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SAVeRS

Defining the Different Parameters which can influence the need and selection of VRS

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CEDR Call2012: Safety: Use of Vehicle Restraint Systems

SAVeRS
Selection of Appropriate Vehicle Restraint Systems

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Executive summary

"SAVeRS" (Selection of Appropriate Vehicle Restraint Systems) is a project funded by a number of CEDR Members within the CEDR 2012 Transnational Road Research Programme "Safety". The first Work Package of the project is aimed at analysing the existing criteria for identifying the need for the placement of a vehicle restraint system and for the identification of the most appropriate performance class.

This report contains the research output of the project Task 1.1: Analysis of National Road Authority Methodologies and Task 1.2 Literature Review.

For this aim both the existing national standard and guidelines and literature documents have been analysed in detail.

The comparative analysis of 35 national standards and guidelines covering most of Europe and several non-European Countries has shown that there are many commonalities and it is possible to identify the most frequently used parameters with reference to safety barriers.

Within the literature review results, safety considerations for safety barriers and vehicle parapets are first presented, containing an assessment of the criteria used in EN1317 (CEN, 2010a) for evaluating the VRS performance; in particular ASI and THIV are discussed. Then the research outputs on placement of safety barriers and vehicle parapets and terminals, transitions and crash cushions are presented. A specific section is devoted to bridge parapets and the protection of third parties. Other two sections have been dedicated to vulnerable road users: Motorcyclist Protection Systems (MPS) and the influence of vulnerable road users on decision making of VRS placement. Cultural influences on decision making of VRS placement are also discussed. Relevant literature review on Run-Off-Road Accidents, which contribute to a disproportionally high number of fatal or severe injury accidents, has also been reported. The literature review concluded with a section dedicated to costs and financial implications of Vehicle Restraint Systems.

The main aim of Work Package 1 was to develop a list of the most influential parameters in the installation and selection of vehicle restraint systems from a detailed analysis of National standard and guidelines, and from a thorough review of literature. From the completion of these two Tasks, the following parameters have been highlighted:

- Parameters related to the consequences of a crash were used more often for the decision as to whether to install a VRS
- Parameters related to the likelihood of a given type of crash were used more often to determine the level of performance required from the VRS
- Roadside and median safety barriers:
    - Factors most frequently used to justify installation:
        - Risk to vehicle occupants;
        - Actual travelled speed;
        - Road geometry;

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        - The distance between the roadside and the hazard;
        - The existence of risk to third parties and traffic;
        - The presence of embankments and cuttings (and their height and gradient);
        - The presence and proximity of vulnerable road users;
        - The presence of railways;
        - The presence of bodies of water;
        - The presence of non-deformable roadside obstacles;
        - The average annual daily traffic;
        - Width of median (for median barriers only);
        - Width of safety zone (roadside barriers only).
    - Factors most frequently used to specify performance:
        - Special risk to third parties;
        - Traffic and road alignment and/or geometry;
        - The presence of structures;
        - The presence of railways;
        - The presence of bodies of water;
        - The presence of non-deformable roadside obstacles;
        - The average annual daily traffic;
        - The average annual daily HGV traffic;
        - Actual travelled speed;
        - The presence of adverse road geometry
- Bridge parapets:
    - Factors most frequently used to justify installation:
        - Risk to vehicle occupants, and
        - The height of the bridge.
    - Factors most frequently used to specify performance:
        - Special risks to third parties, and
        - Obstructions posing a risk to vehicle occupants.

- Crash cushions:
  - Factor most frequently used to justify installation: presence of a non-deformable hazard
  - Factor most frequently used to specify performance: actual speed limit of the road
- Motorcyclist Protection Systems
  - Factors most frequently used to justify installation:
    - Traffic flow, and
    - Percentage of motorcyclists on the road.

These parameters will therefore be taken forward into Work Package 2 for further evaluation and study, utilising crash data to observe their influence with regard to crash numbers.

It was also observed that, whilst the majority of the countries have guidelines and/or standards related to roadside and median barriers, there is generally limited guidance for other VRS systems such as crash cushions, transitions and MPS.

In regard to the influence of cost on the placement of VRS although the literature provides limited information for European wide application, there are useful methodologies that can be exploited for a European economic assessment tool. There is little information within the VRS-specific standards and guidelines.

The main current and future difficulty is to find financial data covering all aspects of a VRS installation and valid beyond a region or national level. Different currencies, organization record keeping systems, and diverse product catalogues make it onerous to develop a generic European tool. However, the tool can be developed and distributed for use at the local level where specific data may be available.

1 Introduction

Run-Off-Road (ROR) crashes are extremely severe road accidents that can often result in severe injuries or fatalities. The accident analysis conducted within the RISER Project, funded by the EU, concluded in 2005, highlighted that even though only 10% of the total accidents are single vehicle accidents (SVA, typically associated to the run-off-road type accidents) the rate of SVA events increases to 45% when only fatal accidents are considered.

To reduce the severity of ROR crashes, “forgiving roadsides” need to be designed and this includes identifying where there is a need for a Vehicle Restraint System (VRS) and what appropriate VRS should be selected for specific location and traffic condition.

At the present time, whilst there are standards covering the testing, evaluation and classification of VRS within Europe (EN1317 part 1 to part 8, EN12767 etc.), their selection, location and installation being based upon national guidelines and standards, often produced by National Road Authorities (NRA) and/or overseeing organisations. Due to local conditions, these national guidelines vary across Europe.

As a result, the aim of the SAVeRS project is to produce a practical and readily understandable VRS guidance document and a user-friendly web-based tool that will allow the selection of the most appropriate solution in different road and traffic configurations for all types of VRS: safety barriers; crash cushions; terminals; transitions and motorcyclist protection systems.

The guidance document and the web-based tool will have with the following goals:

- Ensuring the safety of road users, road workers and third parties;
- Optimising VRS performance in use;
- Maximising VRS serviceable life;
- Minimising VRS whole life costs.

The different solutions considered will be fully compatible with EN 1317 series and related EN standards (for example the European passive safety standards EN12767, EN40 and EN12899).

In order to develop a robust and effective methodology for the appropriate selection of a VRS, it is necessary as a first step, to collate, review, fully understand and appreciate current (and proposed future) national guidelines and standards.

The aim of the first Work Package (WP) of the SAVeRS project is:

- To analyse the differing national guidelines and standards to identify, review and categorise information which is currently available relating to the parameters associated with the choice of VRS to develop a single document outlining the approaches taken in each country;

- To collate, review and fully understand international research which has been carried out regarding the parameters considered when selecting a VRS. This may, or may not be related to the development of the NRAs' guidelines.

In order to achieve these objectives, the WP was split into two distinct Tasks, each investigating the areas outlined in the bulleted list above. These Tasks were as follows:

- **Task 1.1 - Analysis of National Road Authority Methodologies**
- **Task 1.2 - Literature Review**

It is the work conducted within these two Tasks (i.e. the first WP) of the SAVeRs project which is documented within this report, with the subsequent sections outlining the aims, methodology and results from these activities.

The output results of this WP will feed directly into WP2 which has the aim of collating accident data relating to the effects of the parameters identified as being important with regard to VRS placement and selection within WP1.

2 Methodology

2.1 Task 1.1 - Analysis of National Road Authority Methodologies

Task1.1 started with the collection of standards and/or guideline documents from as many countries around the world as possible. At an early stage within the project it was agreed to collect documents from not only European countries but also from other parts of the world as well. This was implemented so that a more general understanding of the worldwide approach would be achieved.

The guidelines and standards were collated from National Road Authorities (NRAs) known to members of the project consortium. Each consortium members had very effective and close working relationships with the NRAs in their own countries, and these links were initially used to gather the guidelines. Approaches to other NRAs for their requirements were then made directly through existing contacts, or via contacts within the respective countries. To facilitate the collation of these documents, an ftp site was established. At this point documents from thirty seven different countries were collected.

The next step was to conduct a detailed analysis of each standard or guideline. At this stage a majority of the standards had to be translated to English. Each standard was then read and analysed in detail to identify the parameters relating to:

- The choice of whether to install a VRS, or not, or
- The selection of VRS performance.

At the end, documents gathered from thirty five countries were reviewed in the final analysis.

A data matrix, as shown in Figure 1, was prepared to store and present the identified parameters, by each country. This was to allow easy identification of those parameters essential for the work within Work Package 2.

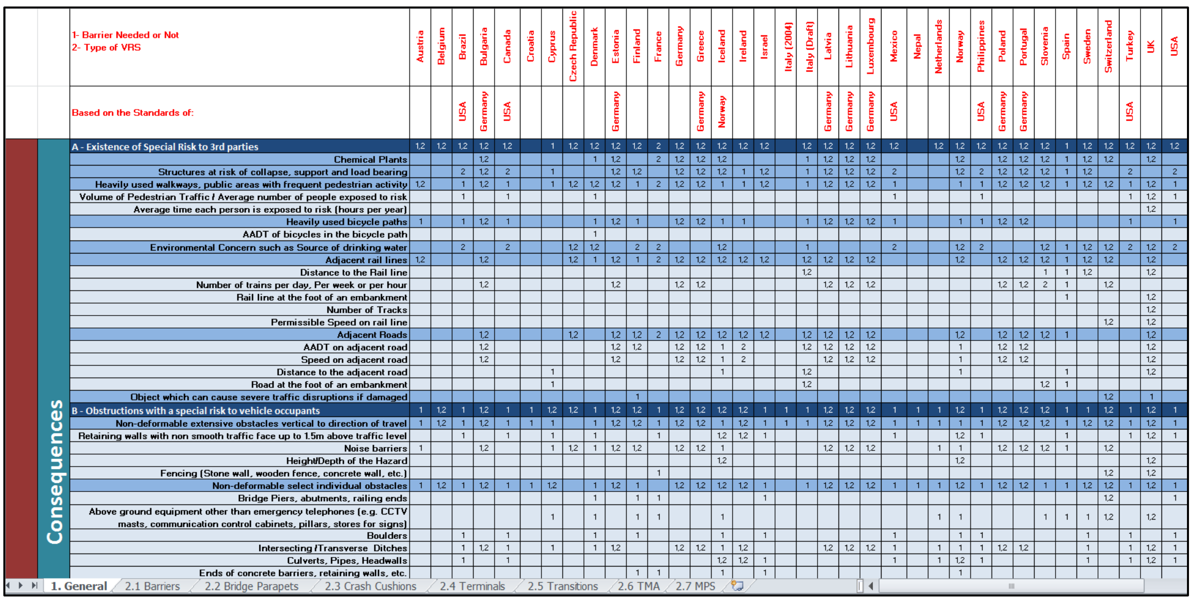


Figure 1 – A screenshot from the Data Matrix

The matrix was modified significantly throughout the analysis process, with the aim of achieving an easy to understand format, as each new document added new parameters to the table.

As shown in Figure 1, it was decided to divide the matrix into separate tabs for each VRS type, those being:

- Roadside and safety barriers;
- Median safety barriers;
- Bridge parapets;
- Crash cushions;
- Transitions;
- Terminals, and
- Motorcyclist Protection Systems (MPS).

This is because it was understood that the parameters related to a certain VRS type differ from each other, and in this way a more meaningful analysis can be conducted. However, due to low level of published guidance for terminals, transitions and motorcyclist protection systems, these were included in the matrix but removed from the following analysis stage.

For each parameter within the analysed National standard/guideline, it was then determined whether they applied to the decision to install a VRS, or whether it was related to the selection of the performance for the VRS, or neither.

As the number of parameters in the matrix increased, it was decided to group the parameters according to an easy to understand classification. At this stage it was decided to adopt the widely used definition of 'Risk' as a product of 'Likelihood' and 'Consequences', as shown in Figure 2.

Figure 2 – The risk model used to categorize the parameters

Each parameter was then grouped either under the 'Likelihood' of having a crash, or 'Consequences' of having such a crash, according to their relevance. The parameters under the 'Consequences' category were then arranged into subcategories of:

- Special Risk to 3rd Parties, and
- Obstructions with a Special Risk for Vehicle Occupants.

The parameters under the 'Likelihood' category were arranged into subcategories of:

- Traffic;
- Speed;
- Road Alignment / Geometry;

- Road Layout;
- Accident History / Frequency.

After the collation of data from National standard/guideline, the final matrix was transferred into SPSS, statistical analysis software, which was used to prepare frequency tables for each parameter for each VRS type. These frequency tables were then analysed to develop evidence-based conclusions, highlighting those parameters which are referenced most frequently in National standards and guidelines.

2.2 Task 1.2 – Literature Review

In a similar way to Task 1.1, relevant published and unpublished reports, conference proceedings and other sources of associated documentation were gathered by the consortium members on an ftp site.

Each of these sources of information was then reviewed, and trends within the research documented to identify those parameters which are considered by the research community to be of most importance in the location and selection of VRS.

3 Summary of NRA Standards & Guidelines

3.1 Australia

“Austroads, Guide to Road Design Part 6: Roadside Design, Safety and Barriers” is the main VRS guidance document for Australia and New Zealand and provides an introduction to roadside design and in particular guidance on roadside safety and the selection and use of road safety barrier systems. While the various states and territories have some commitment to adopting this as their primary design document, most (if not all) jurisdictions continue to maintain jurisdiction-specific documents which reference or supplement the Guide.

The decision of whether to install a roadside safety barrier or not is based on risk assessment. The Austroads guide defines the following five quantitative risk assessment methods for evaluating the risk associated with a hazard and the possible treatment. Jurisdictions in Australia and New Zealand may use one or several of these methods:

- A simple manual method;
- A detailed quantitative manual method;
- The Roadside Incident Severity Calculator (RISC program) developed by the Queensland Department of Transport and Main Roads;
- The Roadside Safety Analysis Program (RSAP) that is the current USA method developed through the NCHRP (National Cooperative Highway Research Program);
- A method developed by the Roads and Traffic Authority in New South Wales, Australia that calculates the risk associated with a hazard and compares it to an intervention benchmark for the particular type of road.

3.2 Austria

There were seven Austrian standards documents (called RVS) that were received for this project. These were:

- VRS Requirements and Installation (RVS 05.02.31);
- Road Work Zone Traffic Control (RVS 05.05.41);
- Steel Rails (RVS 08.23.05);
- Concrete systems (RVS 08.23.06);
- Tunnel Entrance Areas (RVS 09.01.25);
- Bridge Equipment (RVS 15.04.71);
- Motorcycle Safety (RVS 02.02.42).

3.2.1 VRS Requirements for Longitudinal Road Sections

These requirements are presented in the document RVS 05.02.31.

This Austrian guideline lists the areas where the installation of VRS is necessary, as follows:

- **Slopes:** A VRS is necessary on embankment slopes with a gradient > 1:2, and height > 4.0m. A VRS is also necessary on cutting slopes which pose a danger (rock wall, anchoring walls, etc.);
- **Median:** A VRS is necessary on medians of dual carriageways with a speed limit > 70km/h;
- **Engineering Structures:** A VRS is necessary on bridges and other engineering structures where there is a risk of falling. (also refer to document RVS 15.04.71);
- **Objects:** The provision of a VRS regarding fixed objects will be presented on the document RVS 02.02.41, which is still in process of development;
- **Bodies of Water:** A VRS is necessary in areas adjacent to bodies of water, where the depth of water, channel cross section etc. pose a particular risk;
- **Railways:** A VRS is necessary where railway lines run adjacent to roads;
- **Noise Barriers:** A VRS is generally needed in front of noise barriers;
- **Roads and Sites:** Rural roads with adjacent pedestrian or bicycle traffic areas should be fitted with a VRS if run off the road crashes are likely to occur. A VRS is also necessary in areas where people gather, for example children's playgrounds, camping sites, picnic areas;
- **Danger Spots:** A VRS is necessary where evidence points to an increased risk of potential for run of the road accidents and black spots (refer to document RVS 02.02.21);

Minimum performance requirements (containment levels) for VRS on longitudinal road sections are given in Table 1:

Table 1 – Minimum containment levels for VRS on longitudinal road sections (*RVS 05.02.31 - Anforderungen und Aufstellung*, FSV, 2011)

$AADT_{HGV}$	Speed Limit (km/h) for passenger cars	Verge		Median	
		Level of Risk		Median Width	
		Normal	High	>3,50 m	≤3,50 m
≤ 1.000	≤ 100	N1	H1	H1	H2
≤ 1.000	> 100	N2	H1	H1	H2
1.000 < AADTHGV ≤ 5.000	≤ 100				
1.000 < AADTHGV ≤ 5.000	> 100	H1	H2	H2	H3
> 5.000	≤ 100				
> 5.000	> 100	H2	H3 / H4b	H3	H3 / H4b

According to the Austrian guideline, a crash cushion is warranted if safeguarding an obstacle using a VRS parallel to the road is not possible and the danger of a frontal impact exists.

Minimum requirements for the selection of performance level of crash cushions are given in Table 2:

Table 2 – Minimum performance requirements for crash cushions (*RVS 05.02.31 - Anforderungen und Aufstellung*, FSV, 2011)

Speed Limit for passenger cars (km/h)	Performance Level	
	Normal Risk	High Risk
≤ 80	50	50
≤ 100	50	80
> 100	80	100

3.2.2 VRS on Bridges – Parapets

Austrian guidelines for the requirements and installation of VRS on bridges are presented in the document RVS 15.04.71.

The minimum containment levels required for VRS placed on bridges on motorways, expressways and similar roads are presented in Table 3.

Table 3 – Minimum containment levels for VRS placed on bridges on motorways, expressways (*RVS 15.04.71 – Fahrzeugrückhaltesysteme*, FSV, 2011)

System Conditions	Verge	Median
Normal Conditions	H2	H3
Slope> 4% with a length> 400m	H3	H3
Curves on sharp directional changes	H3	H3
Cross sections without hard shoulder, without structural means of separation	H3	H3
High-level bridges over roads or in the range of special protection areas	H3	H3
In the area of crowds	H3	H3
Bridges over railroad tracks, speed limit on road ≥70km/h	H4b	H3
Bridges over railroad tracks, speed limit on road<70km/h	H2	H3

The minimum containment levels required for VRS placed on state roads and similar roads are presented in Table 4.

Table 4 - Minimum containment levels required for VRS placed on state roads (*RVS 15.04.71 – Fahrzeugrückhaltesysteme*, FSV, 2011)

System Conditions	Verge
Normal Conditions	N1
Slope> 6% with a length> 250m	N2
Curves on sharp directional changes	N2
High-level bridges over roads or in the range of special protection areas	H1
In the area of crowds	H1
Bridges over railroad tracks, speed limit on road ≥70km/h	H4b
Bridges over railroad tracks, speed limit on road<70km/h	H2

3.2.3 Motorcyclist Safety

The directive RVS 02.02.42, introduces recommendations for the improvement of the road environment for the safety of motorcyclists.

Problematic areas to be considered for improvement are defined as follows:

- **Incident black spots**, which are defined according to RVS 02.02.21.
- **Incident black lines**, which are defined as strips of road (≤ 1 km) with three or more motorcycle crashes (injury accidents + property damage only) within 5 years.

When an incident black spot or black line is determined, it is checked for the following road characteristics/features that may increase the risk of a motorcycle crash:

- Discontinuities in the lines;
- Strong narrowing curves;
- Lines which lead to excessive speed;
- Sudden and significant reduction of surface grip approaching and in curves;
- Unexpected unevenness in the longitudinal and transverse directions;
- Gravel on the road;
- Improper materials used on joints and cracks;
- Longitudinally milled pavement surface;
- Pollution of the road surface, for example by construction vehicles etc.
- Metallic covers;
- Large scale road markings;
- Non-standard VRS;
- Unshielded fixed obstacles.

When any of the preceding high risk features exist, the following measures should be considered:

Active Measures, which are aimed at reducing the number of accidents by influencing the conscious and unconscious riding behaviour of motorcyclists:

- Traffic engineering measures;
- Road Markings;
- Delineators;
- Traffic Signs;
- Monitoring Measures;
- Measures through structural changes to the infrastructure:
    - Change in the route;
    - Renewal of road surface;
    - Repairing road surface damage;
    - Removal of obstructions;
    - Removal of stationary objects;
    - Removal of hazardous VRS.

Passive Measures, which are motorcyclist protection systems that aim to reduce the consequences of crashes.

3.3 Belgium

The Flanders and Walloon Regions of Belgium both developed their own guidelines for the choice and installation of VRS. Both guidelines are currently being revised. The installation of VRS on roads in the Brussels region is only marginal and has not been considered.

3.3.1 Flanders (Manual for Road Restraint systems, DRAFT, version 02/2013)

The Flanders region applies a risk classification model to evaluate the need to install a VRS and the appropriate performance requirements.

Based on the installation location, the available space and the presence and type of obstacles, a risk category is determined. Two risk classification models exist; one for roads with an authorized speed equal to or greater than 90 km/h, shown in Figure 3, and one for roads with authorized speed below 90 km/h.

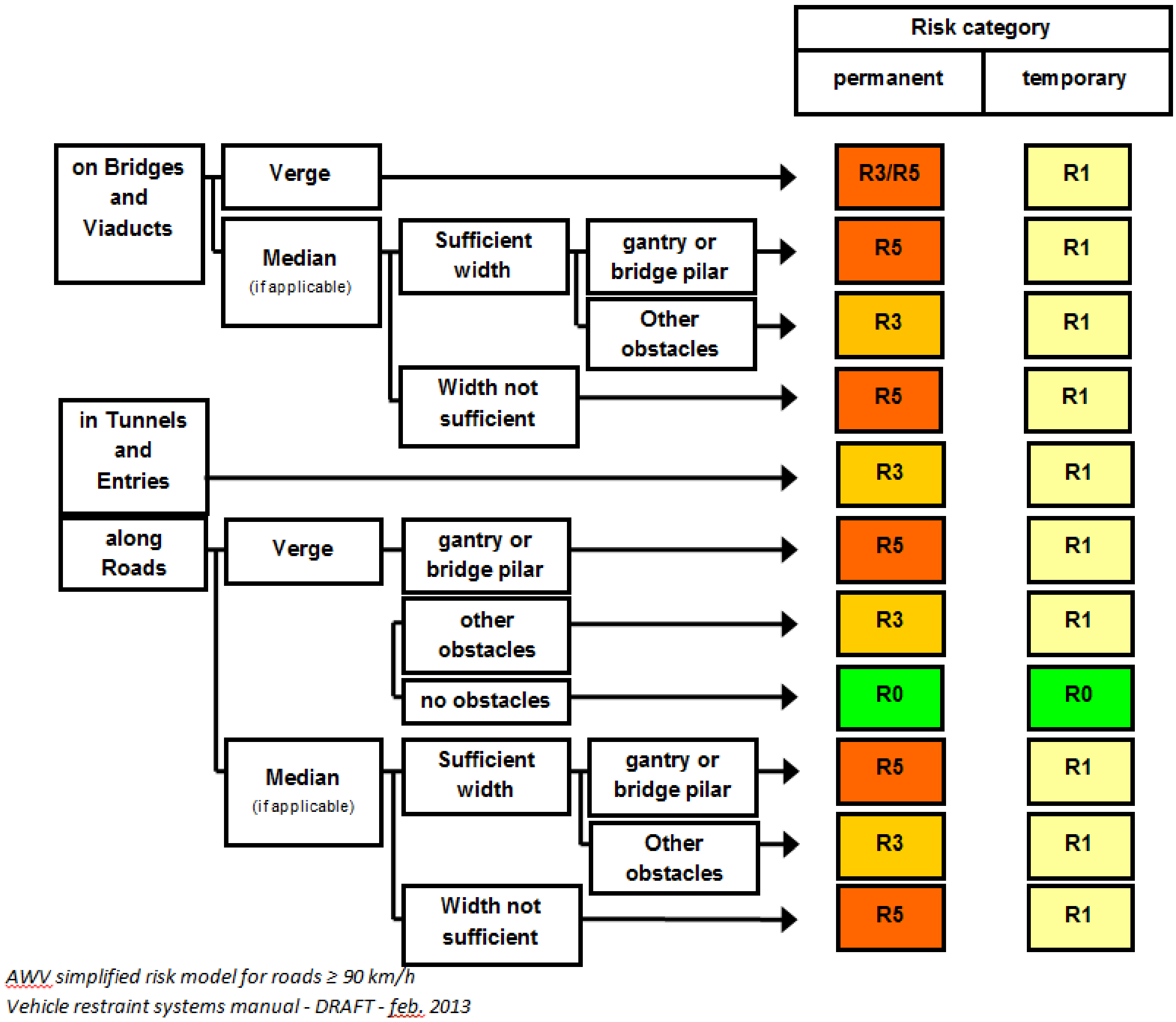


Figure 3 – Risk Classification Model (*Manual for Road Restraint systems - DRAFT*, Administratie Wegen en Verkeer, 2013)

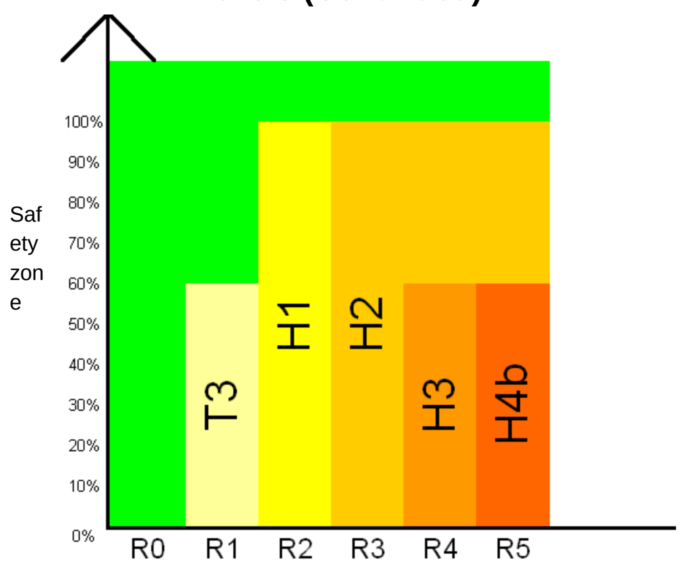
For different risk categories and depending on the availability of the safety zone, different containment levels are subsequently recommended. The recommended safety zone dimensions are listed in the guidelines and depend on the authorized speed. The presence of slopes and / or motorcyclists modifies the recommended safety zone. For roads of a lower category, the recommended safety zone dimensions are reduced.

Table 5 – Recommended safety zone dimensions and minimum containment levels (*Manual for Road Restraint systems - DRAFT*, Administratie Wegen en Verkeer, 2013)

	median	gradient < 24/4					24/4 < gradient < 16/4				
		continuous	curve				continuous	curve			
			standard situations		PTW protective measures			standard		PTW protective measures	
km/h			100<R< 1000	R<100	100<R< 1000	R<100		100<R< 1000	R<100	100<R< 1000	R<100
50	5,00	1,50	2,08	2,67	3,54	3,83	3,00	4,17	5,33	7,08	7,67
70	10,00	3,00	4,17		7,08		6,00	8,33		14,17	
90	16,00	4,90	6,75		11,38		9,80	13,50		22,75	
120	29,00	8,60					17,20				

Recommended safety zone (red to be avoided) for primary roads
Vehicle restraint systems manual - DRAFT - feb. 2013

Table 6 – Recommended safety zone dimensions and minimum containment levels (Continued)



In addition, the following performance characteristics are also imposed:

- H2, W6 for permanent installations (W7 for double installations);
- T3, W2 for temporary installations;
- Only ASI A and ASI B are allowed.

3.3.2 Walloon region (OSDG 1.06.51(01) - Choice of Road Restraint Systems on the Walloon Regional Network)

To determine the need to install a VRS, the Walloon region applies a safety distance concept. This minimum required distance between the lane border (hard shoulder and markings not included) and an eventual hazard depends on the authorized speed. A distinction is made between individual, very local obstacles (for example an isolated tree) and longitudinal obstacles (for example a row of lighting columns). If the distance is not available, and the present obstacle is considered as aggressive, a VRS is recommended.

Table 7 – Minimum required distance between the lane border and the hazard (*Le choix des dispositifs de retenue à placer sur le réseau routier régional wallon,* Service Public de Wallonie, 2006)

Speed (km/h)	Safety Distance (m)	
	Individual Obstacle	Longitudinal Obstacle
120	3,50	7,00
100	2,50	5,00
90	2,00	4,00
80	1,60	3,20
60	0,90	1,80
40	0,40	0,80

A non-exhaustive list of dangerous obstacles is given:

- Gantries;
- Lighting columns, trees and other support structures;
- Ditches with 45° sides;
- Rising slopes depending on height and angle;
- Embankments depending on slope;
- Outer side of curves when the radius is not compliant with road building standards;
- Central reserves for highways:
  - When traffic volume ≥ 10.000 vehicles/day and median width < 4m;
  - When traffic volume ≥ 20.000 vehicles/day, and median width < 8m;
  - For median width > 12 m no VRS is required;
- Infrastructure supports.

The recommended performance characteristics for the VRS depend on the speed allowed and the installation location.

Table 8 - Recommended performance characteristics for VRS (*Le choix des dispositifs de retenue à placer sur le réseau routier régional wallon*, Belgian Standards, 2006)

<table>
<tr><th colspan="3">Side Barriers</th></tr>
<tr><th>Speed limit (km/h)</th><th>Continuous</th><th>Particular hazards</th></tr>
<tr><td>v ≤ 50</td><td>min. N1</td><td>min. H2 or H4b</td></tr>
<tr><td>50 < v ≤ 90</td><td>min. H1</td><td>min. H2 or H4b</td></tr>
<tr><td>90 < v ≤ 120</td><td>min. H2</td><td>H4b</td></tr>
<tr><th colspan="3">Central Reserve Barriers</th></tr>
<tr><th>Road type</th><th>Median barrier, no central reserve</th><th>Central reserve</th></tr>
<tr><td rowspan="2">highway or road 2x2 lanes</td><td rowspan="2">min. H2</td><td>H2</td></tr>
<tr><td>2xH1 and ASI A if width > 6 m</td></tr>
<tr><td>v ≤ 90 km/h</td><td>min. H2</td><td>min. H2</td></tr>
</table>

The Walloon region also only allows ASI A and ASI B.

3.4 Brazil

The Brazilian VRS standard ABNT NBR 15486, “Segurança no tráfego –Dispositivos de contenção viária –Diretrizes, 2007” (Traffic safety – Restraint systems – Guidelines), is mainly a translation of the AASHTO Roadside Design Guide 2002.

3.5 Bulgaria

“*Технически правила* за приложение на *ограничителни системи* за *пътища* по Републиканската пътна мрежа, 2010” (Technical rules for the use of restraint systems for roads on the national road network) is the document that gives the guidelines for VRS application for Bulgaria. This document is a direct translation from the German standard.

3.6 Canada

The "Geometric Design Guide for Canadian Roads, 2011" is the document containing the guidelines for VRS application in Canada. The VRS related chapters in this document are mainly extracted from the AASHTO Roadside Design Guide.

3.7 Croatia

The Croatian standard, "Ordinance of Traffic Signs, Signals and Equipment on the Roads", defines the locations where VRS are necessary as follows:

- In the median, depending on the size of the traffic;
- On road work zones;
- For embankments higher than 3m;
- In front of dangerous point or lateral hazards.

The minimum level of containment is determined according to the road category, as shown in Table 9:

Table 9 - Containment level vs. Road Category (*Pravilnik O Prometnim Znakovima, Signalizaciji I Opremi Na Cestama*, Ministarstvo Mora, Turizma, Prometa I Razvitka - Croatia, 2011)

Road Category	Verge	Median	Bridge
Motorways	H2-H1	H2	H3-H2
State roads and rapid urban roads	H1	-	H2
Other roads	N2	-	H1-H2

3.8 Cyprus

Requirements for the use of VRS in Cyprus are explained in the document: "Geometric Design Standards for Inter-Urban and Rural Roads in Cyprus". This is very similar to the requirements of Italy.

The document states that VRS are to be installed on roads where the design speeds are in excess of 65 km/h and in the circumstances listed below:

- At the outside of shoulders on embankments;

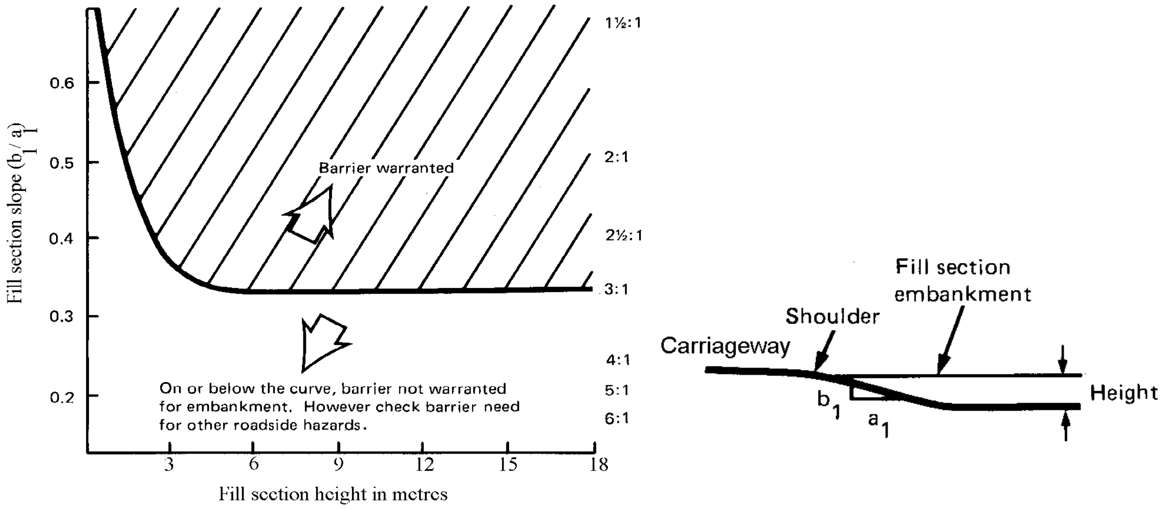


Figure 4 - Barriers at embankments Roadside Features and Standards (*Geometric Design Standards for Inter-Urban and Rural Roads in Cyprus,* Cypriot Standards, 2005)

- On other embankments where there is a permanent or expected water hazard, such as a river, reservoir, stilling pond or lake adjacent to the highway and this water feature is either generally at the same level or below the carriageway;
- Where there is an adjacent and separate road within a distance of 10 metres from the nearest edge of the paved carriageway of the road;
- Where there is a road at the foot of an embankment;
- On the outside only of a bend where the horizontal curve at the edge of the paved carriageway is 850 metres radius or less and there is an embankment greater than 3 metres in height;
- At the top of all reinforced soil embankments which have a height of 0.75 metres or greater and the side slope has a gradient of 1:1 or steeper;
- Where there is a pedestrian subway entrance, drainage culvert headwall or agricultural underbridge passing under the highway and a vehicle parapet is not to be provided;

- Where any of the following highway design features occur at or within 4.5 metres from the edge of the paved carriageway:
  - Retaining walls with a non-smooth traffic face up to 1.5 metres above the carriageway level;
  - Exposed rock faced cuttings slopes, rock filled gabions, crib walling or similar structures and which are less than 1.5 metres above the carriageway level;
  - Reinforced soil cutting slopes or earth banks greater than 1 metres high and with a side slope gradient of 1:1 or steeper;
  - Environmental noise barriers or screens;
  - Structural supports such as overbridge piers, columns and abutments;
  - Sign/signal gantry supports;
  - Above ground equipment other than emergency telephones (e.g. CCTV masts, communication control cabinets, pillars, stores for signs);
  - A single tree with a trunk girth of 500mm or more or several closely spaced trees;
  - Support posts (e.g. for signs) which have a diameter of 150mm and greater (or RHS which have an area of 100mm x 150mm or greater);
  - Where the bottom edge of a sign fascia, which is more than 2 metres in height and is mounted less than 1.5 metres above the level of the adjacent paved carriageway surface (measured vertically);
  - Posts of the truss support type, unless a frangible system is used in accordance with EN 12767.
- Where there are chemical/fuel storage tanks or other similar potentially hazardous installations adjacent to the highway, a safety barrier with a performance class of H4a may be appropriate;
- Where high mast road lighting columns are located 10m or less from the edge of the paved carriageway, the Performance Class shall be Higher Containment Level [H3].

Central Reserves on dual carriageways:

- The normal practice in Cyprus is to use concrete safety barriers on motorways. This should apply where central reserves are less than 10 metres in width. On Class A roads, or on motorways where special circumstances (for example the provision of sight lines) make concrete barriers inappropriate, metal beam safety barrier or wire rope safety fencing may be used;
- Where obstructions such as overbridge and gantry supports are located in the central reserve, the safety barriers must be provided on both sides of the obstruction;
- At sign/signal gantry supports the minimum level of performance class shall be 'Higher Containment Level' as described in Clause 13.11.3 of the standard.

Terminals:

The Cypriot standard requires all terminals of safety barriers (Performance Class N2) to have a minimum Performance Class of P1.

Containment Levels:

The minimum specified containment levels are as detailed in Table 10.

Table 10 - Application and Containment Requirements for Safety Barriers and Parapets (*Geometric Design Standards for Inter-Urban and Rural Roads in Cyprus,* Cypriot Standards, 2005)

Road Class	Design Speed	Traffic	Safety Barrier Containment Level Required		
	km/h	Level	Central Reserve	Embankment Verge or Obstruction	Bridge Parapet
Motorways		I	N2/H3	N2/H3	H3/H4a
Dual Carriageways	≥ 65	II	N2/H3	N2/H3	H3/H4a
		III	H3	H3	H4a
Class A Roads		I	N2/H3	N2	N2/H3/H4a
(Trunk Roads)	≥ 65	II	N2/H3	N2	N2/H3/H4a
		III	H3	N2	H3/H4a
Class B Roads		I	N2/H3	N2	N2/H3/H4a
(District Distributor	≥ 65	II	N2/H3	N2	N2/H3/H4a
Roads)		III	H3	N2	H3/H4a
Class C Roads		I	-	N2	N2/H3/H4a
(Local Distributor		II	-	N2	N2/H3/H4a
Roads)		III	-	N2	H3/H4a
Class D Roads		I	-	N2	N2/H3/H4a
(Access Roads)		II	-	N2	N2/H3/H4a
		III	-	N2	H3/H4a

Explanation of Traffic levels:

Traffic level I: When the AADT is less than or equal to 1000 vehicles per day, with no limits on heavy vehicles; or higher than 1000 vehicles per day, if heavy vehicles (weight > 3000 kg) are less than or equal to 5% of the total traffic.

Traffic level II: When the AADT is higher than 1000 vehicles per day, and heavy vehicles with a weight higher than 3000 kg constitute between 5% and 15% of the total traffic.

Traffic level III: When the AADT is higher than 1000 vehicles per day, and heavy vehicles with a weight higher than 3000 kg constitute more than 15% of the total traffic.

Conditions for the consideration of Very High Containment Level parapets are listed in Table 11. Group A conditions relate solely to the situation below the structure, while Group B conditions refer to a combination of below and on the structure.

Table 11 - Application of Very High Containment Level Vehicle Parapets (*Geometric Design Standards for Inter-Urban and Rural Roads in Cyprus,* Cypriot Standards, 2005)

Group	Below Structure	On Structure
A	Area in immediate vicinity of bridge occupied by people or valuable installations, or used for storage of hazardous materials	Specified for a Very High Containment Level parapet.
B	Exceptionally busy road with maximum speed limit e.g.: a. Motorway or dual three lane all-purpose road with permitted traffic speed of 113 km/h b. Urban primary distributor with permitted traffic speed of 80 km/h	a. Inferior horizontal or vertical road alignment permitted as a departure from current Standards or; b. Reduced clearance between carriageway and parapets permitted as a departure from Standards or; c. Complex interchanges where drivers' error is more likely or; d. Where road junctions are very close to the bridge or its approaches or; e. Existing sites which have a record of accidents and where the supporting deck and sub-structure can accommodate the forces specified for High Containment parapet

The Cypriot standard requires that the minimum Performance Class (e.g. N2, H3 or H4a) is the Normal Containment Level as given below, unless indicated otherwise in Table 11.

- Permanent Deformable and Rigid Safety Barriers on roads with a speed limit of 65km/h or greater:
    - Normal Containment Level = N2
    - Higher Containment Level = H3
    - Very High Containment Level = H4a
- Vehicle Parapets on roads with a speed limit not greater than 65km/h:
    - Normal Containment Level = N2
    - Higher Containment Level = H3
    - Very High Containment Level = H4a
- Vehicle Parapets on roads with a speed limit greater than 65km/h:
    - Normal Containment Level = Not applicable
    - Higher Containment Level = H3
    - Very High Containment Level = H4a

3.9 Czech Republic

The standard from the Czech Republic defines two types of barriers:

- Approved barriers, which are tested and approved according to EN1317;
- “Other” barriers, which are barriers that are designed only as a part of, or to be installed on, certain bridges of artistic or historical importance.

In the Czech Republic, the decision whether and in which locations on the road to place safety barriers, shall be based on the requirements of the Czech Technical Standards (CSN), the designer’s own safety sheet, the requirements of public authorities, and other reasonable requirements.

It is a requirement for safety barriers to be installed for:

- The protection of road users (passenger vehicles and other road users) from hitting obstructions or from driving in to a point of danger (for example a concrete culvert below ground level).
- The protection of an item of infrastructure or the environment (including the protection of persons and buildings near the road).

In addition, it is recommended to take into account the risk of a road with regard to the speed limit, heavy vehicle and traffic intensity, direction and height ratios (for example dangerous descents with a small radius). A length of road which accumulates more than one of these risk factors is considered to be a high risk road.

The minimum required containment levels for safety barriers on the roads in the Czech Republic, according to the road type, are given in Table 12:

Table 12 – Containment level and road type (*Svodidla Na Pozemních Komunikacích*, Ministerstvo dopravy Odbor silniční infrastruktury - Czech Republic, 2010)

Line	Type (category) of road	Containment Level
1	Outer Edges of motorways and dual carriageways	min N2
2	Other	N1 to N2

Table 13 shows the required containment levels for certain hazards. If any of the hazards listed in this table is present, the containment level is determined according to the AADT (HGV) and the level of risk on the road.

For bridge parapets, the minimum allowed containment level is H2 for approved barriers. Table 14 shows the required containment levels for bridge parapets according to the surrounding hazards. If any of the hazards listed in this table is present, the containment level is determined according to the AADT (HGV) and the level of risk on the road.

Table 13 – Containment levels and hazards for roads (*Svodidla Na Pozemních Komunikacích*, Ministerstvo dopravy Odbor silniční infrastruktury - Czech Republic, 2010)

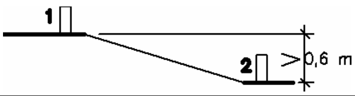
<table>
<tr><th rowspan="2">Line</th><th>AADT(HGV) both directions</th><th colspan="2"><1000</th><th colspan="2">1000 to 5000</th><th colspan="2">>5000</th></tr>
<tr><th>Risk (N-Normal, H-High)</th><th>N</th><th>H</th><th>N</th><th>H</th><th>N</th><th>H</th></tr>
<tr><td>1</td><td>Source of drinking water in the vicinity of highway</td><td>H2</td><td>H3</td><td>H2</td><td>H3</td><td>H3</td><td>H4</td></tr>
<tr><td>2</td><td>Railway or tramway parallel with road</td><td>H1</td><td>H2</td><td>H2</td><td>H3</td><td>H2</td><td>H3</td></tr>
<tr><td>3</td><td>Public areas with frequent pedestrian activity</td><td>H1</td><td>H2</td><td>H2</td><td>H3</td><td>H2</td><td>H3</td></tr>
<tr><td>4</td><td>Civil engineering</td><td>H1</td><td>H2</td><td>H1</td><td>H2</td><td>H2</td><td>H3</td></tr>
<tr><td>5</td><td>Median in dual carriageway</td><td>H1</td><td>H2</td><td>H1</td><td>H2</td><td>H2</td><td>H3</td></tr>
<tr><td>6</td><td>Between parallel roads if at least one of them D, R or MR</td><td>H1</td><td>H2</td><td>H1</td><td>H2</td><td>H2</td><td>H3</td></tr>
<tr><td>7</td><td>Height difference of more than 0.6m in the median

</td><td>H2</td><td>H3</td><td>H2</td><td>H3</td><td>H3</td><td>H4</td></tr>
<tr><td>8</td><td>Running water or standing bodies of water with a depth over 2m</td><td>N2</td><td>H1</td><td>H1</td><td>H2</td><td>H2</td><td>H3</td></tr>
<tr><td>9</td><td>Steep rocky cliff or embankment with height > 3m and slope > 1:1.5</td><td>N2</td><td>H1</td><td>H1</td><td>H2</td><td>H1</td><td>H2</td></tr>
<tr><td>10</td><td>Other dangerous places, such as trees, outside of a curve radius less than 300m with descent over 4% for primary roads</td><td>N2</td><td>H1</td><td>H1</td><td>H2</td><td>H1</td><td>H2</td></tr>
<tr><td>11</td><td>Noise barriers</td><td>N2</td><td>N2</td><td>N2</td><td>N2</td><td>N2</td><td>N2</td></tr>
</table>

Table 14 - Containment level and hazards for bridges (*Svodidla Na Pozemních Komunikacích*, Ministerstvo dopravy Odbor silniční infrastruktury - Czech Republic, 2010)

<table>
<tr><th rowspan="2">Line</th><th>AADT (HGV) both directions</th><th colspan="2"><1000</th><th colspan="2">1000 to 5000</th><th colspan="2">>5000</th></tr>
<tr><th>Risk (N-Normal, H-High)</th><th>N</th><th>H</th><th>N</th><th>H</th><th>N</th><th>H</th></tr>
<tr><td>1</td><td>Source of drinking water near the bridge</td><td rowspan="6">H2</td><td>H3</td><td rowspan="6">H2</td><td>H3</td><td>H3</td><td>H4</td></tr>
<tr><td>2</td><td>Railway or tramway track, parallel with the bridge or crossing</td><td>H3</td><td>H3</td><td rowspan="5">H2</td><td>H3</td></tr>
<tr><td>3</td><td>Public areas with frequent pedestrian activity</td><td rowspan="4">H2</td><td>H3</td><td>H3</td></tr>
<tr><td>4</td><td>Continuous residential or community development (especially for urban elevated roads)</td><td>H3</td><td>H3</td></tr>
<tr><td>5</td><td>Concurrent or crossing the road with heavy traffic volume</td><td rowspan="2">H2</td><td>H3</td></tr>
<tr><td>6</td><td>Other dangerous places, such as outside of a curve of radius less than 300m, descent over 4%, height of 12m.</td><td>H3</td></tr>
</table>

3.10 Denmark

The Danish document "AUTOVÆRN - Opsætning af vejautoværn og påkørselsdæmpere i åbent land, November 2007" (CRASH BARRIERS - Setting up of barriers and crash cushions in rural areas), gives the necessary guidance for the application and selection of safety barriers and crash cushions in Denmark.

