

The Safety Performance Function developed on the basis of the collected data resulted to be extremely accurate but the effect of other roadside related variables, such as the number of obstacle and the distance from the carriageway was confounded by the cross correlation with more relevant parameters, namely the lane width and the shoulder width.

The effect of changing the type of terminal from un unprotected to a flared or energy absorption one could not be established as this type of terminals are not yet installed in the analysed network.

A very important variable in the model resulted to be the presence of gas station which a variable usually not considered in Safety Performance Functions for single carriageways rural roads.

5 Effectiveness of Grooved Rumble Strips

5.1 Introduction

During the summer of 2007 (June - October) grooved rumble strips was implemented on a 200 km stretch of a dual carriageway in western Sweden. The intended effect of these rumble strips is to keep drivers from accidently leaving the lane due to fatigue or inattention and thus reduce the number of single vehicle accidents. Phillips and Sagberg [20] state that as much as 64 % of those drivers that falls asleep on roads with rumble strips implemented are awaken by them.

5.1.1 Aim

This study aims to evaluate the accident reducing effect of the implementation of grooved rumble strips on dual carriageways with a posted speed limit of 110-120 km/h in Sweden.

5.2 Methodology

To evaluate the effect of the grooved rumble strips, accident data for the treated road sections and non treated similar road stretches was obtain from STRADA (Swedish Traffic Accident Data Acquisition). It contains general accident information on all police reported injury accidents. Information from all single vehicle accident between 1st January 2004 to 31st December 2010 was extracted for the road sections of interest. The treatment was implemented during 14th June to 12th October 2007 and this period is therefore excluded in the analysis. The treated road stretch was divided into two sections to be able to exclude a section where it passes through a large city with changes of the road characteristics. Similarly is the not treated road divided into several sections to exclude road sections that differ substantially in their characteristics. The treated road sections are henceforth denominated as T1 and T2 and the not treated as N1, N2 and N3.

In Table 9 the length of the sections and amount of traffic can be seen for the investigated road sections. The total traffic amount (million vehicle km/year) is very similar for the treated and non treated road sections but the non treated roads have a lower traffic density in average. The variation in traffic density is quite large with 2-3 times as much traffic for the most trafficked road (N3) compared to the road section with the least traffic (N2). The Annual Average Daily Traffic (ADT) has not been taken into account in the analysis.

Table 9. Length and traffic for the investigated road sections

Road section	*Start and Endpoint*	*Distance [km]*	*Million vehicle [km/year]*	*Treated*
T1	Kungälv-Gläborg	67.0	506.2	Yes
T2	Karup-Kållered	133.3	1160.0	Yes
N1	Lagan-Jönköping	72.4	368.1	No
N2	Helsingborg-Lagan	101.7	434.4	No
N3	Kronetorp-Hallandsås	71.7	841.4	No

The total investigated road length is approximately 450 km which contain some variations in the road layout. In general, the road sections have a typical layout illustrated in Figure 1 consisting of a dual carriageway with two lanes in each direction, wide paved shoulders and painted edge markings that have some rumbling effect.

Figure 18. Typical layout of the investigated roads

The treatment consists of milled rumble strips on the outer paved shoulder approximately 0.5 m from the painted edge marking. The milling was performed in a pattern called Pennsylvanian rumble strips which can be seen in Figure 2.

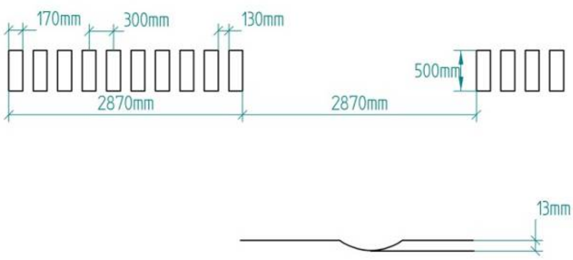


Figure 19. Dimensions of Pennsylvanian rumble strips

5.3 Statistical analysis and result

The statistical analysis is basically a before and after comparison but by using a non treated road as comparison a time correction factor can be added. This factor (later called period effect, c) should capture the changes in accident rate that are not of interest and thus make it possible to state that the improvements are due to the rumble strips.

The period up until 14 June 2007 is considered as the pre-treatment period, denoted B (before), and the period after 12 October 2007 as the post-treatment period, denoted A (after). The accidents is summarised for each roadway in periods B and A in Table 10.

Table 10. Number of accidents per road in the before (B) and after (A) period

Road section	*B*	*A*
N1	66	49
N2	74	85
N3	124	132
Ntot	264	266
T1	64	60
T2	190	125
Ttot	254	185

A Fisher's exact test testing the independence of period and treatment results in a p-value p=0.014 (Odds Ration 0.72). That is, there is a significant effect of the treatment on the number of accidents in the post-treatment period. Other confounding factors such as time and changing policies were not accounted for because the time window is very narrow and is therefore not consider having a significant impact.