3.10.1 Concept of Safety Zone

The decision of whether to install a barrier or not depends on the safety zone concept, which is defined as an area without any collision hazards or dangerous topographic features which can cause an errant vehicle to turn over. If one or more hazards are present within a safety zone and it is not possible to remove, relocate or make the obstacle passively safe, a safety barrier is required. The width of the safety zone depends on the speed limit and radius of horizontal curvature as shown in Table 15 below.

Table 15 - Requirements for the width of the safety zone on flat roads, and on the outside of horizontal curves with a flat terrain (*AUTOVÆRN - Opsætning af vejautoværn og påkørselsdæmpere i åbent land,* Vejregelrådet, 2007)

Speed Limit (km/h)	40	50	60	70	80	90	100	110	120	130
Radius of Horizontal Curvature (m)	Requirements for the width of the safety zone for level terrain									
≥1000	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0
900	2.2	3.6	4.8	6.0	7.2	8.4	9.6	10.8		
800	2.4	3.6	4.8	6.0	7.2	8.4	9.6	11.6		
700	2.4	3.6	4.8	6.5	7.8	9.1	10.4	13.0		
600	2.4	3.9	5.2	6.5	7.8	9.1	11.2			
500	2.6	3.9	5.2	7.0	8.4	10.3	12.0			
400	2.8	4.2	5.6	7.0	9.0	11.0				
300	3.0	4.5	6.4	8.0	9.5					
200	3.4	5.1	7.2							
100	4.8	7.5								

3.10.2 Barrier Warrants for Embankments and Cuts

The decision to place a VRS on an embankment or a cut depends on the width of the safety zone, and on the side slope of the area. The roadside area in the safety zone is divided into three classes depending on the slope and its extent:

- **Terrain Class 1:** Cuts with a slope ≤ 1:2 or embankments with a slope ≤ 1:5 are considered as recoverable flat ground;
- **Terrain Class 2:** Embankments with a side slope between 1:3 and 1:5 are considered as non-recoverable;
- **Terrain Class 3:** Cuts with a side slope > 1:2 or embankments with a slope > 1:3 are considered as critical, with a danger of sudden stop or overturning.

Figure 5 and Figure 6 shows the conditions which require the installation of a barrier for embankments and cuts respectively.

Slope	Terrain Class	Side area width	Barrier required if:
a≥5	1	$l_1+l_2+l_3$	$l_1+l_2+l_3>b$
5>a≥3	2	$l_1+l_2+l_3$	$l_1+l_3>b$
a<3	3	l_1	$l_1>b$

b is the required safety zone width (see Table 15)

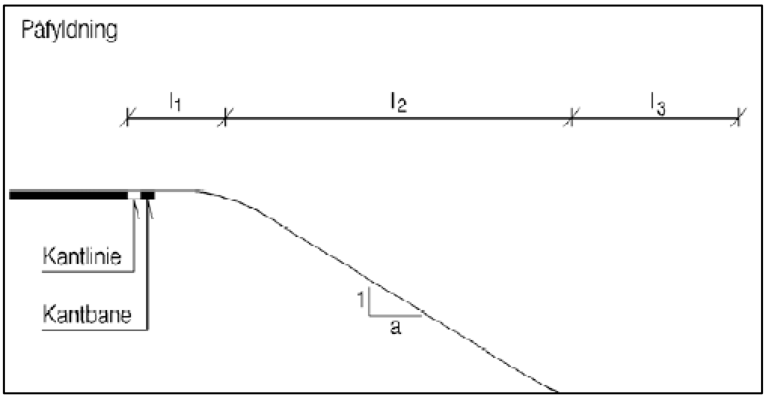


Figure 5- Determination of the width of the safety zone for embankments (*AUTOVÆRN - Opsætning af vejautoværn og påkørselsdæmpere i åbent land,* Vejregelrådet, 2007)

Slope	Terrain Class	Side area width	Barrier required if:
a≥2	1	$l_1+l_2+l_3$	$l_1+l_2+l_3>b$
a<2	3	l_1	$l_1>b$

b is the required safety zone width (see Table 15)

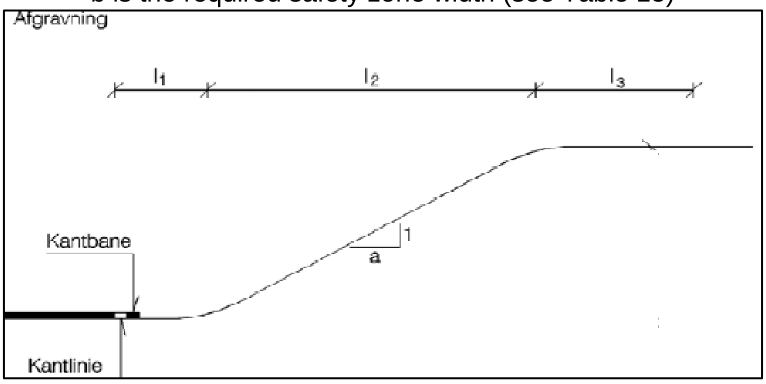


Figure 6 - Determination of the width of the safety zone for cuts (*AUTOVÆRN - Opsætning af vejautoværn og påkørselsdæmpere i åbent land,* Vejregelrådet, 2007)

3.10.3 Barrier Warrants for the protection of the driver, passengers and other road users

The Danish standard also lists examples of hazardous objects that would necessitate the installation of a roadside safety barrier if located within the safety zone:

- Noise barriers and retaining walls;
- Bridge piers and abutments;
- Steel posts with a diameter greater than or equal to 76mm;
- Trees and wooden poles with a diameter of 100mm, located 400mm above ground;
- Foundations, wells and stones higher than 200mm above ground;
- Kerbs with height greater than 200mm;
- Concrete masts regardless of their dimensions;
- Cabinets installed on concrete or other buried foundation;
- Transverse ditches.

Parallel ditches that are located within the safety zone are treated in the same way as cuts and embankments.

Permanent bodies of water situated within the safety zone should be shielded by safety barriers. Barriers are required if staging areas, playgrounds, emergency telephones and other places of public activity are located within the safety zone. For roads with speed limit > 80km/h, a safety barrier is required if there is an adjacent bicycle path within the safety zone. A safety barrier is also required where there is an adjacent railway track, fuel tank or any other similar hazard within the safety zone.

The Danish standard also requires that safety barriers should be installed whenever there is a vertical fall height of more than 1m.

For dual carriageway roads with a speed limit > 80km/h a median barrier is required if the median width is less than the safety zone width.

For rural roads, median safety barriers should be considered if the opposing traffic is within the safety zone, and the AADT for heavy vehicles exceeds 15,000 vehicles.

3.10.4 Choice of Containment Level for Barriers

The selection of the containment level for roadside and median barriers in Denmark depends on factors such as speed limit, AADT and the percentage of heavy vehicle traffic as shown in Table 16.

Table 16 - Selection of Containment Level for Safety Barriers (*AUTOVÆRN - Opsætning af vejautoværn og påkørselsdæmpere i åbent land,* Vejregelrådet, 2007)

Barrier Location	Situation	Containment Level
Roadside	Speed Limit > 80km/h	H1
	Speed Limit ≤ 80km/h	N2 or T2
	Speed Limit ≤ 80km/h, and protection is required for heavy vehicles	T3 or H1
	Speed Limit ≥ 80km/h, where protection is desired for residential areas, water protection areas, etc.	H3 or H4
Median	Speed Limit > 80km/h	H1
	Speed Limit ≤ 80km/h	N2 or T2
	Speed Limit ≥ 80km/h, and percentage of Heavy Vehicles (weight≥10tonnes) is between 5% and 10% and AADT≥50000	H2
	Speed Limit ≥ 80km/h, and percentage of Heavy Vehicles (weight≥10tonnes) is more 10% and AADT≥50000	H3

3.10.5 Terminals

Crash absorbing terminals are required for rural roads with speed limits > 80km/h when the end of a barrier is located within the safety zone. The selection of the performance level is to be completed in accordance with the requirements outlined in Table 17.

Table 17 - Selection of performance class for energy barriers terminals (*AUTOVÆRN - Opsætning af vejautoværn og påkørselsdæmpere i åbent land,* Vejregelrådet, 2007)

Situation	Performance Class
Speed Limit ≥ 80km/h	P3 and P4
Speed Limit < 80km/h	P1 and P2

3.11 Estonia

The Document "Juhend Passiivse Ohutuse Tagamiseks Teedel Sõidukipiirdesüsteemide Abil, 2011" (Guide to road passive safety and vehicle restraint systems), gives the guidelines for VRS application in Estonian roads. This document is a direct translation of the German Standard.

3.12 Finland

"Tien poikkileikkauksen suunnittelu", Liikenneviraston ohjeita 29.2013, is the Finnish document which gives the requirements for the installation of vehicle restraint systems, while "Tiekaiteiden suunnittelu", Liikenneviraston ohjeita 27.2013, is the document that gives the associated performance requirements.

The decision of whether to install a VRS in Finland depends on the concept of 'safety distance' as is the case with the majority of other countries. 'Safety distance' is the recovery distance measured from the edge of the road, which would allow an errant vehicle to slow down before a hazardous collision.

A barrier is warranted if one or more of the following hazardous features are located within the safety distance from the roadside, and if they are not designed to be passively safe:

- Dangerous rock surfaces or elevated sections;
- Bridge pillar and abutments;
- Noise Walls;
- Concrete structures higher than 20cm from the ground;
- Lighting and telephone poles;
- Help signs and billboards;
- Portal columns;
- Electricity, telecommunications, natural gas, and water supply systems of the superstructure (steel tube d/material thickness ≥ 120/2,5 mm or 100/4 mm, or wood d>100 mm);
- Bodies of water deeper than 1m, for at least one month per year;
- Rocks or boulders, with more than 20 cm protruding from the ground;
- Trees with a diameter of over 10 cm (measured from 0.5m above the ground);
- Adjacent roads (ADT 350 to 3000 cars/day) or a railways;
- Cliffs (gravel pit, etc.);
- Public areas of busy pedestrian activity and bicycle paths.

The safety distance is multiplied by 1.5 for the following hazards:

- High- voltage power line poles (110 kV);
- Water more than 1 meter deep, with a width of basin greater than 2 meters;
- Another busy road (ADT> 3000 cars/day) or a high-traffic railway.

3.12.1 Determination of Safety Distance

The width of the Safety Zone is determined differently for three cases:

- Embankments;
- Cuttings;
- Level areas.

On embankments where the lower edge of the barrier is more than 0.75 meters below the surface of the road the safety distance is measured using Figure 7 and Table 18.

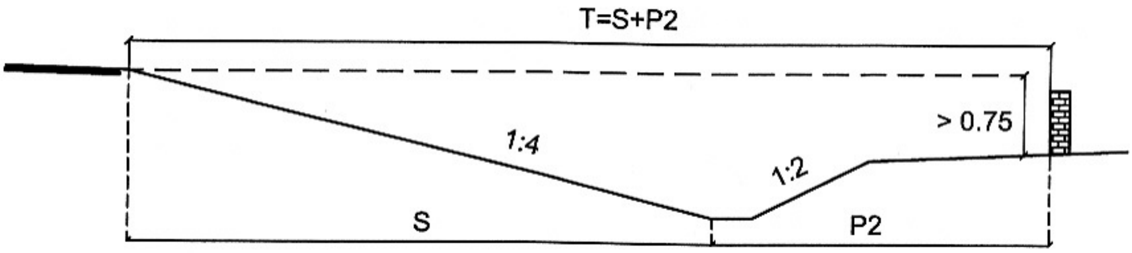


Figure 7 – Safety Distance on embankments (*Tien poikkileikkauksen suunnittelu*, Liikennevirasto, 2013)

Table 18 – Distance P2 for the evaluation of the Safety Distance on embankments (new and existing roads) (*Tien poikkileikkauksen suunnittelu*, Liikennevirasto, 2013)

Speed (km/h)	ADT (veh/day)		
	<1500	1500-6000	>6000
120			6
100	4	4	6
80 (70)	2	4	4
60	2	2	4
50			2

Cuttings with a slope of 1:2 allow drivers to slow down and regain control of the vehicle running off the road. When the lower edge of the barrier is higher than the surface of the road, the safety distance is determined using Figure 8, Table 19 and Table 20. When the lower edge of the barrier is less than 0.75 m below the surface of the road the width of the safety distance is determined using Figure 9, Table 19 and Table 20.

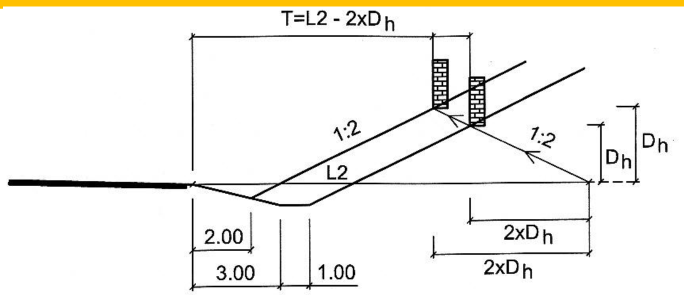


Figure 8 – Safety distance on cuttings (*Tien poikkileikkauksen suunnittelu*, Liikennevirasto, 2013)

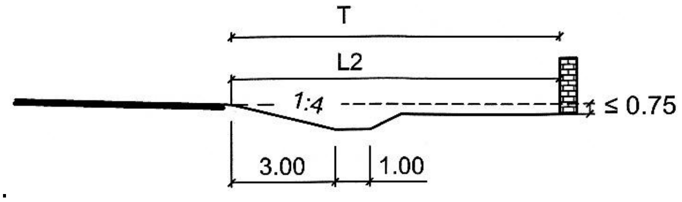


Figure 9 - Safety distance on level area (*Tien poikkileikkauksen suunnittelu*, Liikennevirasto, 2013)

Table 19 - Distance L2 for the evaluation of the safety distance (new roads) (*Tien poikkileikkauksen suunnittelu*, Liikennevirasto, 2013)

Speed (km/h)	ADT (veh/day)		
	<1500	1500-6000	>6000
120			9
100	7	7	9
80 (70)	5	7	7
60	3	5	7
50	3	3	5

Table 20 - Distance L2 for the evaluation of the safety distance (existing roads) (*Tien poikkileikkauksen suunnittelu*, Liikennevirasto, 2013)

Speed (km/h)	ADT (veh/day)		
	<1500	1500-6000	>6000
120			7
100	5	5	7
80 (70)	3	5	5
60	3	3	5
50		3	3

Central Reserves on dual carriageways

On a dual carriageway road, the minimum median width that requires a median barrier depends on the speed limit and the ADT, as shown in Table 21. When the traffic volume exceeds 12,000 veh/day, it is also recommended to use specific means to prevent the crossing of the central area.

Table 21 – Minimum median width in a dual carriage way with no need for a VRS (*Tien poikkileikkauksen suunnittelu*, Liikennevirasto, 2013)

Speed Limit (km/h)	ADT (veh/day)	
	9.000 - 12.000	> 12.000
120	15,0	15,0
100	13,5	12,5
80 (70)	10,5	13,5
60	10,5	13,5

3.12.2 Performance Level Selection

Roadside Barriers

The document "Liikenneviraston ohjeita Tiekaiteiden suunnittelu", 27.2013, explains that N2 containment level roadside barriers are to be installed as a default unless one or more of the following requirements exists:

- high percentage of HGV and coaches;
- presence of bridge pillars that are not designed to withstand a lorry collision, or other objects that require special protection;
- areas where a protection of ground water is required;
- presence of noise barriers;
- concrete barriers installed on embankments;
- retaining wall acting as a concrete barrier.

Median Barriers

The containment level selection for median barriers depends on the width of the median, the traffic volume and the speed limit. With a median width between 4 and 6 meters the containment level must be at least N2, but in specific cases an H2 containment level barrier may be required if the traffic volume exceeds 36,000 veh/day, and the speed limit is more than 100 km/h.

Terminals

On motorways and other roads where the traffic volume exceeds 6,000 vehicles/day and the speed is at least 100 km/h, steel barriers must have a terminal facing oncoming traffic.

Crash Cushions

Crash cushions are required on motorways and in front of bridge columns, portals or similar barriers, where there is not a long enough barrier leading up to it. Crash cushions on motorways should satisfy the requirements of EN 1317-3 at a speed of 100 km/h. On roads where the speed is lower, a crash cushion for a speed of 80 km/h may also be used as an additional form of protection.

3.13 France

"Handling lateral obstacles on main roads in open country, Sétra, November 2002" is the main document which gives guidance on the decision in where to locate VRS on rural roads in France.

"Arrêté du 2 mars 2009 relatif aux performances et aux règles de mise en service des dispositifs de retenue routiers soumis à l'obligation de marquage CE" (Order of 2 March 2009 on the performance and commissioning rules of road restraint systems subject to the requirements for CE marking) on the other hand gives the necessary requirements for the selection of performance and containment level.

3.13.1 Safety Zone Concept

French recommendations define, for main roads in open country, a safety zone where particular requirements are to be applied (for shoulders, ditches, slopes, and single obstacles). If there are one or more hazards within a safety zone, which cannot be removed, relocated or modified, a safety barrier installation is justified.

The recommended width of the safety zone is related to the road type and speed limit as shown in Figure 10 and Table 22.

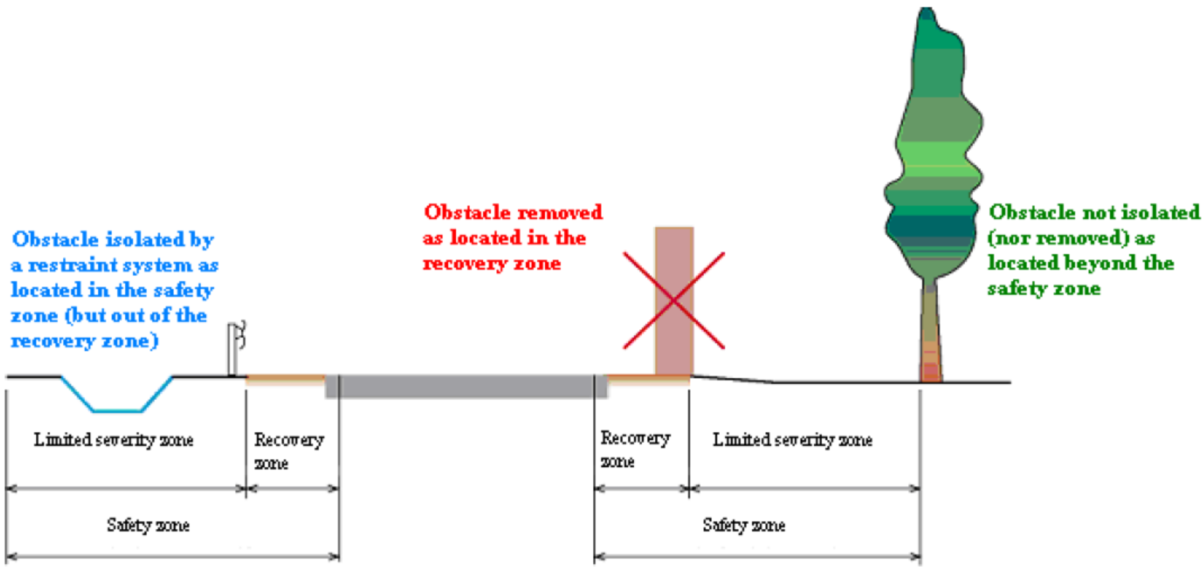


Figure 10 – Safety functions of road shoulders: recovery zone and safety zone (*Handling lateral obstacles on main roads in open country*, Sétra, 2002)

Table 22 - Recommended width of the safety zone (*Handling lateral obstacles on main roads in open country*, Sétra, 2002)

<table>
<tr><th rowspan="2">Type of road</th><th rowspan="2">Subtype</th><th rowspan="2">Standard</th><th rowspan="2">Max speed accepted (km/h)</th><th colspan="2">Width recommended (m)</th></tr>
<tr><th>New road</th><th>Existing road</th></tr>
<tr><td rowspan="6">L: Motorway[1]</td><td rowspan="2">Normal traffic</td><td rowspan="4">ICTAAL</td><td>130</td><td colspan="2">10.00</td></tr>
<tr><td>110</td><td colspan="2">8.50</td></tr>
<tr><td rowspan="2">Moderate traffic</td><td>130</td><td colspan="2">10.00</td></tr>
<tr><td>110</td><td colspan="2">8.50</td></tr>
<tr><td rowspan="2">Difficult relief</td><td rowspan="2"></td><td>90</td><td colspan="2" rowspan="2">7.00</td></tr>
<tr><td>90</td></tr>
<tr><td>T: Expressway</td><td></td><td>ARP</td><td>90</td><td>7.00</td><td></td></tr>
<tr><td rowspan="3">R: Multifunction road</td><td rowspan="2">Interurban main road</td><td rowspan="2">ARP</td><td>90</td><td>7.00</td><td rowspan="3">4.00[2]</td></tr>
<tr><td>110[1]</td><td>8.50</td></tr>
<tr><td>With I pavement</td><td>ARP</td><td>90</td><td>7.00</td></tr>
</table>

(1) In the case of motorways with 2x3 and 2x4 lanes, where safety barriers must be implemented systematically and continuously on the roadside, regardless of the configuration of surroundings, the issue of the safety zone is *de facto* settled.

(2) A speed limitation at 110 km/h on an interurban main road can be considered even when the characteristics of the infrastructure offer a high level of safety. In these conditions, a 4m-wide safety zone seems insufficient; we must rather get closer to the width planned for a new interurban main road.

3.13.2 Hazards

The following is a list of hazards which would necessitate the installation of a safety barrier in France, if located within the safety zone (i.e. they cannot be removed, replaced or modified):

Single Obstacles:

- Trees with a trunk diameters larger than 10 cm and stumps protruding by more than 20cm;
- Telephone or electric posts;
- Masonry structures:
  - Structure piers;
  - Retaining structures;
  - Parapets and bridge heads;
  - Culvert heads, except those implemented along the road or fitted with crash worthy terminals or crash cushions;
  - Walls: angle or wall of a building, fence wall if destroyed (concrete blocks, stones, etc.), any part forming a transverse protrusion;
  - Pedestals, anchoring blocks, etc. protruding by more than 20 cm in respect of the level of the shoulder or ditch;

    - Kerbs protruding by more than 20 cm in respect of the level of the road;
    - Concrete mileposts;
- Lighting columns non fusible, flexible, or deformable;
- Certain operating equipment;
- Sign supports with a resistant moment exceeding 570Nm, more particularly beams, gantries, high masts, and most profiles;
- The ends of non-compliant safety barriers.

Continuous Obstacles:

- Ditches with a depth exceeding 50 cm, except with soft slopes (25%);
- Ditches at the foot of slopes;
- Open gutters (on motorway);
- Cuttings slopes and sloped bunds. In motorways, the maximum acceptable slope is set to 70% (rounded down to 67%). This threshold is also recommended for all main roads;
- High cuttings slopes, except those with soft slopes (25%). The maximum values set by the standards are 4 m, or 1 m in case of brutal grade, although it is often best to isolate slopes with a lower height;
- Fence walls.

3.13.3 Selection of Containment Level

In the French standards, the level of containment required depends upon the location of the VRS, in the roadside, or in the median.

Roadside Safety Barriers:

- For roads and highways where the speed limit is less than 90 km/h, the minimum allowed containment level is N1;
- For roads and highways where the speed limit is greater than or equal to 90 km/h, the minimum allowed containment level is N2, with a working width class compatible with the space available;
- For bridges and retaining walls, a minimum containment level of H2 is required if the consequences of leaving the road can be greatly amplified by the topography such as high gradient, or if leaving the road can cause a significant hazard for users of another lane, road or rail, residential areas or can be particularly severe for the environment (water reservoirs, oil tanks, etc).

Median Safety Barriers:

- On roads and highways, where the speed limit is greater than or equal to 90km/h:
  - If the median width is less than 5 m:
    - Minimum containment level N2, if divided highway, 2×1 + 1 or 2 lanes;
    - Minimum containment level H1, if 2 × 2 lanes;
    - Minimum containment level H2, if 2 × 3 or more lanes;
  - If the median width is not less 5 m, the minimum containment level is N2.

Crash cushions:

In France the standard requires the following performance levels for crash cushions:

- Speed Limit 70 km/h - Performance Level 80/1;
- Speed Limit 90 km /h - Performance Level 80;
- Speed Limit 110 km/h - Performance Level 100;
- Speed Limit 130 km/h - Performance Level 110.

3.14 Germany

The requirements for the use of VRS in Germany are regulated in the "*Guidelines for passive protection on roads by vehicle restraint systems*, FGSV, 2009". This separately considers the following locations on the road environment:

- Outer edge of roadway;
- Median and shoulder strip;
- Edges of bridges and support walls;
- Median and shoulder strip on bridges;
- Walls and portals.

3.14.1 Lane Departure Probability

Lane departure probability must be considered when selecting appropriate VRS, and the standard highlights the following areas as those with an increased risk of lane departure:

- Irregularly designed curves;
- Several successive curves with radii smaller than 1.5 times the permitted minimum radius;
- Sections with non-typically large directional changes;
- Incident black spots;
- Risks to third parties.

3.14.2 Outer edge of roadway (Verge)

The decision of whether to install a barrier, or not depends on the concept of critical distance. A critical distance is determined for each hazard by using speed limit, hazard level and height of slope, as show in Figure 11, Figure 12, and Figure 13. Distance A (continuous line) is used for hazards of level 3 & 4 while the expanded distance AE (dashed line) is used for hazards of level 1 & 2.

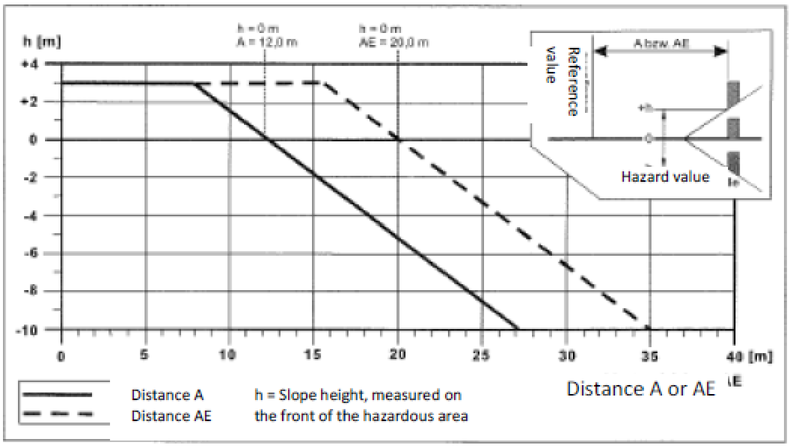


Figure 11 - Critical distances for roads with a speed limit > 100 km/h (*Guidelines for passive protection on roads by vehicle restraint systems*, FGSV, 2009)

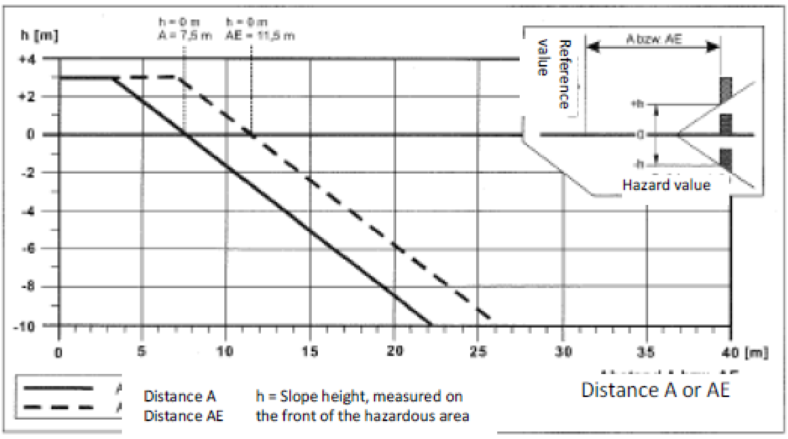


Figure 12 - Critical distances for roads with a speed limit = 80 km/h to 100 km/h (Guidelines for passive protection on roads by vehicle restraint systems, FGSV, 2009)

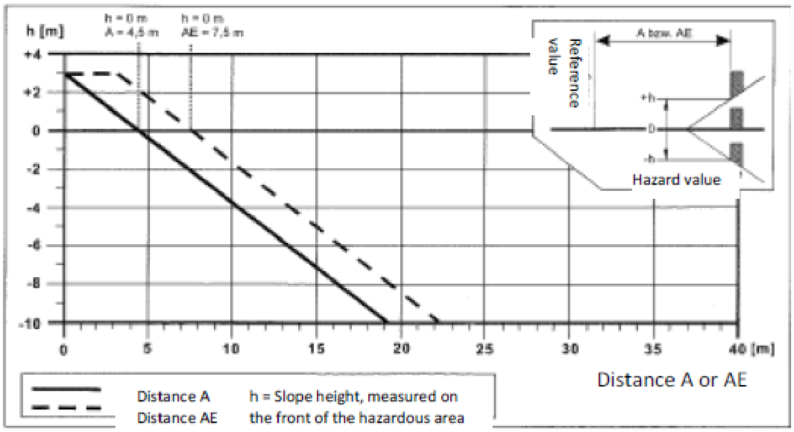


Figure 13 - Critical distances for roads with a speed limit = 60 km/h to 70 km/h (*Guidelines for passive protection on roads by vehicle restraint systems*, FGSV, 2009)

If a hazard is within the critical distance, the flowchart shown in Figure 14 is used to determine if a VRS is necessary, depending on the Hazard Level. If a VRS is necessary, the required containment level is also determined by using Figure 14.

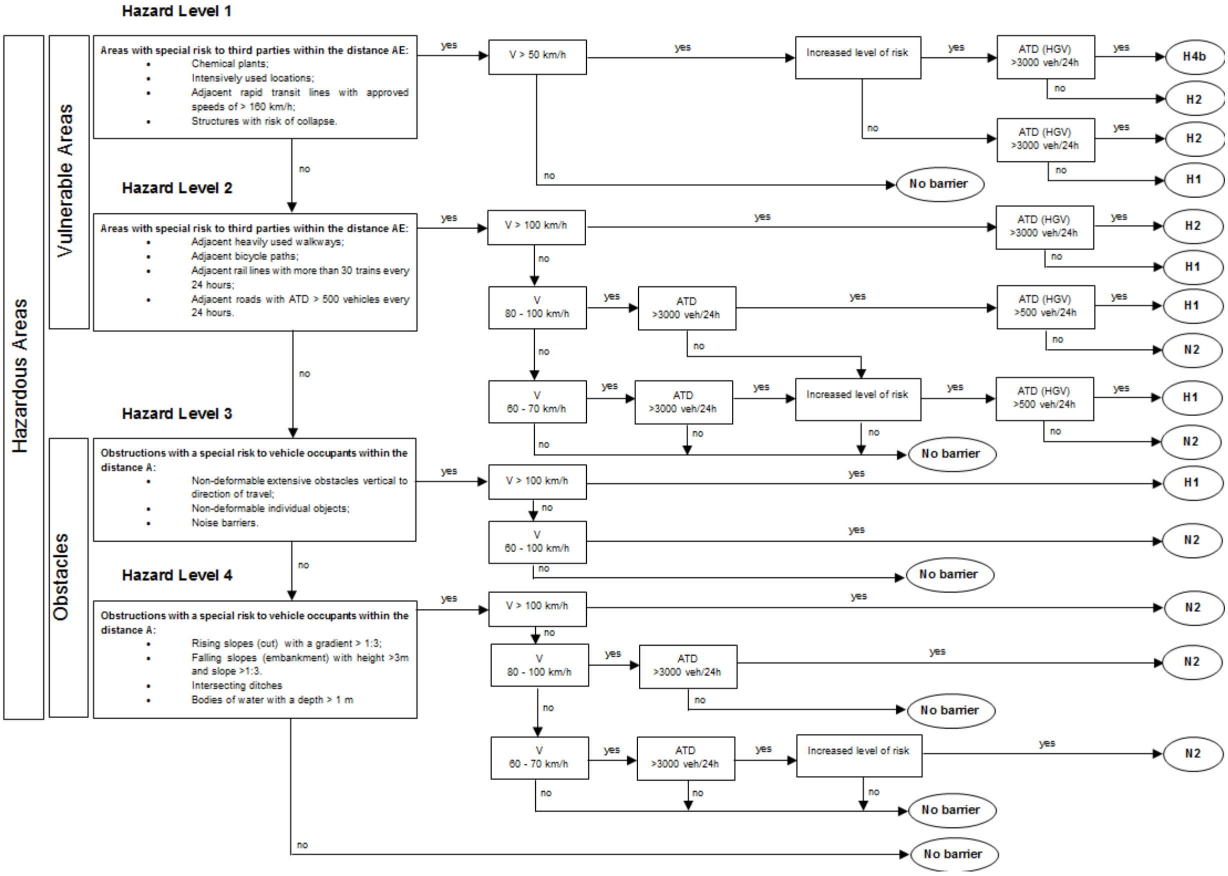


Figure 14 - Flowchart for the decision of barrier warrant and containment level (*Guidelines for passive protection on roads by vehicle restraint systems*, FGSV, 2009)

Risk is categorized into 4 hazard levels:

- Hazard Level 1: Areas with special risk to third parties:
  - Chemical plants;
  - Intensively used locations;
  - Adjacent rapid transit lines with approved speeds of >160km/h;
  - Structures with risk of collapse.
- Hazard Level 2: Areas with special risk to third parties:
  - Adjacent heavily used walkways;
  - Adjacent bicycle paths;
  - Adjacent rail lines with more than 30 trains every 24 hours;
  - Adjacent roads with ATD>500 vehicles every 24 hours.

- Hazard Level 3: Obstructions with a special risk to vehicle occupants:
    - Non-deformable extensive obstacles parallel to direction of travel;
    - Non-deformable individual objects;
    - Noise barriers.
- Hazard Level 4: Obstructions with a special risk to vehicle occupants:
    - Rising slopes (cut) with a gradient > 1:3;
    - Falling slopes (embankment) with height >3m and slope >1:3;
    - Intersecting ditches;
    - Bodies of water with a depth > 1 m.

3.14.3 Median and shoulder strip

A VRS is always required in the median and on shoulder strips of dual carriageway roads with a speed limit greater than 50km/h. This can be achieved with either:

- Double sided VRS set up centrally;
- Double sided VRS set up off centre;
- Single sided VRS with separate posts set up on both edges;
- Single sided VRS with joint posts set up on both edges.

Crash cushions should be added:

- If minimum length of application can't be met.
- If a distance of 50m to the hazardous area cannot be met in median crossings, and the speed limit cannot be limited to 60km/h.

3.14.4 Edges of Bridges and Retaining Walls

A VRS is required for roads higher than 2m, otherwise they are treated as roadsides.

3.14.5 Median and shoulder strip on bridges

A VRS is required for the edges of bridges and retaining walls with a drop of more than 2m.

3.14.6 Walls and portals

Continuous solid walls are not classified as obstructions if they have no projections or recesses exceeding 0.1m.

3.14.7 Crash Cushions

Only re-directive crash cushions are allowed. The selection of performance level is based solely on speed limit as shown in Table 23.

Table 23 - Performance levels for crash cushions of type R (Re-directive) depending on speed limit (*Guidelines for passive protection on roads by vehicle restraint systems*, FGSV, 2009)

Speed Limit (km/h)	Performance level			
	50 R	80 R	100 R	110 R
50	x			
60		x		
70		x		
80		x		
90			x	
100			x	
>100				x

3.15 Greece

The Greek standard is a direct translation of the German standard.

3.16 Iceland

Guidelines for barrier installation in Iceland are presented in Chapter 5.4 of the document: "Veghönnunarreglur (General Guidelines for Road Design), 2010".

The methodology of these guidelines and the majority of the figures and tables used are very similar to the ones that are used in the Norwegian guidelines, although values used within the tables and figures are different to account for local variances.

3.17 Ireland

Safety barriers, terminal and transitions are covered in NRA TD19/13 while bridge and pedestrian parapet are covered in BD52/13. Crash cushions are not covered by NRA standards.

3.17.1 Safety Barriers

According to TD19/13, a safety barrier system is defined as the complete installation of a length of safety barrier at any location and includes terminals, transitions and the individual components used to construct the barrier itself.

The requirements state that a safety barrier is warranted if the consequences of a vehicle striking the barrier are considered to be less serious than those which would result if the vehicle were not to be contained by the safety barrier. The protection of third parties and the protection of supporting structures (such as bridge piers) are also given as reasons for the installation of a safety barrier.

A safety barrier must be provided only when the hazard in the clear zone cannot be removed, relocated or mitigated. The general categories of hazards include: side slopes, central reserves, fixed objects, water and railways, locations with a history of numerous collisions, locations with pedestrian and bicycle usage, playgrounds, monuments and other locations with high social or economic value, and central reserves. Detailed information is given for the need of safety barriers in each of these cases.

Also well-defined is the clear zone which should be kept clear of unprotected hazards. The clear zone in TD19/13 is defined by a combination of vehicle speed, the horizontal curvature of the road and the terrain over which the vehicle passes.

Safety barriers are required in the central reserves and where there is a hazard in the clear zone.

On motorways and Type 1 dual carriageways, barrier in the central reserve are required to be constructed from concrete.

With regard to the Impact severity Level of the barriers used, level A is required for verge applications, whilst a level no worse than B is required for the central reserve. For reserves greater than 7.5m in width, level A is preferred.

Table 24 shows the minimum containment level for safety barriers. Where several hazards are in close proximity, the highest required containment level is needed to be provided throughout the length of the safety fence.

Table 24 - Minimum containment level for safety barriers (*TD19/13: Safety Barriers*, National Roads Authority - Ireland, 2013)

Location			Containment Level
1. Within the Clear zone:			
Embankments:			
	Slope Angle	Slope Height	
	Sleeper than 1:2 (see Note3)	≥ 0.5m	**N2**
	Between 1:2 and 1:3 (inclusive)	> 2m	**N2**
	From 1:3 and up to 1:5	≥ 6m	**N2**
Cuttings:			
	At steep sided cuttings or earth bunds (steeper than 1:2) within the Clear Zone		**N2**
Verge and Central Reserves:			
a)	At individual hazard such as bridge piers or abutments, sign posts, gantry legs and trees, etc.		**N2**
b)	At lighting columns that are not passively safe		**N2**
c)	At substantial obstructions such as retaining walls which extend more than 150mm above the carriageway level		**N2**
d)	At underbridges or at retaining walls >0.5m high supporting the road, where a vehicle parapet or vehicle/pedestrian parapet of the required performance class is not provided		**N2**
Central Reserves:			
a)	At central reserves up to 7.5m wide		**H2**
b)	At central reserves greater than 7.5m wide		**N2**
c)	Where the difference in adjacent carriageway channel levels exceeds 1.0m and the slope across the reserve exceeds 1:4		**H2**
Parapets (see BD 52):			
	For a minimum of 30m in advance of the approach end and 15m after the departure end of a vehicle parapet or vehicle/pedestrian parapet		**N2**
	For a minimum of 30m in advance of the approach end and 15m after the departure end of a vehicle parapet or vehicle/pedestrian parapet over a railway		**H2**
2. Within or Beyond the Clear Zone			
Verges:			
a)	At locations where an errant vehicle may encroach onto an adjacent road (but see Note 6) or impact another significant hazard		**H2**
b)	At locations where an errant vehicle may encroach onto an adjacent railway		**H2**
c)	At hazardous topographical features beyond the road boundary, but within the width defined in Table 4/1		**N2**

3.17.2 Risk Assessment Procedure for schemes involving online realignment on National Roads

To assess the need for a safety barrier on schemes involving online realignment, a risk assessment procedure has been defined in the current Irish National Standard TD19/13 Chapter 8.

The risk assessment is based on three variables: Hazard Ranking, Sinuosity Ranking and Collision Rate Ranking. The assessment procedure is composed of the following steps:

- Establish if the hazard is within the clear zone and if it can be mitigated;

- Rank the hazard as per Appendix D;
- Calculate the sinuosity of that section of road;
- Assess the collision rate threshold for that section of road;
- Assess the risk of a vehicle leaving the road based on sinuosity ranking and collision rate ranking;
- Assess the overall risk rating;
- Undertake a site survey to confirm the need for a safety barrier.

The Hazard Ranking (High, Medium, Low) is detailed for different hazards in the Appendix D of the Standard.

The sinuosity of the road is assessed through the Sinuosity Index which is defined as the actual section length between two points on a road divided by the shortest path between them.

$$\text{Sinuosity Index (SI)} = \frac{\text{Actual section length between A and B}}{\text{Shortest path between A and B}}$$

The sinuosity ranking is then assigned to the road section where the hazard is located as follows:

High (H) - Sinuosity Index > 1.02;
Medium (M) – 1.004 ≤ Sinuosity Index ≤ 1.02;
Low (L) - Sinuosity Index < 1.004

The Collision Rate Ranking is assessed by comparing Collision Rates calculated by the NRA with historical rates. The following thresholds are established:

High (H) - Twice Above Expected Collision Rate;
Medium (M) - Above Expected Collision Rate;
Low (L) - Below Expected Collision Rate and Twice Below Expected Collision Rate.

Once the Collision Rate Ranking and Sinuosity Ranking have been calculated, the Risk of a Vehicle Leaving the Road is obtained using the matrix in TD19/13 Table 8/1 (see below). This information is combined with the Hazard Ranking using the matrix in Table 8/2 which gives the Overall Risk Rating for the location under consideration.

Table 25 – Risk of a Vehicle Leaving the Road and Overall Risk Rating (*TD19/13 Safety Barriers*, National Roads Authority - Ireland, 2013)

Risk of a Vehicle Leaving the Road	**Collision Rate Ranking**		
Sinuosity Ranking	**H**	**M**	**L**
H	H	H	M
M	H	M	L
L	M	L	L
TD19/13 Table 8/1			

Overall Risk Rating	**Hazard Ranking**		
Risk of a vehicle leaving the road	**H**	**M**	**L**
H	H	H	M
M	H	M	L
L	M	L	L
TD19/13Table 8/2			

3.17.3 Terminals

All safety barriers must be terminated to reduce the risk of injury, and TD19/13 gives three options:

- Returning the barrier such that the end is buried in a cutting face or bund
- Ramping the barrier down to ground level, where the terminal is not in the direct line of traffic
- Terminating at a full height terminal of Performance Class P4 where the terminal is in the direct line of traffic.

For roads with a design speed of 100km/h or greater, upstream terminals shall be of Performance level P4 where the terminal is in the direct line of traffic. For lower design speeds upstream terminals shall be of minimum Performance Class P1.
Downstream full height terminals shall be of minimum Performance Class P1.

3.17.4 Transitions

The containment level of the transition should not be less than the lowest of the two connected barrier, nor higher than the highest. The same applies to the Working Width.

3.17.5 Vehicle parapets

Vehicle parapets are required on the edges of all bridges where there is a vertical drop and the bridge is designed to carry vehicular traffic. Vehicle parapets are also required on the edges of retaining walls or similar structures where there is a vertical drop in excess of 1m and there is access for vehicles adjacent to the top of the wall.

The minimum containment level required is detailed in Table 26.

Table 26 – Minimum Parapet Containment Level (*BD52/13: The Design of Vehicle and Pedestrian Parapets*, National Roads Authority - Ireland, 2013)

Location	**Minimum Parapet Containment Level**
All structures in urban areas where the legal speed is 60kph or less, except where: • The structure crosses or adjoins a motorway or railway • The structure is on a horizontal curve and / or gradient and the radius and / or gradient does not comply with relevant desirable minimum standards. Relevant desirable minimum standards are described in NRA TD 9. All accommodation bridges serving a single landholding except accommodation bridges over the railway.	**N1**
All structures not otherwise explicitly dealt with in this table	**N2**
• All structures forming part of partially or fully free flow interchanges • All structures carrying a motorway and crossing or adjoining another	**H2**

national route • All structures carrying a national or regional road where the geometric alignment does not comply with relevant desirable minimum standards within a distance of 215m of either approaches to the structure. Relevant desirable minimum standards are described in NRA TD 9.	
All structures crossing or adjoining the railway or at high risk locations where the consequences of parapet penetration are judged to outweigh the hazards to vehicle occupants or other road users resulting from the effects of the very high containment barrier	**H4a**

Vehicle parapets of Normal Containment Level (N1 or N2) should have Impact Severity Level A. Parapets of Higher or Very High Containment Level may have Impact Severity Level B.

The Working Width shall be no greater than W4.

The form and aesthetics of the parapet are also needed to be considered at the initial stage of the design of the structure.

3.18 Israel

The current approach to VRS installation in Israel is summarised in the document "New guidelines for the approval of barriers and crash cushions".

Israel accepts products which are tested according to either EN1317 or NCHRP 350, as applicable, however an additional consideration of the product's applicability on Israeli public roads have to be discussed and/or approved by a National Approval Committee.

3.18.1 Safety Barriers on Rural Roads

As is the case with many other countries, Israel uses the concept of recovery zone as the main decisive factor for the installation of a VRS. Figure 15 shows the components of the road section for the definition of the 'recovery zone'.

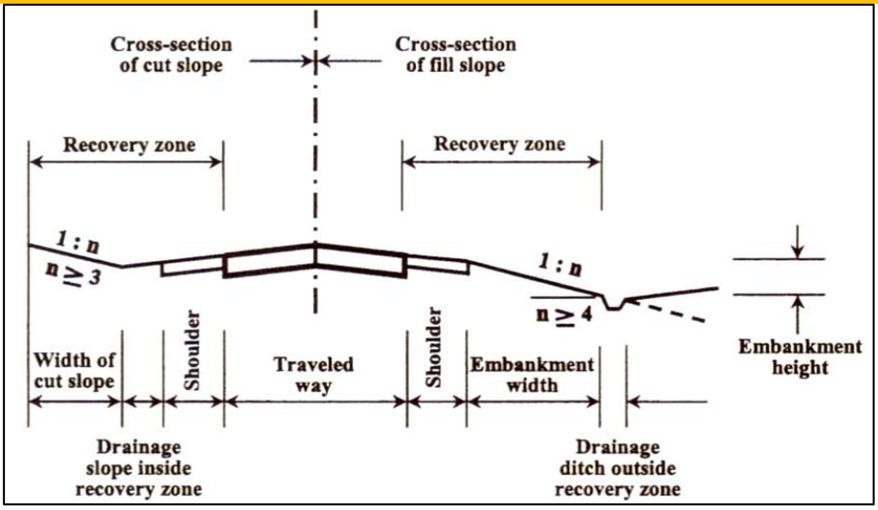


Figure 15 - Components of road cross-section for the definition of recovery zones on roadsides (*New guidelines for the approval of barriers and crash cushions*, Transportation Research Institute – Israel, 2006)

The installation of a safety barrier on the roadside is warranted in each one of the following cases:

1. On a steep slope and high embankment, the barrier is warranted according to the height and slope of the embankment, road type and daily traffic volume, as presented in Figure 16.
2. On moderate fill or cut slopes when the width of recovery zone does not satisfy the demands presented in Table 27.
3. When the recovery zone's width satisfies the demands presented in Table 27, however, beyond the recovery zone a high-risk zone is situated.
4. When rigid obstacles are located close to the roadway.