A more detailed analysis of each roadway and the treatment effect was also performed. Treating each pre- and post-treatment accident count for each roadway as a Poisson variable and performing a likelihood ratio test on the treatment effect parameter. Denoting the accident intensity of each roadway in the pre-treatment period B by I1, I2, I3, I4 and I5 (for the 5 roadways above) where I4 and I5 correspond to T1 and T2. By adding an overall period effect, c, which impacts the accident rate equally for all roadways the accident rate in the post treatment period can be reduced toI1*c, I2*c, I3*c for roadways 1-3.

The parameter c should capture possible improvements to the roadways, vehicle standards etc. that might exist independently from the treatment. The effect of the treatment which is added in the expression for the treated road ways is denoted by E. The accident rate on treated road segments post-treatment can then be expressed as I4*c*E and I5*c*E. The 7 parameters are estimated (5 roadway accident intensity rates, the period effect c, and the treatment effect E) via maximum likelihood. The results are summarised in Table 11.

Table 11. Result of the maximum likelihood test

Parameter	*Estimate*	*Std error*
I1	57.3	5.9
I2	79.2	7.2
I3	127.5	9.7
I4	71.5	7.1
I5	181.7	12.6
c	1.008	0.088
E	**0.728**	**0.095**

The standard errors were obtained from the observed fisher information. The 95% confidence interval for the treatment effects is [0.543, 0.914]. That is, the estimated treatment effect is a 27.2% reduction of the accident intensity rate, but the upper confidence interval boundary indicates this effect could be as low as 8.6%.

The treatment effect E=1 are restricted and re-compute the maximum likelihood estimates of the other parameters. The two likelihood results are compared via a standard likelihood ratio test. The obtained p-value is 0.0124, which declare that the treatment effect significant.

Specific cases:

The data contains some general information about each accident which made it possible to investigate in which conditions the treatment seems to have or lack effect. The conditions found suitable for this analysis was light condition, road surface condition and weather. For each condition of interest the data was subdivided into categories of interest and investigated for which conditions the treatment had significant effect or not. Further analysis on the effect of these conditions was not included.

For light condition the data was categorized into darkness, daylight and dusk/dawn. The results are summarised in Table 12 below and concludes that the treatment has a significant effect for dark driving conditions.

Table 12. Accident categorized by light condition.

Light condition	*B*	*A*	*p-val*
DARK			
N	79	95	
T	69	42	0.007
DAY			
N	156	144	
T	158	122	0.317
DUSK/DAWN			
N	23	25	
T	25	17	0.297

For road surface condition the data was categorized into dry, wet and snow/ice. The results are summarised in Table 13 below and concludes that the treatment has a significant effect for dry driving conditions.

Table 13. Accident categorized by road surface condition.

Surface condition	*B*	*A*	*p-val*
DRY			
N	123	114	
T	120	68	0.014
WET			
N	71	78	
T	77	63	0.24
SNOW/ICE			
N	64	71	
T	54	50	0.51

For road weather the data was categorized into clear, rain and snow. The results are summarised in Table 14 below and concludes that the treatment has a significant effect for rain.

Table 14. Accident categorized on weather condition.

Weather condition	*B*	*A*	*p-val*
CLEAR			
N	176	172	
T	151	123	0.29
RAIN			
N	36	46	
T	54	34	0.03
SNOW			
N	38	36	
T	30	19	0.35

5.4 Discussion and Conclusion

The statistical analysis shows a significant reduction of the number of single vehicle accident on the roads where Pennsylvanian rumble strips has been implemented. The dataset is unfortunately not large enough to estimate the magnitude of the effect with high certainty but the indication of 27% is promising. To get a more detailed result more data is needed or the possibility to distinguish the run of road accidents from other single vehicle accidents as the treatment is targeting this type of accidents. Unfortunately, the data is not detailed enough to know if fatigue was a factor in the accident or not.

As this study does not take the severity of the accident into account it is impossible to know if the effect is evenly distributed between sever and less sever accidents. To investigate this would be an interesting next step reassuring that the severity of the remaining accidents is not increased.

In the dataset it is not possible to distinguish between run of road to the right or to the left. The effect might differ if this parameter was known.

In the study the comparison road sections were selected to be as similar to the treated roads as possible but as there are no identical roads there are some differences that have not been possible to take in to account such as weather, traffic density and traffic composition.

The significant effect of the treatment for rain is not contradicting the lack of significance for wet roadways. The rain condition is a subset of the wet roadway condition (i.e. the roadway can be wet when it is not raining). It can be hypothesize that the significance of the rain condition is the reduced visibility rather than the road condition.

6 Simulation and assessment of forgiving roadside treatments in curves

6.1 *Introduction*

Most common single vehicle accidents are related to a leaving of the road, which is literally described as run-off-road accident. Based on national crash statistics and reconstruction simulations, single vehicle accidents are often a consequence of wrong driver behaviour, like an inadequate speed choice. This leads to the appraisal that the consequences of these accidents can be reduced by either changing the driver behaviour or minimizing the effects of wrong behaviour. The focus of this work is related to the mitigation of accident consequences by looking at measures to forgive human errors.

6.2 *Methodology*

6.2.1 Tools

Simulating the effectiveness of different forgiving roadsides is realized by using infrastructure data measured by RoadSTAR, the software tool MARVin and the simulation tool VIIS (Vehicle-Infrastructure Interaction Simulation) as well as the accident reconstruction software PC Crash (see Annex B with the full research report).

- The RoadSTAR is a mobile laboratory of AIT, which measures all safety relevant road surface and geometry parameters, e.g. skid resistance, texture, alignment parameters etc.
- MARVin is a software tool developed by AIT to detect correlations between road infrastructure and road accidents. It combines the gathered data of the RoadSTAR with the road accident data in Austria.
- VIIS is a project of AIT where the interaction between vehicles and road infrastructure is simulated. The aim is to get detailed information about the effects of various road parameters on the vehicle behaviour. Real accident data and corresponding roadside parameters are linked via MARVin and can be integrated in the simulation model. This allows simulating real accident high risk sites with all necessary information.
- PC Crash is a 3D collision and trajectory simulation software. It enables the user to analyse accidents and incidents regarding motor vehicles.

6.2.2 High risk accident sites

In Austria, a high risk site is defined as a road section, where the responsible road administration has to take measures as soon as they are identified. It is further defined as a location with a maximal range of 250 metres or an intersection, where either five accidents of similar type (including accidents without personal injuries) within one year or at least three similar personal injury accidents within three years happened.

Two accident high risk sites have been investigated within the IRDES project.

Accident high risk site A

The first investigated accident high risk site is interesting in terms of an existing safety barrier. In four out of six ROR accidents, the corresponding circumstance “Crash into a road restraint system” was mentioned. The accident high risk site ranges over 170 m and can be seen in Figure 20. Additionally, the accidents locations are marked as points, whereas one point can refer to more than one accident.

Figure 20: Accident high risk site A

The accidents are distributed over the curve, starting with number one at km 20.75 and ending with number four at km 20.6. At the second point, three accidents are recorded, so that this seems to be the most hazardous position. An important differentiation is the driving direction. Four of the six accidents happened in the downstream direction, while only two happened upstream. At point 2, the distribution is two in downstream and one upstream direction.

The road condition was reported as dry once, while four times the road was wet and one time icy. In two of the six accidents, darkness was recorded by the police.

Accident high risk site B

The second investigated location is accident high risk site B, which is most interesting in terms of accident severity. At this location three ROR accidents occurred within the investigated time period, whereas all three ended fatally. This relates to an average severity rate of 130 based on the Austrian directive RVS 02.02.21. The weighted severity was the highest observed value for all ROR accident high risk sites with 390. In one case, one severely injured person was recorded.

All three accidents happened at the same recorded position (checked also with the police records) and in the same driving direction (downstream). The corresponding accident type is “leaving left side in a right bend”. In one case the accident type ”collision with an obstacle” was indicated. It can be assumed that the fatal accidents were caused by a collision with a tree, but it was not specified in the police report.

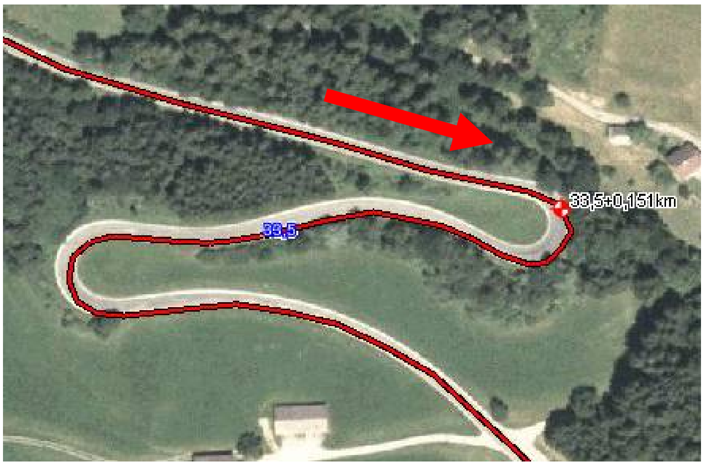


Figure 21: Accident high risk site B

6.2.3 Simulation setup and results

The simulation setup and results can be found in Annex B. The result was assessed by using the following scenarios:

- No forgiving roadside / grass stripe
- Soft shoulder
- Hard shoulder with varying widths or friction coefficients
- Tree accident
- Safety barrier

6.3 Assessment of Effectiveness in terms of safety

By using different scenarios, the effects of roadside measures on injury severity. For this purpose, several different methods are used, which rely on vehicle dynamics data, gathered out of PC Crash during the simulation scenarios. On the one hand, this vehicle information is directly derived from the measured collision parameters (e.g. for tree collisions), while on the other hand, the overall accelerations and velocities are used.