For case 2, within the slope values presented in Table 27, a steeper cut slope is treated as a non-traversable obstacle and is judged similar to other rigid obstacles (case 4).

In the case of a steep cut slope, the installation of a safety barrier is required when the distance from the end of travelled way to the beginning of the slope is lower than the maximum values for cut slopes, which are presented in Table 27, i.e. from 5.0 to 7.0m for a single-carriageway road and 9.0m for a dual-carriageway road.

In case 3, a high-risk zone may exist due to a natural hazard, for example an abyss with a risk of falling from the vehicles, or 'a risk for a third party'. Examples are adjacent railways or roads, houses, rest areas, parking places, schools or industrial buildings situated in the vicinity of the road.

In case 4, the rigid obstacles considered may be non-traversable natural hazards, for example big rocks, lakes, or fixed objects like sign/lighting supports, utility poles, bridge piers, retaining walls, trees, etc. When a rigid obstacle exists, a safety barrier is warranted when the distance to the object from the edge of the carriageway is lower than the width required for the recovery zone, as shown in Table 27.

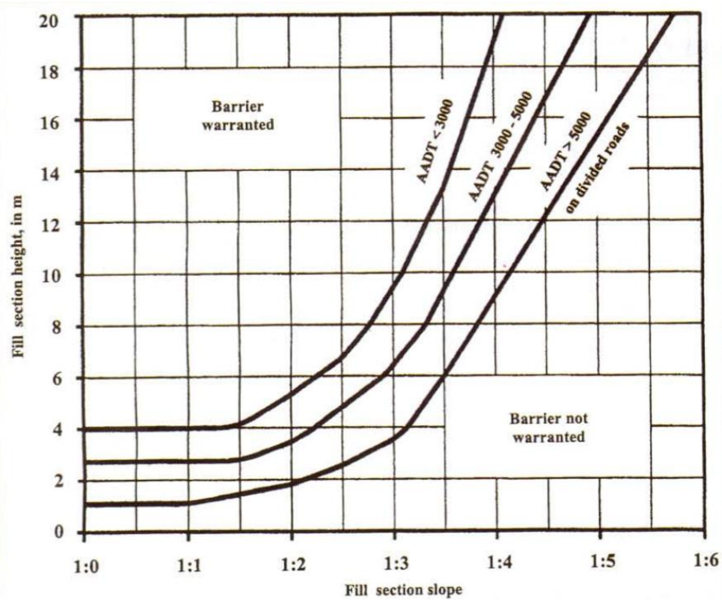


Figure 16 - Warrants for the installation of safety barriers accounting for embankment parameters and traffic volumes (*New guidelines for the approval of barriers and crash cushions*, Transportation Research Institute – Israel, 2006)

Table 27 – Recommended widths of recovery zones on rural Israeli roads (in m) (*New guidelines for the approval of barriers and crash cushions*, Transportation Research Institute – Israel, 2006)

Road Type	Average Daily Traffic	Fill Slope				Cut Slope				
		1:4	1:5	1:6	Flatter	1:3	1:4	1:5	1:6	Flatter
Single Carriageway	<1500	7.5	6.5	5.5	5.0	3.5	4.0	5.0	5.0	5.0
	1500-5000	9.5	7.5	7.0	6.5	4.0	5.0	5.5	6.5	6.5
	>5000	10.5	8.5	7.5	7.0	5.0	6.5	7.0	7.0	7.0
Dual Carriageway	Any Volume	14.0	11.5	10.5	9.0	6.5	8.0	8.5	8.5	9.0

With regard to the medians of dual carriageway roads, in Israel, the requirement for the installation of safety barrier is valid for all rural roads and does not depend on the median's width, or a presence of obstacles.

The required containment levels for safety barriers for Israeli rural roads are presented in Table 28. The containment levels are defined according to EN1317 while equivalent performance levels according to NCHRP 350 are also acceptable.

Table 28 – Barrier performance levels required on rural roads in Israel (*New guidelines for the approval of barriers and crash cushions*, Transportation Research Institute – Israel, 2006)

Road Type	Basic Performance Level		Conditions When Higher Performance Levels are Required
	On Roadside	On median	
Single carriageway	N2	-	1. On roadside, when a high rate* of trucks is present in the traffic and Case 1/Case3 of warrants applied - **H1** level 2. On roadside, when a high rate* of trucks and busses is present in the traffic and Case 1/Case3 of warrants is applied - **H2** level 3. On roadside, when "a high risk for a third party" is recognized - **H4** level
Motorway or dual carriageway	H1	H1	1. On roadside or on median, when a high rate* of trucks and busses is present in the traffic - **H2** level 2.On roadside, when "a high risk for a third party" is recognized - **H4** level 3.On medians of main roads, when a high rate** of heavy trucks presents in the traffic - **H4** level

* High rate of trucks or trucks and buses - over 15% of daily traffic

** High rate of heavy trucks (over 10 ton) - over 5% of daily traffic

3.18.2 Crash Cushions

The road conditions which warrant the installation of a crash cushion are defined as a combination of four parameters which are: the type of road, the type of site, types of objects to be shielded and additional risk factors of the road and/or traffic environment. Table 29 presents the conditions which warrant the installation of a crash cushion, and the corresponding performance level requirements.

Table 29 – Road conditions warranting the installation of a crash cushion, and the required performance levels of crash cushions (*New guidelines for the approval of barriers and crash cushions*, Transportation Research Institute – Israel, 2006)

Road Type	Type of Site	Types of Objects to be Shielded	Additional Risk Factors	Required Performance Level
Motorway	Gore areas at interchange exits	Barrier ends*, bridge piers, walls, sing/lighting poles	-	TL3 (NCHRP350) or 110 (EN1317)
	Recovery zone on roadside	Trees or poles with cut area over $300cm^2$	High travel speeds**, sharp curve with high risk of collisions	
	Median	Concrete barrier ends, bridge piers, sing/ lighting poles	High travel speeds**	
Dual carriageway road, in rural areas	Gore areas at interchange exits/ road diversions	Barrier ends*, bridge piers, walls, sing/lighting poles	High travel speeds**, level differences	TL3 (NCHRP350) or 100 (EN1317)
	Recovery zone on roadside	Trees or poles with cut area over $300cm^2$	High travel speeds**, sharp curve with high risk of collisions	
	Median	Concrete barrier ends, bridge piers, sing/ lighting poles	High travel speeds**	
Single carriageway road, in rural areas	Gore areas at interchange exits/ road diversions	Barrier ends*, bridge piers, walls, sing/lighting poles	High travel speeds**, level differences	TL2 (NCHRP350) or 80 (EN1317)
	Recovery zone on roadside	Trees or poles with cut area over $300cm^2$	High travel speeds**, sharp curve with high risk of collisions	
Urban arterial	Gore areas at road diversions	Barrier ends*, bridge piers, walls, sing/lighting poles	High travel speeds***, level differences	
	Median	Concrete barrier ends, bridge piers, sing/ lighting poles	High travel speeds***	

3.19 Italy

The first technical standard governing the use of Vehicle Restraint System (VRS) in Italy is the Ministry Decree No. 223 of 18.02.1992 which is mandatory for any public road with a design speed equal or above 70 km/h.

This standard has been updated several times since 1992 with the last official revision dated 21.6.2004 (D.M. 2367). A new revision has been prepared in 2013 by the Ministry and has been approved by the High Council of Public Works.

The D.M. 21.6.2004 has adopted the EN1317 standards for VRS testing and since the start of 2011 all new safety barriers (including bridge parapets) and crash cushions (attenuators) have to be CE marked according to EN 1317-5. Removable barrier sections (for medians) and energy absorbing terminals have to be tested according to ENV 1317-4 until the new set of standards are approved by CEN.

Transitions do not require testing and are based on design prescriptions. Temporary barriers and truck mounted attenuators are not regulated by the national standard. A specific standard for motorcycle protection systems has been drafted and is expected to be available as a mandatory Ministry Decree in the near future.

The Ministry Decree No. 2367 of 2004 and the new draft have a similar structure. However, they differ substantially in two points represented by the selection of the minimum vehicle restraint system performance class as related to the local and traffic condition.

D.M. 21.6.2004

The current standard is composed of 8 clauses. Clause 3 "identification of the locations to be protected" defines the criterion to identify the need for a VRS and it addresses the length of need issue. Clause 6 "Criteria for the selection of vehicle restraint systems" defines the minimum performance classes, as defined by EN 1317 standards, to be applied in a specific situation.

Need for a VRS (clause 3):

A VRS is always required in the following situations:

- Edge of any bridge, retaining wall, underpass, independently of its height over the ground below;
- The median of dual carriageways;
- The outer edge in embankment sections where the height above the ground below is not less than 1 m and the slope of the embankment is 2/3 or above. If the slope is below 2/3 the need for a VRS should be defined by the designer considering the combination of height and slope and considering the potential hazards at the end of the slope (presence of buildings, roads, railways, dangerous good deposits o similar situations) but no specific criteria are given to identify the minimum distance after which this is not to be considered an hazard anymore;

- Fixed obstacles (frontal or side obstacles) that can results in an hazard in case if impact of a road vehicles, such as: bridge structures, rocks emerging from the ground, ditches that cannot be crossed by the errant vehicle, trees, lighting poles, sign supports, water streams, buildings and structures that could be damaged in case of an impact. These obstacles need to be protected if their removal is impossible or not convenient as compared to placing a VRS and if they are placed at a distance from the carriageway lower than a "safety distance" which has to be defined by the designer considering the design speed, the traffic volume, the road curvature, the embankment slope, the hazardousness of the obstacle. No criteria are given in the standard on how to define such "safety distance";
- For frontal obstacles crash cushions are recommended unless otherwise specified by the designer.

Minimum performance classes (clause 6):

The minimum performance classes for a safety barrier are defined based on 3 criteria:

- traffic;
- location on the road (median, embankment/wall/small underpasses, bridge);
- road category.

Traffic is classified in 3 "traffic classes" as a function of bi-directional Annual Average Daily Traffic (AADT) and percentage of heavy vehicles (with a mass above 3.5 tons) in the mix, as shown in Table 30.

Table 30 - Selection of traffic type (DM 2367/2004, *Aggiornamento del decreto 18 febbraio 1992, n. 223 e successive modificazioni, Italy*)

Traffic Class	AADT	% heavy vehicle[1]
I	≤1000	Any
I	>1000	≤5
II	>1000	5 ≤ n ≤ 15
III	>1000	> 15

For each road category, for each location on the road, and for each traffic class, the standard provides the minimum class of safety barrier to be adopted, as shown in Table 31. For motorways and dual carriageway rural highways with a traffic type III, the standard provides two performance classes leaving the designer to select the most appropriate. A barrier performance class higher than the ones listed in Table 31 can be used only for specific reasons that have to be clearly explained and justified by the designer.

[1] percentage of vehicles over 3.5 tons

Urban roads categories E and F are listed in the table even though these are roads with a design speed below 70 km/h and therefore are not covered by the D.M. 21.6.2004 requirements. This can be considered only as an indication for situation in which the designer needs to place a barrier in these roads. Walls and small overpasses (with an open width below the underpass of not more than 10 m) are considered as "roadsides" and not as bridges.

Table 31 – Minimum safety barrier requirements (DM 2367/2004, *Aggiornamento del decreto 18 febbraio 1992, n. 223, Italy*)

Road category	Traffic Class	Median VRS	Roadside VRS	Bridge VRS
Motorways (A) and Dual Carriageway Rural Highways (B)	I II III	H2 H3 H3-H4	H1 H2 H2-H3	H2 H3 H3-H4
Rural secondary roads (C) urban collectors (D)	I II III	H1 H2 H2	N2 H1 H2	H2 H2 H3
Urban zonal roads (E) and urban/rural local roads (F)	I II III	N2 H1 H1	N1 N2 H1	H2 H2 H2

Ramps are treated as motorways, and for toll plaza, rest areas and gas stations, the minimum required class is N2.

Removable barriers in the median need to be tested according to ENV 1317-4 and can be of a reduced class compared to the median barriers they are connected to but by no more than two classes.

Crash cushions (attenuators) are required for any diversion (two lanes diverging in a point in the same direction) where the main road has a posted speed above 40 km/h. The minimum performance class is given as a function of the speed limited posted on the primary road, as shown in Table 32.

Table 32 – Minimum crash cushion (attenuators) requirements (DM 2367/2004, *Aggiornamento del decreto 18 febbraio 1992, n. 223, Italy*)

Posted speed limit (V)	Minimum performance class
V ≥ 130 km/h	100
90 km/h ≤ V < 130 km/h	80
V < 90 km/h	50

The standard solution for terminals is considered to be a non-energy absorbing device that has to be designed so to avoid frontal collisions but doesn't need to be tested according to ENV 1317-4. If an energy absorbing device is used, this has to be tested according to ENV 1317-4 with a performance class not lower than those listed in Table 33.

Table 33 – Minimum requirements for energy absorbing terminals (DM 2367/2004, *Aggiornamento del decreto 18 febbraio 1992, n. 223, Italy*)

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

Revised standard (current draft)

Whilst the aforementioned D.M. 21.6.2004 details the current requirements, as stated previously, a new draft standard is currently nearing completion. As this will be the future Italian standard.

Need for a VRS:

The locations that need a VRS are similar to the DM 21.6.2004 with some clarifications (a ditch at the end of the slope can be allowed only if it is not covered in concrete and with a depth of not more than 50 cm; medians wider than 12 m do not require safety barriers).

It is clarified that a support structure is to be considered as a hazard only if the resistant moment is above 5.7 kNm.

It is clarified that a safety barrier is required in any case where the road passes over or within 12 m from a road (excluding local roads with a total AADT below or equal to 1000 vehicles/day), a railway, a building or any other structure that can cause an hazard to others if impacted by the errant vehicle.

Length of need:

In the new revision it is clarified that one third of the crash test length has to be installed prior to the first point where the barrier has to offer the full containment. Similarly after the last point where the barrier has to offer full containment, one third of the crash test length has to be installed.

Minimum performance classes:

The main difference between the 2004 standard and the revised one is the criteria that allow defining the local traffic conditions. While the DM 2367/2004 considers the bidirectional AADT is related to all types of vehicle (light and heavy) and the percentage of heavy vehicles in the mix, the new revision considers directly the bidirectional AADT related only to heavy vehicles.

In addition two different criteria are given for the classification of motorways and rural highways (Table 34) and for the classification of other roads (Table 35). For motorways and dual carriageways rural highways four traffic classes are given, to remove the actual situation in which a range of minimum classes are given for a single traffic class.

Table 34 - Selection of traffic type for motorways and dual carriageways rural highways (*Revised standard - draft, Italy*)

Level of traffic	AADT (heavy vehicle)
AI	AADTh <5000
AII	5000 ≤ AADTh <13000
AIII	13000 ≤ AADTh <21000
AIV	AADTh ≥21000

Table 35 - Selection of traffic type for other roads (*Revised standard - draft, Italy*)

Level of traffic	AADT (heavy vehicle)
BI	AADTh <1000
BII	1000≤ AADTh <5000
BIII	AADTh ≥5000

The minimum requirements for safety barriers set by the draft revision are shown in Table 36 with the following specifications:

- The "bridge" VRS requirement is applicable only for bridges with a total span of more than 20 m. Small bridges, underpasses, retaining walls, are treated as roadsides;
- In any case where the road passes over or within 12 m from a road (excluding local roads with a total AADT below or equal to 1000 vehicles/day), a railway, a building or any other structure that can cause a hazard to others if impacted by the errant vehicle, the minimum classes cannot be below one class above the roadside VRS class, with a minimum of H2;
- For bridges with a total span of 20 to 100 m with traffic IV the minimum class can be reduced to H3 if none of the conditions above occur;
- Ramps are to be considered as secondary rural roads;
- Secondary rural roads should never have medians. For old existing roads that do have a median and for dual carriageway ramps with a median, an H2 class is required;
- Obstacles that cannot be an hazard for others if hit should be protected with an N2 barrier;
- Ditches (if not shaped with a triangular form) have to be protected with an N2 barrier;

- For toll plaza, rest areas and gas stations the minimum required class is N2.

Removable barriers can be either specific products tested according to ENV 1317-4 or median barriers tested with a length shorter or equal to the one that will be installed in the median.

Table 36 - Minimum safety barrier requirements (*Revised standard - draft, Italy*)

Road type	Level of traffic	Median VRS	Roadside VRS	Bridge VRS
Motorways and dual carriageways rural highways	AI	H3	H2	H2
	AII	H3	H2	H3
	AIII	H4	H2	H3
	AIV	H4	H2	H3
Rural Secondary Roads (C)	BI	--	H1	H2
	BII	--	H1	H2
	BIII	--	H2	H2
Urban collectors (D)	BI	H1	N2	H2
	BII	H2	H1	H2
	BIII	H2	H2	H2
Rural local roads (F)	--	--	N1	N2

When a road section overpasses or runs within 12 m of a road class A, B, C, D, E or F (only if the AADT is above 1000 vehicles/day or if, if the AADT is unknown, the carriageway width is above 5 m) la minimum class are one class above the Roadside VRS with a minimum of H2. A class H4 is required in these conditions for Motorways and dual carriageways rural highways. Similarly an H4 class is required for Motorways and dual carriageways rural highways on bridges with a span above 100 m and traffic class AIV.

Crash cushions (attenuators) are required for any diversion (two lanes diverging in a point in the same direction) where the main road has a posted speed above 40 km/h. The minimum performance class is given as a function of the speed limited posted on the primary road, as shown in Table 37.

Table 37 – Minimum crash cushion (attenuators) requirements (*Revised standard - draft, Italy*)

Posted speed limit (V)	Minimum class
V ≥ 130 km/h	100
90 km/h ≤ V < 130 km/h	80/1
V < 90 km/h	50

The standard solution for terminals is considered to be a non energy absorbing device that has to be designed so to avoid frontal collisions (flared) but doesn't need to be tested according to ENV 1317-4. If an energy absorbing device is used, this has to be tested according to ENV 1317-4 with a performance class not lower than those listed in Table 38.

Table 38 – Minimum requirements for energy absorbing terminals (*Revised standard - draft, Italy*)

Posted speed limit (V)	Minimum class
V > 130 km/h	P4
90 km/h ≤ V ≤ 130 km/h	P3
V < 90 km/h	P1

3.20 Latvia

The Latvian standard is a mainly a translation of the German standard.

3.21 Lithuania

The Lithuanian standard is a direct translation of the German standard.

3.22 Luxembourg

Luxembourg does not have a separate standard for barriers, but they implement the German standards.

3.23 Mexico

Mexican Official Standard, NOM-037-SCT2-2012 "Barreras de Proteccion en Carreteras y Vialidades Urbanas" (Protective Barriers in Urban Highways and Roads), is mainly a translation of AASHTO Roadside Design Guide 2002, with the following modifications:

- For embankments on roads with operating speeds under 50km/h and an AADT less than 1,000, installation of a roadside barrier is optional;
- A roadside barrier is required if there is an adjacent lateral obstacle located within a distance of 2.7m (9ft) to the road traffic;
- Median barriers are not required for dual carriageways with median widths greater than 10m;

The selection of containment level is completed according to the operating speed and AADT, as shown in Table 39.

Table 39 - Minimum allowed containment levels according to the characteristics of the traffic and the speed of operation (*Barreras de Proteccion en Carreteras y Vialidades Urbanas*, Mexican Standards, 2012)

Speed of Operation km/h	Minimum containment level of the barrier				
	Dual Carriageway with one lane in each direction			Dual Carriageway with two or more lanes in each direction	
	AADT			AADT	
	<1.000	1.000-9.999	≥10.000	<10.000	≥10.000
≤50	NC-1	NC-1	NC-1	NC-1	NC-1
51-70	NC-2	NC-2	NC-2	NC-2	NC-3[(1)]
71-100	NC-3	NC-3[(1)]	NC-3[(1-2)]	NC-3[(1-2)]	NC-3[(1-2)]
101-120	NC-3	NC-3[(1-2)]	NC-4[(3)]	NC-4[(3)]	NC-5

- A minimum containment level of NC-4 is required if 25% or more of the AADT are buses which carry passengers;
- A minimum containment level of NC-4 is required if 25% or more of the AADT are heavy vehicles with weights more than 8000kg;
- A minimum containment level of NC-5 is required if 25% or more of the AADT are heavy vehicles with weights more than 18000kg.

3.24 Nepal

His Majesty's Government of Nepal Road Safety Notes 6 – July 1997, gives technical advice on the application of safety barriers in Nepal.

According to this document, the following three situations may warrant a safety barrier:

- To protect vehicles from falling down a slope - this applies where there is a drop of 3m or more at or near the edge of the road, and the slope is steeper than 1 in 4;
- To protect vehicles from hitting a roadside object - this applies where there is a hazardous object, such as a bridge pier, large sign post, wall, rocky face, or the end of a bridge parapet which is close to the edge of the carriageway;
- To prevent out-of-control vehicles from crossing over the central median - this applies on the known crossover-accident locations along a dual carriageway.

There are a number of other factors that need to be taken into account, including:

- Whether there have been run-off-road or crossover accidents at the site - in the case of an existing road;
- Whether the site is on a sharp bend - defined as a bend where the design speed (safe speed to negotiate the bend) differs from the 85th percentile approach speed by more than 15 km/h;
- Whether it is a busy road - defined as a road with an ADT>1,000;
- Whether the traffic speed (85th percentile speed) approaching the site is greater than 50 km/h.

If two or more of these considerations apply there is probably a good case for installing a safety barrier. A bad record of casualty accidents involving run-off-road vehicles (3 or more a year) will, in itself, be sufficient justification for the installation of a safety barrier.

3.25 Netherlands

To guide the decision on whether the installation of a VRS is required or not, the Dutch apply two different guidelines; one for highways and a second document for other roads. For each situation, the desired dimensions of the safety zone *(obstakelvrije ruimte)* are defined. If these dimensions cannot be maintained, the installation of a VRS is recommended.

Table 40 – Dimensions of the safety zone for highways (*Componentspecificatie Voertuigkering*, Ministerie van Infrastructuur en Milieu – Netherlands, 2012)

Highways			
Design Speed (km/h)	**Width (1)**	**Width (2)**	**Width (3)**
120	13,00	10,00	25,00
100	10,00	10,00	20,00
80	6,00	6,00	12,00
50	4,50	4,50	9,00
(1) safety zone for new roads and reconstruction			
(2) safety zone for minor maintenance works			
(3) safety zone between two opposite driving directions (median)			

RWS divided the road into different components. For each component (including vehicle restraint systems), a set of specific characteristics were developed (functional, installation, aesthetic, etc.) and guidelines to determine the requirements for each characteristic were developed. For each characteristic, RWS developed guidance on the choices to be made.

The maximum ASI-value (VK.F.01) is function of the available space, as shown in Table 41.

Table 41 - Maximum ASI-value as a function of the available space (*Componentspecificatie Voertuigkering*, Ministerie van Infrastructuur en Milieu – Netherlands, 2012)

Available space x (m)	ASI
$x > 1,80$	$\leq 0,8$
$1,80 \geq x > 1,30$	$\leq 1,0$
$1,30 \geq x \geq 0,90$	$\leq 1,2$
$x < 0,90$	$\leq 1,4$

For the required containment level, the following recommendations in Table 42 apply.

Table 42 - Minimum containment levels for safety barriers (*Componentspecificatie Voertuigkering*, Ministerie van Infrastructuur en Milieu – Netherlands, 2012)

<table>
<tr><th colspan="6">VRS on continuous sections (VK.F.02)</th></tr>
<tr><th>Road category</th><th>Speed</th><th colspan="2">Third party risk</th><th colspan="2">Driver and passengers risk</th></tr>
<tr><td>Highway (NSW)</td><td>120 km/h</td><td colspan="2">H2</td><td colspan="2">H2</td></tr>
<tr><td>Regional Road (RSW)</td><td>100 km/h</td><td colspan="2">H2</td><td colspan="2">H1</td></tr>
<tr><td>Trunk Road (GOW)</td><td>80 km/h</td><td colspan="2">N1 (*)</td><td colspan="2">N1 (*)</td></tr>
<tr><td>Local Road (ETW)</td><td>60 km/h</td><td colspan="2">T1 (*)</td><td colspan="2">T1 (*)</td></tr>
<tr><th colspan="6">VRS on bridges (VK.F.03)</th></tr>
<tr><th colspan="2"></th><th colspan="4">Crossing infrastructure</th></tr>
<tr><th>Crossed infrastructure</th><th>Speed</th><td>NSW</td><td>RSW</td><td>GOW</td><td>ETW</td></tr>
<tr><td>Highway (NSW)</td><td>120 km/h</td><td>H2</td><td>H2</td><td>H2</td><td>N1</td></tr>
<tr><td>Regional Road(RSW)</td><td>100 km/h</td><td>H2</td><td>H2</td><td>H2</td><td>N1</td></tr>
<tr><td>Trunk Road (GOW)</td><td>80 km/h</td><td>H2</td><td>H1</td><td>N1</td><td>N1</td></tr>
<tr><td>Local Road (ETW)</td><td>60 km/h</td><td>H2</td><td>H1</td><td>N1</td><td>T1</td></tr>
<tr><td>Railroad</td><td></td><td>H2</td><td>H2</td><td>H2</td><td>N1</td></tr>
<tr><td>River / canal</td><td></td><td>H2</td><td>H1</td><td>N1</td><td>N1</td></tr>
<tr><td>Ditch</td><td></td><td>H2</td><td>H1</td><td>N1</td><td>T1</td></tr>
<tr><td colspan="6">(*) only in exceptional situations</td></tr>
</table>

For MPS (VK.F.18), RWS requires a test result according to the French test protocol, UNE 135900 or CEN/TS 1317-8.

3.26 New Zealand

The NZTA (New Zealand Transport Agency) adopted the “Austroads Guide to Road Design” as the primary reference guideline for their network, from the 1st August 2010.

The previous primary reference document “The State Highway Geometric Design Manual”, contained VRS installation and selection guidelines taken directly from the AASHTO Roadside Design Guide, and was phased out by the end of 2011.

3.27 Norway

The Norwegian Manual 231 E "Vehicle Restraint Systems and Roadside Areas, December 2011" contains the general guidelines for the selection and installation of VRS.

3.27.1 Safety Zone Concept

The decision to install a barrier, or not, is related to the safety zone concept. Safety zone is defined as a width of clear space from the edge of the road, which would allow errant vehicles to return to the carriageway in a controlled manner or come to a gradual stop without rolling over or hitting any hazards. A safety barrier is required if there is one or more hazards within the safety zone and if it isn't possible to remove, relocate or make the hazard breakaway, and if impacting the hazard is more dangerous than impacting a safety barrier.

The safety zone width is established based on the amount of traffic, speed limit, curvature, distance to oncoming traffic lanes if there is a median, and the design or content of the roadside terrain, as shown in Table 43 and Table 44.

Table 43 - Calculating the width of the safety zone (*Vehicle Restraint Systems and Roadside Areas*, Statens Vegvesen - Norway, 2011)

Calculating the width of the safety zone			
$S = A + T_1 + T_2 + T_3 + T_4 + T_5$			
A, safety distance	Determined on the basis of the AADT and speed at the location		
T_1 addition for sharp curves	Curves with horizontal radius $R < R_{min}$*		$T_1 = 2$ m
T_2 addition/deduction for gradients	Embankment (Falling gradient)	1:4 or Flatter	$T_2 = 0$ m
		Steeper than 1:4	T_2 = side slope width
	Slope (Rising gradient)	Flatter than 1:2	$T_2 = 0$ m
		1:2	$T_2 = 0$ m, or S is limited by the distance to a road cut height of 2.0 m above the carriageway level if this lies within A
		Steeper than 1:2	$T_2 = 0$ m, or S is limited by the distance to a road cut height of 1.6 m above the carriageway level if this lies within A
T_3 addition for	Road or footway/cycle way under road		$T_3 = 0.5 \times A$
	Railway		$T_3 = A$
T_4 addition for high risk hazards	Playground, schools, fuel tanks, water reservoirs etc.		$T_4 = 0.5 \times A$
medians			$T_5 = A$

*R_{min} for the various road classes is found in Manual 017

Table 44 - Determination of safety distance (*Vehicle Restraint Systems and Roadside Areas*, Statens Vegvesen - Norway, 2011)

AADT	Speed Limit (km/h)			
	50	60	70 and 80	≥90
0 - 1500	2.5 m	3 m	5 m	6 m
1500 - 4000	3 m	4 m	6 m	7 m
4000 - 12000	4 m	5 m	7 m	8 m
>12000	5 m	6 m	8 m	10 m

3.27.2 Hazards that necessitate barriers

The Norwegian manual states the hazards that may necessitate the installation of a barrier as follows:

Embankments:

The decision to install a barrier or not on at the top of an embankment depends on the gradient, height, speed limit, AADT and the distance from the roadside, as shown in Table 45 and Table 46.

Table 45 - Highest permitted bank height (H) according to falling gradients, traffic and speed limit (*Vehicle Restraint Systems and Roadside Areas*, Statens Vegvesen - Norway, 2011)

AADT	Bank Height (falling gradient) H			
	Bank gradient	Speed limit ≤ 60 km/h	Speed limit 70 og 80 km/h	Speed limit ≥ 90 km/h
0 - 4000	1 : 1.5	3 m	2 m	1,5 m
	1 : 2	5 m	3 m	2 m
	1 : 3	8 m	6 m	4 m
4000 - 12000	1 : 1.5	3 m	2 m	1 m
	1 : 2	4 m	3 m	1.5
	1 : 3	7 m	4 m	3 m
> 12000	1 : 1.5	2 m	1.5 m	1 m
	1 : 2	3 m	2 m	1.5 m
	1 : 3	5 m	3 m	2 m

Table 46 - Highest permitted bank height (H) without safety barriers at falling gradients of 1:1.5 or steeper (*Vehicle Restraint Systems and Roadside Areas*, Statens Vegvesen - Norway, 2011)

Height (metres)	0 - 1 metres from the carriageway	1 - 3 metres from the carriageway
0 - 0.3	No need for safety barriers	No need for safety barriers
0.31 - 1.0	Need for safety barriers	No need for safety barriers
1.01 - 4.0	Permitted for pedestrians/cyclists Need for safety barriers	Need for safety barriers
≥ 4.0	Need for safety barriers, height ≥ 1.2 m, H2 class	Need for safety barriers, H2 class

Cuttings and Deep Ditches:

A barrier is needed in road cuttings if dangerous roadside obstacles are located within the safety zone in the ditch or on the ditch slope and cannot be secured in any other way, and when the obstacle is located less than 1.6 m/2.0 above the carriageway.

In rock cuttings, a barrier is required if any parts protrude more than 0.3m in the safety zone.

To avoid safety barriers against ditches, the ditch depth shall be 0.3 m. On roads with speed limits ≤ 80 km/h, an alternative ditch depth of 0.6 m can be used.

Hazardous Roadside Obstacles:

Examples of hazardous fixed obstacles include:

- Bridge pillars and abutments;
- Non-passively safe posts, lighting columns and sign posts;
- Trees and wooden poles with a diameter greater than 15 cm, measured 40 cm above the ground;
- Large, non-passively safe traffic portals or similar;
- Retaining walls, masonry structures or similar (with edges that protrude more than 30 cm);
- Noise barriers with protruding parts or dangerous posts within or in connection with a structure that may be subject to fragmentation;
- Concrete buffers at toll stations;
- Concrete foundations, manholes, rocks buried in the earth, tree stumps and similar objects that protrude more than 15 cm above the ground;
- Culvert outlets, drain pipes etc. in embankments;

- Large, sturdy cabinets, e.g. telephone cabinets, electricity cabinets, control cabinets and similar installations;
- Tunnel openings and tunnel arches that extend out from the tunnel wall;
- The end of earth banks steeper than 1:10 and steep ditch terminations (1:6) at junctions and exit roads across the direction of the traffic.

Safety barriers or earth embankments are required in the median for multi-lane roads if the distance between the edges of the carriageways with traffic in opposite directions is less than twice the safety distance width, and the ditch has a slope of 1:5 or less. Roads with speed limits less than or equal to 60 km/h are subject to special consideration.

Safety barriers are to be installed along rivers and other bodies of water within the safety zone where the water depth is more than 0.5 m at high tide. Normal spring floods in waterways are included.

In addition, the Norwegian requirements state that safety barriers shall be used on all bridges, retaining walls and precipices with gradients steeper than 1:1.5.

Where there is a road parallel to the priority road with a speed limit equal to 70 km/h or more, safety barriers must be installed against the parallel road if the AADT on the parallel road is 1500 or more, and the distance from the priority road to the parallel road (between carriageway edges) is less than the safety zone width.

If there are railway or metro lines within the safety zone, safety barriers must be installed.

It may be appropriate to protect other areas than those mentioned above against errant vehicles, for example, playgrounds, day-care centres, schoolyards, parking areas, camping sites, residential areas etc.

3.27.3 Selection of Containment Level for Barriers

The basis for the selection of containment levels is the road speed limit, the traffic volume and the shape of the roadside terrain. Normally, safety barriers designed for passenger cars (N1 and N2) are used, since passenger cars collisions are the most common. However at special locations, where the run-off of larger vehicles from the carriageway will result in serious consequences, safety barriers of higher containment level (H2 or H4) are used. Minimum containment levels for safety barriers are selected based on the requirements shown in Table 47.

Higher containment levels can be used in special cases.

Table 47 - Selection of containment levels for safety barriers (*Vehicle Restraint Systems and Roadside Areas*, Statens Vegvesen - Norway, 2011)

Containment level	Road conditions
N1	• Speed limit ≤ 60 km/h and AADT ≤ 12 000 • Speed limit ≥ 70 km/h and AADT ≤ 1 500
N2	• Speed limit ≤ 60 km/h and AADT ≤ 12 000 • Speed limit ≥ 70 km/h and AADT > 1 500 • By retaining walls and precipices (gradients steeper than 1:1.5) that are higher than 1.5 - 4m • For bridges and culverts with lengths ≤ 4 m and an AADT < 1 500 • On motorways
H1	• On narrow medians < 2 m on motorways and other roads with high speed levels > 80 m/h
H2 or L2	• On bridges and retaining walls higher than 4 m • By precipices (gradient steeper than 1:1.5) higher than 4 m or by water deeper than 0.5 m • On narrows medians < 2 m on motorways and other roads with high speed levels > 80 km/h and a high portion of heavy traffic > 20%) • Locations where consequential damage/injury will be significant, e.g. next to water reservoirs, railways, metro lines, tunnels, fixed obstacles etc., collision with large fuel tanks etc.
H4 or L4	• On or under bridges where there is danger of serious damage to the bridge's load bearing structure which upon collapse of the bridge could entail danger for many other road user etc. • Special locations on the motorway and other roads with high speed levels > 80 km/h and a high proportion of heavy traffic > 20%, where the risk of driving off the road is greater than usual or where the consequences of driving off the road would be particularly significant. • On bridges that cross high-speed railways, and along roads where high-speed railways lie within the safety zone
Tunnel	• Safety barriers in tunnels are not deformable

3.27.4 Selection of Performance Class for Terminals

Decisive factors for the selection of performance class for terminals include the containment level of the safety barrier that the terminal is connected to and speed limit, as shown in Table 48.

Table 48 - Minimum requirements for the selection of performance classes for safety barrier terminals (*Vehicle Restraint Systems and Roadside Areas*, Statens Vegvesen - Norway, 2011)

Safety barrier's containment level	Terminal's performance class (minimum)	Speed limit (km/h)
N1	P1	< 80
N1	P2	≥ 80
N2	P2	< 80
N2	P3	≥ 80
H2	P4	All speed limits
H4	P4	All speed limits

3.27.5 Crash Cushions

Crash cushions are primarily installed in front of hazardous roadside obstacles that lie within the safety zone and cannot be moved, protected in a satisfactory way with safety barriers or made to yield. Roadside obstacles such as the ends of retaining walls, abutments, bridge piers, the beginning of concrete safety barriers (especially in medians), large sign columns/sign gantries, tunnel portals and blunt walls in tunnels (e.g. in the case of poorly executed emergency lay-bys), concrete buffers at toll stations, blunt walls or concrete barriers at exit ramps etc. are given as examples.

The road's speed limit is an important factor in the selection of performance level for crash cushions and hence, selection of the crash cushion is based on the speed limit, as specified in Table 49.

Table 49 - Selection of performance level for crash cushions (*Vehicle Restraint Systems and Roadside Areas*, Statens Vegvesen - Norway, 2011)

Crash cushion performance level	Speed limit
50	≤ 50 km/h
80/1	60 - 70 km/h
80	80 km/h
100	90, 100 km/h
100	> 100 km/h

3.27.6 *Protection for Motorcyclists*

Safety barriers with a motorcyclist protection system (MPS) can be erected in locations where there is a significant risk of motorcyclists rolling over and impacting the barrier, and where motorcyclists' speed is great. This can apply to the outer bend of roads along lengths with a high level of motorcycle traffic. On existing roads, MPSs can be mounted if the curve radii are less than those shown in Table 50. On new roads with speed limits ≥ 80 km/h, MPDs can be mounted for radii R ≤ 500 m.

Table 50 - Minimum curve radius allowed without the use MPSs at different speed levels (*Vehicle Restraint Systems and Roadside Areas*, Statens Vegvesen - Norway, 2011)

Speed level	Curve radius
< 60 km/h	No requirements
60 km/h	R = 90 m
70 km/h	R = 135 m
80 km/h	R = 180 m
≥ 90 km/h	R = 200 m

3.28 Philippines

The Republic of the Philippines Department of Public Works and Highways – Highway Safety Design Standards Part 1: Road Safety Design Manual – May 2012, contains the standards and guidance related to VRS for Philippines. The VRS related information presented in this document is mainly taken from AASHTO Roadside Design Guide.

3.29 Poland

The Polish standard is a translation of German standard.

3.30 Portugal

The Portuguese standard is mainly a modified version of the German standard with several modifications and additions.

3.31 Slovenia

Slovenian Barrier standards are presented in the document “Varnostne Ograje Pogoji In Nacin Postavitve”, Republika Slovenija, Ministrstvo Za Promet, 2010 (“TSC 02/210:2010)

3.31.1 General Installation Conditions

Steel safety fence is the default barrier of choice in Slovenia unless the occasion arises to use other types of barriers. Concrete barriers are used:

- When the necessary containment levels can’t be achieved by steel safety fences;
- On dual carriageways with at least one direction having AADT > 7000;
- On dual carriageways with at least two lanes travelling at the same direction having AADT > 39000.

Wooden safety fences are used mainly in low traffic roads, where nature conservation or aesthetic reasons do not allow for the use of other types of barrier.

3.31.2 Safety Fence in Built-up Areas

In built up areas, safety fences need not be installed except in cases where the road runs:

- Parallel to a stream, with water depth 2m or more, and is less than 6m away from the edge of the carriageway;
- A high embankment, which is less than or equal to 6m from the edge of the carriageway;
- On a bridge over a river (with a mean water depth of 2 m or more), a railway line or other transport route;
- A retaining wall that is less than 6m from the edge of the carriageway, while at the edge of the carriageway;
- If the edge of the shoulder or emergency lane is not defined by a kerb height of between 15 cm and 18 cm.

3.31.3 Safety Barriers on the Median

The decision to on whether to install a safety barrier on the median, or not, is based on AADT and median width, as shown in Figure 17.

The installation of barriers on the median is mandatory for motorways and expressways with median widths less than 8m, irrespective of the AADT.

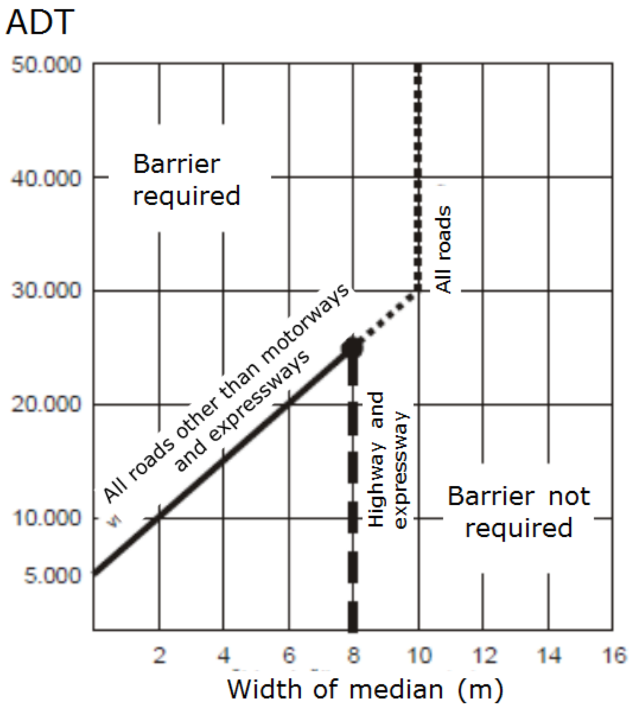


Figure 17 - The parameters which determine the installation of barriers on the median (*Varnostne Ograje Pogoji In Nacin Postavitve,* Republika Slovenija, Ministrstvo Za Promet, 2010)

3.31.4 Safety barriers at water protection areas

Barriers are required along the carriageway, if the road crosses protected sources or bodies of water.

3.31.5 Safety fence on the embankment

The decision to install a barrier on an embankment, or not, is based on embankment slope and height, as shown in Figure 18.

Installation of a barrier is not required if the distance between the beginning of the slope and the edge of the carriageway or shoulder or emergency lane is:

- Greater than 10 m and the permitted speed V ≥ 70 km/h, and
- Greater than 6 m and the permitted speed V < 70 km/h.

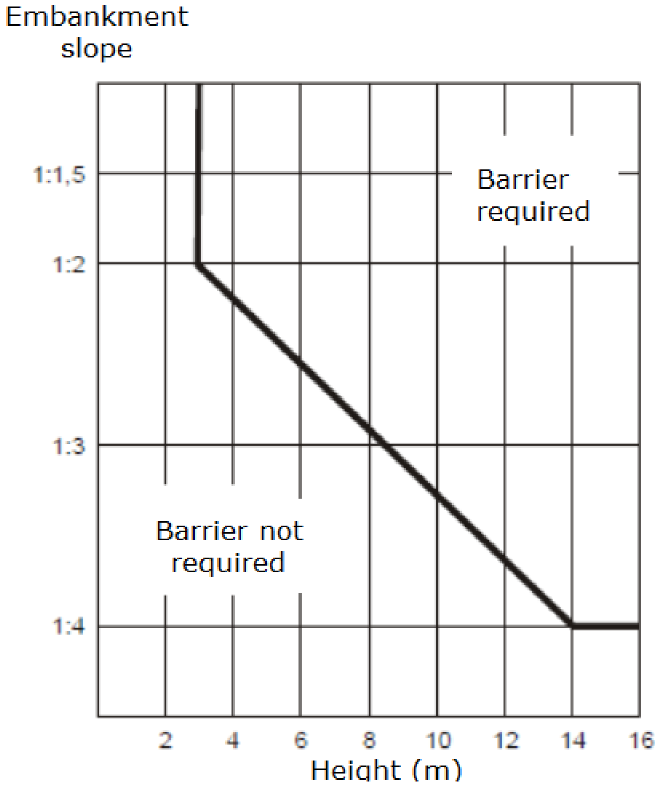


Figure 18 - The parameters that determine the installation of barriers on embankments (*Varnostne Ograje Pogoji In Nacin Postavitve,* Republika Slovenija, Ministrstvo Za Promet, 2010)

3.31.6 Safety barriers and dangerous obstacles

A safety barrier is required if the distance between the dangerous obstacles and the edge of shoulder or emergency lane is less than the value specified in Table 51.

In Table 51, hazardous obstacles of type A are:

- Streams of water with depth of 0.5 m in the middle;
- Particularly dangerous buildings with hazardous chemicals and flammable substances, etc.;
- Gantry or sign posts with a pole diameter greater than 76 mm or box-shaped side profile of at least 18 cm and a wall thickness greater than 2.9 mm;
- Poles or other supporting structures of buildings.

In Table 51, hazardous obstacles of type B are:

- Lines of trees with a diameter greater than 15 cm,
- Road lighting columns or other fixtures, except passively safe designs (EN12767).

Table 51 - Limits of distance from the edge of the carriageway edge or emergency lane to dangerous obstacles (*Varnostne Ograje Pogoji In Nacin Postavitve,* Republika Slovenija, Ministrstvo Za Promet, 2010)

Road Axis	Carriageway road with two or more lanes		
	Embankment slope	**Dangerous obstacle type A**	**Dangerous obstacle type B**
Horizontal curvature R>1500m inside of the curve regardless of the size of the radius	in the plane, the cut irrespective of the slope and embankment slope <1:8	10m	6m
	embankment slope 1:8 to 1:5	12m	8m
	embankment slope > 1:5	14m	10m
Road in a curve with R<1500m	in the plane, the cut irrespective of the slope and embankment slope <1:8	12m	10m
	embankment slope 1:8 to 1:5	14m	12m
	embankment slope > 1:5	16m	14m
Road Axis	**Road with two lanes of traffic and two-way traffic**		
	Embankment slope	**Dangerous obstacle type A**	**Dangerous obstacle type B**
Horizontal curvature R>500m inside of the curve regardless of the size of the radius	in the plane, the cut irrespective of the slope and embankment slope <1:8	7.5m	4.5m
	embankment slope 1:8 to 1:5	9m	6m
	embankment slope > 1:5	12m	8m
Road in a curve with R<1500 m	in the plane, the cut irrespective of the slope and embankment slope <1:8	12m	10m
	embankment slope 1:8 to 1:5	14m	12m
	embankment slope > 1:5	16m	14m

3.31.7 Safety fence near adjacent roads and rail lines

A barrier should be placed along the roadside:

- If the distance to an adjacent road, which is used by motor vehicles, is less than 10 m;
- If the distance between the outer edge of the shoulder, and an adjacent cycle path is less than 1.5 m;
- If the distance between the outer edge of the shoulder, and an adjacent cycle path is less than 10 m and the cycle path is located along the outer edge of the road in a curve with a radius less than or equal to 175 m;

- If the road runs parallel to the railway line and the distance between the edge of carriageway, shoulder or emergency lane and the nearest rail is less than 10 m;
- If there is a railway, or another surface transport line located at the bottom of an embankment, which has a slope steeper than 1:3; and the distance between the edge of the carriageway or shoulder or emergency lane and the nearest railway or other type of transport line is less than 30 m; with the distance of the lower edge of the embankment from the first track and the other edge of the road surface is less than 10 m; and a height difference between the level roadway edge, the edge of the shoulder or emergency lane and the other edge of the road surface or the top of the nearest rail is larger than 3 m.

3.31.8 Additional protection for motorcyclists

Additional protection for motorcyclists should be installed to existing safety barriers on rural roads if the following conditions are met:

- If the percentage of motorcycle traffic in the period from June to September is greater than or equal to 2%;
- If the number of traffic accidents involving motorcycles on the road section is greater than or equal to five for the last 5 years.

In the event that the above conditions are met, additional protection for motorcyclists is only installed on existing barriers on bends where the radius of curvature is less than 80m.

3.31.9 Containment Level Selection

The selection of the minimum vehicle containment level for a safety barrier is determined by the category of the road, as shown in Table 52.

Table 52 - Levels of containment for various road categories (*Varnostne Ograje Pogoji In Nacin Postavitve,* Republika Slovenija, Ministrstvo Za Promet, 2010)

Road Category	Containment Level
Highway	**Minimum N2**
Expressway	
Regional road 1st order	
Regional road 2nd order	
Road with physically separated carriageways outside the village	
Other public road	**N1 to N2**

The minimum containment level is increased in specific roadside areas on dangerous sections of road (Table 53) and in the vicinity of bridges and other structures (Table 54).

Table 53 - Levels of containment for dangerous sections of road and roadside space (*Varnostne Ograje Pogoji In Nacin Postavitve,* Republika Slovenija, Ministrstvo Za Promet, 2010)

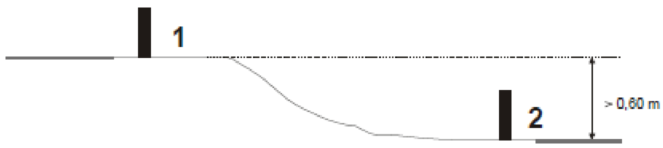
	Specific roadside space and dangerous road segments	**Containment level**
1	The road through the protected areas (zone 1), where permissible speed> 90 km/h	**H2 to H3**
2	Motorways, expressways, main and regional road I. or II. order, which runs parallel to the railroad tracks with heavy traffic	
3	The road, which runs along the particularly dangerous buildings in which they are present hazardous chemicals or flammable materials	
4	Motorways, expressways, main and regional road I. or II. the order in which they are in the vicinity of public places with heavy foot traffic	
5	Area of support and load-bearing structures along the carriageway	
6	Median width≤2.80 m	
7	Median	**H1 to H2**
8	The road where the speed limit driving≤ 90 km / h, parallel to the railway or tramway track	
9	Between parallel roads with at least one category of motorways, express roads, main and regional roads I or II. order	
10	A steep rocky slope deeper than 6 m, with a slope steeper than 2:3 On the walls deeper than 2 m	
11	Dangerous places, such as curves with a radius R <300 m long downhill with a longitudinal slope of the road≥ 4%, the main regional road or I. or II. order (does not apply to area intersections, etc.).	
12	Road running - Parallel to the stream with a mean water level of water>2m - The protected stream (regardless of water depth) - Through the water protection area (Zone 2), where permitted speed> 90 km / h	**N2 to H1**
13	The road on noise barriers if it is not designed as a safety fence	
14	The road on which they are sharp rocks or walls with rough or very cracked surface (vehicle, obstacle cannot slip)	
15	Separation of traffic that passes through the several levels (e.g. splitter shelf, or between parallel roads) 	1:**H2** for Motorways, Expressways, main and regional roads 1 and 2 **H1** for other roads 2:**N2**

Table 54 - Levels of containment for dangerous sections of bridges and other structures (*Varnostne Ograje Pogoji In Nacin Postavitve,* Republika Slovenija, Ministrstvo Za Promet, 2010)

	The area bridges and other structures and dangerous sections the road ahead	Containment level
1	Bridging the facility protection area (zone 1) and bridging facility over the river an average depth of 2 m, where permissible speed > 90 km/h	H2 to H3
2	Bridging facility, where allowed speed> 90 km / h, which is parallel to the railway line or crosses	
3	Bridging facility, where allowed speed> 90 km / h, at a public place with heavy foot traffic	
4	Bridging facility, which runs along particularly dangerous buildings in which they are present hazardous chemicals or flammable materials, where permitted speed> 90 km / h	
5	Populated areas along the road, which mainly concerns urban viaducts to be the driving speed> 90 km / h	
6	Viaducts and longer supporting walls in places that are subject to motorways, highways, main and regional roads I or II. order) are higher than the level of facilities in the village	
7	Range of support and load-bearing structures of the second bridging structure along the carriageway	
8	Median width≤ 2.80 m	
9	Median	H1 to H2
10	Bridging facility, parallel railway or tramway track, which is permitted speed≤ 90 km / h	
11	Parallel walkways with heavy foot traffic in and / or under the bridging facility	
12	Bridging facility, which takes place - Parallel to the stream with a mean water level of water>2 m - The protected stream (regardless of water depth) - Through the water protection area (zone 2), which is authorized speed>90 km / h	
13	Danger of bridges and other structures such as curves with a radius R <300 m long downhill slope with a longitudinal road≥ 4% in the category of highway roads, highways, main and regional roads I or II. order (does not apply to area intersections, etc.).	
14	The road on noise barriers if it is not designed as a safety fence	
15	Intersection of two busy roads heavily on different levels	
16	Another dangerous places (e.g. depth under bridges, in excess of 10 m, etc.).	

3.32 Spain

"Criterios de aplicación de barreras de seguridad metálicas, 28/2009" is the Spanish standard detailing the application criteria of metal safety barriers.

3.32.1 Installation Criteria

The Spanish standard lists the following two cases where installation of a metal safety barrier is justified:

- Areas which are detected to have very serious, serious or normal accident risk, as a result of the presence of obstacles, slopes or other risk elements close to the road, and it is not possible to remove, replace or modify the obstacle;
- Areas, which protection has been included among the precautions derived from an Environmental Impact Statement (such as lakes, wetlands, streams, archaeological sites, etc.).

In the first case, a barrier is required if an obstacle with a very serious, serious or normal accident risk is located closer than the respective minimum distance to the road as shown in Table 55.

The respective level of accident risk for each different type of hazard is given in Table 56.

Table 55 – Minimum distances (m) from the edge of the road to an obstacle or slope, under which a roadside barrier is required (*Criterios de aplicación de barreras de seguridad metálicas*, Dirección General de Carreteras - Spain, 2009)

Road Type	Type of Alignment	Side slope (Vertical : Horizontal)	Accident Risk	
			Very Serious or Serious	Normal
Single Carriageway	Straight or curve of radius> 1 500 m	<1:8	7.5	4.5
		1:8 to 1:5	9	6
		>1:5	12	8
	Outside of a curve of radius <1500 m	<1:8	12	10
		1:8 to 1:5	14	12
		>1:5	16	14
Dual Carriageway	Straight or curve of radius> 1 500 m	<1:8	10	6
		1:8 to 1:5	12	8
		>1:5	14	10
	Outside of a curve of radius <1500 m	<1:8	12	10
		1:8 to 1:5	14	12
		>1:5	16	14

Table 56 - Level of accident risk for different hazards (*Criterios de aplicación de barreras de seguridad metálicas*, Dirección General de Carreteras - Spain, 2009)

<table>
<tr><th>Risk Of Accident</th><th colspan="2">Hazard</th></tr>
<tr><td rowspan="6">Very Serious</td><td rowspan="3">Existence of Adjacent:</td><td>High-speed rail line.</td></tr>
<tr><td>Railroad with an annual average of more than 6 trains per hour.</td></tr>
<tr><td>Railroad with an annual average of more than 6 trains per week, which contains at least one wagon loaded with flammable materials or toxic gasses.</td></tr>
<tr><td colspan="2">Existence of a railway parallel to the road and located more than 1m below the road</td></tr>
<tr><td colspan="2">Existence of lower than road level, adjacent work site, storage of hazardous substances or public areas of general interest.</td></tr>
<tr><td colspan="2">Existence of a railway, highway or expressway at a lower level than a road, which has a horizontal or vertical curve below the allowable standard.</td></tr>
<tr><td rowspan="6">Serious</td><td colspan="2">Cases, which lack the requirements described to be considered as very serious accident risk, with an ADT>10000</td></tr>
<tr><td rowspan="2">design speed > 60km/h and:</td><td>Existence of structures with a risk of collapse on the road (such as overhead gantries, building structures, noise barriers, etc.), where the design speed > 60 km/h</td></tr>
<tr><td>Existence of obstacles which are structural elements of a building or an overpass, where the design speed > 60km/h</td></tr>
<tr><td rowspan="2">design speed > 80km/h and:</td><td>Existence of rivers, reservoirs and other bodies of water with strong current or water depth > 1m</td></tr>
<tr><td>Existence of access to bridges, tunnels and narrow passages.</td></tr>
<tr><td colspan="2">Existence of parallel roads with opposite direction of traffic, in which the width of the median, driveways or between the main road and the service is less than that provided in Table 55</td></tr>
<tr><td rowspan="14">Normal</td><td colspan="2">Cases, which lack the requirements described to be considered as serious accident risk</td></tr>
<tr><td rowspan="9">design speed > 80km/h and:</td><td>Existence of barriers, trees or poles with a diameter > 15cm</td></tr>
<tr><td>Existence of breakaway obstacles (EN 12787) which can cause damage to third parties during collapse.</td></tr>
<tr><td>Walls, sheet piling, buildings, facilities, foundations or surface drainage elements, protruding from the ground more than 7cm.</td></tr>
<tr><td>Existence of steps and kerbs higher than 15cm and ADT > 1500</td></tr>
<tr><td>Cuts with a slope > 1:3 if the cross slope changes are not rounded</td></tr>
<tr><td>Cuts with a slope > 1:2 if the cross slope changes are rounded</td></tr>
<tr><td>Embankments with a slope > 1:5 if the cross slope changes are not rounded.</td></tr>
<tr><td>Embankments with a slope > 1:3 if the cross slope changes are rounded.</td></tr>
<tr><td>Or in any case where an embankment height > 3m</td></tr>
<tr><td colspan="2">Existence of retaining walls with a very rough surface, and a speed limit > 60m km/h</td></tr>
<tr><td rowspan="3">unique locations such as:</td><td>Successive curves, which may cause a driver error.</td></tr>
<tr><td>Intersections located in the vicinity of an underpass</td></tr>
<tr><td>Sites with abnormally high accident rates</td></tr>
</table>

3.32.2 Selection and Containment Level

The minimum required level of containment is determined using accident risk and the AADT of heavy vehicles as shown in Table 57.

Table 57 – Containment level selection for metal safety barriers by accident risk (*Criterios de aplicación de barreras de seguridad metálicas*, Dirección General de Carreteras - Spain, 2009)

Accident Risk	Containment level	$AADT_{HGV}$	Containment Level
Very Serious	Very High		H3 - H2 - H1
Serious	High	$AADT_{HGV} \geq 5000$	H2 - H1
		$400 \leq AADT_{HGV} < 5000$	H1
		$AADT_{HGV} < 400$	H1 - N2
Normal	Normal		H1 - N2

3.33 Sweden

The need for VRS in Sweden is described in documents for roads, bridges, and tunnels. There are different document levels; some with "requirements" which define performance requirements and dimensions for road elements and "recommendations" which provide guidance. The following documents were used in this compilation of VRS requirements in Sweden:

- "*Krav för Vägars och gators utformning* – Requirements for road and street design" (Swedish Transport Administration publication 2012:179)
- *"Råd för Vägars och gators utformning* – Recommendations for road and street design" (Swedish Transport Administration publication 2012:180)
- "*TRVK Bro 11 Trafikverkets tekniska krav Bro* – Technical requirements for bridges" (Swedish Transport Administration publication 2011:085)
- "*TRVR Bro 11 Trafikverkets tekniska råd Bro* - Technical recommendations for bridges" (Swedish Transport Administration publication 2011:086)
- "*Fritt utrymme utmed banan – Free space around the railbed" (*Rail Administration Directive BVF 586.20, 1998)

3.33.1 General Design Requirements

VRS are installed on Swedish roads when the safety zone required for the road cannot be kept obstacle free. Side slopes steeper than 1:4 also require barriers. The size of the safety zone is specified by the road type and speed. Rural roads that are not separated also use ADT to dimension the safety zone.

The general safety zone dimensions are shown in Table 58:

Table 58 – Safety zone width
(*Krav för Vägars och gators utformning,* Trafikverket, 2012)

Road Type	Safety Zone Width [m]
Motorway (120 km/h)	12
Motorway (110 km/h)	11
Separated road (110 km/h):	
ADT > 8000	11
ADT ≤ 8000	10
Separated road (100 km/h):	
ADT>4000	10
ADT≤4000	9
Rural Road (100 km/h)	9
Rural Road (80 km/h):	
ADT>8000	8
4000>ADT≤8000	7

The safety zone size can be modified depending on horizontal curvature and vertical drop of the slope.

3.33.2 Barrier Containment and Working Width

All safety barriers must conform to EN1317. The general requirement for roadside and median barriers is N2. Bridges must be equipped with H2 barriers. Barrier capacity must be increased if there are high risk objects in the vicinity of the road such as drinking water reservoirs, chemical industry, rail lines, and other situations deemed critical for society.

The working width of the safety barrier must be smaller than any permanent objects that are being shielded.

3.33.3 Minimum Barrier Lengths

The minimum length of barrier installations in Sweden (excluding terminals) are defined by the reference speeds for the road unless they are shorter than the minimum length specified by the manufacturer. Both normal and high capacity barrier lengths are defined in the following table.

Table 59 - Minimum barrier lengths, unless shorter than manufacturers recommendations (*Krav för Vägars och gators utformning,* Trafikverket, 2012)

Speed (km/h)	120	110	100	80	≤60
Minimum Length (m)	120	110	100	80	60

The free space behind a barrier must be 10 m if the barrier is placed in a tight curve. Deflecting concrete barriers must have a level surface behind the barrier.

3.33.4 Terminals and Crash Cushions

Terminals are generally required to be energy absorbing if they are placed near traffic, and they shall be tested to EN1317-3 with the following requirements. Turned down barrier ends are permitted if they are flared from the roadway.

Table 60 – Performance class required for terminals (*Krav för Vägars och gators utformning,* Trafikverket, 2012)

Reference Speed	**Performance Class**
≥ 100 km/h	P4
≤ 80 km/h	P3

Crash cushions are used to protect specific objects, and their speed class shall be in accordance with Table 61. Crash cushions are to be redirective with deformations not allowing the vehicle to interfere with the obstacle. Vehicle deformation class Z2 specified in 1317-3 is required unless special permission is given by the road authority.

Table 61 – Speed class required for crash cushions
(*Krav för Vägars och gators utformning,* Trafikverket, 2012)

Reference Speed	Speed Class (km/h)
≥ 100 km/h	110
80 km/h	100
≤ 80 km/h	80

3.33.5 Other VRS Issues

Swedish roads are subject to winter road conditions and the VRS installed must be suitable for weather and maintenance (e.g. snow ploughing, salt, etc.).

Motorcycle Protection Systems (MPS) should be installed for roads where there is significant motorcycle traffic. Guidelines for the installation of such systems are under development and are not yet published. Any MPS system installed in Sweden must conform to the 1317-8 test requirements.

Barriers installed on bridges or overpasses where there is a risk that falling objects will affect the environment below the elevated road section shall have nets to catch these elements.

3.34 Switzerland

"Schweizer Norm 640566, Passiver Schutz im Straßenraum" (Passive Protection in Roadways) is the Swiss Standard which gives the requirements for VRS application in Switzerland.

3.34.1 Level of Risk

There are two levels of risk which are defined for the decision of installation and selection of VRS. These are:

High Risk:

High probability of accidents with a particular risk of serious consequences for third parties, such as:

- Threat to a large number of people (school yard);
- Endangering the environment in case of a fall or impact against an obstacle or installation;
- Disruption of important equipment for international communications and supply of the country (railways, pylons overhead power lines etc.).

Small Risk:

Low probability of accidents combined with reduced risk for people or installations out of traffic areas, such as:

- Crash or drop risk of vehicles with few occupants;
- Crash or drop risk with normal damage.

3.34.2 Installation Criteria

The need for a barrier is determined by the concept of "decisive distance". Protective equipment is required if a dangerous obstacle is located within the decisive distance, measured from the edge of the road. Decisive distance is determined by the road type, embankment height, speed and the level of risk as shown in Figure 19 and Figure 20 below. In Figure 20 the distance A2 is used for low risk and A3 is used for high risk situations.

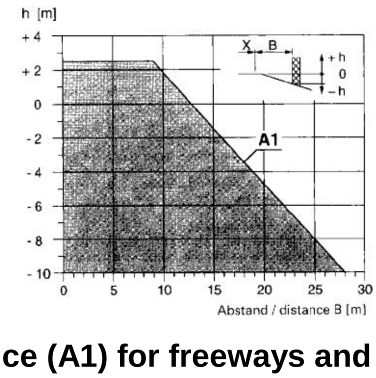


Figure 19 - Decisive distance (A1) for freeways and highways (*Passiver Schutz im Straßenraum,* Vereinigung Schweizerischer Straßenfachleute, 1995)

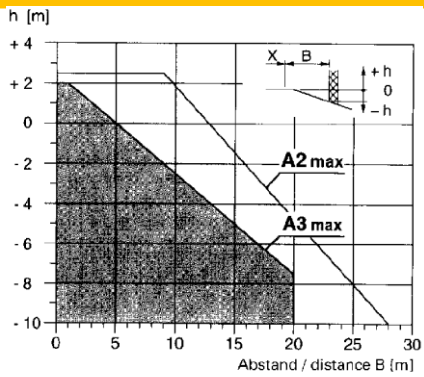


Figure 20 - Maximum decisive distances of the roadway as the basis for the use of protective devices on mixed traffic lines for road speeds between 50 and 80km/h (*Passiver Schutz im Straßenraum,* Vereinigung Schweizerischer Straßenfachleute, 1995)

3.34.3 *Containment Level Selection*

The containment level selection and positioning criteria are given in Table 62 and Table 63.

Table 62 – Containment levels and the positioning of protective equipment from dangerous obstacles with high impact risk (*Passiver Schutz im Straßenraum,* Vereinigung Schweizerischer Straßenfachleute, 1995)

Distance B (m)	Extra clear width C		Distance D (m)	Containment Level/Working Width
	Kerbside (m)	Hard shoulder edge (m)		
<1.00	0.3	0	-	H2/W3
1.00-1.50	0.3	0	min 0.70	H2/W3
1.50-2.50	0.5	0.5	min 1.00	H2/W3
>2.50	0.8	0.5	min 1.70	H2/W5

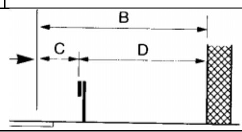


Table 63 – Containment levels and positioning of protective equipment from dangerous obstacles with low impact risk (*Passiver Schutz im Straßenraum,* Vereinigung Schweizerischer Straßenfachleute, 1995)

Distance B (m)	Extra clear width C		Distance D (m)	Containment Level/Working Width
	Kerbside (m)	Hard shoulder edge (m)		
<1.00	0.3	0	-	H1/W2
1.00-1.50	0.5	0.5	min 0.50	H1/W2
1.50-2.50	0.5	0.5	min 1.00	H1/W2
>2.50	min 0.8	min 0.8	min 1.70	H1/W2

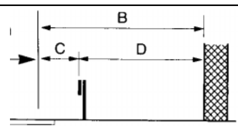


Table 64 - Application, system selection and positioning of protective equipment at the outer edge of the carriageway of highways and motorways (*Passiver Schutz im Straßenraum,* Vereinigung Schweizerischer Straßenfachleute, 1995)

Hazard	Use	Performance class		Comments
	Decisive distance	Containment Level	Working Width	
Structures 1)	A1	Table 62 and Table 63		1) abutment supports of bridges, etc. 2) need not apply if the foot of the support in a rising slope is more than 2.50 m above the ground
signal gantries	A1	Table 62		3) signalling reversible gates are not applicable
Noise barriers	A1	Table 62 and Table 63		4) need not apply if the noise protection wall with respect to impact meets the requirements according to the European standards
Trees	A1	Table 62 and Table 63		5) For trees with D <0.08 m no use of a protective device
lighting poles	A1	Table 63		6) The use of passively safe lighting poles shall be tested.
signal post	A1			7) Use of passively safe constructions
emergency phones	A1			8) emergency telephones located on the hard shoulder or edge of the roadway shall be designed passively safe because of the small distance of the protection system 9) Do not interrupt because other criteria necessary protective equipment
tracks	A1 10)	H2	W5	10) Based on the gauge or the road-side leading edge of catenary
Facilities to protect particularly 11)	A1	H2	W5	11) recreational areas for larger groups of people, chemical plants, etc.
Rest Areas	A1	H1	W5	12) Minimum distance 15 m after the physical nose of the exit
Water transverse to the road	A1	H1	W5	13) Consideration will be given to cover the streams in the area bounded by the critical distance area A1
Waters parallel to the road with a mean water level> 1.0 m or a dangerous channel profile	A1	H1	W5	14) Coverage of rivers should be considered
Level concrete walls				
Walls made of rubble stone, stone baskets etc.	A1			
Falling slopes with slope> 1:3 and a height of more than 3.0 m	A1 15)	H1	W5	15) Distance to the edge of the slope
Rising slopes with inclination > 1:3, when the slope foot is not rounded 16)	A1 17)	H1	W5	16) Rounding with radius> 5.0 m 17) Distance to the edge of the slope
Water protection zone S	A1			The installation, choice and implementation guidelines are set by the federal Department of the Interior. [9]

Table 65 - Installation, selection and implementation of restraint systems on roads with mixed traffic (*Passiver Schutz im Straßenraum,* Vereinigung Schweizerischer Straßenfachleute, 1995)

Hazard	Use	Performance class	
	Decisive distance	Containment Level	Working Width
Buildings 3), signal bridges	A2/A3	Table 62 - Table 63	
Noise barriers	A3	Table 63	
Trees	A3	Table 63	
Lighting poles, signal Stands	A3	N2/H1	Table 63
Railroad tracks with more than 40 trains/24h and trams with separate roadbed and v> 80 km/ h	A2/A3	H1	W5
Facilities to protect especially 10)	A2	H1/H2	W5
Waters across the street	A3	N2/H1	W5
Waters along the street with a mean water level> 1.0 m or a dangerous channel profile 12)	A3	N2/H1	W5
Level concrete walls			
Walls made of rubble stone, stone baskets, etc.	A2/A3	N2/H1	Table 63
Falling slopes with slope> 1:3 and a height of more than 3.0 m	A2/A3	N2/H1	W2/W5
Rising slopes with slope> 1:3 if the slope foot is not rounded 14)	A3	N2/H1	W5
Water protection zone S			

3.34.4 Median Barriers

The selection of the performance class for median safety barriers is conducted as shown in Table 66 below.

Table 66 – Performance class selection for median safety barriers (*Passiver Schutz im Straßenraum,* Vereinigung Schweizerischer Straßenfachleute, 1995)

Width of Median (m)	Performance class for single barrier in the middle of median	Barriers on both edges of the central strip	
		Performance class	Extra clear width
<1.20	H1/W4	-	
1.20-2.00	H1/W4	-	-
2.00-3.00	H1/W4	H1/W5	0.5
3.00-3.50	H1/W6	H1/W5	0.5
≥4.00	H1/W6	H1/W5	0.8

3.34.5 Parapets for Bridges and Retaining Walls

The selection of the performance level for parapets on bridges and retaining walls is completed according to road type, bridge length, traffic speed, existence of pedestrian sidewalk and pedestrian traffic volume, as shown in Table 67, Table 68 and Table 69.

Table 67 - Performance class selection for parapets on the outer edge of the freeway and semi-highway bridges (*Passiver Schutz im Straßenraum,* Vereinigung Schweizerischer Straßenfachleute, 1995

Bridge Length	Risk	Performance Class	
		Bridge without service passage	Bridge with service passage
L < 50m		H1/W4	H1/W5
L > 50m	Low	H1/W3	H1/W5
	High	H2/W3	H2/W5

Table 68 – Performance class selection for parapets on mixed traffic road bridges without walkways (*Passiver Schutz im Straßenraum,* Vereinigung Schweizerischer Straßenfachleute, 1995)

Traffic Speed	Level of Risk	Variation of Restraint Systems	
2	High	Kerb Height, h=0,25m & Pedestrian Restraint System	VRS - N1/W3 or H1/W5
	Low	Kerb Height, h=0,20m & Pedestrian Restraint System	VRS - N1/W3
> 50 km/h	High	VRS - H1/W3	In specific cases, consider H2/W3
	Low	VRS - N1/W3 or H1/W5	

Table 69 - Performance class selection for parapets on mixed traffic road bridges with walkways (*Passiver Schutz im Straßenraum,* Vereinigung Schweizerischer Straßenfachleute, 1995)

Pedestrian Traffic	Traffic Speed	Level of Risk	Execution of the Bridge Edge	
High	≤ 50 km/h	High		
		Low		
	> 50 km/h	High		H1/W5
		Low		H1/W5
Low	≤ 50 km/h	High	H1/W4	
		Low	H1/W4	
	> 50 km/h	High	H1/W5	H1/W3 H2/W3
		Low		H1/W3 H1/W5
	Vehicle Restraint System		Pedestrian Restraint System	

3.34.6 Crash Cushions

The need for a crash cushion should be investigated with a safety plan, however common conditions for the application can be given as follows:

Typical Traffic Conditions:

- Traffic Speed > 60 km/h;
- Large ADT;
- Diversion areas with inadequate visual guidance.

Typical locations:

- Merge and diverge areas on bridges;
- In tunnel junctions;
- Dangerous obstacles in motorways with limited space;
- Dangerous obstacles on the road pavement edge where no protective equipment can be arranged.

3.35 Turkey

Chapter 7 of "Karayolları Genel Müdürlüğü, Karayolu Tasarim El Kitabi, 2005" (Turkish Directorate of Highways, Highway Design Manual), contains the VRS application guidelines for Turkey and is a direct translation from the AASHTO Roadside Design Guide 2nd Edition, 1996.

3.36 United Kingdom

The current VRS standard in the UK for motorways and trunk roads consists of two parts:

- TD 19/06 (DMRB Volume 2, section 2, Part8) ‘Requirement for Road Restraint Systems’, which is a written standard and the
- 'Road Restraint Risk Assessment Process (RRRAP)', which is a Microsoft Excel based risk assessment tool.

TD19/06 is the written standard and gives the mandatory requirements and provides general guidance for the provision of VRS and also explains the general risk assessment and mitigation approach. RRRAP is the risk assessment tool and enables the designer to calculate the level of risk resulting from each hazard on a site without a VRS or with VRS of different lengths and performance classes.

3.36.1 General Risk Approach

TD19/06 classifies risk into three categories using the principles of 'as low as reasonably practicable (ALARP) ', as it is represented in Figure 21. As the risk gets higher it becomes less tolerable and after a certain point becomes unacceptable. TD 19/06 approach is to lower any risk within the unacceptable and tolerable region to a broadly acceptable level within the ALARP principles.

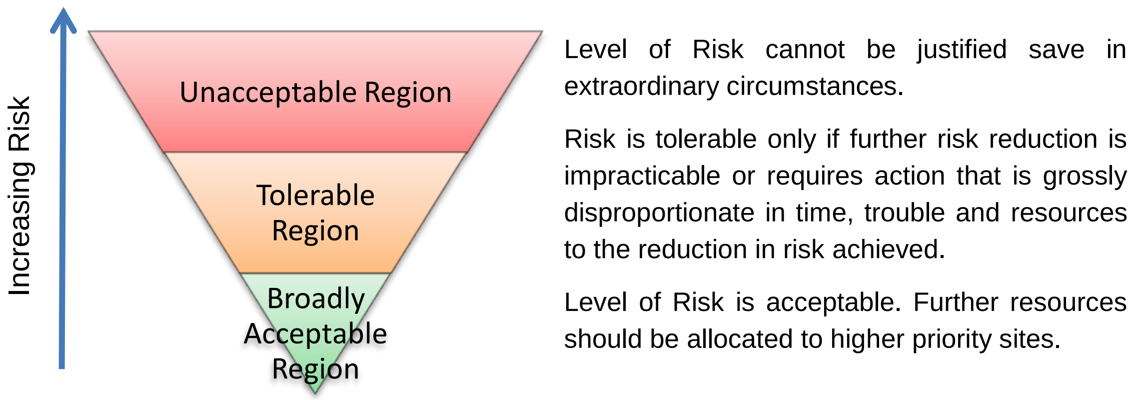


Figure 21 - Levels of risk defined in TD19/06

3.36.2 The RRRAP Guidance Manual

RRRAP is a Microsoft Excel based tool which uses many different parameters from a site to calculate the level of risk without a roadside barrier and if necessary with barriers of certain containment levels.

RRRAP calculates risk by multiplying the Likelihood of an errant vehicle hitting a hazard with the resulting Consequences, and expresses it in equivalent fatalities per 100 million vehicle km.

Figure 22 - Calculation of risk in RRRAP

RRRAP calculates the **Likelihood** using the following parameters:

- the probability of a vehicle leaving the road, which is estimated using:
  - Road Type;
  - Road Geometry;
  - Traffic Flow and Type;
  - Accident History;
  - Junction Location;
- and the probability of a vehicle reaching the hazard, which is estimated using:
  - Hazard Location;
  - Topography;
  - Speed of Vehicle;
  - Type of Vehicle.

Consequences are estimated considering:

- effect on occupants of errant vehicle if it reaches hazard, which is based on:
  - Speed of Errant Vehicle;
  - Aggressiveness of Hazard;
  - Percentage of Heavy and Medium sized vehicles
- and the effect on Others.

RRRAP defines the total risk at a hazard as a combination of the risk posed on vehicle occupants (cars, LGVs, MGVs) and on others (using adjacent road or railway or occupying a building, etc.).

Figure 23 - Calculation of total risk in RRRAP for vehicle occupants and Others

3.36.3 Permanent Safety Barriers

Permanent Deformable or Rigid Safety Barriers must be provided where the outcome of the RRRAP indicates that a VRS is necessary. The Design Organisation must identify local hazards, within or immediately adjacent to the highway, that need to be examined through the RRRAP. These are hazards that may cause a danger to the occupants of an errant vehicle or give rise to a secondary event were the vehicle to reach the hazard. In addition, the risk of an errant vehicle to others must also be examined.

Table 70 – Hazards to be considered for the decision of VRS installation (*Requirement for Road Restraint Systems*, Highways Agency, 2006)

#	Hazard
1	Above ground structural supports, bases or foundations which are positioned less than 3 m above the adjacent paved carriageway.
2	Drainage culvert headwall.
3	Restricted headroom at a Structure or part of a structure
4	A retaining wall which does not have a smooth face adjacent to the traffic extending for at least 1.5 m above the adjacent carriageway level.
5	An exposed rock faced cutting slope, rock filled gabions, crib walling or similar structures.
6	Soil cutting slopes and earth bunds greater than 1 m high and with a side slope gradient of 1:1 or steeper.
7	Embankments and vertical drops.
8	Strengthened or geotextile reinforced slopes.
9	Environmental noise barriers or screens.
10	Highway boundary fences and walls.
11	Dwarf retaining walls surrounding hazards such as drainage access manholes and communication cabinets.
12	Permanent or expected water hazard with depth of water 0.6 m or more, such as a river, reservoir, stilling pond or lake or other hazard which, if entered, could cause harm to the vehicle occupants.
13	Road lighting columns.
14	High mast road lighting columns.
15	Sign and signal gantry supports.
16	Sign posts not meeting the requirements of BS EN 12767 which exceed the equivalent section properties of a tubular steel post having an external diameter of 89 mm and a nominal wall thickness of 3.2 mm.
17	Large signs (typically those higher than 2 m) located in a position where the fascia could be struck by an errant vehicle.
18	Above ground communications control cabinets, pillars and equipment (other than emergency telephones), CCTV Masts.
19	Stores for emergency/diversion signs and similar permanent structures.
20	A tree or trees having, or expected to have, trunk girths of 250 mm or more (measured at a height of 0.3m above ground level) at maturity.
21	Non-motorised User (NMU) subway entrance or agricultural underbridge passing under the highway. (*)
22	A railway, canal or separate road or carriageway. (*)
23	Public meeting places where a number of people would be present for some time such as schools, hospitals, recreational, retail facilities or factories. (*)
24	Chemical works, petroleum storage tanks or depots, facilities manufacturing or storing hazardous materials in bulk. (*)

(*) Hazards where Others could be affected.

The containment level requirements for safety barriers in UK are:

Permanent Deformable and Rigid Safety Barriers:

- On roads with a speed limit of 50 mph or more:
  - Normal Containment Level = N2
  - Higher Containment Level = H1 or H2
  - Very High Containment Level = H4a
- On roads with a speed limit of less than 50 mph:

- Normal Containment Level = N1

Where the RRRAP indicates a containment level that is higher than the minimum, as indicated above, higher containment level must be specified.

The impact severity level for safety barriers must not normally exceed Class B as stipulated in EN 1317-2.

Central Reserves

A safety barrier must be provided on dual carriageway roads where the width of the central reserve measured between opposing edges of carriageway road markings (or kerb faces where no markings) is 10 m or less. Where the central reserve is wider than 10 m, the Design Organisation must assess the need for safety barriers and record any findings using the RRRAP, and agree the provision of safety barriers with the Overseeing Organisation.

On motorways or roads constructed to motorway standard with a two-way AADT greater or equal to 25,000 veh/day, where a VRS is required, the safety barrier must be a rigid concrete safety barrier with an H1 or greater containment level. This is to minimise cross-over accidents and reduce the need for safety barriers to be repaired or maintained and hence, minimise the costs and congestion arising from temporary traffic management and reduce the risk to maintenance workers.

The use of an H1 rigid concrete safety barrier may not be practicable for lengths of 500 m or less. Therefore, where the provision of a rigid concrete safety barrier would, in total, be 500 m or less, Normal Containment Level N2 safety barrier may be used.

Motorcyclists

At sites identified, e.g. through accident records, to be high risk to powered two-wheel vehicles, such as tight external bends, consideration must be given to the form of VRS chosen to minimise the risk to this category of driver. Any special requirements must be stated in the contract. At such high risk sites, it is recommended to use an 'add on' motorcycle protection system to post and rail type safety barriers to minimise the risk of injury to motorcyclists. The Design Organisation must check with the safety barrier manufacturer that any such proposed protection will not invalidate the tests on the safety barrier. Such 'add-on' products must be approved by the Overseeing Organisation and be compatible with the safety barrier to which it is being attached as these products are not included within BS EN 1317.

3.36.4 Vehicle Parapets

The Containment Levels required for vehicle parapets are:

- On roads with a speed limit of 50 mph or more:
  - Normal Containment Level = N2
  - Higher Containment Level = H2
  - Very High Containment Level = H4a

- On roads with a speed limit of less than 50 mph:
    - Normal Containment Level = N1
    - Normal Containment Level = N2
    - Higher Containment Level = H2
    - Very High Containment Level = H4a

The lowest Containment Levels given in above must be provided on road bridges and structures and on bridges and structures over, or adjacent to, roads unless the RRRAP or the text below shows that a higher containment level must be provided.

Other than in Northern Ireland, on new bridges and structures (other than accommodation bridges) carrying a road over, or adjacent to, a railway, Very High Containment Level (H4a) vehicle parapets must be provided regardless of the road class. Where an existing parapet has to be replaced on existing bridges and structures (other than accommodation bridges) carrying a road over, or adjacent to, a railway, the containment level must be the highest practicable containment level that can be achieved without undue cost, but must not be less than N2. An acceptable level of cost for the provision of the required Containment Level must be based on a cost benefit analysis, the criteria for which must be agreed by the Overseeing Organisation and the Railway Authority.

In Northern Ireland and for accommodation bridges carrying a road over, or adjacent to, a railway, the minimum Containment Level for vehicle parapets is Normal Containment Level (N2). Where a higher Containment Level is derived from the RRRAP, the level of provision must be confirmed with the Overseeing Organisation and the Railway Authority.

On a new bridge or structure (including accommodation bridge) that is carrying a road, that is not over, or adjacent to, a railway, the minimum containment level must be that derived from the RRRAP that gives a ‘broadly acceptable’ level of risk.

On an existing bridge or structure (including accommodation bridge) that is carrying a road that is not over, or adjacent to, a railway, the containment level requirements must be determined as follows:

(i) Where the existing bridge or structure can support a parapet with a containment level that gives a ‘broadly acceptable’ level of risk as derived from the RRRAP, this level of containment must be provided.

(ii) Where the existing bridge or structure cannot meet the requirements of (i) above, a further assessment will be required to determine the level of containment which can be achieved without strengthening.

(iii) If the risks associated with the provision of the lower level of containment determined from the assessment in (ii) above are As Low As Reasonably Practicable (ALARP) this lower level of containment may be acceptable.

(iv) If the risks of providing the lower level of containment do not satisfy the ALARP principle, then strengthening of the bridge or structure will be required so as to allow the provision of a containment level, which would satisfy the requirements derived from the RRRAP. If such strengthening is impracticable or cost prohibitive, strengthening to provide a containment Level which would satisfy the ALARP requirements would be acceptable.

(v) Any proposal to provide a containment level that does not produce a 'broadly acceptable' level of risk as derived from the RRRAP must be supported by a Departure from Standards.

The Design Organisation must use the RRRAP to determine whether the above minimum requirements are sufficient in the particular circumstances being examined and to record the proposed level of containment and length of need.

The impact severity level for vehicle parapets must not normally exceed Class B as stipulated in BS EN 1317-2.

The Working Width Class for each vehicle parapet installation must be the same as, or numerically less than, that specified by the Design Organisation.

The Working Width Class for vehicle parapets must not be numerically greater than:

(i) Normal Containment Levels (N1 & N2) - W4

(ii) Higher Containment Levels (H1 to H3) - W4

(iii) Very High Containment Level (H4a) - W5

Ideally, the parapet should be located so that, if it is impacted, there will be no gap arising between the edge of the bridge deck and the front face of the parapet that will affect the performance of the parapet. This must be demonstrated by information from the parapet manufacturer.

3.36.5 Terminals

All terminals must conform to the requirements of ENV 1317-4.

The Design Organisation must specify the Performance Class requirements for each terminal installation in terms of Performance Class, Impact Severity Level, the Permanent Lateral Displacement Zone (PLDZ) characteristic D.x.y and the Exit Box Class (more details on these performance classes can be found in ENV 1317-4).

The Performance Class requirements for terminals are as follows.

- On roads with a speed limit of 50 mph or more:
  - For terminals that face oncoming traffic, e.g. those at both ends of a VRS on a two-way single carriageway road, the minimum performance class must be P4. Ramped end terminals must not be used;
  - For terminals that do not face oncoming traffic, e.g. departure ends on dual carriageways or on a one-way road, the minimum performance class must be P1.
- On roads with a speed limit of less than 50 mph:
  - Terminals must have a minimum Performance Class of P1 or greater.

The ISL for terminals must not exceed Class B in ENV 1317-4.

3.36.6 Transitions

Where a transition is used to connect a Very High Containment vehicle parapet (H4a) to a Normal Containment (N1) vehicle parapet, the end section of the Normal Containment (N1) vehicle parapet must be strengthened to Normal Containment Level (N2).

Where a connection is required between a vehicle parapet and a transition, it must be capable of developing the full strength of the transition and if necessary, the vehicle parapet must be strengthened to resist this force.

The ISL for transitions must not exceed Class B in ENV 1317-4.

A transition must be provided at all changes of type and/or Performance Class of Vehicle Restraint Systems (VRS) to provide a gradual change in performance from the first to the second and prevent the hazards of an abrupt variation.

Where the transition is composed of posts and rails, the end(s) of a terminated upper rail(s) must be treated so as to avoid the possibility of an errant vehicle impacting directly with it.

3.36.7 Crash Cushions

The Performance Class requirements for crash cushions are:

Table 71: Crash Cushion Requirements (*Requirement for Road Restraint Systems*, Highways Agency, 2006)

Crash cushions on roads with a speed limit of greater than 50 mph:

Type	Performance Level	Acceptance Tests					
Redirective (R)	110	TC 1.1.100	TC 1.3.100	TC 2.1.100	TC 3.3.110	TC 4.3.110	TC 5.3.110
Non-Redirective (NR)	110	TC 1.1.100	TC 1.3.100	TC 2.1.100	TC 3.3.110	-	

Crash cushions on roads with a speed limit 50 mph or less:

Type	Performance Level	Acceptance Tests					
Redirective (R)	100	TC 1.1.100	TC 1.2.100	TC 2.1.100	TC 3.2.100	TC 4.2.100	TC 5.2.100
Non-Redirective (NR)	100{80 (HA)}	TC 1.1.100	TC 1.2.100	TC 2.1.100	TC 3.2.100	-	-

ISL must not exceed Class B, as stipulated in Table 4 of BS EN 1317-3.

On a new or improved major road, there is unlikely to be any justification, except in exceptional circumstances, for the installation of crash cushions.

On existing roads, a crash cushion should only be considered for provision where special features on the highway or particular circumstances warrant its installation.

At a potential crash cushion site, an evaluation based on the Risk assessment process must first be undertaken by the Design Organisation of the cost benefit of provision together with possible options for reducing the number, or severity of accidents, by other highway design measures.

3.37 United States

In the United States, each state has its own VRS policy. However, AASHTO (American Association of State Highway and Transport Officials) Roadside Design Guide (4th edition, 2011), presents a synthesis of current information and operating practices in the U.S. related to roadside safety, including vehicle restraint systems. The U.S. approach to determination of the need for a VRS and the selection of the appropriate VRS type is explained through the guidelines presented in that book.

3.37.1 Roadside Barriers

The decision to place a roadside barrier, or not, relies heavily on the clear roadside concept. A clear zone is defined as an unobstructed, traversable area provided beyond the edge of the through travelled way for the recovery of errant vehicles. As shown in Table 72 and Figure 24, the required clear zone distance is related to the slope of the roadside topography, design speed and ADT.

Table 72 - Clear-zone distances in meters from the edge of the travelled way (*Roadside Design Guide*, AASHTO, 2011)

DESIGN SPEED	DESIGN ADT	FORESLOPES			BACKSLOPES		
		1V:6H or flatter	1V:5H to 1V:4H	1V:3H	1V:3H	1V:5H TO 1V:4H	1V:6H or flatter
60 km/h or less	UNDER 750	2.0 - 3.0	2.0 - 3.0	**	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
	750 - 1500	3.0 - 3.5	3.5 - 4.5	**	3.0 - 3.5	3.0 - 3.5	3.0 - 3.5
	1500 - 6000	3.5 - 4.5	4.5 - 5.0	**	3.5 - 4.5	3.5 - 4.5	3.5 - 4.5
	OVER 6000	4.5 - 5.0	5.0 - 5.5	**	4.5 - 5.0	4.5 - 5.0	4.5 - 5.0
70 - 80 km/h	UNDER 750	3.0 - 3.5	3.5 - 4.5	**	2.5 - 3.0	2.5 - 3.0	3.0 - 3.5
	750 - 1500	4.5 - 5.0	5.0 - 6.0	**	3.0 - 3.5	3.5 - 4.5	4.5 - 5.0
	1500 - 6000	5.0 - 5.5	6.0 - 8.0	**	3.5 - 4.5	4.5 - 5.0	5.0 - 5.5
	OVER 6000	6.0 - 6.5	7.5 - 8.5	**	4.5 - 5.0	5.5 - 6.0	6.0 - 6.5
90 km/h	UNDER 750	3.5 - 4.5	4.5 - 5.5	**	2.5 - 3.0	3.0 - 3.5	3.0 - 3.5
	750 - 1500	5.0 - 5.5	6.0 - 7.5	**	3.0 - 3.5	4.5 - 5.0	5.0 - 5.5
	1500 - 6000	6.0 - 6.5	7.5 - 9.0	**	4.5 - 5.0	5.0 - 5.5	6.0 - 6.5
	OVER 6000	6.5 - 7.5	8.0 - 10.0	**	5.0 - 5.5	6.0 - 6.5	6.5 - 7.5
100 km/h	UNDER 750	5.0 - 5.5	6.0 - 7.5	**	3.0 - 3.5	3.5 - 4.5	4.5 - 5.0
	750 - 1500	6.0 - 7.5	8.0 - 10.0	**	3.5 - 4.5	5.0 - 5.5	6.0 - 6.5
	1500 - 6000	8.0 - 9.0	10.0 - 12.0	**	4.5 - 5.5	5.5 - 6.5	7.5 - 8.0
	OVER 6000	9.0 - 10.0	11.0 - 13.5	**	6.0 - 6.5	7.5 - 8.0	8.0 - 8.5
110 km/h	UNDER 750	5.5 - 6.0	6.0 - 8.0	**	3.0 - 3.5	4.5 - 5.0	4.5 - 5.0
	750 - 1500	7.5 - 8.0	8.5 - 11.0	**	3.5 - 5.0	5.5 - 6.0	6.0 - 6.5
	1500 - 6000	8.5 - 10.0	10.5 - 13.0	**	5.0 - 6.0	6.5 - 7.5	8.0 - 8.5
	OVER 6000	9.0 - 10.5	11.5 - 14.0	**	6.5 - 7.5	8.0 - 9.0	8.5 - 9.0

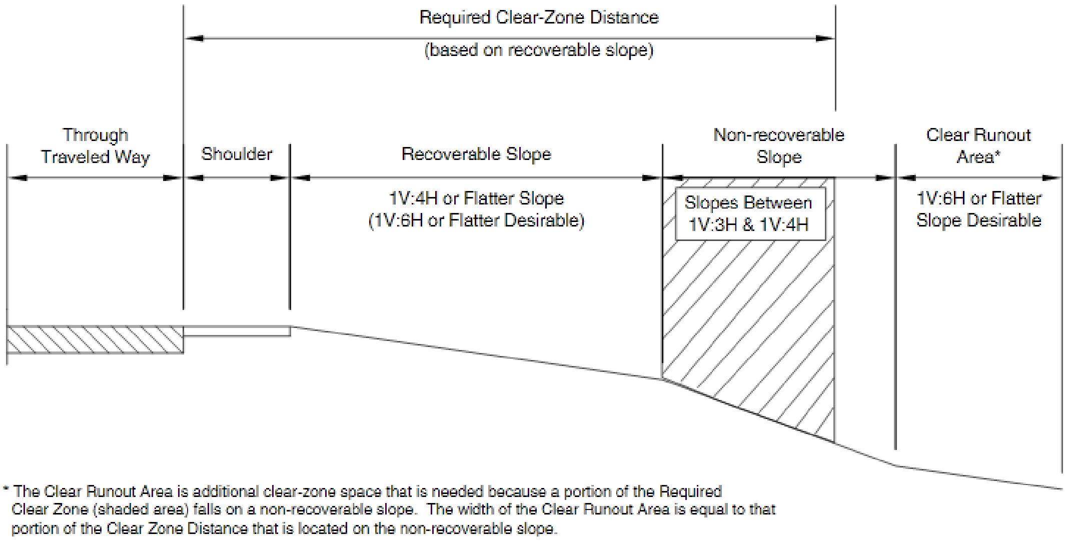


Figure 24 – Example showing the clear–zone concept (*Roadside Design Guide*, AASHTO, 2011)

The recommended practice is to consider placing a roadside barrier where an obstacle or a dangerous side slope is present within the clear zone distance from the edge of the travelled way; and if it isn't possible to remove, relocate the obstacle or to make it passively safe.

The AASHTO Roadside Design Guide defines three main highway conditions that would require the installation of a roadside barrier:

- Embankments;
- Roadside obstacles;
- Bystanders, Pedestrians and Bicyclist.