6.3.1 Accident Severity Measurement Methods

The described accident severity measurement methods mainly refer to methods, which are used during crash tests to determine the requirements of a traffic barrier, as described in the EN 1317 [P 2] (see Annex B for further details).

- Delta-V
- Energy Equivalent Speed (EES)
- Acceleration Severity Index (ASI)
- Head Injury Criterion (HIC)
- Abbreviated Injury Scale (AIS)

6.3.2 Assessment for accident high risk site A

For all assessments of the injury severity, the estimated Maximum AIS (MAIS) level is stated. The scenarios and their results are stated in the following table.

Table 15: Simulation results for accident high risk site A

Scenario	Roadside friction coefficient	Run-off	dV	EES	ASI	HIC	MAIS
No forgiving roadside (1)	0.1 (grass)	Yes	-	-	0.08	6	6
Soft shoulder (2)	0.3 (gravel)	No	-	-	0.08	7	2
Hard shoulder (3,4,5)	0.45 (pavement)	No	-	-	0.08	8	0
Tree (6)	0.1 (grass)	No	23.56	31.73	0.64	1985	6
Safety barrier (7)	-	No	1.61	3.69	0.1	10	1

It must be highlighted, that the first three MAIS-values are 'only' assumed due to there is no correlation between the HIC and the MAIS for lateral collisions.

In scenario one, only minor accelerations could be observed, but the vehicle exceeded the roadside. The ASI value of 0.08 as well as the HIC value of 6 is negligible. However, entering the roadside leads to severe or fatal consequences, according to a higher rollover probability, depending on the slope. Therefore the MAIS of 6 can be stated.

In scenario 2, the vehicle is forced to turn by 180 degree. The acceleration forces do not show significant indications for a hazardous situation with an ASI of 0.08 and an HIC of 7. However, due to vehicle rotation, a higher acceleration can be observed leading to an increased injury probability. Hence a MAIS value of 2 is assumed.

The implementation of a hard shoulder showed an optimal measure. The vehicle resumes its original driving manoeuvre. Figure 22 illustrates the longitudinal (red), lateral (blue) and vertical (green) accelerations during this scenario (about 1.5 sec)

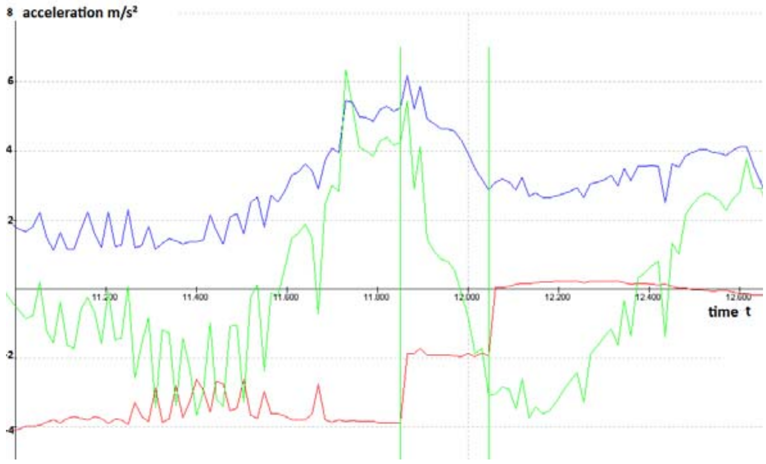


Figure 22: Acceleration forces for scenario 3 (hard shoulder) of accident high risk site A

The separate accelerations do not exceed a value of 6 m/s², so that the maximum average acceleration for this scenario was 9.22 m/s² (at t=11.73). Typically the acceleration during the curve is between 4 and 8 m/s². Therefore, it only slightly increased in this case and can be seen as harmless. The ASI is still 0.08, the HIC is 8 and therefore no injuries are expected. Hence the MAIS is 0.

In scenario six the consequences of hitting a tree are simulated and the results showed a difference to the prior ones. It is the first scenario, where besides the ASI and HIC also the EES and delta-v could be measured efficiently. The delta-v can be considered dangerous with a value of 23.56. The EES of 31.73 km/h indicates a high probability for severe or fatal consequences.

The ASI value is 0.64, which would be still a suitable value for safety barriers, according to the EN-1317. On the other hand, the HIC value is 1985, where fatal consequences have to be assumed. This shows that the ASI value is not a suitable measure for lateral collisions, since it is mainly considered to evaluate frontal impacts. Because of the high HIC value, MAIS of 6 can be stated.

In the last scenario of accident high risk site A, a safety barrier is implemented. The vehicle is directed in a smooth way back onto its original trajectory. The delta-v of 1.61 and EES of 3.69 support this observation. Also the ASI with 0.1 and the HIC with 10 do not show significant deviations, leading to a MAIS of 1.

Summary of the results for accident high risk site A:

- As expected, the simulation of a tree accident showed high accelerations and deformations at the vehicle. It is recommended to remove, relocate or shield trees on the roadside.
- The implementation of a soft shoulder showed an improvement, but it is not suitable for higher speeds, since the vehicle slides along the road in a dangerous way (especially for other road users).
- The hard shoulder resulted in no injuries and only slight acceleration forces.
- The safety barrier was a suitable solution, but it caused a collision, leading to vehicle deformations and slightly increased accelerations.
- Another option, in general, would be a proper signage or a lower speed limit.

6.3.3 Assessment for accident high risk site B

For accident high risk site B the scenarios show major differences compared to accident high risk site A. The summary of the scenarios can be seen in Table 16.

Table 16: Scenarios accident high risk site B

Scenario	Roadside friction coefficient	Run-off	dV	EES	ASI	HIC	MAIS
No forgiving roadside (1)	0.1 (grass)	Yes	-	-	0.1	17	6
Soft Shoulder (2)	0.3 (gravel)	Yes	-	-	0.1	17	6
Hard Shoulder (3)	0.45 (pavement)	Yes	-	-	0.1	17	6
Hard Shoulder (4)	0.6 (pavement)	No	-	-	0.1	17	1
Tree (5)	0.1 (grass)	No	16.75	13.3	0.31	309	6
Safety Barrier (6)	-	No	6.6	17.4	0.16	58	3

For this specific run-off-road accident case, the first four scenarios have identical values for ASI and HIC and the implementation of soft and hard shoulder does not affect the vehicle behaviour. However, the vehicle still runs off the road, whereas a MAIS of 6 is stated.

When applying a hard shoulder with a higher friction value than the traffic lane, positive safety effects can be observed. However, in reality this case not likely nor practical. For this scenario, the ASI and HIC values are still the same, but the vehicle is now able to stop before leaving the road. The corresponding MAIS is 1, since minor injuries are still likely.

As expected, the collision with the tree (scenario 5) shows an increased injury severity. The

HIC does not seem to be dangerous with a value of 309, since a HIC of 1000 is assumed to be the limit for slight injuries. But a closer look at the accident shows that the vehicle laterally crashes into the tree, while the driver is seated on the impact side. The probability of the driver's head to penetrate the side window is high, since this is reached with a HIC of 200. Combining this with the limited flexibility of the head in the transversal direction, a fatal accident is likely. The impact speed is low with 24 km/h, but a delta-v of nearly 17 km/h can be considered dangerous. Moreover, the EES of 13 is high, which leads to an MAIS level of 6.

In scenario 6, a safety barrier is implemented. Similar to accident high risk site A, the vehicle laterally crashes into the safety barrier. Four collision points could be observed, before the vehicle was able to resume its original driving manoeuvre. This caused an overall speed reduction of 17 km/h over a time period of 30 ms. The highest measured impact resulted in a delta-v of 6.6 km/h. The overall deformation for all four impacts leads to an EES of 17.3 km/h. The ASI of 0.16 and the HIC of 56 are relatively low. Considering the high EES and the four impact points, an MAIS of 3 can be assumed.

Summary of the observations of accident high risk site B:

- The tree showed a higher risk potential so that the removing or relocation is recommended.
- The soft shoulder showed no positive effect on safety.
- The hard shoulder was only useful with a greater friction coefficient than the traffic lane (which is not likely nor practical).
- The safety barrier was effective against the tree accident, but it showed strong deformations and accelerations.
- Another option (as for high risk site A), would be a proper signing and/or lower driving speeds

6.4 Conclusion and discussion

The assessment of forgiving roadside treatments in curves is carried out by simulating ROR accidents. A simulation-based framework was developed to replicate high-risk accident sites in a virtual environment and simulate vehicles running off the road. The road and roadside models are created from laser measurement data and are imported into the 3D collision and trajectory simulation tool PC-Crash. In a kinetic simulation procedure, the vehicle model runs off the road with a specific driving speed. Several roadside treatments are implemented to evaluate their effectiveness on safety. Important indicators for the evaluation are the head injury criterion (HIC) and the abbreviated injury scale (AIS), which describe the injuries to occupants involved in collisions.