For embankments, height and slope are the basic factors considered in determining barrier need as shown in Figure 25. Embankments with slope and height combinations that are on or below the curve do not require the installation of a safety barrier, unless they contain obstacles within the clear zone.

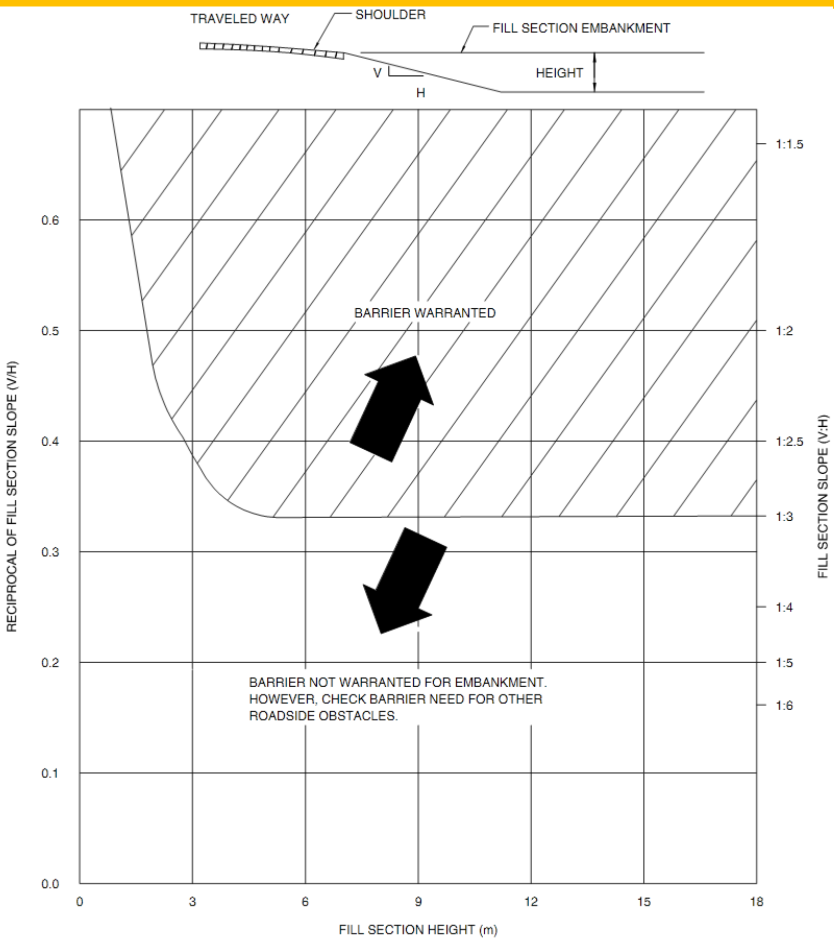


Figure 25 – Comparative barrier consideration for embankments (*Roadside Design Guide*, AASHTO, 2011)

Figure 25, however, does not take into account either the probability of an encroachment occurring, or the relative cost of installing a roadside barrier versus leaving the slope unshielded. A recommended procedure to address this problem is the modification of the chart by introducing other parameters such as ADT, length of slope, etc. Figure 26 is a modified barrier consideration chart that addresses the decreased probability of encroachments on lower volume roads. Figure 27 is another example of a modified barrier consideration chart, one which considers the cost-effectiveness of barrier installation for the site-specific conditions noted on the chart.

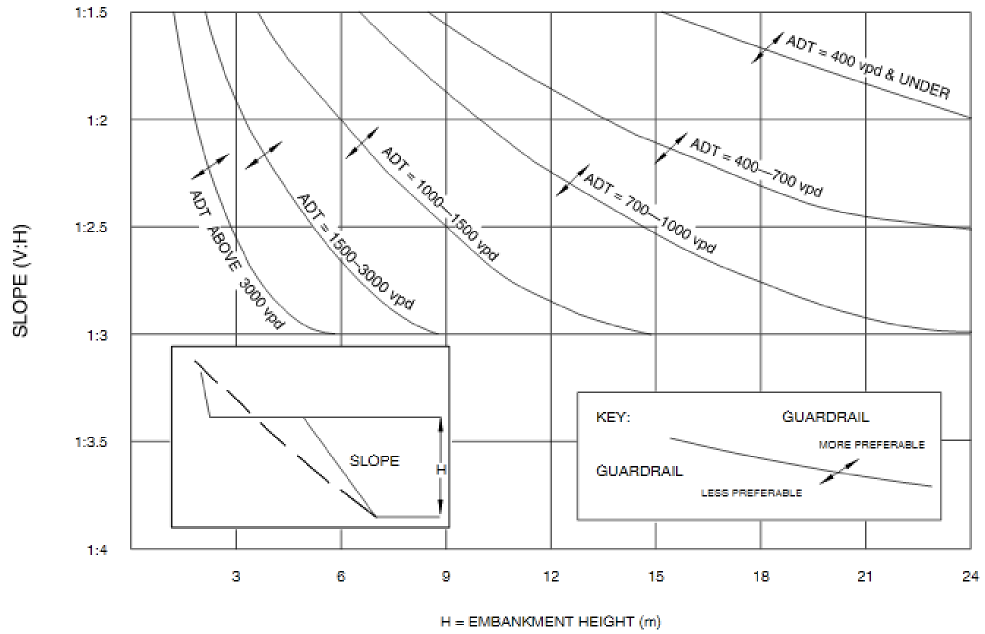


Figure 26 – Example design chart for embankment barrier consideration on fill height, slope and traffic volume (*Roadside Design Guide*, AASHTO, 2011)

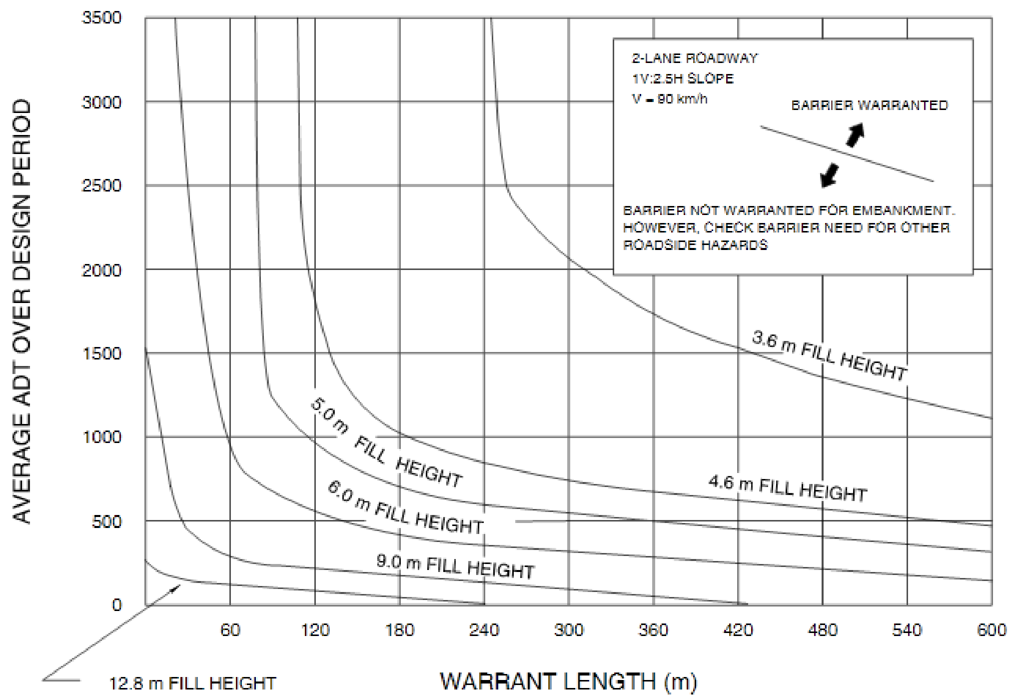


Figure 27 – Example design chart for cost-effective barrier consideration for embankments based on traffic speeds and volumes, slope geometry and length of slope (*Roadside Design Guide*, AASHTO, 2011)

Roadside obstacles that normally require the installation of a safety barrier and the recommended guidelines are listed in Table 73.

Consideration may be given to installing a barrier to shield businesses and residences that are near the right-of-way, particularly at locations having a history of run-off-the-road crashes. Pedestrians and cyclists along a route are a concern that might be given design consideration. When sidewalks or multi-use paths are adjacent to the travelled way of high-speed facilities, some provision might be made to shield the sidewalk or path from vehicular traffic on the roadway. Factors to consider for barrier protection include traffic and pedestrian volumes, roadway geometry, sidewalk/path offset, and cross-section features.

Table 73 – Barrier guidelines for non-traversable terrain and roadside obstacles (*Roadside Design Guide*, AASHTO, 2011)

Obstacle	Guidelines
Bridge piers, abutments and railing ends	Shielding generally needed
Boulders	Judgment decision based on nature of fixed object and likelihood of impact
Culverts, pipes, headwalls	Judgment decision based on size, shape and location of obstacle
Fore slopes and back slopes (smooth)	Shielding not generally needed
Fore slopes and back slopes (rough)	Judgment decision based on likelihood of impact
Ditches (parallel)	Refer to Figures
Ditches (transverse)	Shielding generally needed if likelihood of head-on impact is high
Embankment	Judgment decision based on fill height and slope
Retaining walls	Judgment decision based on relative smoothness of wall and anticipated maximum angle of impact
Sign/luminaire supports	Shielding generally needed for non-breakaway supports
Traffic signal supports	Isolated traffic signals within clear zone on high-speed rural facilities may need shielding
Trees	Judgment decision based on site-specific circumstances
Utility poles	Shielding may be needed on a case-by-case basis
Permanent bodies of water	Judgment decision based on location and depth of water and likelihood of encroachment

For the selection of performance level, consideration of the following factors is recommended by AASHTO:

- Traffic volume;
- Heavy truck traffic volume;
- Speed;
- Locations with poor geometrics;
- Consequences of barrier penetration on third parties;
- Life-Cycle Costs;
- Maintenance;
- Aesthetic and Environmental Considerations.

3.37.2 Median Barriers

The AASHTO Roadside Design Guide recommends that median barriers be considered for high-speed, fully controlled-access roadways that have traversable medians, as shown in Figure 28.

As shown in the Figure, a median barrier is recommended on high-speed, fully controlled access roadways for locations where the median is 9.1m in width or less, and the average daily traffic (ADT) is greater than 20,000 vehicles per day (vpd). For locations with median widths less than 15.2m and where the ADT is less than 20,000vpd, a median barrier is optional. For locations where median widths are greater than 9.1m but less than 15.2m and where the ADT is greater than 20,000vpd, a cost/benefit analysis or an engineering study may be conducted to determine the appropriate application for median barrier installation. The analysis should include the following factors in the evaluation:

- Traffic volumes;
- Vehicle classifications;
- Median crossover history;
- Crash Incidents;
- Vertical and horizontal alignment relationships;
- Median-terrain configurations.

For median widths equal to or greater than 15.2m, a barrier is not normally considered except in special circumstances, such as a location with a significant history of cross-median crashes

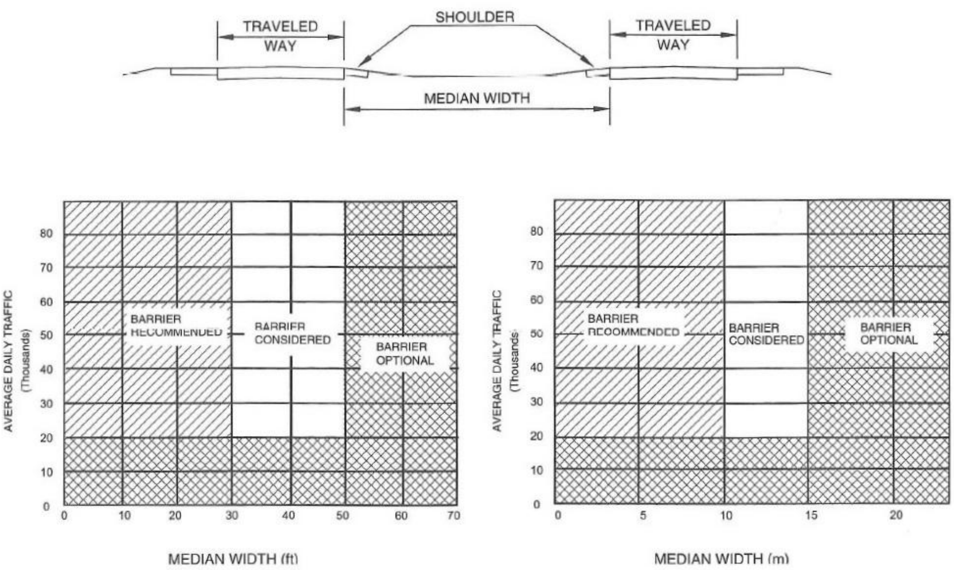


Figure 28 - Suggested guidelines for median barriers on high-speed roadways (*Roadside Design Guide*, AASHTO, 2011)

For the selection of median barrier performance level, the following factors are to be considered:

- Percentage or ADT of heavy vehicle traffic;
- Adverse geometrics (horizontal curvature);
- Severe consequences of vehicular (cargo) penetration into opposing traffic lanes.

4 Analysis of National VRS Guidelines & Standards

4.1 Distribution of National VRS Guidelines & Standards in Other Countries

The analysis of the collected guidelines and standards revealed many similarities among different countries. It is understood that some countries completely adopt and/or adapt guidelines from other countries instead of writing their own, while some of the countries use them partially, and some have their own. Figure 29 and Figure 30 show the distribution of the National guidelines and standards in the different countries around the World and Europe respectively.

It can be observed that there are some dominant guidelines / standards in different parts of the World. This is most probably related to the different VRS testing standards that are adopted in different parts of the world. While EN1317 is the VRS testing standard for Europe, NCHRP350 & MASH are the old and new standards for the US. Since the performance classification is different in each test standard, it is logical that countries adopt a guideline that uses the same performance classification, as their adopted testing standard. It can be seen that guidelines from the US are adopted by countries around the Americas, while Australia and New Zealand have their own.

In Europe, although the German standard stands out as the most widely adopted, the majority of the countries have their own dedicated guidelines and standards. However it is still very common to see many shared approaches, decision processes, tables and graphs.

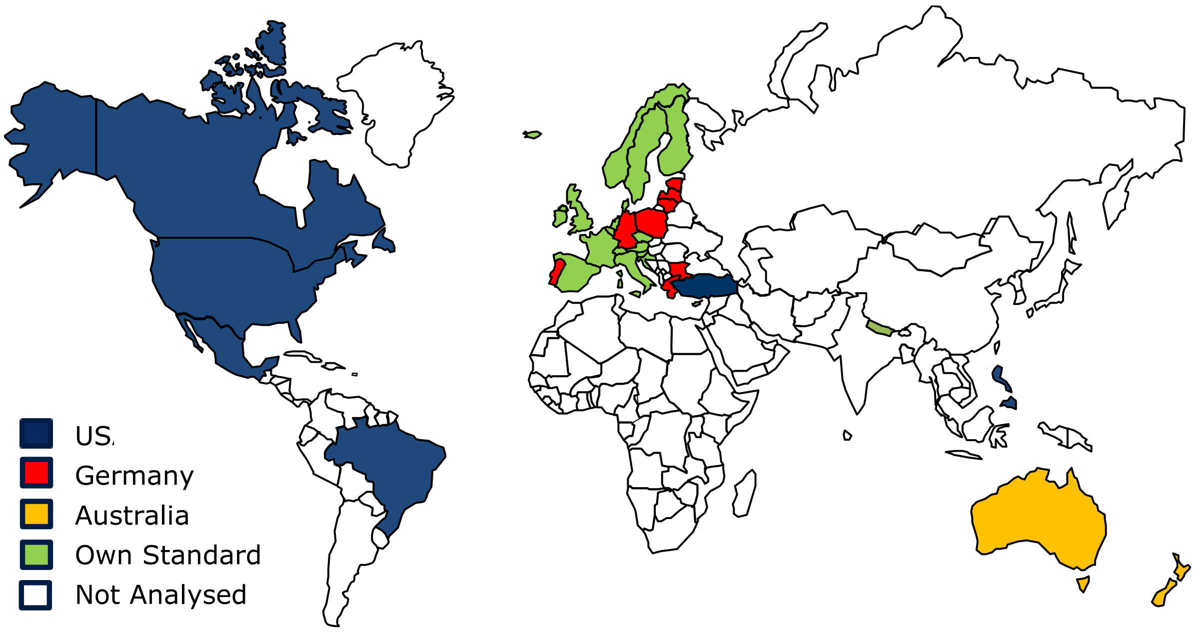


Figure 29 – Distribution of National Guidelines in Other Countries (Worldwide)

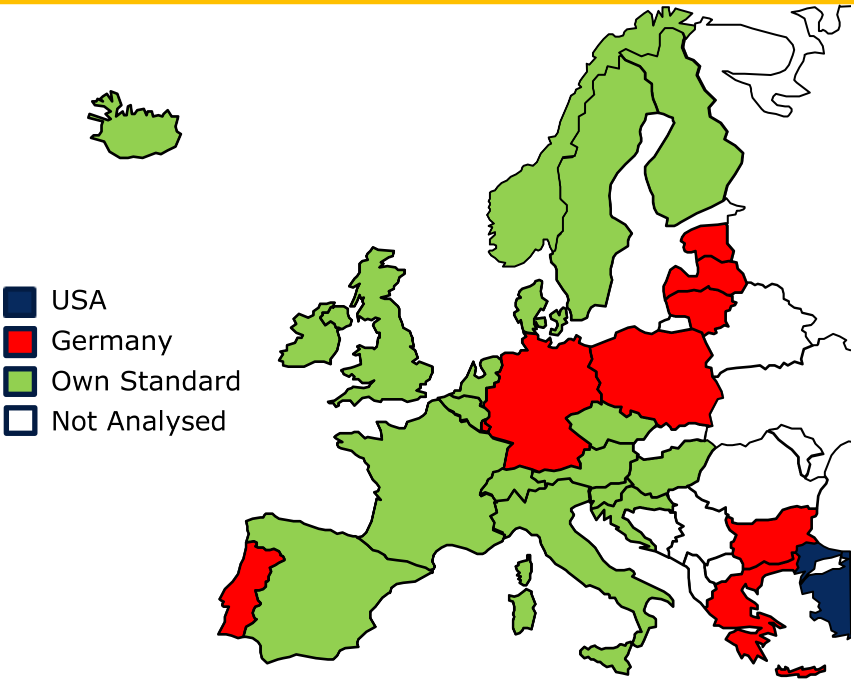


Figure 30 – Distribution of National Guidelines in Other Countries (Europe)

4.2 The Data Matrix & Identified Parameters

4.2.1 The Data Matrix Explained

As explained in the Methodology section, a matrix was formed to store the data gathered from each National standard/guideline. As it can be seen from the screenshot of Figure 31, the matrix mainly shows which parameters are used, by which countries and for which decision.

	1- Barrier Needed or Not 2- Type of VRS	Austria	Belgium	Brazil	Bulgaria	Canada	Croatia	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Iceland	Ireland	Israel	Italy (2004)
	Based on the Standards of:			USA	Germany	USA					Germany				Germany	Norway			
Consequences	A - Existence of Special Risk to 3rd parties	1,2	1,2	1,2	1,2	1,2		1	1,2	1,2	1,2	1,2	2	1,2	1,2	1,2	1,2	1,2	
	Chemical Plants				1,2					1	1,2		2	1,2	1,2	1,2			
	Structures at risk of collapse, support and load bearing			2	1,2	2		1			1,2	1,2		1,2	1,2	1,2	1	1,2	
	Heavily used walkways, public areas with frequent pedestrian activity	1,2		1	1,2	1		1	1,2	1,2	1,2	1	2	1,2	1,2	1	1	1,2	
	Volume of Pedestrian Traffic / Average number of people exposed to risk			1		1				1									
	Average time each person is exposed to risk (hours per year)																		
	Heavily used bicycle paths	1		1	1,2	1				1	1,2	1		1,2	1,2	1	1		
	AADT of bicycles in the bicycle path									1									
	Environmental Concern such as Source of drinking water			2		2			1,2	1,2		2	2			1,2			
	Adjacent rail lines	1,2			1,2				1,2	1	1,2	1	2	1,2	1,2	1,2	1,2	1,2	
	Distance to the Rail line																		
	Number of trains per day, Per week or per hour				1,2						1,2			1,2	1,2				
	Rail line at the foot of an embankment																		
	Number of Tracks																		
	Permissible Speed on rail line																		
	Adjacent Roads				1,2				1,2		1,2	1,2	2	1,2	1,2	1,2	1,2	1,2	
	AADT on adjacent road				1,2						1,2	1,2		1,2	1,2	1	2		
	Speed on adjacent road				1,2						1,2			1,2	1,2	1	2		
	Distance to the adjacent road							1								1			
	Road at the foot of an embankment							1											
	Object which can cause severe traffic disruptions if damaged											1							
	B - Obstructions with a special risk to vehicle occupants	1	1,2	1	1,2	1	1	1,2	1,2	1	1,2	1,2	1	1,2	1,2	1,2	1,2	1	1
	Non-deformable extensive obstacles vertical to direction of travel	1	1,2	1	1,2	1	1	1		1	1,2	1,2	1	1,2	1,2	1	1,2	1	1
	Retaining walls with non smooth traffic face up to 1.5m above traffic level			1		1		1		1			1			1,2	1,2	1	
	Noise barriers	1			1,2			1	1,2	1	1,2	1,2		1,2	1,2	1			
	Height/Depth of the Hazard															1,2			
	Fencing (Stone wall, wooden fence, concrete wall, etc.)												1						
	Non-deformable select individual obstacles	1	1,2	1	1,2	1	1	1,2		1	1,2	1		1,2	1,2	1,2	1,2	1	
	Bridge Piers, abutments, railing ends									1		1	1					1	
	Above ground equipment other than emergency telephones (e.g. CCTV masts, communication control cabinets, pillars, stores for signs)							1		1		1	1			1			
	Boulders			1		1				1		1				1		1	
	Intersecting /Transverse Ditches			1	1,2	1		1		1	1,2			1,2	1,2	1	1,2		
	Culverts, Pipes, Headwalls			1		1										1,2	1,2	1	
	Ends of concrete barriers, retaining walls, etc.											1	1			1		1	

	1- Barrier Needed or Not 2- Type of VRS	Italy (Draft)	Latvia	Lithuania	Luxembourg	Mexico	Nepal	Netherlands	Norway	Philippines	Poland	Portugal	Slovenia	Spain	Sweden	Switzerland	Turkey	UK	USA
	Based on the Standards of:		Germany	Germany	Germany	USA				USA	Germany	Germany					USA		
Consequences	A - Existence of Special Risk to 3rd parties	1,2	1,2	1,2	1,2	1,2		1,2	1,2	1,2	1,2	1,2	1,2	1	1,2	1,2	1,2	1,2	1,2
	Chemical Plants	1	1,2	1,2	1,2				1,2		1,2	1,2	1,2	1	1,2	1,2		1,2	
	Structures at risk of collapse, support and load bearing	1	1,2	1,2	1,2	2			1,2	2	1,2	1,2	1,2	1	1,2		2		2
	Heavily used walkways, public areas with frequent pedestrian activity	1	1,2	1,2	1,2	1			1	1	1,2	1,2	1,2	1	1,2	1,2	1	1,2	1
	Volume of Pedestrian Traffic / Average number of people exposed to risk					1				1							1	1,2	1
	Average time each person is exposed to risk (hours per year)																	1,2	
	Heavily used bicycle paths	1	1,2	1,2	1,2	1			1	1	1,2	1,2					1		1
	AADT of bicycles in the bicycle path																		
	Environmental Concern such as Source of drinking water	1				2			1,2	2			1,2	1	1,2	1,2	2	1,2	2
	Adjacent rail lines	1,2	1,2	1,2	1,2				1,2		1,2	1,2	1,2	1	1,2	1,2		1,2	
	Distance to the Rail line	1,2											1	1	1,2			1,2	
	Number of trains per day, Per week or per hour		1,2	1,2	1,2						1,2	1,2	2	1		1,2			
	Rail line at the foot of an embankment													1				1,2	
	Number of Tracks																	1,2	
	Permissible Speed on rail line															1,2		1,2	
	Adjacent Roads	1,2	1,2	1,2	1,2				1,2		1,2	1,2	1,2	1				1,2	
	AADT on adjacent road	1,2	1,2	1,2	1,2				1		1,2	1,2						1,2	
	Speed on adjacent road		1,2	1,2	1,2				1		1,2	1,2						1,2	
	Distance to the adjacent road	1,2							1					1				1,2	
	Road at the foot of an embankment	1,2											1,2	1					
	Object which can cause severe traffic disruptions if damaged															1,2		1	
	B - Obstructions with a special risk to vehicle occupants	1	1,2	1,2	1,2	1	1	1	1,2	1	1,2	1,2	1,2	1	1	1,2	1	1,2	1
	Non-deformable extensive obstacles vertical to direction of travel	1	1,2	1,2	1,2	1	1	1	1	1	1,2	1,2	1,2	1	1,2	1,2	1	1,2	1
	Retaining walls with non smooth traffic face up to 1.5m above traffic level					1			1,2	1				1			1	1,2	1
	Noise barriers		1,2	1,2	1,2			1	1		1,2	1,2	1,2	1		1,2			
	Height/Depth of the Hazard								1,2									1,2	
	Fencing (Stone wall, wooden fence, concrete wall, etc.)															1,2		1,2	
	Non-deformable select individual obstacles	1	1,2	1,2	1,2	1	1	1	1,2	1	1,2	1,2	1	1	1,2	1,2	1	1,2	1
	Bridge Piers, abutments, railing ends															1,2			1
	Above ground equipment other than emergency telephones (e.g. CCTV masts, communication control cabinets, pillars, stores for signs)							1	1				1	1	1	1,2		1,2	
	Boulders					1			1	1					1		1		1
	Intersecting /Transverse Ditches		1,2	1,2	1,2	1		1	1	1	1,2	1,2			1		1	1,2	1
	Culverts, Pipes, Headwalls					1		1	1,2	1					1		1	1,2	1
	Ends of concrete barriers, retaining walls, etc.								1										

Figure 31 - A screenshot from the Data Matrix

Parameters, that are used for 'the choice of whether to install a VRS, or not', are coded '1', whilst those used for 'the selection of VRS performance' are coded '2'. If a parameter is used for both decisions it is coded '1,2'.

For example, as shown in Figure 32, the existence of a 'heavily used walkway or another public area with frequent pedestrian activity' in the vicinity of a road is considered as a reason to install a VRS in Austria, Brazil, Bulgaria & Canada, while this parameter is also used in the decision of the VRS type for Austria & Bulgaria.

1- Barrier Needed or Not 2- Type of VRS	Austria	Belgium	Brazil	Bulgaria	Canada	Croatia
Based on the Standards of:			USA	Germany	USA	
A - Existence of Special Risk to 3rd parties	1,2	1,2	1,2	1,2	1,2	
Chemical Plants				1,2		
Structures at risk of collapse, support and load bearing			2	1,2	2	
Heavily used walkways, public areas with frequent pedestrian activity	1,2		1	1,2	1	
Volume of Pedestrian Traffic / Average number of people exposed to risk			1		1	
Average time each person is exposed to risk (hours per year)						
Heavily used bicycle paths	1		1	1,2	1	

Figure 32 – Example of coding used in the matrix

The parameters used for the decision of the need for a VRS and for the selection of VRS performance level differs from one VRS type to another. In order to get more meaningful results in the analysis stage, it was decided to separate the parameters related to each VRS type. For this purpose separate matrices were developed for each VRS type, i.e. roadside safety barriers, median safety barriers, bridge parapets, crash cushions, transitions, terminals and MPS. Each was therefore provided within separate tabs, as shown in Figure 33.

An additional 'General' tab is also provided, which is a cumulative sum of all the other tabs and shows the general situation for VRS as a whole. Due to low level of published guidance for terminals, transitions and motorcyclist protection systems, these were removed from the later analysis stage.

30	Conse	Non-deformable select individual obstacles	1	1,2	1	1,2	1	1	1,2		1		1,2	1,2	1,2	1,2	
31		Bridge Piers, abutments, railing ends									1	1					
32		Above ground equipment other than emergency telephones (e.g. CCTV masts, communication control cabinets, pillars, stores for signs)							1		1	1			1		
33		Boulders			1		1				1				1		
34		Intersecting /Transverse Ditches			1	1,2	1		1		1		1,2	1,2	1	1,2	
35		Culverts, Pipes, Headwalls			1		1								1,2	1,2	
36		Ends of concrete barriers, retaining walls, etc.										1			1		

1. General / 2.1 Barriers / 2.2 Bridge Parapets / 2.3 Crash Cushions / 2.4 Terminals / 2.5 Transitions / 2.6 TMA / 2.7 MPS

Figure 33 – Categorization of the data by VRS type using separate tabs

A classification system is used to present the large number of identified parameters in a more easily understandable format. For this purpose, the definition of 'Risk' as a product of 'Likelihood' and 'Consequences', as shown in Figure 34, is adopted.

Figure 34 – The risk model, which was used to categorize the parameters

It is assumed that majority of the parameters can be categorized either under the 'Likelihood' of having an incident, or 'Consequences' of having such an incident. The parameters under the 'Consequences' category are arranged into subcategories of:

- Special Risk to third parties, and
- Obstructions with a special risk to vehicle occupants.

The parameters under the 'Likelihood' category are arranged into subcategories of:

- Traffic;
- Speed;
- Road Alignment / Geometry;
- Road Layout;
- Accident History / Frequency.

A colour coding is used to differentiate the different levels of categorization. A darker colour is used for more general parameters (as listed above), while lighter colours are used for subcategories as the level of detail increase. An example is presented in Figure 35.

OF RISK
Consequences

Road at the foot of an embankment							[illegible]				
Object which can cause severe traffic distruptions if damaged											
B - Obstructions with a special risk to vehicle occupants	1	1,2	1	1,2	1	1	1,2	1,2	1	1	1,
Non-deformable extensive obstacles vertical to direction of travel	1	1,2	1	1,2	1	1	1		1	1	1,
Retaining walls with non smooth traffic face up to 1.5m above traffic level			1		1		1		1	1	
Noise barriers	1			1,2			1	1,2	1		1,
Height/Depth of the Hazard											
Fencing (Stone wall, wooden fence, concrete wall, etc.)										1	
Non-deformable select individual obstacles	1	1,2	1	1,2	1	1	1,2		1		1,
Bridge Piers, abutments, railing ends									1	1	
Above ground equipment other than emergency telephones (e.g. CCTV masts, communication control cabinets, pillars, stores for signs)							1		1	1	
Boulders			1		1				1		
Intersecting /Transverse Ditches			1	1,2	1		1		1		1,
Culverts, Pipes, Headwalls			1		1						
Ends of concrete barriers, retaining walls, etc.										1	
Trees			1		1		1		1	1	
Trunk girth of a single tree							1		1	1	
High Mast lighting poles			1		1		1,2		1	1	
Sign/signal gantry supports			1		1		1,2		1	1	
Diameter of support posts							1		1		
Height of gantry							1,2				
Fall Height (Height from lower surface for bridges, retaining walls etc)	1			1					1	2	[illegible]
Falling Slopes (Embankments)		1			1	1	1	1,2	1	1,2	1,

Figure 35 – Colour coding of parameters according to their level of hierarcy

It can be seen that 'Trunk girth of a single tree' is a subcategory of 'Existence of trees in the area', therefore it is presented in a lighter colour. While some countries use the 'existence of trees in the area' as a parameter for the decision of VRS installation, some add an additional level of detail by defining the 'trunk girth of a single tree' as a necessary parameter for the decision. Likewise, 'Existence of trees' is the subcategory of 'Existence of non-deformable select individual objects', which is a subcategory of 'Existence of obstructions with a special risk to vehicle occupants'. It can be observed that as the parameters go from specific to general the colour tone used gets darker. It can be observed that a colour coding in the shades of blue is used for the parameters related to the 'Consequences' of a crash, while shades of green is used for the parameters related to the 'Likelihood'.

In line with the colour coding, it can also be observed that the general parameters represent a cumulative sum of the more specific parameters listed under them. For example if 'trunk girth of a single tree' is defined as a parameter used for the decision of VRS installation, its upper category, 'existence of trees in the area', is automatically defined as a parameter used for the same decision, since the information of the 'trunk girth of a tree' automatically implies that there must be trees in the area. In other words, when one of the codes '1', '2' or '1,2' is used for a parameter, the same code is repeated in the upper categories automatically.

4.2.2 Identified Parameters

The whole list of the parameters identified within the National standards and guidelines is presented in detail in this section. A detailed analysis of the most frequently used parameters within these standards and guidelines follows in the following sections.

Figure 36 shows the parameters identified which relate to the existence of special risk to third parties. These are a group of high risk features which may result in a level of risk to third parties in the event of a run off the road crash in the area. Existence of these features in an area plays an important factor in the decision of VRS installation and type selection, due to the possible consequences.

A - Existence of Special Risk to 3rd parties
Chemical Plants
Structures at risk of collapse, support and load bearing
Heavily used walkways, public areas with frequent pedestrian activity
Volume of Pedestrian Traffic / Average number of people exposed to risk
Average time each person is exposed to risk (hours per year)
Heavily used bicycle paths
AADT of bicycles in the bicycle path
Environmental Concern such as Source of drinking water
Adjacent rail lines
Distance to the Rail line
Number of trains per day, Per week or per hour
Rail line at the foot of an embankment
Number of Tracks
Permissible Speed on rail line
Adjacent Roads
AADT on adjacent road
Speed on adjacent road
Distance to the adjacent road
Road at the foot of an embankment
Object which can cause severe traffic disruptions if damaged

Figure 36 – Parameters identified relating to the existence of special risk to third parties

Figure 37 shows the identified parameters related to the obstructions with a special risk to vehicle occupants. These are a group of hazardous roadside features or objects that would represent a level of risk to vehicle occupants in case of a run-off-the road crash. Existence of these features is usually an important factor in the decision of a whether to install a VRS, or not, and if so which to performance level(s) to select.

Figure 38 shows the factors identified related to traffic conditions. As this is in green, it indicates that this is the first of the Figures related to the likelihood of an errant vehicle leaving the road.

The factors identified in Figure 38 are important for the decision of whether to install a VRS since the exposure level and consequently the likelihood of an errant vehicle reaching a hazard increases as the traffic increases. They are also important for the selection of VRS type because as the number of heavy vehicles increases, so too does the likelihood of a heavy vehicle reaching an area or a roadside hazard, in which case the selection of a higher containment level VRS may become more appropriate.

B - Obstructions with a special risk to vehicle occupants
Non-deformable extensive obstacles parallel to direction of travel
Retaining walls with non-smooth traffic face up to 1.5m above traffic level
Noise barriers
Height/Depth of the Hazard
Fencing (Stone wall, wooden fence, concrete wall, etc.)
Non-deformable select individual obstacles
Bridge Piers, abutments, railing ends
Above ground equipment other than emergency telephones (e.g. CCTV masts, communication control cabinets, pillars, stores for signs)
Boulders
Intersecting /Transverse Ditches
Culverts, Pipes, Headwalls
Ends of concrete barriers, retaining walls, etc.
Trees
Trunk girth of a single tree
High Mast lighting poles
Sign/signal gantry supports
Diameter of support posts
Height of gantry
Fall Height (Height from lower surface for bridges, retaining walls etc.)
Falling Slopes (Embankments)
Slope
Height
Surface of the slope (short grass, long grass, bush, etc.)
Rising (Cutting) Slopes
Slope
Height
Surface of the slope (short grass, long grass, bush, etc.)
Permanent bodies or streams of water
Water depth
Distance to water from the edge of carriageway

Figure 37 – Parameters identified parameters relating to obstructions with a special risk to vehicle occupants

A - Traffic
Average annual daily traffic (AADT)
Average annual daily HGV traffic (AADTHGV)
Percentage of Motorcycle Traffic

Figure 38 – Parameters identified relating to the traffic conditions

Speed, as shown in Figure 39, is also an important factor, which affects the likelihood of a run off the road crash and the likelihood of an errant vehicle reaching the hazard. The Local Speed Limit is the posted speed limit for the road, whilst the Design Speed is the optimum speed for which the road was designed. In general, the Design Speed is greater than the Local Speed Limit. Whilst completing the analysis, the Local Speed Limit was taken to be the posted speed limit and/or the average traffic speed on the road.

B - Speed
Local Speed Limits
Design Speed

Figure 39 – Parameters identified relating to speed

Figure 40, shows the identified parameters related to road alignment / geometry. These are those road features that would affect the likelihood of a run off the road crash and the likelihood of an errant vehicle reaching the hazard. For example 'distance between the edge of traffic lane and hazard' is a parameter that is widely used for the decision of VRS installation as it defines the likelihood of an errant vehicle reaching a hazard. 'Radius of curvature' on the other hand is a parameter which defines the likelihood of a vehicle running off the road.

C - Road Alignment / Geometry
Distance between the edge of traffic and hazard
Width of median
Vertical Alignment (Slope)
Bridge Length
Geometry of diverge (parallel, trapezoid, etc.)
Radius of curvature
Kerb Height
Roadside Topography (in terms of likelihood of reaching hazard)
Adverse Geometrics
Stopping Sight Distance not up to the standard
Curve Radius Shorter than allowed design value
Several successive curves with radii smaller than permitted
non-typically large directional changes
Sleep related problematic design (featureless rural roads, etc.)

Figure 40 – Parameters identified relating to road alignment / geometry

Figure 41 shows the identified parameters related to the road layout. Once again, this is an important factor as each road type will have its own associated risks and characteristics which will influence the likelihood of an errant vehicle leaving the road.

D - Road Layout
Road Type (e.g. Single or Dual Carriageway)
Road Class (e.g. Public Roads or Local Roads)
One-way or two way traffic?
Number of Lanes

Figure 41 – Parameters identified relating to road layout

Figure 42 shows the parameters identified relating to accident history/frequency. It is obvious that the frequency of accidents in an area can affect the choice of VRS installation, since the likelihood of a run off the road accident is directly proportional to the accident frequency in the area.

E - Accident History / Frequency
Accident Frequency
Accident History

Figure 42 – Parameters identified relating to Accident History / Frequency

Figure 43 shows the other identified parameters that are not related to either likelihood or consequences of a run off the road accident. These are considerations that are mainly related to the selection of VRS type, after it is decided to install one.

Other
Aesthetics
Maintenance costs
Life-cycle costs

Figure 43 – Other Identified Parameters

4.3 Analysis of Most Frequently Used Parameters

Following the identification of parameters within the National standard and guidelines relating to the decision on whether to install a VRS, or not, and which level of performance the VRS should have, the data matrix was transferred into SPSS, a data analysis programme. This was then used to conduct a frequency analysis to identify those factors which occur most frequently within the analysed documentation. This section reports on those findings.

During the analysis there were a number of factors which were not included as they were not specifically referenced within the reviewed documentation in the majority of cases. However they are inherently important within the decision making process. Such considerations included cost – whilst specific elements of cost, such as maintenance and life-cycle costs were referenced, the underlying cost of the safety system itself was referenced in only a small number of cases. As a result, such factors are not specifically identified within the analysis, although they are important steps within the decision making process. In many cases, such considerations are covered by global procurement policy, and not specifically for the location and selection of VRS.

In almost all cases the forgiving roadside concept (remove – relocate - make passively safe) was applied, either by specific reference, or implied through the techniques and requirements contained within the documentation. For example, a barrier is only needed if an obstacle cannot be removed. Since this is the case for almost all of the standards, this was considered to be an underpinning requirement in all cases, and therefore not included in the analysis. Another example is the need for a terminal at the end of a safety barrier – this is also an underpinning requirement and hence, has not been included within the analysis.

In each Figure, the red line indicates that half of the standards/guidelines examined made reference to the parameter.

4.3.1 Roadside Barriers

4.3.1.1 Parameters Related to Roadside Barrier Installation

Most Frequently Referenced High-Level Parameters

Figure 44 shows that in the case of roadside barriers, the decision of whether to install a barrier, or not, is reliant heavily on the risk to vehicle occupants, road speed, road alignment/geometry and the existence of special risks to third parties (in that order).

Figure 45 to Figure 50 give further breakdown of these high level factors (in the same way that the darker colours are used within the data matrix to indicate hierarchy).

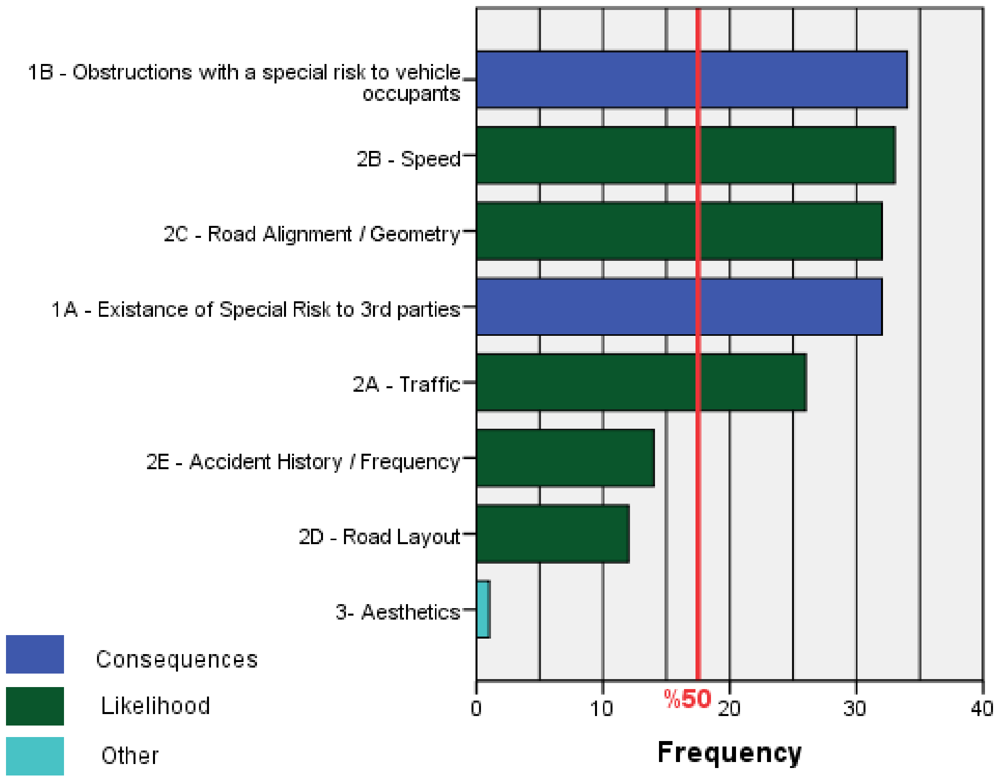


Figure 44 – Most frequently referenced ‘high-level’ parameters, roadside barrier installation

Risk to Vehicle Occupants

As shown in Figure 44, the risk to vehicle occupants is the joint most frequently referenced parameter relating to the installation of a roadside barrier, or not. Detailed examination of the characteristics within that category shows that the most frequently referenced parameters within National standards and guidelines are the existence of non-deformable objects, perpendicular to the direction of travel, and the presence of embankments, cutting slopes and bodies of water. It is therefore important that the crash statistics relating to these parameters are considered within the future studies of the SAVeRs project.

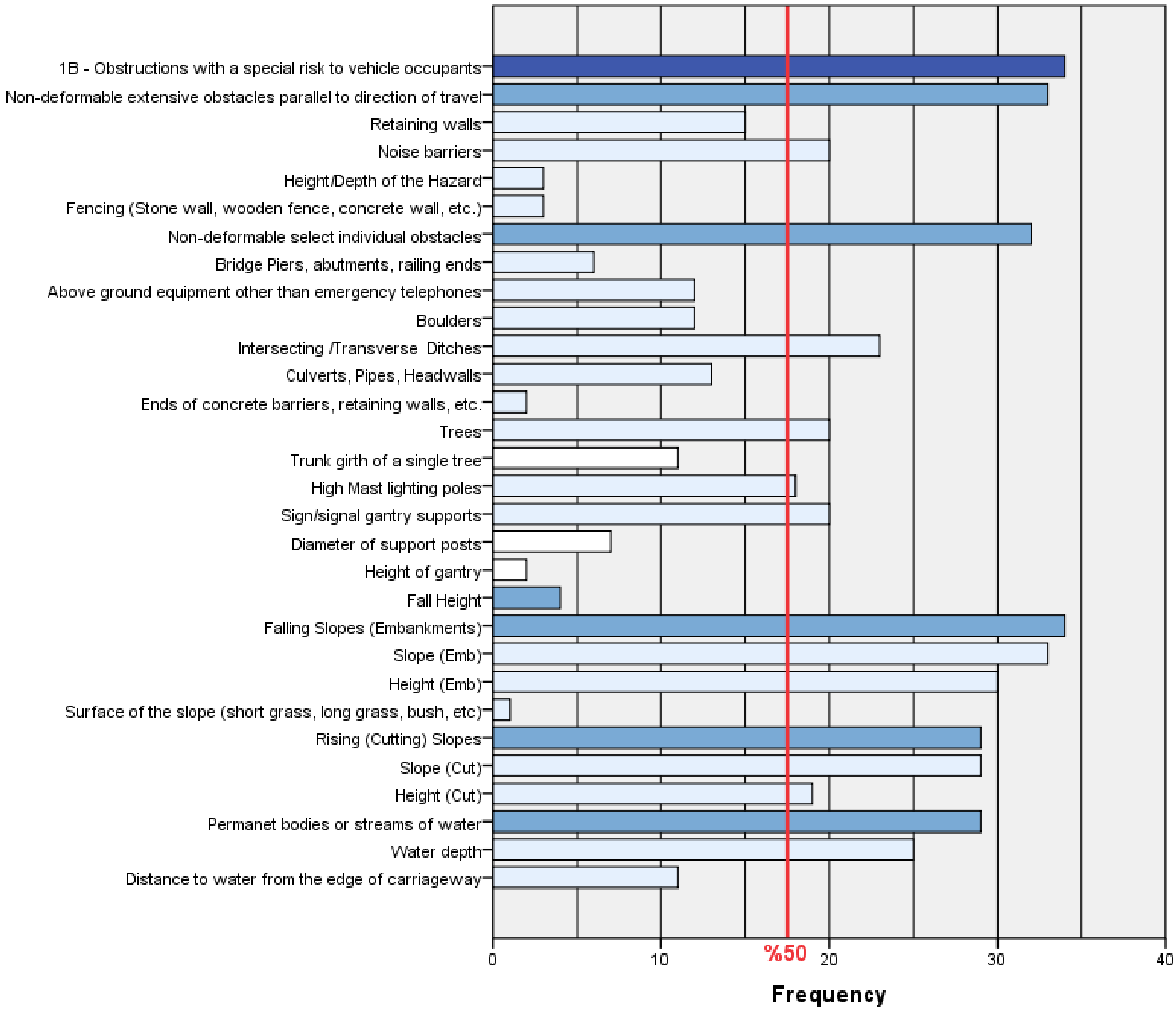


Figure 45 – Most frequently referenced 'risk to vehicle occupants' parameters, roadside barrier installation

Risk to Third Parties

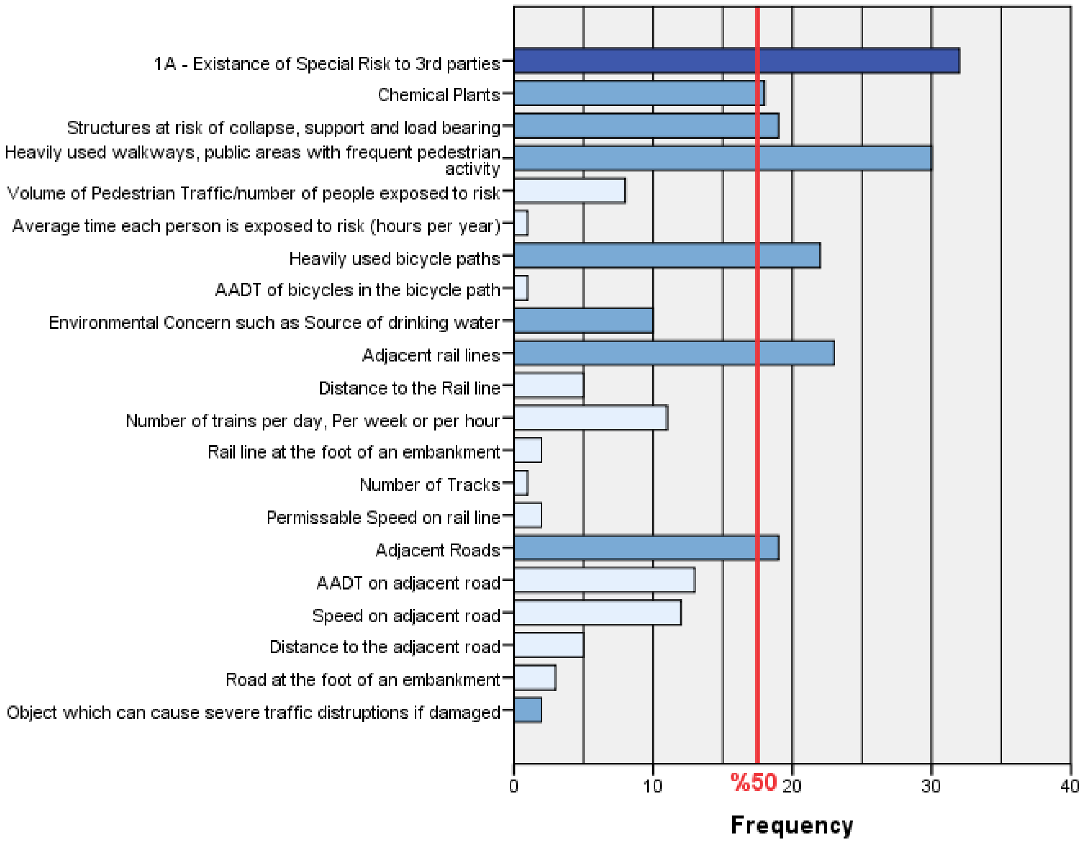


Figure 46 – Most frequently referenced 'risk to third party' parameters, roadside barrier installation

When the influence of third parties in the decision of whether to install a roadside barrier is considered, it is the presence of vulnerable road users which is referenced most frequently, be those pedestrians or cyclists. One other third party often acknowledged within the National standards and guidelines is the presence of railways. It is worthy of note that whilst the presence of these third parties is often referenced, the characteristics of them is not, i.e. although the presence of a railway is referenced in 20 documents, the frequency of its use is only a consideration in half of these.