The simulation and assessment framework was applied to two curvy road sections in Austria, which were identified as high-risk accident sites. The implementation of a soft shoulder can be seen as useless in those specific case studies. A soft shoulder in conjunction with a barrier (large working width) would probably be of benefit. It shows an improvement for the drawn-out curve with a reduced probability to exceed the roadside, but on the other hand the risk to slide is increased. This causes a reduction of injury severity, but on the other hand an increased hazard for other road users. It can be said that this measure is not appropriate for the speed of 90 km/h and should mainly be used on sections with lower speed. Also in sharp curves the implementation of soft shoulders is not suitable, as the analysis of the second accident high risk site has shown. The vehicle passes the shoulder without any reaction. Therefore this measure was the least effective one for the two test cases.

The second measure, the implementation of a hard shoulder, prevented the vehicle to leave the road in the drawn-out curve. The shoulder acts as an extended traffic lane. This enables the vehicle to stay on its original trajectory, without strong steering or braking sequences.

Therefore the consequences of the ROR were minimized. For the sharp curve, an extended traffic lane was not suitable. Only the implementation of a shoulder with better friction value than the traffic lane would increase roadside safety. However, this measure is not practical, since high friction variations between road and shoulder surface should be avoided.

An effective measure for both spots was the implementation of a safety barrier. In both cases, the safety barrier redirected the vehicle back onto its original trajectory, without any indications of sliding or overturning. However the impact on the barriers caused increased accelerations and deformations at the vehicle. Therefore this measure should be only used in cases, where other measure are not possible, or do not show any positive effect.

The tree accident scenario at both spots shows high decelerations and deformations at the vehicle. Therefore the risk of severe injuries within these accidents is high. Removing the trees in the near surrounding of the traffic lane is strongly recommended. If this is not possible, shielding with safety barriers is a suitable measure, since the severity of the impact is much lower.

The investigated sharp curve (accident high risk site B) is a good example for a location, where only safety barriers seem to be an effective measure. The other measures or the implementation of a safety zone are not practical. Due to the surrounding forest on the roadside, the space for measures is limited, and the removing of all trees is no alternative. The same is true, when investigating the real surrounding of the drawn-out accident high risk site A. Due to the trees and the steep ditch, space for a hard shoulder is not available, although it would be an effective measure according to the simulations.

In general, the methodology used for assessing roadside treatments in curves allows an effective evaluation of roadside safety. Accurate replications of high-risk road sites are crucial for applying this methodology. Therefore, a measurement device for capturing road alignment, surface parameters and roadside elements is necessary. For the final decision on roadside treatments, it may also be necessary to perform an additional inspection at the spot. Other factors such as environmental impacts or cost-benefit ratio have to be included in this decision.

7 Conclusion and recommendations

7.1 Variations of shoulder width

Part of the study was to evaluate driver behaviours before and after treatment with a tool, called Observatory of Trajectories (OT), composed by rangefinder and cameras. However, due to delays in the modifications of the road only measurement before the modifications could be conducted and analysed. The analysis of the measurements of the before situation concluded that:

- Measured speed and lateral position show reliable results.
- Number of measured vehicles is insufficient to analyse other parameters as required (e.g. the situation where another vehicle was approaching in the opposite lane).
- The percentage of removed data is higher for trucks than for cars.
- The recording time needs to be increased to have more free vehicles tracked (2 minutes instead of 30 seconds).
- Measurements of the central marking in the rangefinder referential are needed to improve accurate calibration.
- It is a need to use two rangefinders at different heights for the car and heavy goods vehicle measurement respectively.
- The recording period should be increased to at least two weeks to ensure a larger data sample.

7.2 Removing unprotected barrier terminals

The statistical analysis conducted on a typical secondary rural network in Italy shows a significant reduction of the number fatal and injury crashes when the number of unprotected terminals is reduced. A Crash Modification Factor (CMF) was derived as a function of the reduction in the number of unprotected terminals.

The equation relating the CMF with the number of unprotected terminals per km is given by:

$$CMF = e^{0.02381 \times UT}$$

The Safety Performance Function developed on the basis of the collected data resulted to be accurate. However, the effect of other roadside related variables, such as the number of obstacle and the distance from the carriageway was confounded by the cross correlation with more relevant parameters, namely the lane width and the shoulder width.

An important variable in the model resulted to be the presence of gas stations which a variable usually not considered in Safety Performance Functions for single carriageways rural roads.

A test with a validation dataset has shown that there the model can be used also to predict accidents for other roads than the one analysed. Given the small set of data used for the analysis the application leads to realiable estimations only for roads having parameters comparable with those used for the calibration of the model.

7.3 Grooved rumble strips

To assess the effectiveness of the implementation of grooved rumble strips on dual carriageways comparisons between treated and non-treated roads were evaluated by statistical methods. Accident data from several years with and without treatment are needed to perform the analysis.

The statistical analysis shows a significant reduction of the number of single vehicle accident on the roads where Pennsylvanian rumble strips has been implemented. It was not evaluated if the effect is evenly distributed between severe and less severe accidents.

The significant effect of the treatment for rainy weather conditions is not contradicting the lack of significance for wet roadways. The rain weather condition is a subset of the wet roadway condition (i.e. the roadway can be wet when it is not raining). It can be hypothesize that the significance of the rainy weather condition is the reduced visibility rather than the road condition.

7.4 Treatments in curves

The method of using Vehicle Infrastructure Interaction Simulation (VIIS) was tested in two case studies.

In both cases the implementation of a soft shoulder did not show any positive results. The extended roadside reduced the probability to exceed the roadside, but increased the risk of skidding. The injury risk was reduced but the due to the uncontrolled vehicle it increased the risk for other road users. The case studies showed that soft shoulder is not appropriate for the speeds of 90 km/h and in sharp curves.

Implementation of a hard shoulder, showed an ideal vehicle manoeuvre for the extended curves but not for sharp curves. For the case with the same friction value, the shoulder acts as an extended traffic lane. This enables the vehicle to stay on its original trajectory, without strong steering or braking sequences. Therefore the consequences of the ROR were minimized in an optimal way. For the sharp curve the positive effect was only found when the shoulder had a better friction value than the traffic lane.

For both spots the implementation of a safety barrier showed positive effect. In both cases the safety barrier redirected the vehicle back onto its original trajectory, without any indications of sliding or overturning. However, the impact on the barriers caused increased accelerations and deformations at the vehicle.

Removing the trees in the near surrounding of the traffic lane or shielding with safety barriers is recommended. The deceleration of the vehicle is lower in impacts with safety barriers decrease the risk of injuries.

The methodology shows that VIIS (Vehicle-Infrastructure Interaction Simulation) can be used as assessment tool for estimating the effectiveness of forgiving roadside measures in a practical way. The critical point is the availability of data to create a 3D road model, since laser measurement data are not commonly used in road data bases. The interface to simulation software is not the key problem for designing that simulation tools. This methodology can be easily transferred to different software solutions.

Glossary

Arrester bed
An area of land adjacent to the roadway filled with a particular material to decelerate and stop errant vehicles; generally located on long steep descending gradients.

Back slope (see ditch)
A slope associated with a ditch, located opposite the roadway edge, beyond the bottom of the ditch.

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 support
A sign, traffic signal or luminaire support designed to yield or break when struck by a vehicle.

Abutment
The end support of a bridge deck or tunnel, usually retaining an embankment.

Vehicle parapet (on bridges)
A longitudinal safety barrier whose primary function is to prevent an errant vehicle from going over the side of the bridge structure. It can be constructed from either steel or concrete.

CCTV Masts
A mast on which a closed circuit television camera is mounted for the purpose of traffic surveillance.

Carriageway
The definition of the ‘carriageway’ differs slightly amongst countries. The edge of the carriageway is delineated by either the “edge line” or, if no edge line is present, the edge of the paved area.

Central reserve
An area separating the carriageways of a dual carriageway road.

Clearance
The unobstructed horizontal dimension between the front side of safety barrier(closest edge to road) and the traffic face of the.

Clear/Safety zone
The area, starting at the edge of the carriageway, that is clear of hazards. This area may consist of none or any combination of the following: a ‘hard strip’, 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
A vehicle which comes in contact with a road restraint system and does not pass beyond the limits of the safety system.

Containment level
The 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 and tested to (EN 1317).

Crash cushion
A road vehicle energy absorption device (road restraint system) installed in front of a rigid object to contain and redirect an impacting vehicle ("redirective crash cushion") or to contain and capture it ("non-redirective crash cushion").

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.

Cut slope
The earth embankment created when a road is excavated through a hill, which slopes upwards from the level of the roadway.

Design speed
The speed which determines the layout of a new road in plan, being the speed for which the road is designed, taking into account anticipated vehicle speed on the road.

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 central reserve 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 protruding above the ground level at the edge of the paved surface.

Dual carriageway
A divided roadway with two or more travel lanes in each direction, where traffic is physically divided with a central reserve and/or road restraint system. See also ‘divided roadway’.

Edge line
Road markings that can be positioned either on the carriageway surface itself at the edge of the carriageway, or on the ‘hard strip’ (if present) next to the carriageway.

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

Encroachment
A term used to describe the situation when the vehicle leaves the carriageway and enters the roadside area.

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
An earth embankment created when extra material is packed to create the road bed, typically sloping downwards from the roadway.

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

Fore slope (see ditch)
The fore slope is a part of the ditch, and refers to the slope beside the roadway, before the ditch bottom.

Forgiving roadside
A forgiving roadside mitigates the consequence of the “run-off” type accidents and aims to reduce the number of fatalities and serious injuries from these events.

Guardrail
A guardrail is another name for a metal post and rail safety barrier.