Speed

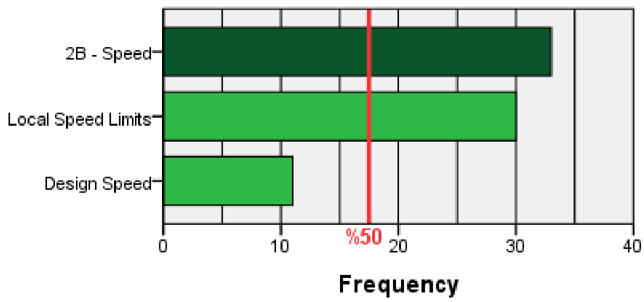


Figure 47 – Most frequently referenced 'speed' parameters, roadside barrier installation

Within those parameters most frequently referenced when deciding whether to install a roadside barrier, or not, it is speed which is referenced joint most frequently. As shown in Figure 47, it is most often the local speed limit which is used, rather than the design speed.

Road Alignment / Geometry

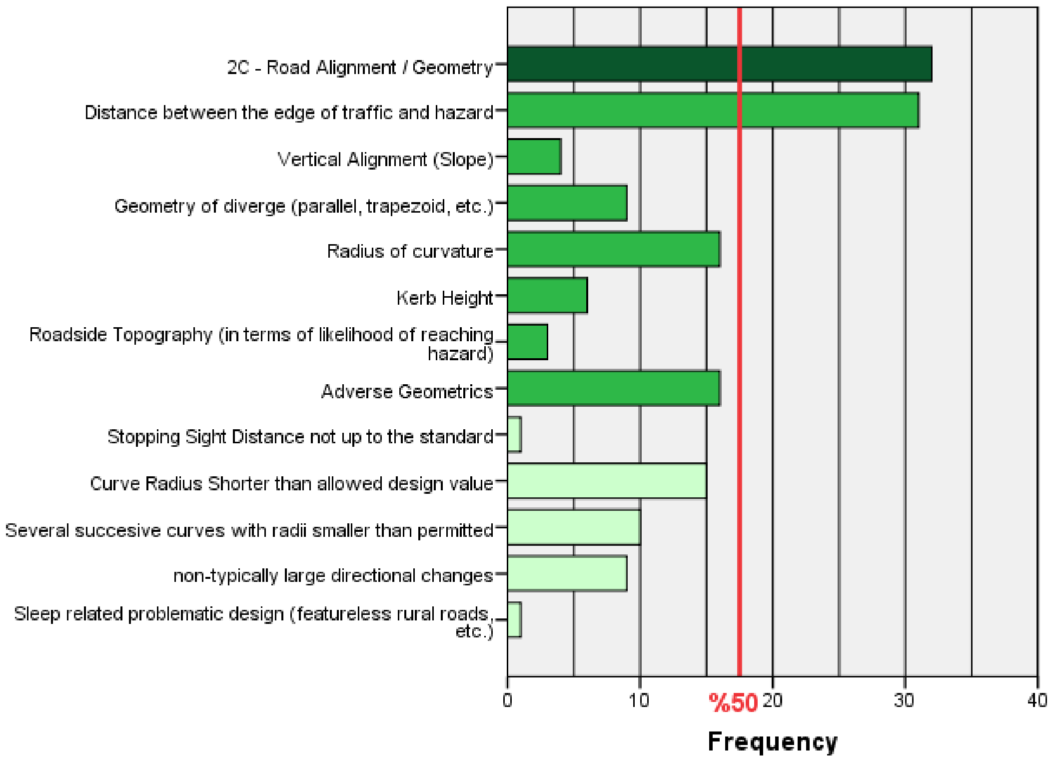


Figure 48 – Most frequently referenced 'road alignment/geometry' parameters, roadside barrier installation

With regard to parameters relating to road alignment/geometric issues shown in Figure 48, it is overwhelmingly the distance between the traffic and the hazard which is of most relevance when deciding on whether to install a roadside safety barrier. This is mainly due to the fact that the majority of the analysed countries adapted the 'Forgiving Roadsides' concept in their decision making process. The likelihood of an errant vehicle to reach a hazard on the roadside gets lower as the distance between the edge of the travelled way and the hazard increases. For this reason, majority of the countries warrant the installation of a roadside barrier only if the hazards are close enough to the roadside to pose a significant risk.

Traffic

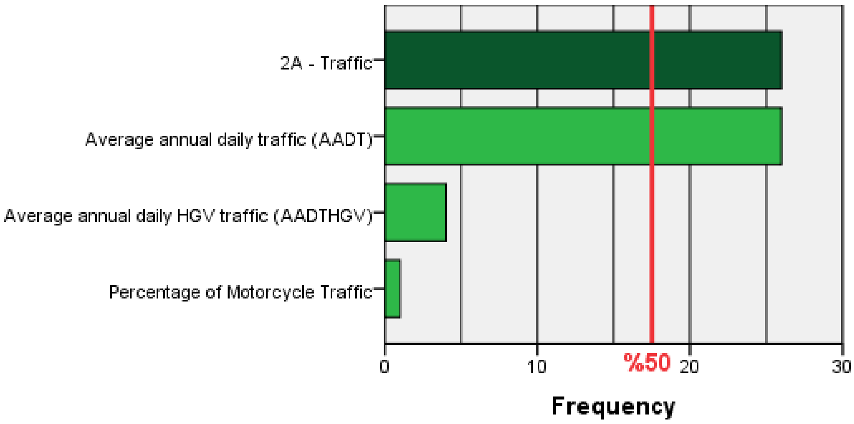


Figure 49 – Most frequently referenced ‘traffic’ parameters, roadside barrier installation

The decision on whether to install a roadside barrier is influenced by AADT in 23 of the 33 documents examined (see Figure 49). However, it is worthy of note that the way in which that traffic is made up is not a frequently used parameter when deciding whether to install a roadside barrier, i.e. the AADT of HGV and motorcyclists within that traffic is rarely considered.

Accident History/Frequency

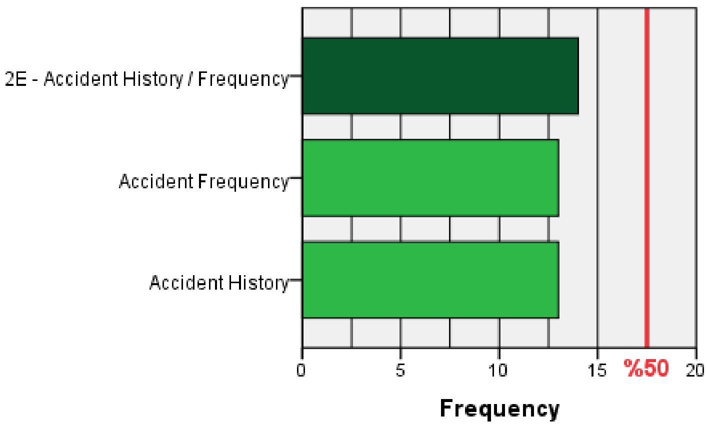


Figure 50 – Most frequently referenced ‘accident history/frequency’ parameters, roadside barrier installation

Perhaps surprisingly, the accident history/frequency of a location is referenced infrequently within the examined documentation when considering whether to install a roadside barrier (see Figure 50). This may be due to the fact that consideration of previous accidents are included in more general road safety documents and are not specific consideration for the installation of VRS. The analysed documents were more focused on the geometric applications for the location and selection of VRS rather than general road safety policy. It may also be because many National documents are written for new roads, and do not apply retrospectively.

Road Layout

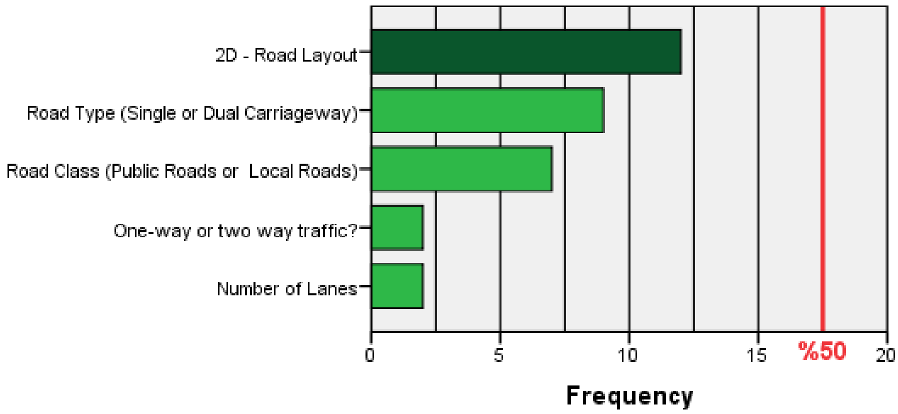


Figure 51 – Most frequently referenced 'road layout' parameters, roadside barrier installation

Figure 51 shows that the layout of a road has very little influence on whether a roadside safety barrier should be installed. This may be due to National standards and guidelines only applying to certain types of road.

4.3.1.2 Parameters Relating to the Selection of Roadside Barrier Type

Most Frequently Referenced High-Level Parameters

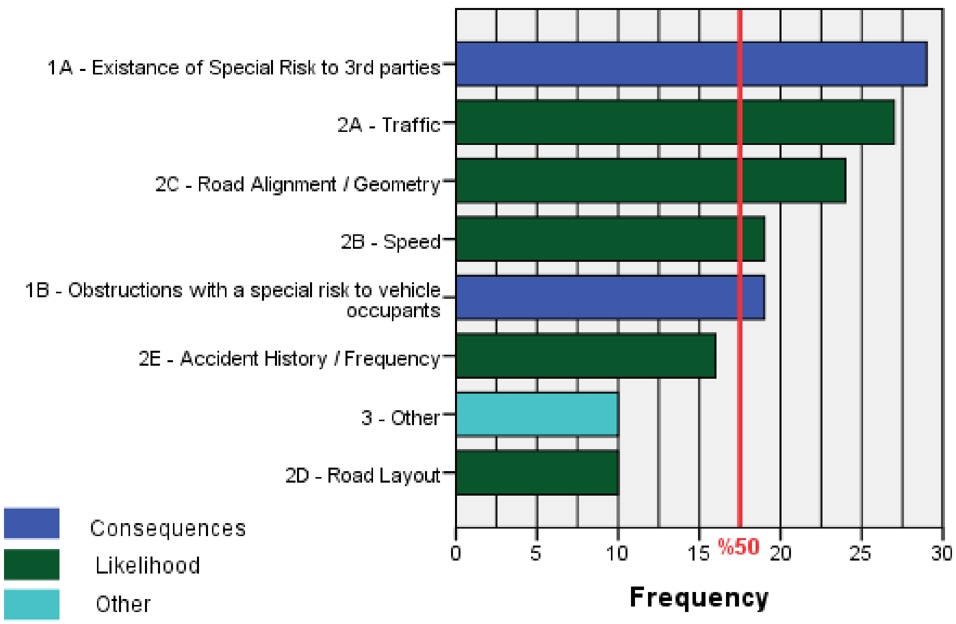


Figure 52 – Most frequently referenced 'high level' parameters, roadside barrier selection

Figure 52 shows that in the case of roadside barriers, the decision of which type of barrier to install is reliant heavily on the risk to third parties, traffic and road alignment/geometry (in that order). It is worthy of note that when selecting the type of barrier, the risk to third parties outweighs the risk posed to vehicle occupants.

Risk to Third Parties

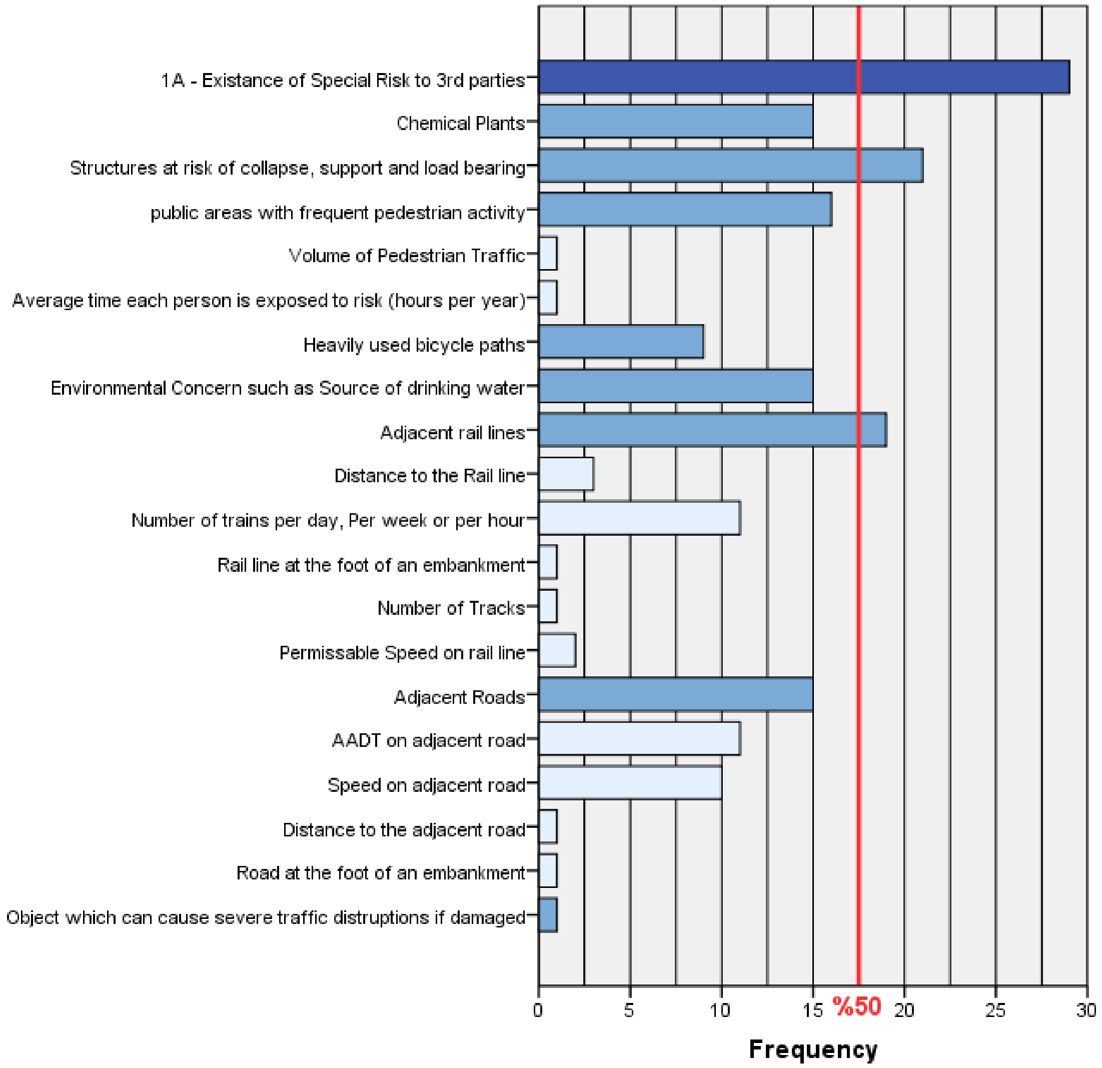


Figure 53 – Most frequently referenced ‘risk to third party’ parameters, roadside barrier selection

As shown in Figure 52, the risk to third parties is the most frequently considered parameter when establishing which performance of roadside safety barrier to install. In particular, it is the risk of collapsing structures and the presence of an errant vehicle on a railway line which is to be mitigated (see Figure 53). However, It should also be noted that while majority of the countries mention the existence of special risk to 3rd parties as an important parameter, not all of them go into the detail and list each specific hazard type to be considered. This is perhaps due to the fact that some of the guidelines encourage the use of engineering judgment instead of describing prescriptive measures.

Risk to Vehicle Occupants

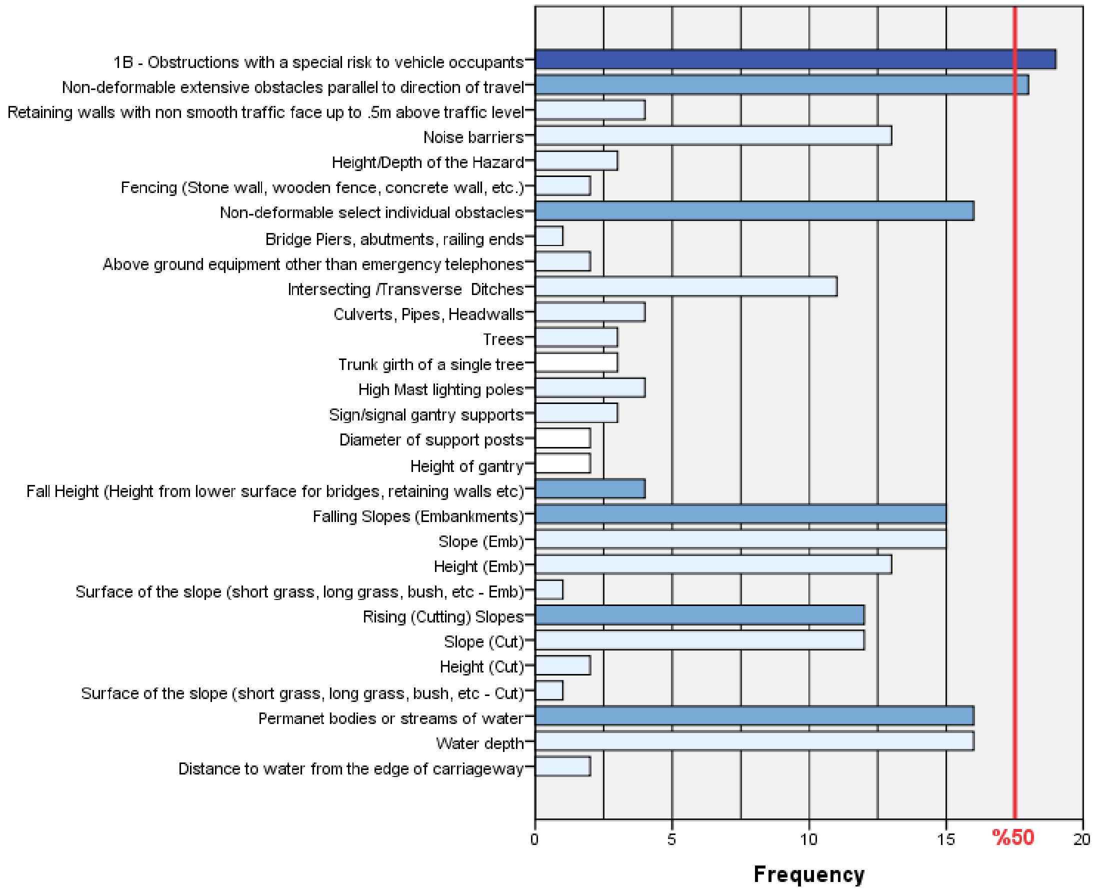


Figure 54 – Most frequently referenced 'risk to vehicle occupants' parameters, roadside barrier selection

Whilst the risk to vehicle occupants is only considered in 19 of the 35 standards and guidelines examined, Figure 54 shows that it is still the presence of non-deformable hazards and the presence of water which are often considered when selecting the performance of a roadside barrier.

Traffic

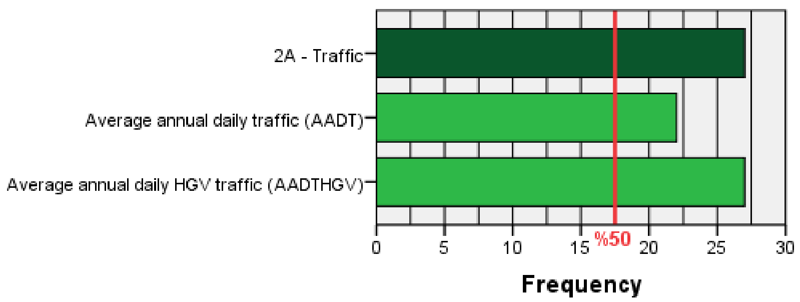


Figure 55 – Most frequently referenced 'traffic' parameters, roadside barrier selection

As for the decision on the selection of performance level, Figure 55 shows that it is the volume of HGV traffic which has the most influence in the choice of barrier containment level. This obviously due to the fact that higher containment levels are required to contain heavier vehicles and as the volume of heavy vehicles increase so does the likelihood of one leaving the road.

Road Alignment/Geometry

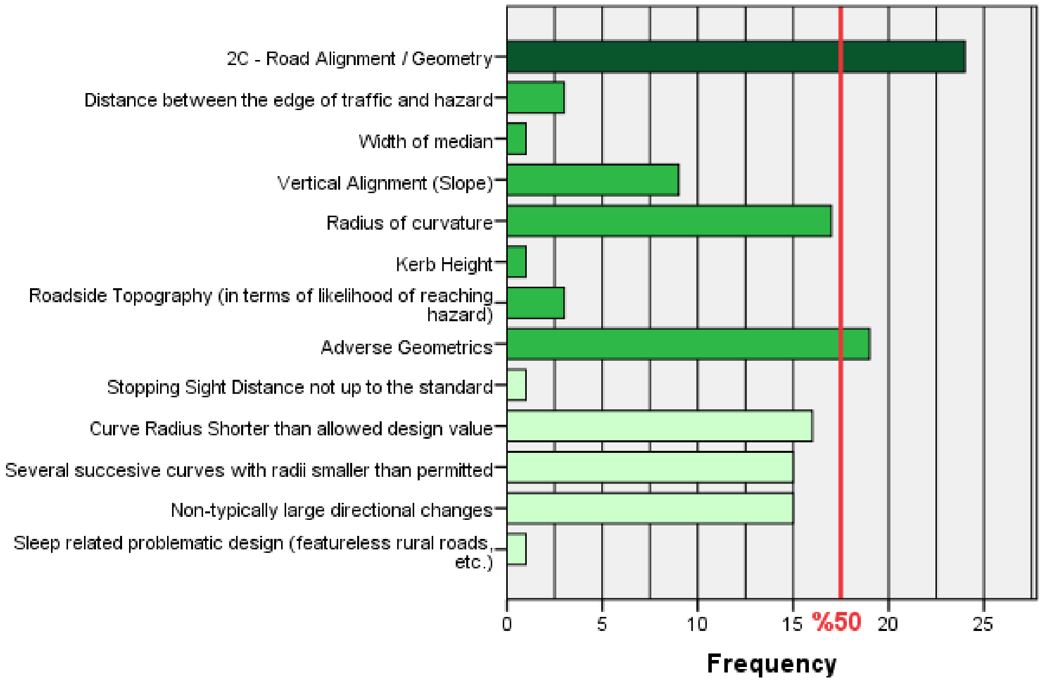


Figure 56 – Most frequently referenced ‘road alignment/geometry’ parameters, roadside barrier selection

Figure 56 shows that it is the presence of adverse geometrics, and the presence of numerous tight curves which can influence the choice of roadside barrier. It is perhaps surprising that these factors have less of an influence when deciding whether to install a barrier.

Speed

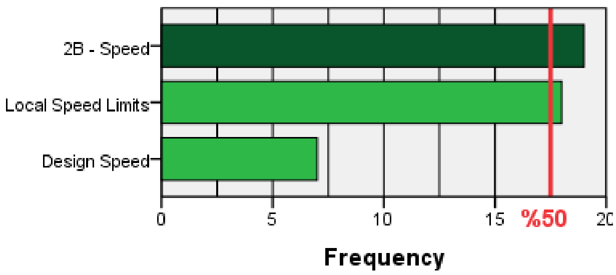


Figure 57 – Most frequently referenced ‘speed’ parameters, roadside barrier selection

Figure 57 clearly shows that it is local speed limits which dominate considerations on roadside barrier selection (where speed is considered).

Accident History/Frequency

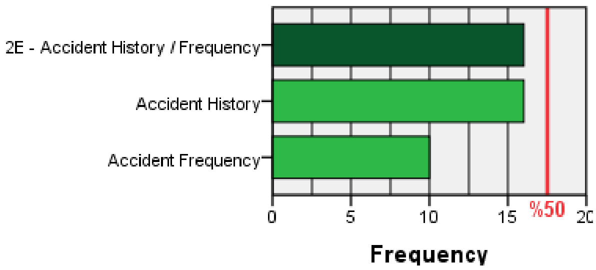


Figure 58 – Most frequently referenced ‘accident history/frequency’ parameters, roadside barrier selection

In those cases where accident history/frequency is considered (15 of the 33 standards/guidelines), it is the accident history which is most frequency referenced within the documents (see Figure 58).

Road Layout

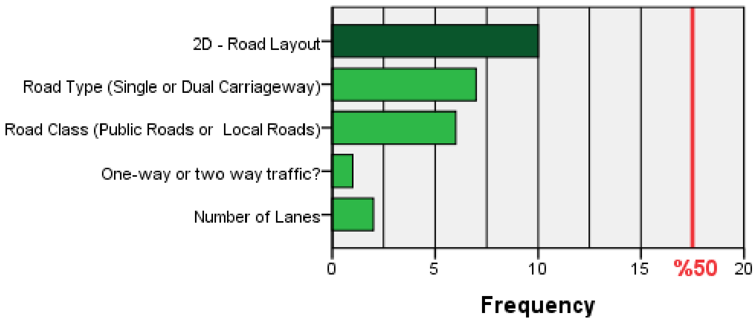


Figure 59 – Most frequently referenced ‘road layout’ parameters, roadside barrier selection

As shown in Figure 59, road layout is not referenced very frequently within National standards/guidelines, and therefore has little influence on the performance specification for installed roadside barriers.

Other Parameters

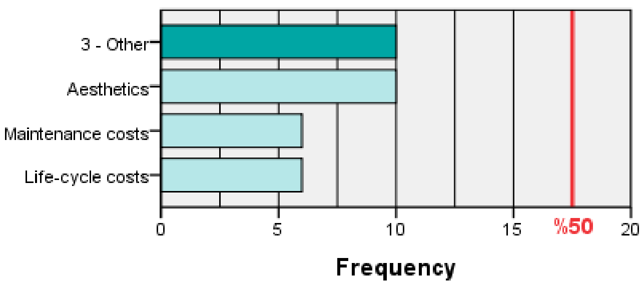


Figure 60 - Most frequently referenced ‘other’ parameters, roadside barrier selection

These other parameters (see Figure 60) are those considerations which need to be considered when selecting a roadside barrier, but they are not critical in the decision on which system to install. As these are all important factors, it is perhaps the case that these aspects are covered in more detail in supporting documents, not specific to roadside barriers.

4.3.2 Median Barriers

4.3.2.1 Parameters Related to Median Barrier Installation

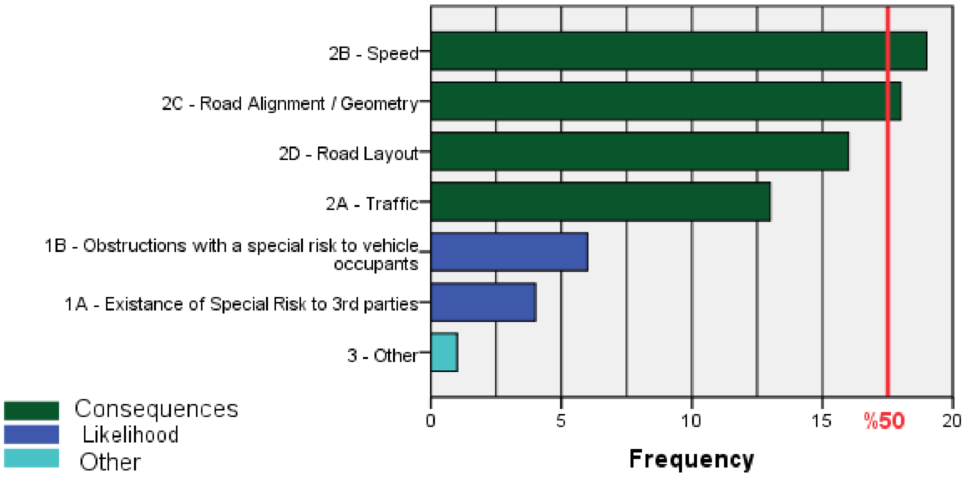


Figure 61 – Most frequently referenced high-level parameters, median barrier installation

Figure 61 shows that when making a decision as to install a median barrier, or not, it is the speed of the road and its alignment and layout which are considered most frequently within National standards/guidelines. This is perhaps to be expected as in many countries, for reasons of practicality, median barriers can only be installed if there is sufficient room available for them (and their deformation characteristics) and hence, they are often not suitable for some road layouts. These three factors will also give a level of indication as to the likelihood of a crash, and it is this which could be mitigated by the presence of a median barrier.

4.3.2.1 Parameters Relating to the Selection of Median Barrier Type

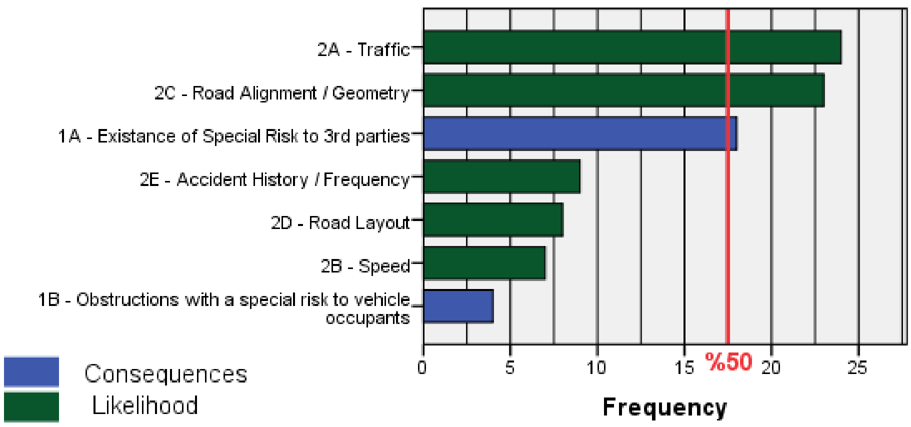


Figure 62 – Most frequently referenced high level parameters, median barrier selection

Furthermore, as shown in Figure 62, once it has been decided that a median barrier should be installed, the selection of that system will be dependent on the traffic, with the amount of HGVs using the road being a prominent consideration. One of the main reasons given within the standards and guidelines for the provision of median barrier is to reduce the risk of a vehicle travelling through the median and into the opposing carriageway. It is therefore of no surprise that a higher presence of HGVs will need to be a consideration when attempting to mitigate this risk.

4.3.3 Bridge Parapets

4.3.3.1 Parameters Related to Bridge Parapet Installation

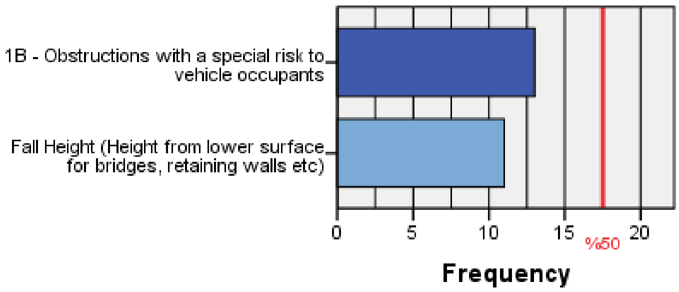


Figure 63 – Most frequently referenced high-level parameters, bridge parapet installation

With regard to the decision on whether to install a parapet on the side of a bridge, the main consideration is the fall height (see Figure 63). It is perhaps worthy of note that in most cases, the National standard/guidelines stated that bridge parapets should be installed on all bridge edges and hence, there is often little decision to be made in this regard.

4.3.3.2 Parameters Relating to the Selection of Parapet Type

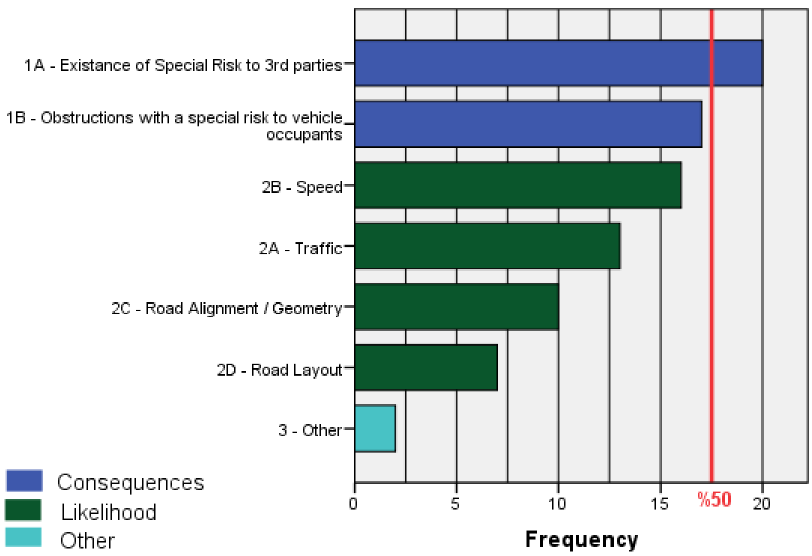


Figure 64 – Most frequently referenced high level parameters, bridge parapet selection

Whilst the decision of whether to install a bridge parapet is often prescribed, the performance of that parapet is not. Examination of the standards/guidelines has shown that it is the risk to third parties (over which the bridge will often pass) which is of paramount concern (see Figure 64). This exceeds the consideration of the risk to vehicle occupants, and points to the fact that in a number of cases it is the containment of the vehicle on the bridge which is of the greater importance.

4.3.4 Crash Cushions

4.3.4.1 Parameters Related to Crash Cushion Installation

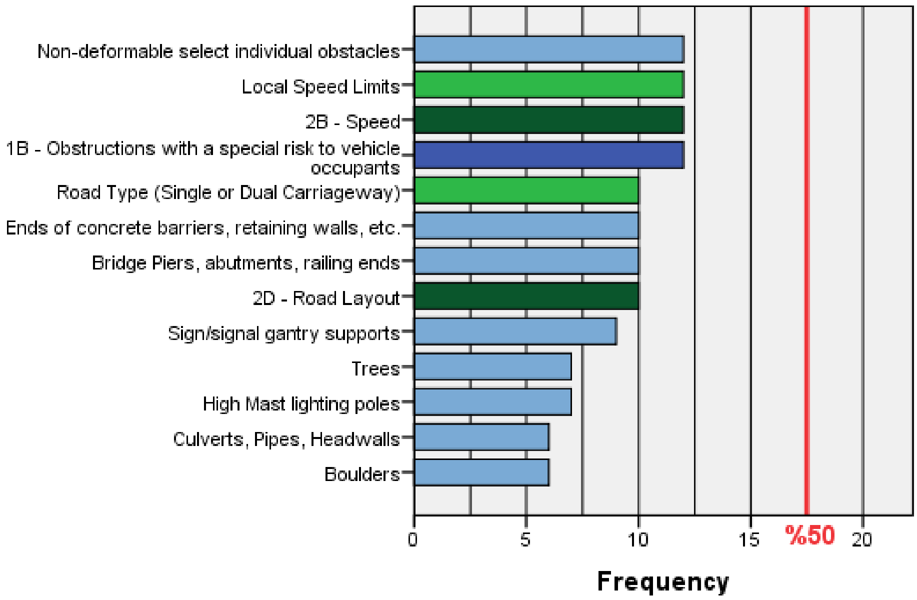


Figure 65 – Most frequently referenced parameters, crash cushion installation

It is first worthy of note that guidance on whether to install a crash cushion is limited, with guidance being provided in only 12 of the 35 countries examined (see Figure 65). Given the function of a crash cushion, it is perhaps unsurprising that the presence of a non-deformable single object would give rise to the installation of a crash cushion system. The other parameters in Figure 65 are simply examples of such.

4.3.4.2 Parameters Relating to the Selection of Crash Cushion Type

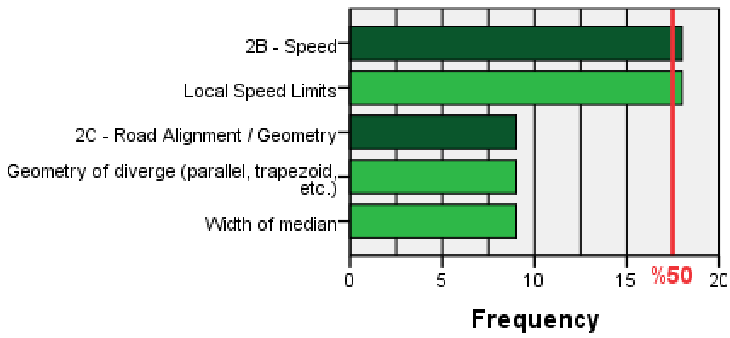


Figure 66 – Most frequently referenced high level parameters, crash cushion selection

With regard to the selection of the crash cushion performance, there is more guidance given than for the locating of such devices. This is perhaps surprising as the standards/guidance therefore give information on which performance is required, but not in which locations. With regard to the performance requirements, Figure 66 shows that it is the local speed limit which should be used as the defining parameter. Given that speed based performance classes are one of the ways in which crash cushions can be selected in accordance with the testing and classification standard EN1317 this is, perhaps, to be expected.

4.3.5 Terminals

4.3.5.1 Parameters Related to Terminal Installation

There were no parameters identified associated with whether to install a terminal, or not, as in many cases it was specified that each barrier should be fitted with an appropriate terminal by default.

4.3.5.2 Parameters Relating to the Selection of Terminal

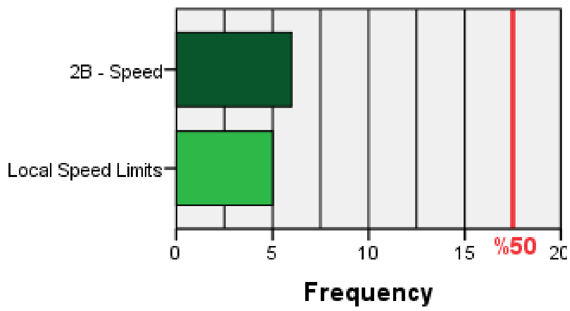


Figure 67 – Most frequently referenced high level parameters, terminal selection

As shown in Figure 67, there is very little guidance given on the performance of terminals within the examined standards/guidance. However in 6 of the 35 countries, local speed limits should be considered. As for the selection of crash cushion performance, this is perhaps not surprising as speed based performance classes are one of the ways in which terminals can be selected in accordance with the testing and classification standard EN1317. In a small number of countries, the required level of terminal performance is determined by its location on the barrier (i.e. whether it is on the approach or departure end of the barrier). This is the case in Sweden, Ireland and the UK.

5 Review of Published Literature

The goal of Task 1.2 is to find out how the placement and choice of suitable VRS is approached and assessed by researchers. In fact the actual decisions taken by NRAs are mostly based on national tradition and acknowledged studies while on-going research should be able to point out to changes driven by the development of the road infrastructures. For the sake of simplicity, the review has been approached by searching how different actors play a role in the decision making of VRS placement. The point of view of policy makers, vulnerable road users such as cyclist and pedestrians and motorcyclists were investigated and the available analyses of crashes involving safety barriers were assessed looking at both financial implications and safety.

5.1 *Safety considerations for safety barriers and vehicle parapets*

Due to the specific function of vehicle restraint systems, in that they are used within the roadside to reduce the risk of injury to road users in the event of a loss of control, etc., one of the most important aspects of the systems used is that they present less of a risk to road users than the roadside hazards which are located in front of.

This is reflected within the current impact testing standards for vehicle restraint standards where, in general, test matrices have been established which evaluate both the ability of the vehicle restraint system to contain and redirect an errant vehicle whilst, at the same time, providing levels of occupant deceleration which were thought at the time of initially drafting the standards, to be survivable (CEN 2002, 2010a, 2010b, 2010c, 2012b). (CEN 2012a)

During such tests, deceleration is recorded in all three planes (x, y, and z), whilst yaw rate is also recorded using a rate sensor (or established from high speed video photography following the test). Once the test has been completed these data are then filtered using a standard 13Hz filter and used to compute the values of two criteria; the Acceleration Severity Index (ASI) and the Theoretical Head Impact Velocity (THIV) (CEN 2010a). ASI is calculated using the following formula:

$$\mathrm{ASI} = \sqrt{\left[\left(\frac{A_x}{12}\right)^2 + \left(\frac{A_y}{9}\right)^2 + \left(\frac{A_z}{10}\right)^2\right]}$$

Where Ax, Ay and Az are the filtered components of vehicle acceleration at any one point in time. The maximum value of ASI during the impact event is then identified, reported and classified as follows:

Impact severity level	Index values
A	ASI ≤ 1,0
B	ASI ≤ 1,4
C	ASI ≤ 1,9

THIV is the velocity with which a free moving (unrestrained) head would impact the side of theoretical box measuring 0.6m in depth and 0.3m in width (on either side), using the vehicle-based instrumentation. In all tests, the value of THIV must be below 33 km/h for the test to be deemed compliant.

Whilst the use of ASI and THIV have now become well established within the roadside safety community, little work has been completed to date to identify whether the approach, and indeed limiting values, correspond well to the levels of injury and impact severity seen within on-road crashes. A good summary of the limited study work is made by Roque and Cardoso (Roque & Cardoso 2013). They conclude that whilst work has been undertaken to relate ASI and THIV to injury, much of the work has looked at impacts solely in the frontal configuration, not using the angular approach of EN1317 testing and hence, correlation is difficult to achieve with any degree of certainty. They continue by stating that safety barriers of impact severity level A and B appear to provide similar levels of injury to vehicle occupants, with little distinction between the two categories. As a result, they identify safety barriers of severity level C to require additional consideration before use (as the level of impact severity and actual injury is elevated in terms of numbers of fatalities and those seriously injured).

Today, as reported by Gabauer and Gabler (Gabauer & Gabler 2010), the presence of primary and secondary safety features within vehicles on the road (such as seat belts and airbags) could significantly reduce the risk of injury to vehicle occupants in the event of an impact with a vehicle restraint system. Based on a sample of 686 crashes, they calculated that compared with an unbelted occupant, seat belted occupants with an airbag have a decreased risk of receiving a serious injury of 97%. A similar decrease was also identified if the occupant was wearing a seat belt, without an airbag. They conclude that their findings suggest that current longitudinal barrier occupant risk criteria (ASI and THIV) may over-estimate injury potential for restrained occupants involved in such impacts.

Schneider et al (2009) also found that unbelted drivers were up to 10 times more likely to suffer fatal injuries in crashes involving safety barrier systems. Gabauer and Gabler (Gabauer & Gabler 2010) added that airbags were seen to deploy in some 70% of all tow-away impacts, with greater deployment in impacts with concrete barriers. They added that in their study (based on US data), seat belt usage was found to be 86% in airbag-equipped vehicles.

However, whilst the benefits of impact severity reduction through the inclusion of in-vehicle systems may be somewhat easily identifiable, work by Grzebiata, et al. gives warning that such in-vehicle systems can, in themselves cause additional hazards to vehicle occupants during an impact with a vehicle restraint system. They identify the fact that the timing of airbag inflation is generally tuned to the slower speed frontal impact of other regulatory testing, not to the high speed angular impacts witnessed during EN1317 testing. Due to the flexible nature of some vehicle restraint systems, it is possible that in the event of an impact with a flexible safety barrier system, the airbag may inflate late in the impact event, when the occupant's head has already moved too close to the airbag cover. Firing of an airbag too late can guide the occupant's head towards the vehicle's A-pillar (see glossary), increasing the risk of injury and considerably hindering the driver's recovery process. They continue by identifying that the main issue for barrier designers and barrier manufacturers is to ensure that when a vehicle strikes the barrier system the airbags do not unnecessarily inflate and/or, they inflate at the correct time during the impact event.