Hard/Paved shoulder
An asphalt or concrete surface on the nearside of the carriageway. If a ‘hard strip’ is present, the hard shoulder is immediately adjacent to it, but otherwise, the shoulder is immediately adjacent to the carriageway. Shoulder pavement surface and condition as well as friction properties are intended to be as good as that on the carriageway.

Hard strip
A strip, usually not more than 1 metre wide, immediately adjacent to and abutting the nearside of the outer travel lanes of a roadway. It is constructed using the same material as the carriageway itself, and its main purposes are to provide a surface for the edge lines, and to provide lateral support for the structure of the travel lanes.

Highway
A highway is a road for long-distance traffic. Therefore, it could refer to either a motorway or a rural road.

Horizontal alignment
The projection of a road - particularly its centre line - on a horizontal plane.

Impact angle
For a longitudinal safety 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. 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 unit intended to separate areas of different surfacings and to provide physical delineation or containment.

Lane line
On carriageways with more than one travel lane, the road marking between the travel lanes is called the 'lane line'.

Limited severity zone
An area beyond the recovery zone that is free of obstacles in order to minimize severity in case of a vehicle run-off.

Length of need
The total length of a longitudinal safety barrier needed to shield an area of concern.

Median
See 'central reserve'.

Motorways
A dual carriageway road intended solely for motorized vehicles, and provides no access to any buildings or properties. On the motorways itself, only grade separated junctions are allowed at entrances and exits.

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, surface dressing or concrete (e.g. grass, gravel, soil, etc).

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 (or an obstacle).

Paved shoulder
See 'hard shoulder'.

Pedestrian restraint system
A system installed to provide guidance for pedestrians, and classified as a group of restraint systems under 'road restraint systems'.

Pier
An intermediate support for a bridge.

Point Hazard
A narrow item on the roadside that could be struck in a collision, including trees, bridge piers, lighting poles, utility poles, and sign posts.

Recovery zone
A 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, particularly a wall built to support or prevent the advance of a mass of earth.

Road restraint system (RRS)
The general name for all vehicle and pedestrian restraint systems used on the road (EN 1317).

Road equipment
The 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 roadway.

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

Roadway
The roadway includes the carriageway and, if present, the hard strips and shoulders.

Rock face cuttings
A rock face cutting is created for roads constructed through hard, rocky outcrops or hills.

Rumble strip (Shoulder rumble strips)
A thermoplastic or milled transverse marking with a low vertical profile, designed to provide an audible and/or tactile warning to the road user. Rumble strips are normally located on hard shoulders and the nearside travel lanes of the carriageway. They are intended to reduce the consequences of, or to prevent run-off road events.

Rural roads
All roads located outside urban areas, not including motorways.

Safety barrier
A road vehicle restraint system installed alongside or on the central reserve of roads.

Safety zone
See ’clear zone’.

Self-explaining road
Roads designed according to the design concept of self-explaining roads. The concept is based on the idea that roads with certain design elements or equipment can be easily interpreted and understood by road users. This delivers a safety benefit as road users have a clear understanding of the nature of the road they are travelling on, and will therefore expect certain road and traffic conditions and can adapt their driving behaviour accordingly. (Ripcord-Iserest, Report D3, 2008).

Set-back
Lateral distance between the way and an object in the roadside for clearance).

Shoulder
The part of the roadway between the carriageway (or the hard strip, if present) and the verge. Shoulders can be paved (see 'hard shoulder') or unpaved (see 'soft shoulder').
Note: the shoulder may be used for emergency stops in some countries; in these countries it comprises the hard shoulder for emergency use in the case of a road with separate carriageways.

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/Unpaved shoulder
A soft shoulder is defined as being a gravel surface immediately adjacent to the carriageway or hard strip (if present). In some countries it is used as an alternative for hard shoulders.

Soft strip
A narrow strip of gravel surface located in the roadside, beyond the roadway (normally beyond a hard strip/shoulder).

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.

Transition
A vehicle restraint system that connects two safety barriers of different designs and/or performance levels.

Travel/Traffic lane
The part of the roadway/carriageway that is travelled on by vehicles.

Treatment
A specific strategy to improve the safety of a roadside feature or hazard.

Underpass
A structure (including its approaches) which allows one road or footpath to pass under another road (or an obstacle).

Underrider
A motorcyclist protection system installed on a road restraint system, with the purpose to reduce the severity of a PTW rider impact against the road restraint system.

Undivided roadway
A roadway with no physical separation, also known as single carriageway.

Unpaved shoulder
See ‘soft shoulder’.

Vehicle 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. These are classified as a group of restraint systems under ‘road restraint systems’.

Verge
An unpaved level strip adjacent to the shoulder. The main purpose of the verge is drainage, and in some instances can be lightly vegetated. Additionally, road equipment such as safety barriers and traffic signs are typically located on the verge.

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

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