5.2 Placement of safety barriers and vehicle parapets

5.2.1 Introduction

The placement of vehicle restraint systems is ruled from the need of protecting road users from risks related to cross over collisions and impact with fixed objects, in both the central reserve and the roadside. A large number of studies have been undertaken to allow optimisation of the number, length and location of vehicle restraint systems installed in the roadside and the central reserve of roads. Most of these studies have utilised collated crash data, although the number, quality and relevance of the crashes investigated should be understood, in all cases. In some cases it is the vehicle restraint systems itself which is being examined, in others, the general application of the restraint systems as a safety measure.

Alluri, et al. (Alluri, K. & Gan 2012) have examined the effectiveness of two safety barrier types prevalent in the US; the GA-type strong post, corrugated beam safety fence system and a wire rope median barrier. In the case of the strong post system they identified that on a 1,652.3 km length of the barrier there were 8,674 cases in which the safety barrier was impacted. Of these impacts, 94.5% of the impacts resulted in the impacting vehicle being contained by the barrier system. It is important to note that some of the impacts with the barrier will have been outside of the design parameters of the barrier system (e.g. an impact in which the weight and/or speed and/or angle exceeds the level to which the system has been designed and tested). They noted that compared to roadside safety barriers, median barriers accounted for a slightly higher percentage of crashes in which the barrier was breached by the impacting vehicle. By comparison, when a 162.5 km long installation of wire rope median barrier was examined, it was reported that 549 impacts occurred and, of these, containment occurred in 83.6% of cases. Overall 98.1% of cars and 95.5% of light trucks that hit the barrier were prevented from crossing the median. In addition to the in-service performance of the central reserve rope barrier itself, Alluri, et al. (Alluri, K. & Gan 2012) also examined the before and after effects of the central reserve rope barrier's installation. They found that the installation of the median barrier had reduced the fatal impact rate by 42.2%, the severe injury rate by 20.1% and the minor injury rate by 11.6%. However, the rate of crashes involving possible injury and property damage rose by 53.1% and 88.1% respectively, resulting in an overall impact rate increase of 37.8%. This emphasises that safety barriers are, in themselves, also hazards and hence, their use should only be as a last resort where other safety measures cannot be implemented.

Work by Candappa et al. (Candappa et al. 2009) has also examined the effectiveness of flexible barrier systems, this time on the Australian road network. In this case, a total of 101.6 km of road length was installed with wire rope safety barrier. The study compared the impact frequency at road sections before and after the treatment. The results indicated that the barriers could be associated with significant reductions in the risk to both casualty and serious casualty rates. These reductions varied from site-to-site, but were, on average, around 76% for all casualty impacts and 77% for serious casualty impacts. The report also states that these figures align closely with work from previous international studies citing, in particular, reports from Sweden and the US. The report concludes that the introduction of flexible barrier systems, such as wire rope, is likely to produce substantial reductions in crash occurrence, in particular in cases of off-road and head-on impacts for both casualty and serious casualty impacts.

A further examination of the effectiveness of median barriers (Martin & Quincy 2001) showed that the crossover event was rare, identifying that in 0.5% of car crashes and in 7% of crashes in which the median barrier was struck by a truck, the vehicle was not contained by a safety barrier. This was further clarified by stating that concrete profiled New Jersey barriers had been breached in 0.3% of crashes, whereas steel barriers had seen a 1.3% crossover rate. However the authors emphasised that although there was a greater level of containment by the concrete profile, the number of casualties from impacts with concrete barriers was 1.7 times greater. They added that this increase in severity is not observed if the focus is jointly on serious and fatal injuries. The authors also conclude that crossover crashes are more serious than other types of crashes with 19% resulting in fatalities and 43% resulting in some level of injury. As a word of warning, the authors state that in recent years in France, extra traffic lanes have been added to existing motorway sections, which has often led to a reduction in central reserve strip width. New motorways are being built with a maximum 5 m wide median barrier (to limit ground surface requirements and cost). It should be noted that this type of limitation is starting to become a problem in the United States, in particular for urban expressways. According to the authors in these median-strip-width conditions, one possible strategy to reduce the number of median barrier crossings significantly is to place barriers with higher containment capacities (level H2 or over) than those most commonly used, and this is a process which has been implemented by numerous National Road Authorities across Europe.

Whilst the safety benefits of vehicle restraint systems are therefore well documented, there are occasions where safety barriers are purposely not installed due in part to the hazard posed by their installation. Instead wide central reserves (9 m) have been used as a lane separator. The positive effects of this are that there is the removal/non installation of a longitudinal hazard (the safety barrier), however the lack of any positive restraint within the central reserve does not eliminate the hazard. This is well documented by Davis and Pei (Davis & Pei 2005) who reconstructed five crashes in the US where a wide central reserve (greater than 9 m) without an installed safety barrier was traversed, causing fatalities on the opposite carriageway. In the US, a 9 m (30 ft) wide central reserve is thought to be sufficiently wide for 80% of out-of-control drivers to regain control of their vehicle. Davis and Pei conclude that whilst the 9 m central reserve was in place, fatal crashes still occurred and could have been mitigated had a normal containment (TL3) safety barrier been in place.

The use of the clear central reserve has also been examined by Donnell et al. (Donnell, E. et al. 2002). In this particular case, the Pennsylvanian Department of Transportation’s design policy was reviewed which stated that safety barriers were not required for central reserves with a width of 10 m or more and with an average daily traffic of 20,000 vehicles per day. The report concluded that crossover crashes, whilst rare, result in fatal injuries in 15% of cases, with 72% crashes resulting in nonfatal injuries. The report also states, however, that on earth-divided roads, crossover crashes decrease as the central reserve width increases (due to the increase in vehicle recovery time). In addition, it was found that crossover crashes occur more frequently downstream of interchange entrance ramps, and that they are more likely to occur during periods of adverse weather (wet or icy) than other types of crash.

Donnell and Mason Jr (Donnell, E., K. & Mason Jr 2004) then took the 2002 study further by developing models for central reserve-related impact severity. Data were collected to model impact severity, including cross-section, traffic volume, and environmental predictor variables. Logistic regression models were then used to analyse the data. The results indicated that modelling crash severity as an ordinal response provided appropriate results for cross-central reserve crashes, whereas a nominal response was more appropriate for median barrier crashes. Explanatory variables such as pavement surface conditions, use of drugs or alcohol, presence of an interchange entrance ramp, horizontal alignment, crash type, and average daily traffic volumes can all affect the degree of impact severity. Furthermore, they reported that approximately 0.7% of median barrier impacts on the Interstate system resulted in a fatality, whereas 43% were property-damage-only impacts and about 56% were injury impacts. More than 17% of cross-central reserve collisions were fatal, and 67% involved injury.

Later, in 2005, Miaou et al. (Miaou, Bligh & Lord 2005) conducted similar work to Donnell et al. (Donnell, E. et al. 2002), looking at similar aspects within the roads of Texas. Their research concentrated further on the modelling of crashes, basing this more directly on the benefit-cost relationship, rather than on the pure safety considerations in the Donnell et al study. They concluded that a positive cost-benefit could be achieved with clear wide central reserves.

Although central reserve safety barriers are an absolute means of providing positive levels of protection for road users, Tarko et al. (Tarko, Villwock & Blond) also consider that the introduction of central reserve safety barriers can also cause additional crashes to occur. An example would be that if the opposing carriageway is free of traffic whilst the travelled carriageway contains queuing traffic. In such cases, the argument could be made that it might be safer to allow the vehicle to pass through the central reserve, instead of redirecting it into the queuing traffic. Hence, being able to predict the safety impact of different barrier systems can be beneficial to all stakeholders involved in road safety.

Realistic impact prediction models sensitive to the central reserve design would provide the needed guidance useful in designing adequate central reserve treatments on widened freeways. The impact of central reserve designs on crash frequency was investigated by Tarko et al. (Tarko, Villwock & Blond) through regression and before-and-after studies based on data collected in eight participating states. The separate effects of changes in central reserve geometry were quantified for single-vehicle, multiple-vehicle same direction, and multiple-vehicle opposite direction impacts. The results were significantly different and indicated that reducing the central reserve width without adding barriers (the remaining central reserve width is still reasonably wide) increases the severity of impacts, particularly opposite direction crashes. Further, reducing the central reserve and installing concrete barriers eliminates opposite direction crashes but doubles the frequency of single-vehicle crashes and tends to lessen the frequency of same direction crash. The impact severity also tends to increase.

Similar results were also developed by Elvik (Elvik 1995) who also concluded that median barriers are found to increase crash rate, but reduce crash severity. In general terms, he also concluded that roadside safety barriers and crash cushions reduce both crash rate and severity, adding that safety barriers reduce the chance of sustaining a fatal injury by about 45%, given that a crash has occurred. The chance of sustaining a personal injury is reduced by about 50%.

Whilst the central reserve has been the focus for many papers and research articles, there has been limited study for the effectiveness of roadside barriers. One such study was that of Schneider et al. (Schneider IV, Savolainen & Zimmerman 2009). Their specific area of study was in the locating of safety barriers within horizontal curves on rural two-lane highways in Texas. This study involved the development of numerical models to assess driver injury severity resulting from single-vehicle impacts on such roads. Likelihood ratio tests warranted the development of separate injury severity models for curves of small, medium, and large radius. Various driver, vehicle, roadway, and environmental characteristics were found to affect injury severity among the 10,029 impacts analysed. Run-off-the-road crashes, particularly those resulting in collisions with roadside objects, were found to increase injury severity significantly. Females were more likely to sustain injury and older drivers to be critically injured, particularly on curves of smaller radius. Various driver actions and behaviours were also significant determinants of injury severity. Drivers who were uninsured, fatigued, or under the influence of drugs or alcohol were more likely to be seriously injured. Several of these behavioural factors were more pronounced on sharper curves.

Within the new chapter for the prediction of crashes on freeway segments developed within the NCHRP 17-45 Project “Safety prediction methodology and analysis tool for freeways and interchanges” to be included in the new edition of the HSM (Bonneson et al., 2012), a specific crash modification function (CMF) and severity distribution function (SDF) has been developed allowing to estimate the effect of having a clear zone of a given width or a safety barrier on the expected number of fatal and injury crashes. These models show that the number of fatal crashes is generally lower with a 9 m clear zone than with a safety barrier placed at the edge of the shoulder but in many cases the latter solution reduces fatalities as compared to having limited clear zone widths (5-6 m) even though the effectiveness of placing a safety barrier is dependent on the specific conditions and should be evaluated on a case by case basis. For narrower clear zones the placement of safety barriers tends to increase the crash frequency while the crash severity is reduced.

The study by Ventataraman et al. (Venkataraman et al. 2000) examined the in-service performance of bridge parapets. The report highlights that whilst the application of bridge parapets is to be applauded, the consequences of substandard parapet installations is to be avoided, at all costs due to the subsequent likelihood of injury. The report advises that where it is evidenced that bridge parapets are not performing as designed, in any way, retrospective alterations should be made to regain the expected levels of performance.

Ironically, as identified by Duijm (Duijm 2009) standard safety management tool such as ‘safety-barrier diagrams’, designed as risk analysis and safety management tools can be very effective at identifying the risks associated with the installation of safety barrier systems, indicating to the user all of the risks which should be borne in mind before going ahead with any safety and/or risk related scheme.

Whilst there are large number of considerations to be made regarding when and where to install a safety barrier, a barrier is only effective if it is sufficiently long to provide adequate protection to road users. A barrier too short may allow an errant vehicle to traverse behind the barrier, whilst a barrier too long in length will present an additional hazard to road users. A study by Tomasch et al. (Tomasch et al. 2011) looked at the specific case of vehicles running behind safety barriers, highlighting the hazards which may be presented to the occupants of the errant vehicle. In order to ascertain guidelines for the minimum length of safety barrier to be installed, the authors analysed the speed with which vehicles leave the roadway from a National (Austrian) crash database. The result concluded that the required length of safety barrier was considered to be the length that reduces the vehicle speed by a maximum possible deceleration of 0.3 g behind the barrier.

To determine the desired length of a barrier ahead of a hazard, Tomasch et al. (Tomasch et al. 2011) developed a relationship between barrier length and the speed at which vehicles depart the roadway. If an impact is to be prevented, the minimum length of a safety barrier at the road departure speed at 130 km/h and impact speed of 64 km/h is approximately 180 m. Using an acceptable impact speed of 40 km/h, a minimum length of 213 m is required. If the initial length of barrier is flared away from the carriageway, the required length will be reduced by up to an additional 30%. The authors demonstrated that application of this approach would reduce the number of fatalities among occupants of vehicles striking bridge abutments by approximately 8%.

5.2.2 Main findings

- Central reserves have been the focus of many papers and research articles; there has been limited associated study for the use of roadside barriers.
- Several studies focus on the effectiveness of rigid and flexible barriers on reducing accident severity (Alluri, K. & Gan 2012; Candappa et al. 2009; Martin & Quincy 2001).
- Most of the studies on central reserve conclude that median barriers are found to increase crash rate, but reduce crash severity (Alluri, K. & Gan 2012; Martin & Quincy 2001).
- Wide central reserves (9 m or more) used as a lane separator positively results in a the removal/non installation of a longitudinal hazard (the safety barrier) (Miaou, Bligh & Lord 2005; Tarko, Villwock & Blond). However, this does not completely eliminate the crossover hazard (Davis & Pei 2005; Donnell, E. et al. 2002).
- In recent years in Europe economic and practical reasons have often led to a reduction in central reserve strip width up to 2.5 m. In these central reserve-strip-width conditions numerous National Road Authorities have decided to erect barriers with higher containment capacities (level H2 or over) than those most commonly used

(level N2), (Martin & Quincy 2001). The same finding is starting to be acknowledged in the US.

- According to (Elvik 1995) safety barriers reduce the chance of sustaining a fatal injury by about 45%, given that an accident has occurred. The chance of sustaining a personal injury is reduced by about 50%.
- The study by Ventataraman et al. (Venkataraman et al. 2000) highlights that whilst the application of bridge parapets is to be applauded, the consequences of substandard parapet installations is to be avoided, at all costs due to the subsequent likelihood of injury.
- Risk analysis and safety management tools such as 'safety-barrier diagrams' can be very effective at identifying the risks associated with the installation of safety barrier systems.

5.3 Bridge safety barriers and third parties protection

5.3.1 Introduction

The review of standards from different European countries has shown that in many cases, the containment level of bridge parapets is higher than for roadside safety barriers for the same road type and the traffic level.

The studies conducted by Domenichini et al. (2004), Duprè and Bisson (2006) and Shankar et al (2000), in addition, show that the selection of appropriate bridge vehicle restraint system (B-VRS) and the determination of its containment level should be the result of risk and cost-benefit analyses.

Projects conducted in different country by J. Kuebler (2013) and H. Ngo (2012) and the Technical document published by Queensland Government (2009) and NSW Government (2013) show that the selection and installation of B-VRS is defined as a function of level of risk determined in the risk analysis and the cost-benefit assessment that describe the social cost connected to the environmental vulnerability (damage to the third parties under the bridge).

The selection procedures described in the literature analysed are similar and allow to define the protection level of the bridge roadside as a function of the following variables:

- Horizontal distance between bridge edge and vulnerable environment (rail corridor, residential area, chemical plant, river, pedestrian or bicycle path);
- Embankment slope (in the approach to the bridge);
- Geometric road element (horizontal curve);
- Environment vulnerability;
- Road “status” (type, design speed and AADT);
- Need to increase the barrier height;
- Need to prevent vehicles from falling off the edge of the structure.

The different papers analysed allow to identify the following procedure to selecting the need of VRS and, where is need, the appropriate VRS.

5.3.2 Selection of barrier adjacent to rail corridors

The research conduct by S. Barlow (2009) based on the Queensland Government Technical Specification QR MCE-SR-007 (2009) defines basic methodologies to select the appropriate barriers adjacent to rail corridors.

First, in the selection procedure, in necessary analysed the railway and road status classified as a function of their use (railways) and their class of traffic (roads).

In Table 74 and in Table 75 the main characteristics considered for the rail corridors are summarized.

Table 74 - Railways status (S. Barlow, 2009)

Railway status	Description
MPE	Main-line electrified (high passenger train frequency), i.e. the suburban network
MC & DG	Main country passenger and goods lines (eg. NCL) & light trafficked dangerous goods lines (i.e. explosive or highly flammable)
SP	Secondary passenger and/or goods lines. 1-5 trains / 24 hours
L	Light country lines >7 trains per week
C	Coal / mineral lines

Table 75 - Road/Road Bridge Overpass Status (S. Barlow, 2009)

Road status	Description	Speed (km/h)	Traffic volume (veh/day)
1A	Arterial & dual carriageway	110	100,000
1B	Arterial & dual carriageway	80	70,000
1C	Arterial & dual carriageway	60	50,000
2A	Arterial, connection roads and rural highways	110	50,000
2B	Arterial, connection roads and rural highways	80	30,000
2C	Urban road	70	10,000
3	Residential street	60	1,000

The selection of barrier performance level and the barriers height are based on Table 76 in which the minimum requirements defined in the Queensland Government Technical Specification QR MCE-SR-007 (2009) as a function of road and rail status are shown.

Table 76 - Selection of the bridge safety barriers (S. Barlow, 2009)

Road status	Barrier Height (m) and Barrier Perfromance Level to AS 5100				
1A	2.0 (Special)	1.5 (Special)	1.5 (Medium)	1.1 (Medium)	1.5 (Special)
1B	1.5 (Special)	1.5 (Medium)	1.1 (Medium)	1.1 (Regular)	1.5 (Medium)
1C	1.5 (Special)	1.5 (Medium)	1.1 (Medium)	1.1 (Regular)	1.5 (Medium)
2A	1.5 (Special)	1.5 (Medium)	1.5 (Medium)	1.1 (Medium)	1.5 (Medium)
2B	1.5 (Special)	1.5 (Medium)	1.1 (Medium)	1.1 (Regular)	1.1 (Medium)
2C	1.5 (Medium)	1.1 (Medium)	1.1 (Regular)	1.1 (Regular)	1.1 (Medium)
3	1.1 (Regular)	1.1 (Medium)	1.1 (Regular)	1.1 (Regular)	1.1 (Regular)
Rail Status	**MPE**	**MC & DG**	**SP**	**L**	**C**

Note: [1.1 (Regular)] denotes the barrier is 1100mm high, measured from the edge of the adjacent road lane pavement level with a barrier performance level "Regular".

The paper (S. Barlow, 2009) specified also that suitable reinforced concrete barriers are to be provided over the full length of the railway corridor on both sides of road over rail bridges and on bridge approaches (the length of the approach barrier is to be determined by a risk assessment).

The Table 77 defines the relative risk level associated with the barriers performance levels shown in the Table 76.

In Table 78 the selection matrix for road rail barrier selection for each risk level associated at railway and road status are finally defined.

Table 77 - Relative Risk level for different road and rail corridors (S. Barlow, 2009)

Road Status	Relative Risk Level for different road and rail corridors				
1A	RL10	RL8	RL6	RL5	RL8
1B	RL9	RL7	RL5	RL4	RL6
1C	RL8	RL6	RL5	RL6	RL6
2A	RL9	RL7	RL6	RL5	RL6
2B	RL8	RL6	RL5	RL3	RL5
2C	RL6	RL5	RL4	RL3	RL4
3	RL4	RL3	RL2	RL1	RL2
Rail Status	**MPE**	**MC & DG**	**SP**	**L**	**C**

Table 78 – Road/Rail interface barrier selection (S. Barlow, 2009)

Road /Rail corridor characteristics	1A-MPE	1B-MPE 2A-MPE	1C-MPE 1A-MC 1A-C 2B-MPE	1B-MC 2A-MC	1C-MC 2B-MC 1A-SP 2A-SP 2A-C 1B-C 2C-MPE 1C-C	2C-MC 1B-SP 2B-SP 2B-C 1A-L 2A-L 1C-SP	2C-SP 2C-C 1B-L 3-MPE	1C-L 2B-L 2C-L 3-MC	3-SP 3-C	3-L
Relative Risk level	RL10	RL9	RL8	RL7	RL6	RL5	RL4	RL3	RL2	RL1
Effective Horizontal distance, X_E (m)										
4	TL6 2.0	TL6 1.5	TL6 1.5	TL5 1.5	TL5 1.5	TL5 1.1	TL4 1.1	TL4 1.1	TL4 1.1	
5	TL6 2.0	TL6 1.5	TL6 1.5	TL5 1.5	TL5 1.5	TL5 1.1	TL4 1.1	TL4 1.1	TL4 0.8	
6	TL6 2.0	TL6 1.5	TL6 1.5	TL5 1.5	TL5 1.5	TL5 1.1	TL4 1.1	TL4 0.8		
7	TL6 1.5	TL6 1.5	TL5 1.5	TL5 1.5	TL5 1.5	TL4 1.1	TL4 0.8			
8	TL6 1.5	TL5 1.5	TL5 1.5	TL5 1.5	TL5 1.1	TL4 1.1				
9	TL5 1.5	TL5 1.5	TL5 1.5	TL5 1.1	TL5 1.1	TL4 0.8				
10	TL5 1.5	TL5 1.5	TL5 1.5	TL5 1.1	TL5 1.1					
11	TL5 1.5	TL5 1.5	TL5 1.1	TL5 1.1	TL4 1.1					
12	TL5 1.5	TL5 1.1	TL5 1.1	TL5 1.1	TL4 1.1					
13	TL5 1.1	TL5 1.1	TL5 1.1	TL5 1.1	TL4 1.1					
14	TL5 1.1	TL5 1.1	TL5 1.1	TL4 1.1	TL4 0.8					
15	TL5 1.1	TL5 1.1	TL4 1.1	TL4 1.1						
16	TL5 1.1	TL5 1.1	TL4 1.1	TL4 1.1						
17	TL5 1.1	TL5 1.1	TL4 1.1	TL4 0.8						
18	TL5 1.1	TL4 1.1	TL4 1.1	TL4 0.8						
19	TL4 1.1	TL4 1.1	TL4 0.8							
20	TL4 1.1	TL4 1.1	TL4 0.8							
21	TL4 1.1	TL4 1.1								
22	TL4 1.1	TL4 1.1								
23	TL4 1.1	TL4 0.8								
24	TL4 1.1	TL4 0.8								
25	TL4 0.8									
26	TL4 0.8									
27	TL4 0.8									
28										
29										
30										
31										
32										
33										
34										
35										

Note: Light Green shaded area denotes that a barrier may be required where directed by the Road and/or Rail authority as determined by a risk assessment.

Note: The distance from the road to the rail corridor is measured from the edge of the road carriageway to the nearest track centreline or to nearest part of structure of high importance

The number of vehicles encroaching onto the verge will increase as the curvature of the horizontal curve increases. The selection procedure (see Table 79) provides the adjustment factors to increase the clear zone at horizontal curves. The coefficient is equal to 1.0 in a straight road.

Table 79 - Horizontal curve conversion factors (S. Barlow, 2009)

Radii (m)	60 km/h	70 km/h	80 km/h	90 km/h	100 km/h	110 km/h
100	0.56	0.50	0.43	*	*	*
150	0.66	0.60	0.54	0.47	0.41	*
200	0.72	0.67	0.61	0.54	0.48	0.41
250	0.76	0.71	0.66	0.60	0.53	0.47
300	0.80	0.75	0.70	0.64	0.58	0.51
400	0.84	0.80	0.75	0.70	0.65	0.58
500	0.87	0.83	0.79	0.75	0.69	0.64
600	0.89	0.86	0.82	0.78	0.73	0.68
700	0.90	0.88	0.84	0.81	0.76	0.71
800	0.91	0.89	0.86	0.83	0.78	0.74

The approach considers also that the higher value of embankment slope increases the chance of vehicle reaching a railway track. In Table 80 the values of slope adjustment factors are summarized.

Table 80 - Slope adjustment factors (S. Barlow, 2009)

Embankment Slope (V to H)	Fs
Horizontal / Flat	1.00
Less than 1 to 4	1.00
1 to 4	0.38
1 to 3.5	0.29
1 to 3	0.17
1 to 2.5 or steeper	0.00

S. Barlow (2009) in his research, based on the Technical Specification QR MCE-SR-007 of the Queensland Government (2009), specifies that some individual structures in rail corridors (for example, signal boxes, transformers) may require local protection (for example, earth mounds, safety barriers or strengthening of the structure itself). The solution will need to be determined by a risk analysis on a case-by-case basis.

According to Domenichini et al. (2004) and Italferr (1999) the protection is needed when the distance between road edge and railway is less 10 m. The papers, to define the need for protection consider also the minimum height of the edge of the railway section respect to the final point of the fall down path and the distance between the edge of the highway embankment and the railway embankment and the configuration of interposed area.

In (Italferr, 1999) the levels of protection of the road edge are defined as a function of the following chasracteristics:

- Horizontal distance between road and rail;
- Height difference between road and rail.

Table 81 – Need and type of protection (Italferr, 1999)

Difference of height between the railway line and the road pavement	Horizontal distance between roadway and railway (L)	Type of protection
≤ 3.0 m	L<16.5 m	H4 barriers to be placed at the roadway edge
	16.5 m ≤ L ≤ 50 m	Configuration of the area between the roadway and the railway with an embankment or cut to prevent the railway invasion
	L > 50 m	No specific protection needed
>3 m	-	No specific protection needed for the railway. The railway embankment or retaining wall shall be treated as a potential hazard for the roadway users

Generally most of national standards and guidelines define the need of protection as a function of distance between road edge and rail (T. Edl 2009). All procedures require a risk assessment.

5.3.3 Third parties protection

There was little international literature concerning this subject. Generally, the roadside design procedures used around the world are limited to describe where a barrier is required to protect the occupants of the impacting vehicle. However, where a road passes a school or infrastructure that requires protection, an engineer may require a higher containment barrier or may recommend the installation of a barrier even if the school or other infrastructure is outside the recommended clear zone. For bridge barriers, the usual procedures are related to the mass and type of vehicle to be restrained and to the height of the bridge and what it spans (S. Barlow, 2009).

The German guidelines requires a barriers to be used in the condition described in Figure 68 (J. Kuebler, 2013).

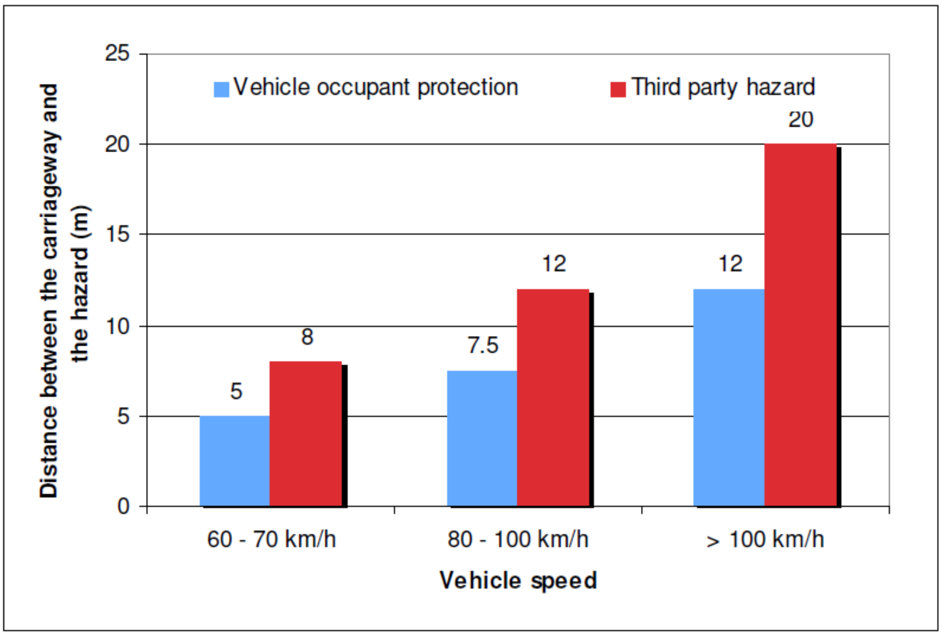


Figure 68 - Summary of German guidelines for the minimum distance between the hazard and the road for a barrier not to be required (S. Barlow, 2009)

The procedure to define the need of protection for the third parties as based on the risk category:

a. High risk category;

b. Low risk category.

In the Table 82 the main variables considered in the definition of the risk category are summarized.

Table 82 - German guidelines for protecting third party 'hazard' (S. Barlow, 2009)

Risk category	Condition	Truck Volume	CEN 1317 Test Level	Equivalent NCHRP 350 Test Level
High	Speeds > 50 km/h - High accident risk or a 'blackspot'	> 3000 trucks / day	H4b	TL6
		< 3000 trucks / day	H2	TL4
	Speeds > 50 km/h - Not a high accident risk or 'blackspot'	> 3000 trucks / day	H2	TL4
		< 3000 trucks / day	H1	TL2 - TL3
	Speeds < 50 km/h		No barrier required	
Low	Speeds between 60 and 70 km/h - High accident risk or a 'blackspot' and AADT > 3000 veh / day	> 500 trucks / day	H1	TL2 - TL3
		< 500 trucks / day	N2	TL2
	Speeds between 80 and 100 km/h - High accident risk or a 'blackspot' and AADT > 3000 veh / day	> 500 trucks / day	H1	TL2 - TL3
		< 500 trucks / day	N2	TL2
	Speeds > 100 km/h	> 3000 trucks / day	H2	TL2
		< 3000 trucks / day	H1	TL2 - TL3

5.3.4 Special protection

Special performance level, non-penetrable barriers shall be provided at specific locations agreed by the relevant road authority where vaulting by high mass and high centre of gravity vehicles must be prevented (H. Ngo, 2012) and (J. Kuebler, 2013).

Special protection is required where any of the following criteria apply (H. Ngo, 2012):

a. roads pass over the railway main control room;
b. bridges with heavy, high centre of gravity vehicles on high speed freeways, major highways and urban arterial roads with a high volume of commercial vehicles (greater than or equal to 30% AADT) in a high risk situation.

Special performance level barriers shall be provided, subject to an appropriate Benefit/Cost justification, for bridges with heavy, high centre of gravity vehicles on high speed freeways, major highways and urban arterial roads with a high volume of commercial vehicles (greater than or equal to 30% AADT) not in a high risk situation (H. Ngo, 2012).

5.3.5 Main findings

The need for a safety barrier is identified as a function of the level of risk in the selection point. Many of the analysed papers require a specific risk assessment to evaluate the level of risk in the considered area. Many standards and papers define three level of risk as a function of the site condition: low, medium and high.

The definition of the level of risk is the first variable to consider in the identification of need of VRS for the protection of third parties. If the site condition show a low level of risk the area does not required the installation of VRS, otherwise, is necessary to the other variables required to selection the most appropriate VRS.

For the selection of the most appropriate VRS for medium and high level of risk the following variables need to be evaluated:

- Traffic data: AADT for Heavy Vehicles (HGV) or AADT and percentage of HGV;
- Characteristic of the road: design speed, geometry characteristics;
- Bridge characteristics: bridge width, height;
- Under bridge conditions: chemical plants, pedestrian or bicycle paths, presence of the water and water depth, presence of rail and horizontal distance, presence of the residential areas, presence of the other roads and their type and traffic conditions.

Specific procedures are defined for conditions where road and rail run in parallel. The main variables to consider in this case in are summarized as follows:

- Horizontal distance between roads edge and rail line;
- Embankment configuration;
- Road geometry: horizontal curve (R);
- Traffic condition on the rail corridors: type and frequency;

- Need of increase barrier high.

The Italian RFI standard provides the following requirements:

- If the rail runs is under the bridge or if the distance between the road and the rail is less than 16.5 m it is necessary to install an H4 barrier;
- If the distance between road and rail is between 16.5 m and 50.0 m it is sufficient to shape the terrain to prevent the invasion of the rail corridor by errant vehicles and a barrier is considered only the terrain cannot be properly shaped. If the rail elevation is greater than 3.0 m compared to the road elevation no specific treatment is required.

5.4 Terminals, transitions and crash cushions

5.4.1 Introduction

Looking at the whole range of Vehicle Restraint Systems, terminals, transitions and crash cushions constituted in the recent past the most overlooked parts of the system. However, due to the development of new materials and manufacturing technologies, crash cushions and deformation zones (terminals and crash cushions) are now much more cured and used and they prove their worthiness on the roads every day.

There are many different variations of terminals, transitions and crash cushions in terms of materials, design and construction and in particular the design changes according to the impact angle. The decision on the choice and positioning of the different devises, based on optimum performance considerations, is mostly responsibility of road managers.

Literature dealing specifically with terminals, transitions and crash cushions is very scarce. In fact, most of the available information consists of advises about correct positioning of different types of terminals, transitions and crash cushions; information on different designs and materials used for their production; commercial product reports from manufacturing companies; and some findings about efficiency.

Terminals, transitions and crash cushions can be manufactured from different materials, depending on their intended use and installation. The materials most used are stainless or galvanized steel and plastic (PVC) in combination with eventual other fills to provide enough strength and resistance of the VRS. More and more, however, manufacturers invest in research on new materials that are more durable, less costly and low-maintenance such as special PVC foams or fabrics. Research and testing on innovative, computer modelled designs are also carried out.

In relation to cost, a part from a few prices from different manufacturers, there is no numerical data related to the choice and the positioning of terminals, transitions and crash cushions. Some National Road Authorities carry out life-cycle cost analyses but there are not commonly recognized procedures or unified parameters.

An example of a terminal and a crash cushion are shown in Figure 69 and Figure 70 .

Figure 69 - Permanently installed steel end terminal. Photo by (Trinity highway products).

Figure 70 - Permanently installed steel crash cushion. Photo by (Trinity highway products).

5.4.2 Crash cushions

Crash cushions can be installed in three distinct variations: as permanent systems, as temporary systems or as moveable ones, that is mounted on a trailer, personal vehicle or truck. Permanent crash cushions are installed on locations where high traffic is regularly expected, for protecting critical sections of the road such as small radium curves and as complementary devises for the protection of motorcyclists on existing safety barriers. Temporary crash cushions are usually installed in work zones, detours, etc.

When selecting an impact attenuator system, it is necessary to identify the hazard (Alberta Infrastructure and Transportation, 2007). The first criterion to consider in selecting crash cushions should be based on the crash history and Annual Daily Traffic (ADT) (Department of transportation of main road) (Roadside Safety Manual, 2013). In fact, for existing roads the crash history and roadway characteristics will provide the designer with important information for selecting the appropriate type of system (K.D. Schrum, 2012).

Several other factors must be evaluated when determining which of the recommended crash cushions should be used. There is therefore no simple and systematic selection procedure. The main factors that normally affect the selection of the most appropriate crash cushions type are following summarized (Washington State Department of Transportation 2012) (New Jersey Department of Transportation, 2013)(Stoncipher, 2012):

- Site characteristics:
    - dimension of the obstruction;
    - geometric of the site;

  - physical condition of the site;
  - road alignment;
  - road layout;
  - Posted speed
  - Average Daily Traffic (ADT)
  - Repair crew exposure
  - Proximity to the roadway
  - Portion of the impact attenuator that is reusable/non-reusable.
  - Anticipated number of yearly impacts
- Structural and safety characteristics of the system:
  - available space (length and width)
  - foundation;
  - backup structure requirements;
  - anchorage requirements;
  - redirection characteristics;
- System cost:
  - site preparation cost;
  - initial cost;
  - maintenance cost;
  - repair and replacement cost;
  - duration (permanent or temporary use[2]);
- Maintenance characteristics:
  - Regular/routine maintenance;
  - Crash maintenance;
  - Material inventory need.

Geometrical and physical road characteristics influence the selection of redirective vs non-redirective devices.

Redirective crash cushions should be chosen where collisions can occur to the front and side because non-redirective crash cushions do not satisfy the side impact test requirements (K.D. Schrum, 2012).

It is very important to note that if the redirection performance is not required an adequate zone adjacent to the system must be realized, for example with sand barrel arrays, to minimize the danger of a vehicle penetrating the barriers from the side and hitting the obstruction (New Jersey Department of Transportation, 2013).

[2] It is necessary to evaluate the particular installation condition in temporary work zone areas.

An example of recommended placement details is shown in Figure 71.

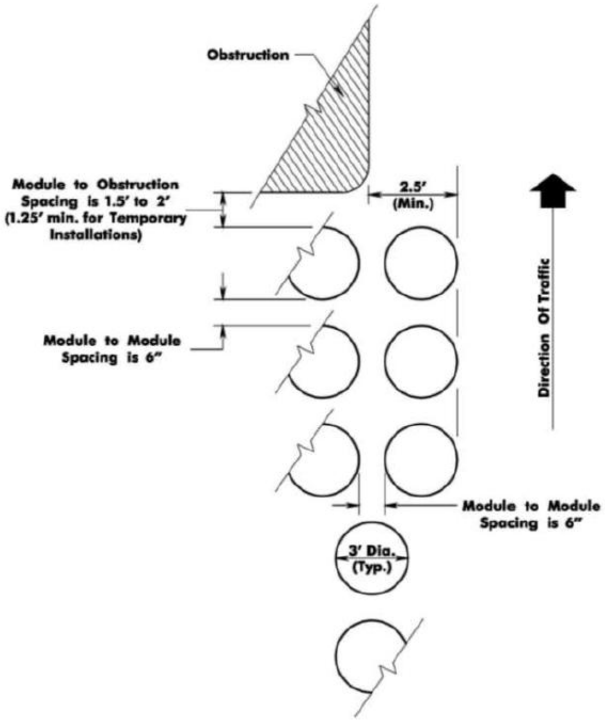


Figure 71 – Suggested Layout for the inertial barriers (New Jersey Department of Transportation, 2013)

Schrum recommends (K.D. Schrum, 2012) that the selection of redirective capabilities of crash cushions should be based on the number and type of crash event. He also suggests that non-redirective (as sand barrel) are recommended only for small traffic volumes (≤ 1000 vpd) on divided rural arterials with offsets greater than 20 ft (6.1 m).

Most of the studies focus on the type of crash cushion in terms of reusability. In the Table 83 an example of type of crash cushions system selection as a function of Roadway Location Characteristics is shown (Stoncipher, 2012).

Table 83 - Non Gating redirective crash cushions classification (Stoncipher, 2012)

Non-Gating Crash Cushion Classification	Roadway Location Characteristics			
	ADT	Impact Fraquency per Year	Distance (D) from Travel Way (feet)	Repair Considerations
Sacrificial	< 25,000	N/A[1]	D > 10	Requires entire system replacement when hit
Reusable	< 25,000	1-2	D > 10	Many reusable components, unlimited repair time
Low Maintenance / Self Restoring	≥ 25,000	3 or more	D ≤ 10	Time and work space limitations, Multiple hits before repairs needed

[1] Low history or expectation of impacts occurring over lifetime of crash cushion.

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In the analysis of the road layout characteristics it is important to evaluate if there is the adequate space to install the crash cushions selected. In Table 84 some preliminary space evaluation as a function of design speed are summarized in terms if minimum dimension of the reserved area preferred installation conditions (Figure 72).

Table 84 - Area Available for crash cushions installation (Stoncipher, 2012)

Design Speed on Mainline (mph)	Dimensions for Crash Cushion, Reserve Area (feet)								
	Minimum Dimensions						Preferred Conditions		
	Restricted Conditions			Unrestricted Conditions					
	N	L	F	N	L	F	N	L	F
30	6	8	2	8	11	3	12	17	4
50	6	17	2	8	25	3	12	33	4
70	6	28	2	8	45	3	12	55	4

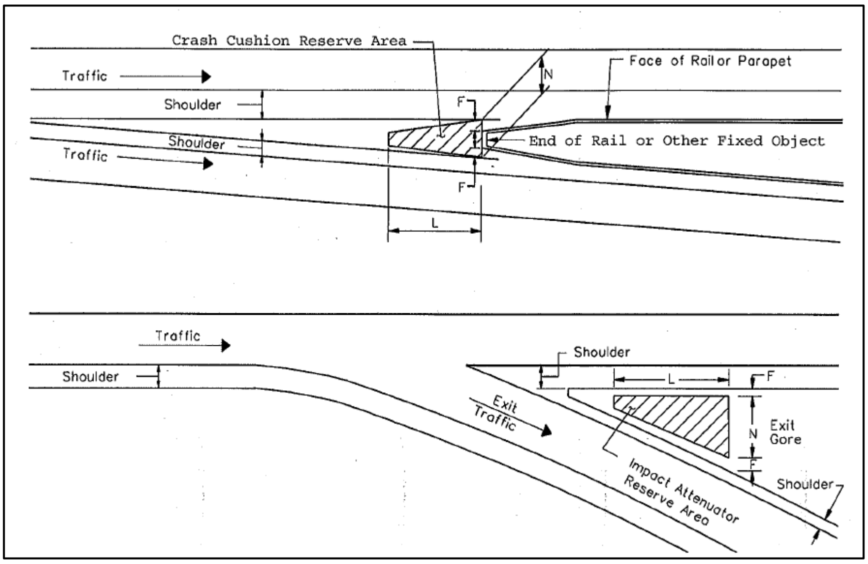

Figure 72 – Definition of available area for crash cushion installation (Stoncipher, 2012)

In the selection of the appropriate crash cushions it is important to consider if there is a kerb that can seriously reduce the effectiveness of a crash cushion (New Jersey Department of Transportation, 2013). It is recommended that all kerbs and islands be removed approximately 15 m in front of a crash cushion and as far back as the unit backup. While new kerbs should not be built where crash cushions are to be installed, it is not essential to remove existing kerbs less than 10 cm in height. Kerbs from 10 cm to 15 cm in height should be removed unless consideration of the kerb shape, site geometry, impending overlays that would reduce the kerb height, and cost of removal justify leaving the kerb in. Kerbs over six inches (15 cm) high shall be removed before installing a crash cushion. When a kerb is terminated behind a crash cushion, the kerb should be gently flared and/or ramped. Flares of 15:1 and ramps of 20:1 are recommended on high speed facilities.

The evaluation of the structural and safety characteristics (anchorage requirements, foundation, general requirement and redirection) allow to select the type of crash cushion: contain, non-gating, non-redirective or redirective crash cushions.

Finally, it is necessary to evaluate the cost of the various crash cushion system. Cost considerations should include site preparation cost, initial material and installation cost, maintenance cost and repair or replacement cost. The last factor could be significant in the selection process, especially at location where frequent hits are expected.

For the cost analysis crash cushions are classified in in (Stoncipher, 2012) (Department of transportation of main road)(New Jersey Department of Transportation, 2013):

- Sacrificial Crash Cushions: non-gating crash cushions considered sacrificial (replaceable) are generally designed for a single impact (low initial cost, low crash history and ADT < 25000).
- Reusable Crash Cushions: It has some parts that will be to be replaced after an impact to make the unit crashworthy again, however, major components of the non-gating system may survive an impact (more expensive than sacrificial, ADT < 25000 and 1-2 crash per year).
- Low Maintenance/Self Restoring Crash Cushions: This systems are premium non-gating system designed for high traffic areas and locations where vehicular impacts can be expected frequently (high cost, high-speed, high volume roadways: ADT > 25000, ramps or median where high frequency of impact >3 per year). They can sustain multiple impacts before repairs are needed.
- Gating Crash Cushions: Systems characterized by a lower initial cost (compared with non-gating) but relatively high maintenance costs. These should be considered for location well off the roadway where frequent impacts are not expected or locations where no other safety device product will fit the location.

When the designer is selecting the appropriate crash cushions it is necessary to consider future inspection and maintenance procedures to ensure that the installed system remains fully functional as intended.

The literature also shows that for temporary work zones, the designer should select a crash cushion system consistent with the expected site conditions that may be present at the given location. The selection procedure for temporary crash cushions is equal to that used for selecting a permanent crash cushions system.

In selecting a system, the exposure to traffic of the road workers should be considered, see (Washington State Department of Transportation 2012). In areas with high traffic exposure, a low maintenance system that can be repaired quickly is most desirable. Some systems need nearly total replacement or replacement of critical components (such as cartridges or braking mechanisms) after a head-on impact while others simply need resetting.

The selection of impact attenuators having low-maintenance cost should be limited to:

- Locations with an Average Daily Traffic (ADT) of 25,000 or more or a history/anticipation of multiple impacts each year.
- Sites with limitations on repair time or locations within 3 meters of the travelled way.
- Sites requiring night repairs or merge and diverge areas.

5.4.3 Truck Mounted Attenuators (TMA)

Vehicle or Truck Mounted Attenuators (TMA) are designed to protect motorists and workers in a given work area. They are mounted both on vehicles used for short duration operations (moving shadow vehicle, see Figure 73) and on vehicles used for stationary shoulder and lane closures (barrier vehicles) (NYSDoT 2009; Steele & Vavrik 2009). The energy dissipation occurs as steel mandrels, attached to the impact head, are driven into the trailer frame members. When properly used, truck mounted attenuators will (Safety Trailers Inc.):

1. Reduce the severity of impact for occupants of errant vehicles that collide with the rear of a shadow or barrier vehicle.
2. Reduce crash severity for occupants of shadow vehicles.
3. Minimize or prevent damage to the barrier or shadow vehicle.
4. Reduce the time required to clear the accident scene and restore traffic flow.

Impact attenuators are placed so that they do not constitute a hazard for opposing traffic. For central reserve and reversible lane locations, the backup structure or attenuator-to-object connection is designed to avoid being snagged by opposing traffic. Before an impact attenuator is installed it is desirable that existing kerbing are removed and the surface smoothed with asphalt or cement concrete pavement.

Figure 73 - Truck-mounted attenuator, trailer-mounted attenuator and attenuator in folded transport position (Steele & Vavrik 2009).

Figure 74 – Truck mounted attenuator. Photo by (Trinity highway products).

5.4.4 Terminals

An extensive study on barrier terminals has been conducted within the ERANET Project ‘IRDES’ and is in the process of being published as the CEDR Forgiving Roadside Design Guide. The IRDES Project is a European project and it is not based on US data, including examples and analysis based on European terminals.

In several countries, flared non-energy-absorbing terminals are accepted based on design criteria with no crash test requirements. In other countries (such as in Germany), only devices tested in accordance with ENV1317-4 are allowed.

Even though road barrier terminals are commonly recognised as an important roadside safety hazard, there is currently no way of quantitatively estimating the safety effects of removing them.

The NCHRP Report 490 'In-service performance of safety barriers' analyses several studies concerning barrier terminals. However, it concluded that they are essentially devoted to understanding how a specific terminal works rather than quantifying the effect of modifying the terminal configuration (Ray et al., 2003).

In the recently published 'Highway Safety Manual', the Roadside Hazard Rating doesn't take account of the configuration of the terminal (AASHTO, 2010).

One of the reasons for this is that crashes against terminals are rare and, as a result, 'before/after' analysis cannot be performed in these cases.

In Sweden (Fagerlind et al., 2012), a procedure for the determination of a Crash Modification Factor (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 was reduced. A CMF was also derived as a function of the reduction in the number of unprotected terminals.

The effect of changing the type of terminal from a “non crashworthy” terminal to a flared or energy-absorbing terminal could not be established as this type of terminal has not yet been installed on the analysed network.

It should be noted, however, that the extensive in-service performance evaluation conducted in the USA (Ray et al. 2003) led to the conclusion that flared non-energy-absorbing terminals (in this specific case the MELT and the Breakaway Cable Terminal which is similar to the MELT but with an added cable) 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.

Even though design guidelines for placing terminals can be found in the CEDR Guide, no indication is given on the criteria to select the most appropriate VRS class when an energy absorbing terminal is adopted.

5.4.5 Transitions

Transitions are not standalone devices but components of a system where two different safety barriers have to be connected.

Given the fact that a current (2014) draft of EN1317-4 is not adopted yet as a final standard there is currently no research available to guide the different NRAs on how to select a given assessment level. It is envisaged that such research will develop in the following years, once the requirements of the testing standard have been finalised.

5.5 Motorcyclist Protection Systems (MPS)

5.5.1 Introduction

Powered Two Wheeler (PTW) riders as part of vulnerable road users suffer the highest risks of receiving severe or fatal injuries during a crash. Even the best protective clothes (except the helmet) being designed to protect against abrasion injuries, have their limits, especially when riders impact rigid objects at high speeds. Motorcyclist protection systems (MPS) are an additional system to existing VRS with the overall objective to minimize the injury risks of PTW riders.

In the last decade, several motorcycle organizations have pushed vigorously to find solutions to this problem. Specific MPS have been developed by the industry and some countries also developed test protocols e.g. (AENOR 2008); French LIER test protocol (Le LIER Laboratoire d'essais INRETS Equipements de la Route 1995). These test methods have been recently used to develop a common European test method - CEN/TS 1317-8 (CEN 2012b), which only takes into account sliding impact. Lately the issue of considering also impact in the upright position has been raised but this type of test is not yet considered as a standard.

The following data (Bloch, 2010) gives an idea of the relevance of the issues raised by motorcycle organizations:

- There are approximately 33 million of PTWs in EU 27 (~ 14% of private vehicle fleet)
- PTW fatalities are the 17% of all road fatalities (but only 2% of the total distance travelled)
- About 10% of PTW accidents are collisions with infrastructure elements with a specific prevalence of impacts with road restraint systems
- In collision with crash barriers, riders are 15 times more likely being killed than car passengers.

Concerning impacts of motorcyclists into infrastructure, a review of existing literature on motorcycle-infrastructure interactions showed that collisions with an obstacle occur in 4.2% (urban area) to 19.7% (rural area) of all motorcycle accidents, depending on the respective area (ACEM 2004). Roadside barriers are involved in 2.4% to 4% of all PTW fatalities. The typical barrier impact location is a curve, and in about half of the cases the rider impacts in upright position (Molinero 2006).

5.5.2 Variables identified

Since PTW safety and development of MPS have become a specific issue in accidentology, key literature can be found in several PTW research projects around the globe. While some of them are dealing with crash reconstruction and the expected effects of MPS, others are more general in terms of analysing common crash circumstances. When it comes to test procedures and standards regarding MPS, several FEMA (Motorcyclists`Associations 2012) initiatives are visible in European literature. The EU-project Smart RRS (IDIADA 2012), together with results of the first naturalistic riding project (Saleh 2010) offers deeper insights to various MPS aspects. Specific parameters (e.g. crash/impact speed or angle, riders`position on the PTW) should be further investigated within the SAVeRS project.

The analysed literature and projects mainly cover the so-called "underrider" protection systems (shields, tubes…) on continuous systems, but also elements to mitigate the potential risk of the support posts of discontinuous VRS. MPS can also include the protection of the upper end of the VRS (fall over accident), e.g. prototype Euskirchen Plus in Germany (MEHRSi 2013).

5.5.2.1 Placement

Comparable analyses of in-depth data from Germany, Spain and Austria show that most Run-Off-Road Accidents (RORA) in bends occur at radii between 50 and 150 m (between 60 and 80%). Radii relations (R1/R2>1) and disharmonic trace, high bendiness and high gradients are critical safety issues for PTW riders. Run-off-road accidents involving PTW are more likely to occur in left hand curves than right hand curves (Saleh 2010).

Exposed guardrail posts are the most dangerous aspect of guardrails with respect to motorcyclists. The risk of injury due to hitting a fixed object is related to the impact area and rigidity of the object. Hence, small rigid objects such as support posts are most likely to cause the most severe injuries as they concentrate the impact forces on a small area of the human body (IDIADA 2012).

Most motorcycle collisions with crash barriers occur at angles between 10° and 45° (in the European standard (CEN 2012b) the prescribed crash test angle is 30°). For support posts positioned every 2.5 m, the probability of hitting one of the posts, for impact angles between 30° and 15°, is between 35% and 70% (IDIADA 2012).

5.5.2.2 Choice of MPS type

Several studies, among them (Berg et al. 2005) investigate both sliding and upright crash positions of riders. 2-BE-SAFE (Saleh 2010) results show the same tendencies, that both crash types are equally relevant, especially from in-depth analysis of Spanish data. Also crashes with riders still sitting on bike while a sliding accident (so-called "lowsider" crashes) must be considered.

Figure 75 - New, innovative protection system BASYC: special impact attenuator mesh used for personal vehicles and motorcyclists collision protection. Photo by (Sistemas de Seguridad Vial)

Figure 76 - PVC foam made impact attenuators for bollards
Photo by (Vieira et al. 2008)

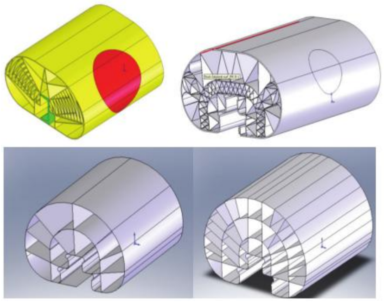

Figure 77 - Computer modelling of an impact attenuator
Photo by (Vieira et al. 2008)

For riders remaining in an upright position when impacting a crash barrier, most injuries occur at shallow impact angles, i.e. the rider slides and tumbles into the top of the supporting posts. When a rider impacts with a barrier in an upright position, the motorcyclist is likely to be thrown over the guardrail system if the height of the barriers is too low (Duncan et al. 2000).

Impacts with posts can, depending on the part of the body involved, cause fatal injuries even at an impact velocity as low as 20 km/h. The sigma post has considerably less sharp edges compared to the IPE post and will perform better when it comes to avoiding cut injuries (Figure 78 and Figure 79). Impact attenuators have a significant protective effect for motorcyclists and are suitable elements of passive safety measures.

Figure 78 - Sigma post.
Source: http://german.alibaba.com/product-gs/sigma-post-218515045.html.

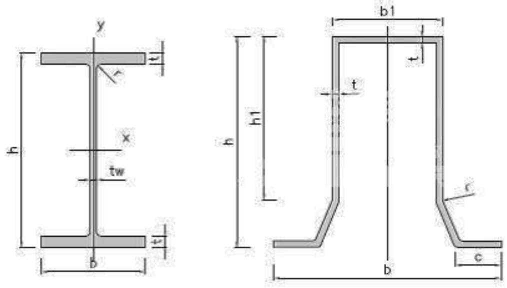

Figure 79 - IPE, FG and sigma post.
Source: http://www.pvpowerway.com/news/994.html.

The safety performance of concrete barriers, despite the higher stiffness, is superior compared to conventional metal guardrail systems in a sliding impact scenario, at least for shallow angles. However, in a comparison between metal guardrails with an additional lower rail and concrete barriers, the performance of the metal guardrail appeared to be less aggressive than the concrete wall (IDIADA 2012).

ATSB 2000 (*ATSB Annual Review 2000* 2000) recommends using concrete barriers, arguing that concrete barriers are a more economically viable option when maintenance costs are taken into account. Furthermore, ATSB recommends that vehicle rollovers can be prevented by the use of ‘F profile’ concrete barriers, providing an overall beneficial solution (Figure 80).

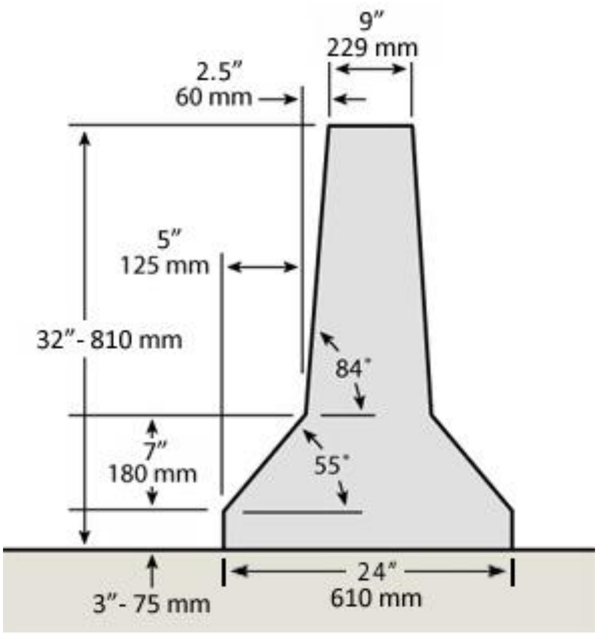

Figure 80 - F Shape Barrier Profile Dimensions.
Source: http://www.jjhooks.com/profiles.shtml.

Due to the limited and discontinuous contact area of the design, the Wire Rope Safety Barrier system (Figure 81) is viewed by motorcyclists as the most aggressive form of Vehicle Restraint Systems causing the most severe injuries to riders. This view is supported by some computer simulations and crash tests which clearly indicate that injuries will be severe if a rider hits the cables or the exposed supporting posts of Vehicle Restraint Systems (Berg et al. 2005). However, according to other studies (Jama et al. 2011; Rizzi et al. 2012), real crashes with wire rope barriers are not significantly more dangerous than those involving other types of barriers.

Figure 81 - Wire Rope Safety Barrier.
Source: http://www.hbsonline.co.uk/default.aspx?CATID=1007.

5.5.3 Main findings

- The main goal of MPS is to avoid sliding into and under a VRS, as well as protection against sharp edged posts.
- Steel wires are not particularly dangerous, but vertical posts are problematic.
- Crash statistics and in-depth analyses point out specific areas of higher risks (bends between 50 m and 150 m).
- Placement of proper MPS is needed in roads with high exposure of PTWs.
- Different crash positions must be considered in different impact angles.
- Upright testing is currently not considered in standard testing and should be further investigated.
- National standards for type certification (crash test) have been developed and a common European test method has been voted from CEN members as technical specification. This will probably result in a European norm in the near future.

5.6 Influence of vulnerable road users on decision making of VRS placement

Standards in Europe consider the introduction of a safety barrier recommended where the elimination of all hazards within the Safety Zone is not reasonably practicable. Among the hazards, locations with a high accident history and locations with pedestrian and bicycle usage are also considered (NRA National Road Authority 2009). One of the reasons for installing a safety barrier is, in fact, to protect vulnerable road users who may be affected by errant vehicles.

Usually policy papers define pedestrians, cyclists and motorised two wheelers as typical road user groups but each categorisation entails a good degree of arbitrariness. On one hand other road actors such as wheelchair users, roller-skaters, young and elderly car passengers are sometimes included and on the other, motorised two wheelers are considered to be responsible of hazard for other categories (Avenoso & Beckmann 2005). This section focuses on activities of pedestrians and cyclists although the approaches found in the literature are quite wide.

In most papers, in fact, the interaction between pedestrian and vehicle activity is dealt with not by stating a number of rules or countermeasures but by embracing a vision of road infrastructures and investigating strategies to achieve it:

"*This paper presents the results of research partnerships between landscape architects, safety engineers, planners and health industry researchers seeking to identify environmental variables that have a positive correlation with driver safety and encourage pedestrian activity.*" (Naderi 2003, p. 119).

"*Deciding on the set of treatments that will provide the greatest benefits in terms of providing safety and mobility requires transportation and land-use planners, engineers, law enforcement officials, and community leaders to engage in problem-solving.*" (Harkey & Zegeer 2004, p. 29).

Especially in countries which have already relatively safe road transport systems and for which car commuting is a major way of transportation, community development and public health through pedestrian activity instances are felt as important as those of mobility:

"Traditionally, the introduction of landscape features into the clear zone is discouraged in transportation policy (Task Force for Roadside Safety of the Standing Committee on Highways Subcommittee on Design 1996). Communities across the United States however put tremendous pressure on the transportation industry to provide landscape and trees within the clear zone as part of their community economic development, neighbourhood beautification or traffic calming endeavours. This has resulted in a serious conflict that has become part of a national research strategy and the focus of much research (National Cooperative Highway Research Program NCHRP 2000; Zeigler 1986, 1987). At the same time, the Context Sensitive Design movement is beginning to provide the engineering community with skills and new standards and policies related to incorporating community references and needs into traditional transportation projects. Still, managing and maintaining clear zones have serious liability issues attached and many states have developed intricate policies to address the need on a broad basis" (Naderi 2003, p. 120).

Other countries as Norway and Sweden presented safety in the form of an ethical absolute. Vision Zero is a long-term vision of a road system that does not lead to fatalities or permanent injury (Belin, Tillgren & Vedung 2011; Elvebakk 2007). This approach implies a consistent physical separation between different road users and implies a *more complex and costly road system.*

A part from cost and resource implications, motorcyclists, environmental organisations and cyclists have disputed that the road should be for necessary transport only and that transport should take place only in cars. The road user segregation strategy of the North-European countries is disputed also by another approach such as Urban Design(Hamilton-Baillie 2004) in mainland Europe and more recently in UK. This approach, although limited to urban environment, aims at improving safety by modifying traffic behaviour through Legible Urban Design. It is believed in fact that removing standard kerbs, barriers, highway signs and road markings, forces motorists to use eye contact with other road users and pedestrians, for which they need to be travelling at less than around 30 km/h. In this case, as in Unites States (Naderi 2003) the social and health instances of the local communities are preferred to the efficiency and mobility need of car users. In Belgium (Avenoso & Beckmann 2005) this principle was translated into legislation in two different ways. To make car drivers more aware of their responsibility, in the early 90s the car insurance was extended to compensate all physical damage suffered by vulnerable road users in case of an accident, regardless of the side on which the fault of the accident lied. Moreover, since 2004, general traffic rules it have been introduced where the motorised road users have an obligation to be very careful towards vulnerable road users, especially towards children, elderly and disabled people.

5.6.1 Information on high risk locations

Among the methodologies for increasing the safety of vulnerable road user, the one most closely related to the decision of VRS placing, is the analysis of high risk accident location. However, according to (Avenoso & Beckmann 2005) the collection of accident data in case of pedestrian-motor vehicle crashes is affected in Europe and in the SEC belt especially (Southern, Eastern and Central European Countries) by underreporting and poor comprehensiveness and quality.

When information is available the review of historical crash data, is aimed at both the identification of high-crash locations and the detailed examination of pre-crash manoeuvres that lead to pedestrian-motor vehicle crashes. Although it is difficult to obtain information so detailed as to provide the sequence of events leading to the crash, information related to analysis of locations, time of the day and day of the week, victim age, gender and injury severity should be available and is most needed for understanding the best fitting countermeasures.

Methods of analysing crash locations include using computerized Geographic Information Systems (GIS), using walkability checklists and calculating a pedestrian level of service. (Raford & Ragland 2003) use pedestrian exposure rates to create a Relative Risk Index for accident locations. Pedestrian exposure is defined as a pedestrian’s rate of contact with potentially harmful vehicular traffic. The method uses pedestrian volume data coupled with accident data. High volume intersections may in fact experience a large number of collisions per year, but they may be relatively safer than intersections that experience less annual collisions but also less usage.

Among the methods for predicting pedestrian movement and thus pedestrian volume three main strategies can be found in the literature: Sketch plan models, Network analysis models and Micro-simulation (or agent based) models (Raford & Ragland 2005). They vary for both the necessary input and the scale of application: Sketch plan models focus on regional demand estimation, network analysis models focus on city-wide and neighbourhood levels, and micro-simulation focuses on single or a small number of streets, intersections, open spaces, or building interiors.

When it comes to countermeasures, the common approach is a crash-type definition which allows narrowing the list of solutions to a few that will be most suitable for a specific location.

In US the National Highway Traffic Safety Administration (NHTSA) has developed since 1970s methods to better define the sequence of events and actions leading to pedestrian/motor vehicle crashes. The crash-typing methodology has evolved over time and has been refined as part of a software package known as the Pedestrian and Bicycle Crash Analysis Tool (PBCAT). This information is provided under The Pedestrian Safety Guide and Countermeasure Selection System (PedSAFE) website together with a wealth of data and guidelines (Harkey & Zegeer 2004), crash statistics, crash analysis, case studies and so on.

Twelve crash typing groups are also defined with the goal of selecting treatments. Among the treatments for high vehicle speed and/or high volume streets the "*installation of barriers or signs to prohibit crossings and direct pedestrians to safer crossing locations nearby*" is always indicated together with a batch of countermeasures such as adding sidewalk, walkway and kerb ramps; increase lateral separation between pedestrians and motor vehicles (e.g., bike lanes or landscape buffers); provide lighting; construct gateway or install signs to identify neighbourhood as area with high pedestrian activity; use speed-monitoring trailers; increase police enforcement of speed limit, etc. The Installation of pedestrian fencing or barriers along roadway right-of-way is indicated as a countermeasure only for the case of Pedestrians routinely crossing section of expressway.

Crossroads is a commercial specialized crash analysis software that can be integrated with GIS software and provides queries and reports, including historical, high incidence, and monthly, as well as collision reports by day and hour and other parameters as well as collision types graphs and charts. A comparison between Crossroads and PedSAFE countermeasure plans can be found in (Ragland, Markowitz & MacLeod 2003).

The assessment of the most suitable countermeasures includes a discussion also on possible constraints such as high cost, the need for public and policy-maker review, the need for experimental authorization, technical or physical requirements or barriers, and uncertainty about effectiveness.

There is a great cost range for example for different countermeasures such as sidewalk-widening projects compared to sign installations; also traffic-calming countermeasures are much more difficult to implement due to the number of formal evaluations needed and related legislative approval issues that need to be addressed (Ragland, Markowitz & MacLeod 2003).

5.6.2 Main findings

- Information on the placement of VRS in relations to pedestrians, cyclists and other vulnerable road users is limited in the literature.
- Most of the papers reviewed treat the topic of safety of vulnerable road uses as a theme requiring a holistic approach and the necessity of embracing a vision of road infrastructures. Often the topic is treated in relation to public community needs and public health instances.
- High risk locations for vulnerable road users are assessed using computerized Geographic Information Systems (GIS), walkability checklists and pedestrian level of service.
- The *Pedestrian Exposure Rate* is the main variable which correlates pedestrian volume and collision rate. It is used to create a Relative Risk Index for accident locations.
- Once that the need of increasing the safety of a location has been decided, crash-type definition is the approach used. In this context VRS placement is always presented as one of the many possible countermeasures and set of solutions are usually indicated to increase the safety of pedestrians and cyclists.
- Among the sources reviewed the Pedestrian Safety Guide and Countermeasure Selection System (PedSAFE) project website, sponsored by the US Dept. of Transport, contains statistics, crash analysis, case studies, a crash-typing and countermeasure software and guidelines.

5.7 Cultural influences on decision making of VRS placement

As shown in the section on Vulnerable Road Users the decision on the placement of vehicle restraint system is affected also by cultural reasons. Especially in countries which have already relatively safe road transport systems and for which car commuting is a major way of transportation, community development and public health instances are felt as important as those of mobility.

The attention to public health is particularly felt in the Unites States on one hand and in Sweden and Norway on the other, although the public discussion in these countries has produced very different views of the role of road infrastructures in the society. Concern for both road safety and protection of the cultural and natural heritage is a hot topic in Europe.

In Norway and Sweden safety has assumed the form of an ethical absolute. In 1997 the Swedish Parliament, followed by the Norwegian Parliament in 2000, passed a Road Traffic Safety Bill stating that road safety work in Sweden would in the future be based on Vision Zero, a vision of a road traffic system that does not result in fatalities or serious injuries (Elvebakk 2007; Belin, Tillgren et al. 2011).

The Swedish Road Administration claimed that a person will normally survive a head-on collision without permanent injury if the speed of the collision does not exceed 70 km/h, and a side impact if the speed of the collision does not exceed 50 km/h (Elvebakk 2007). On the basis of this calculation roads with higher speed limits than these should have the speed limits reduced or be treated with central reserve and roadside barriers so that that these collisions cannot occur. Also, pedestrians, bicyclists and car users should not share the same road space because:

"*Rather than seeking to improve interaction and cooperation between the various actors, Vision Zero aims to remove encounters between them, whenever feasible*", (Elvebakk 2007).

Obviously this view has effects on both the functional design of the road infrastructure and the resources allocated for it. According to Vision Zero road safety is not to be dealt as a question of cost-benefit analyses, but in terms of ethics, and road accidents are to be considered problems of Health, Environment and Safety (HES). Moreover the road space is considered public not only in the sense that it is subject to laws and regulations, but also because the state and not the individual is responsible for it with the consequence that the driving styles and the personal road user behaviours can be subjected to a discipline stricter than the normal traffic regulations.

The discussion on the relation between public health and road infrastructure design has resulted in a very different outcome in the United States. According to (Naderi 2003) the US Center for Disease Control and the Surgeon General's Office study all the variables which favour active lifestyle living such as pedestrian and bicycle use over the automobile and can improve national health by reducing obesity and related medical care costs.

In this context it is believed that improving the aesthetic aspect of transportation corridors can be beneficial in a double way: by reducing accident frequency and severity and by increasing pedestrian activity.

However, boulevard treatment and the introduction of green infrastructure within transportation corridors have resulted difficult in relation to the treatment of the Safety Zone. Local communities have, in fact, pushed the transportation industry to provide landscape and trees within the Safety Zone as part of their community economic and social development, and this has focused the engineering community on new standards and policies for incorporating community references and needs into traditional transportation projects.

In 2001, Texas State Department of Transportation (TxDOT) published its Landscape and Aesthetics Design Manual (TxDOT 2001) which provided engineers and transportation staff with guidance on the design and implementation of roadside safety criteria in landscapes treatments. Planting guidelines aims at accomplish specific goals of sight-distance, clear view of obstructions, erosion control, and aesthetics. According to it plants must not be planted where they may obstruct any signs, sightlines, or driver visibility, they must be limited to low-growing varieties in intersection areas and landscape improvements must avoid the creation of unsafe conditions for motorists or maintenance personnel.

In response to community expectations and requests for concrete barrier treatments and bridge rails that contribute to the overall aesthetic of highways, the US National Cooperative Highway Research Program (NCHRP) has published a report on Aesthetic Concrete Barrier Design (Bullard et al. (2006). The goal of the report is to develop engineering design guidelines for aesthetic surface treatments of concrete barriers and to assist designers in improving the aesthetic of transportation systems. The same goal is shared by the California Department of Transportation which published the California Highway Barrier Aesthetics (2002) based on a series of crash tests reported in Crash Testing of Various Textured Barriers, (Speer et al. 2002).

The need of road infrastructures both safe and aesthetically integrated is also shared by the National Association of Australian State Road Authorities (NAASRA) in its Road Landscape Manual (Queensland Government 1997).

In Europe several projects have been funded in the last twenty years to achieve safer road infrastructures. Among them Forgiving Roadsides (European Transport Safety Council - ETSC 1998), IRDES (Improving Roadside Design to Forgive Human Errors) a cross-border joint programme funded by European National Road Authorities, and RISER (Roadside Infrastructure for Safer European Roads) a project funded by the 5th RTD Framework Programme. These projects share the importance of the safety zone as a zone adjacent to the road and free of obstructions and hazards and indicate that trees when they are too big and too close to the running carriageway should be relocated at a safer distance.

On the other hand the European Directorate of Culture and Cultural and Natural Heritage has produced a report for the protection of tree avenues in the landscape (Committee for Cultural Heritage and Landscape CD-PATEP 2009). The document supports the idea that tree-lined roads and streets constitute an important shared heritage in the history of Europe:

"*They [tree lined roads] bear witness to local history, they play an important role in terms of climate, pollution and biodiversity and they contribute to road safety. Governments and public authorities should recognise tree-lined roads and streets as a form of cultural identity which is inextricably linked to their inherent environmental and road safety functions and must therefore be safeguarded*".

As in US the beneficial role of trees for safety is stressed:

"*Rows of trees along a road contribute to safety by signalling bends, crossroads and the approach to built-up areas more effectively than road signs. They make it easier for drivers to read the road ahead, a key factor in helping them anticipate and adapt their driving to their environment, both in normal weather and even more so in snow or fog, or at night.*"

However, although landscaping as a tool to achieve safer roads is socially recognized, researchers are trying to assess quantitatively its effect on driver behaviour. Several case studies have been produced: a study on five arterial roads in Toronto, between 1992 and 1995 (Rosenblatt & Bahar 1998); a comparison between the safety performance of 12 couples of parkways and freeways, in four US states (Mok, J. & Landphair 2003); the crash rate before and after landscape improvement in 10 study sites in Texas (Mok, J.-H., Landphair & Naderi 2006), and a correlation analysis to identify weak relations between the quantity of car accidents and some aesthetic properties of road landscape in Lithuania (Matijošaitienė & Navickaitė 2013). The Fatal Accident Rate (FAR) and the Accident Cost (AC) constituted the dependent variables for comparing the safety performance of parallel sections of selected parkways and freeways in (Mok, J. & Landphair 2003).

All these studies showed a positive correlation (although sometimes weak as in the case of (Matijošaitienė & Navickaitė 2013) between the aesthetic enhancement of the road landscape and the road collision rate. Also all the authors concluded that the research results were limited and more detailed analyses of accidents in relation to landscaping were needed.

(Mok, J.-H., Landphair & Naderi 2006) study is particularly relevant due to the analysis of tree collisions before and after landscape improvements. The research hypotheses of this study were that crash rates significantly decreased after the landscape improvement at study sites and that a decrease in the number of tree collisions occurred after landscape improvements. Of the 61 study sites initially chosen because many corridors were treated by other treatments, such as pedestrian sidewalk widening, expansion of existing shoulders, or installation of bicycling path and only ten were in the end left to study the effect of aesthetics on safety. Results showed a decrease in crash rate in eight of ten study sites; in two sites an increase in crash rate after the landscape treatment was observed. The factor of tree collisions showed a decrease of about 70.83% after landscape treatment but there were no extreme changes in tree collisions before and after landscape treatments except for one location. After the installation of roadside landscape improvement the site showed a significant decrease in tree collisions. The change was assessed to be associated with a landscape treatment occurred in 1992 and thus it could be explained by TxDOT landscape design guidelines which brought the site into compliance with clear zone (Safety zone) rules and planting setback rules: "*trees should not be placed forward of any light standard and retaining wall*" (TxDOT 2001).

As for the causes of the safety enhancement in presence of roads whose aesthetical aspect had been treated there is a very limited and dated body of research. Recently (Edquist 2008) analysed the effect of visual disorder on road safety. Chaotically located road signs, advertising, buildings, electrical transmission lines etc. are called as visual disorder and the research revealed that visual disorder in road landscape decreases driver attention while driving and negatively affect safety on the roads.

5.7.1 Main findings

- Safety, public health and protection of the cultural and natural heritage are the main actors in the debate on geographical and cultural influence on VRS placement. In particular the role of the Safety Zone in corridors and rural roads is discussed.
- The need to protect and enhance public health has led to different outcomes in Europe and in North America, according to the most felt instance between increasing physical activity and reducing casualties. These approaches will push to provide landscape and trees within the Safety Zone on one side or to minimize interaction between different road users and between vehicles driving in different directions using central reserve and roadside barriers on the other.
- In 2001, Texas State Department of Transportation (TxDOT) published the Landscape and Aesthetics Design Manual (TxDOT 2001)) which provides guidance on planting and landscapes treatments in the context of roadside safety. Sight-distance, clear view of obstructions, erosion control, and aesthetics are discussed.

5.8 Run-Off-Road Accidents

5.8.1 Relevancy

Run-Off-Road Accidents (RoRA) are typically single vehicle accidents, i.e. vehicles leaving the road, entering the roadside or central reserve and sometimes also hitting an obstacle. Belgian accident statistics (2004-2009) show that 16% to 19% of all accidents involve single vehicles hitting a fixed object near the road. Those accidents contribute to 36% to 41% of all fatalities. In the United States, a similar situation exists (Noyce 2008). In the period 2001-2007, 55% of all fatalities were the result of ROR crashes. 40% of the fatal crashes were single vehicle accidents. Also in the Netherlands, SWOV (Wijen, Mesken & Vis 2010) concluded that one third of all fatal accidents are ROR crashes and that this type of accidents is decreasing less than average (Davidse 2011).

The accident severity of single vehicle ROR crashes is significantly higher than average. This is not surprising as the 'collision partner' is often a rigid obstacle with limited possibilities to absorb all or part of the impact energy.

In the Netherlands(2004), most single vehicle ROR accidents occur on 80 km/h roads, representing 65% of the number of fatalities and injured casualties. Analysing the respective road authority, it appears that most crashes take place on roads that are managed by local or provincial road authorities. The number of ROR accidents on roads with a moderate speed regime (60 km/h) remains low.

There is not much information concerning the causation of ROR accidents. Most often, excessive speeding, distraction and lack of experience are identified as primary causation factors. Sometimes, infrastructure also plays a role (narrow bends, insufficient skid resistance) in accident causation and influences accident outcome (Davidse 2011).

Most policies aiming to reduce the consequences of ROR accidents, do not consider the reasons why accidents take place or whom to blame. Once an accident can no longer be avoided, the focus shifts to the consequences of the accident (Duurzaam Veilig (NL), Safe System (*National Road Safety Strategy 2011-2020* 2011) (AU), Vision Zero (S) (Belin, Tillgren & Vedung 2011; Elvebakk 2007).

Single vehicle ROR accidents do not represent the major share of accidents. However, they contribute to a disproportionally high number of fatal or sever traffic accidents. Even at moderate speeds, the consequences of an impact against a sharp and rigid object can be catastrophic. In several cases, the consequences of this type of crashes can be reduced by relatively simple infrastructural measures which have an immediate effect.

In 1997, the Swedish Parliament adopted Vision Zero philosophy (Elvebakk 2007) which aims at the reduction of the consequences of those accidents. From an engineering point of view, this means that traffic participants should not be exposed to energy levels that are not tolerable for the human body. Various principles allow to manage and limit this exposure; for example by avoiding collisions with rigid objects in the roadside. The Dutch approach 'Duurzaam veilig' (Koornstra et al. 1990) admits that even a road with an optimal design cannot prevent human error. From that perspective, forgiving road principles have also been incorporated into this Dutch approach.

5.8.2 Safety zone and recuperation zone

Different studies have been made to determine the run-off-road distance of vehicles accidentally leaving the road. Those attempts were based on mathematical models or real accident data. A flat and unobstructed recovery distance of 3 m (10 ft) can be associated with an accident reduction of 25% (Lynam 2005). 6m (20 ft) recovery zones resulted in 50% accident reduction. Based on collisions with trees at different distances from the side of the road in the Netherlands and considering 10% collisions as acceptable, 3,5 m (regional roads), 7 m (federal roads) and 10 m (highway) are considered as acceptable obstacle free zones (Lynam 2005). In France, 75% of all fatalities due to a ROR accident on roads outside urban areas, relate to crashes into obstacles that are located on max 4 m from the edge of the carriageway (SETRA Service d'Etudes sur les Transports les Routes et leurs Aménagements 2002).

Several countries developed their own guidelines for a recommended width of the safety zone, above all for different speed regimes and sometimes also corrected for curves (BE) or different type of obstacles or road users (in Belgium/Flanders an increased presence of PTW can motivate an increase of the recommended width of the safety zone). In the Netherlands and France, distinction is also made between renovation works on existing roads and construction of new roads. For central reserves, the width of the safety zone should be increased to deal with the risk of vehicles crossing over to the opposite direction. Also, the vocabulary used is not always identical. In the Netherlands, this zone is designated as an obstacle free zone (which obviously is the ideal situation), most countries however use 'safety zone'. In France, the safety zone is differentiated into a so called recuperation zone (zone de récuperation) and a zone with reduced injury severity (zone de gravité limitée), as shown in Figure 82.

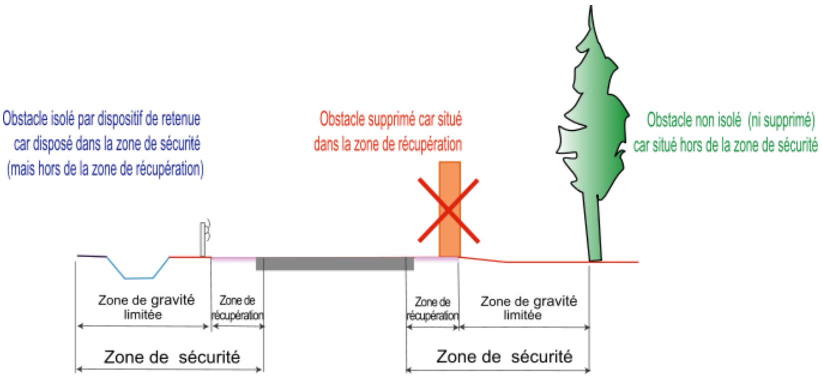

Figure 82 - France: distinction between recuperation zone and zone with reduced injury severity (Handling lateral obstacles on main roads in open country, Sétra, 2002)

A small strip in the safety zone, next to the outer lane, can serve as a recuperation zone. It allows drivers of errant vehicles to correct their trajectory and to avoid accidents. This recuperation zone should be flat, semi-paved (2008) and without or only a limited level difference (2004) to the adjacent road surface to avoid wheel blocking and overcompensation by the driver of the errant vehicle. Absolutely no objects are tolerated in this recuperation zone as they compromise any correcting action. Very often, the paved shoulder can serve as recuperation zone. Profiled markings or other acoustical warnings (2004) between the outer lane and the recuperation zone could warn users leaving the carriageway. The recuperation zone should be sufficiently wide (depending on the speed allowed). On the other hand, excessive widths should be avoided to make sure this strip is not used for overtaking, parking or as bicycle lanes.

Although one might think that most ROR accidents occur at the outer border of a curve, this cannot be confirmed by real data. Accident analysis in the Netherlands (2004) and France (SETRA Service d'Etudes sur les Transports les Routes et leurs Aménagements 2002) showed that an almost equal percentage of accidents occurred on straight sections.

5.8.3 Roadside hazards

Running off the road doesn't necessarily results in injuries. If there is sufficient space available to slow down and stop the vehicle, most crashes will remain without consequences. Most often however, objects or terrain conditions can cause an abrupt slowdown or destabilization of the vehicle leading to injuries for the vehicle occupants. Trees heavily contribute (5% - 10%) to fatal accidents (SETRA Service d'Etudes sur les Transports les Routes et leurs Aménagements 2002). Tree crashes obviously are more frequent on roads other than motorways. In the Netherlands trees contributed for 85% of all fatal crashes with fixed obstacles on roads (but non motorways) outside urban areas (CROW 2004). Lighting columns and other isolated supports also represent an important share, varying around 7% of all fatal accidents (STATS19 database, period 1998-2002) (Lynam 2005). On motorways, single vehicle ROR accidents involving Vehicle Restraint Systems VRS are responsible for 20% - 30% of fatal accidents (Lynam 2005). Unfortunately, accident statistics generally are not sufficiently detailed to give information about the type of Vehicle Restraint System impacted or impact details. Although recent VRS are being designed to mitigate the consequences of a vehicle impact as much as possible, inadequate installation, inappropriate maintenance or lack of repair may turn these safety devices into dangerous obstacles. Ditches can be considered as a special type of obstacle. Much depends on the cross-section of the ditch (depth, slope). Often however, entering a ditch will destabilize the vehicle (Thomson 2002). In some cases, a vehicle that enters a ditch can be guided onto a rigid construction at the end of the ditch (see Figure 83).

Figure 83 - Ditches can guide errant vehicle onto a rigid construction (source unknown).

Embankments represent a second type of 'special' obstacle. Cut slopes with a gradient below 1:3 are considered as relatively safe (2011), although some countries allow higher gradients (The Netherlands allow cut slopes with a 1:2 gradient when the transition from horizontal to sloped surface is rounded (CROW 2004)). Based on existing recommendations and numerical simulations, a gradient of 1:3 is the threshold to consider a slope as an obstacle or not (Pardillo-Mayora 2010). With a higher gradient, the vehicle risks to encroach the sloped surface or rollover after having travelled a certain distance on the side. For fill slopes, slope and height determine whether this type of obstacle is acceptable or not (Figure 84). If the slope becomes steeper, the risk that the vehicle that leaves the road loses contact with the surface when it enters the embankment and is 'launched' increases. In such cases the fall height should be reduced to limit possible consequences (CROW 2004) (SETRA Service d'Etudes sur les Transports les Routes et leurs Aménagements 2002). Again, a rounded transition from horizontal surface to sloped surface increases the allowed slope (CROW 2004) in the Netherlands.

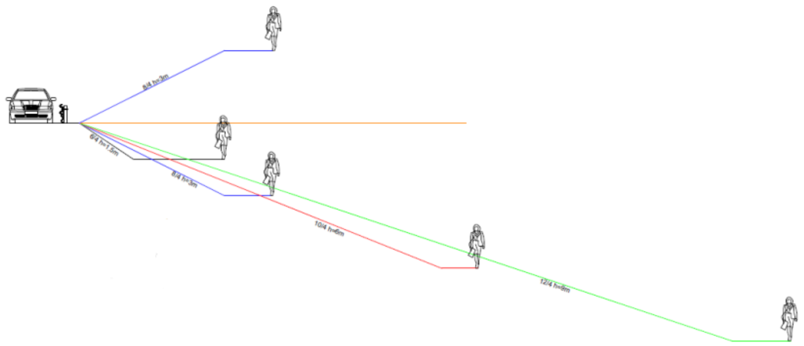

Figure 84 - Acceptable gradients and heights for cut and fill slopes. Source: Service Public de Wallonie (Belgium).

5.8.4 *Measures*

Recommended measures to reduce possible consequences of ROR accidents almost always follow a four step approach:

1. Allowing drivers from errant vehicles to correct their trajectory by providing a small recuperation zone next to the carriageway. Profiled road markings or other mechanisms may warn distracted drivers that they are running off the road and that they should correct their behaviour.
2. Removing potentially aggressive objects from the safety zone creating sufficient space for errant vehicles to slow down and stop without any consequences for the car occupants. In some cases objects, i.e. traffic signs, can be moved further away from the edge of the road or can be combined to reduce the number of obstacles.
3. If hazardous objects cannot be removed, consider replacing them by non-harmful variants. For road equipment supports (lighting columns, utility poles, sign supports, etc), (EN 12767: Passive safety of support structures for road equipment - Requirements and test methods 2008), offers a method to evaluate the behaviour

upon impact of a personal vehicle and possible consequences for the vehicle occupants. For other objects, the approach should be that sharp, hazardous objects should be avoided and other alternatives should be considered. Trees for instance can be replaced by hedges which will have similar benefits (guidance) in terms of helping the driver to read the road ahead but not lethal consequences when impacted. If harmless variants for present objects are not an option or if the terrain conditions are creating a risk, the installation of a VRS becomes a viable option. It is important to choose a VRS that is appropriate for the local traffic conditions (type and number of vehicles, speed) and for the risks that need to be mitigated. When choosing performance classes provided by EN 1317, a Road Authority should keep in mind that the containment capacities of an installed VRS during an impact not only depend on the intrinsic product characteristics as determined during the EN 1317 impact tests, but also on the type of impact (vehicle mass and type, speed, ...) and installation conditions. A VRS by itself is also an obstacle and injury risk can never be excluded. Installation of a longitudinal VRS to isolate a local obstacle might reduce the accident severity but could also increase the impact probability. The above considerations should be taken into account in the same order in which they are mentioned. Whether a measure is feasible, it will probably depend on the local situation.

5.8.5 Main findings

- Although single vehicle ROR accidents are not the most common type of road traffic crashes, they contribute to a high number of fatal or severely injured casualties from road traffic accidents. The severity of ROR crashes is considerably higher than the average severity of the of all road crashes.
- Several guidelines recommend dimensions for the width of the safety zone, often depending on traffic and local conditions. To prevent accidents, a small recuperation zone next to the carriageway allows drivers to correct their behaviour.
- Available documents concerning ROR accidents generally consider only the safety of the traffic participant. ROR accidents however can also have severe consequences for the road environment when a vehicle that leaves the road ends up in an ecological fragile environment, in an industrial or urban environment, housings or other areas. This aspect has not been considered.
- Different national recommendations for safety zone dimensions or which obstacles or terrain conditions should be considered as potentially dangerous are comparable. Differences can probably be explained by local (national) habits and the feasibility of what is recommended.
- Among all objects, trees are the most impacted obstacle. They have an important contribution to the number of fatalities.

5.9 Costs and financial implications of Vehicle Restraint Systems

5.9.1 Introduction

It is not possible to select a vehicle restraint system without considering the financial consequences of the selection. Unfortunately this is an area that is difficult to quantify due to the difficulty in collecting information covering the relevant costs and benefits for a particular system. There are notable attempts at developing generic tools to address roadside safety design costs, with the Roadside Assessment Program (RSAP) (Ray et al. 2012) in the US being the most ambitious. This is a good example of a method to estimate the costs and benefits associated with different design concepts. A similar evaluation was applied in Sweden in the doctoral thesis of Karim (Karim & Magnusson 2008) using Life-Cycle Costs (LCC). Similar approaches may be applied in other countries but no other published articles could be obtained in this review.

The key elements of RSAP and Karim's LCC model are:

1. Statistical estimates of the accident frequency and severity for the road under investigation.
2. Construction costs for the system under review.
3. Repair costs for different impact severities expected for the collisions predicted in point 1.
4. Maintenance costs associated for the systems.
5. Injury costs for the different accidents predicted in point 1.

RSAP analyses different design alternatives using a Monte Carlo simulation to simulate the service life of the VRS. Results from the analysis are presented in terms of Benefit-Cost Ratios where the societal savings (in terms of lowered injury costs) are divided by the construction and service life costs. A Benefit-Cost Ratio of 1 indicates a break even case. Many US agencies expect B-C ratios greater than 2 to warrant an investment. The LCC analysis of Karim (Karim & Magnusson 2008) also used a Monte-Carlo simulation of the service life but the results are presented as total costs - summing injury, construction, and operational costs – where the different systems are compared and the lowest cost is the preferred solution. Each of the analyses needs the elements identified above and is a challenge for an analyst. There are no readily available tables or formulas that can be sourced from the literature without investigating local experience. RSAP(Ray et al. 2012) has drawn on extensive data collection in various US states for the different systems included in the program's library. Karim (Karim & Magnusson 2008) was able to access maintenance and accident databases in Sweden for the road under investigation. No known data exists for general European application.

5.9.2 Overview of literature

There are few publications documenting cost-benefit analyses for VRS with product specific data. Papers identified by the SAVeRS consortium with actual cost information are from the

US and Sweden. This does not indicate that no other jurisdictions conduct these analyses, only that easily accessible documentation is not available. The main obstacle for these analyses is the availability of data for accidents that are inherently difficult to document. Single vehicle collisions are problematic for documenting in detail and many minor collisions are unreported. Maintenance costs for these collisions, especially detailing specific hardware components, are not always available electronically. Some documents reporting general cost information for different countermeasures are available such as the RANKERS project and the Handbook of Road Safety Measures (Elvik et al. 2009). Specific cost information are reported in technical reports such as RSAP documents (Ray et al. 2012), PhD Thesis (Karim & Magnusson 2008), and technical reports (Carlsson 2009).

5.9.3 Methodologies

The main research approach for cost effectiveness or Life-cycle Cost analyses of VRS was to use statistical analysis of available crash databases to identify crash performance of different systems for different environments. The crash performance was used as a predictor in Monte Carlo simulations. Financial data was extracted various sources and broken into construction, repair, and maintenance costs. This cost information was often incomplete and some analyses were limited to just construction costs. Most latter research attempts to provide generic information to serve as initial estimates when detailed data is not available.

5.9.4 Main findings

- Although the literature provides limited information for European wide application, there are useful methodologies that can be exploited. Essentially the approaches in RSAP and Karim's LCC analyses are valid frameworks for a European economic assessment tool.
- The main current and future difficulty is to find financial data covering all aspects of a VRS installation and valid beyond a region or national level. Different currencies, organization record keeping systems, and diverse product catalogues make it onerous to develop a generic European tool. However, the tool can be developed and distributed for use at the local level where specific data may be available.
- Different levels of cost analysis have been reported. In RSAP (Ray et al. 2012), costs for construction, maintenance, and repairs can be assigned to specific VRS components. The injury and repair costs are calculated based on probabilistic models of accident severity. RSAP has been applied using construction and injury costs, but limited maintenance and repair costs data, to provide guidelines for selecting barriers (Sicking 2009).
- Karim (Karim & Magnusson 2008) not only included specific repair and maintenance costs, but even estimated the cost due to traffic disruption due to an accident. In RANKERS , Handbook for Roads Safety Measures (Elvik et al. 2009) and similar compendiums, a cost effectiveness of different countermeasures is often provided as "low", "medium", and "high" to give a general indication of the system costs but without quantifying the costs.

6 Conclusions

6.1 Conclusions from the review of National Guidelines and Standards

As one might anticipate it was observed that the parameters related to the consequences of an accident were used more often for the decision as to whether to install a VRS, or not since these are basically a list of hazards that would necessitate the installation of a VRS to mitigate the danger. Conversely, parameters related to the likelihood of a given type of accident were used more often to determine the level of performance required from the VRS, since these include parameters such as traffic volume of heavy goods vehicles.

Examination of those parameters most frequently referenced within national guidelines and standards has shown that in terms of the justification for roadside safety barrier, it is the risk to vehicle occupants, travelled speed, road geometry, the existence of risk to third parties and traffic which are the most frequently included parameters (in that order). For median barriers, the same factors are most frequently referenced, but it is speed which is mentioned most frequently. When considering those factors which are used for determining the performance requirement of a roadside safety barrier, it is factors such as the existence of special risk to third parties, traffic and road alignment and/or geometry which are considered most frequently (in that order). For median barriers, again, these are factors which are frequently referenced, but with traffic being the most frequently referenced characteristic. When such factors are examined in further detail, it is the presence of embankments and cuttings (and their height and gradient), the presence and proximity of vulnerable road users (such as pedestrians and cyclists), railways, bodies of water and non-deformable roadside obstacles, the average annual daily traffic and actual speeds which are most prominent in determining the need for a roadside safety barrier. When selecting the performance of a roadside barrier, it is factors such as the presence of structures and railways lines, the presence and proximity of bodies of water and non-deformable roadside obstacles, the average annual daily traffic, the average annual daily HGV traffic and actual speeds and the presence of adverse road geometry which are most prominent. Whilst factors such as aesthetics and cost are mentioned in some national guidelines and standards, their frequency is low.

For bridge parapets there is less specific guidance than for roadside and median safety barriers, however obstructions with a special risk to vehicle occupants and the height of the bridge, are the most common factors. When determining the performance of a bridge parapet, it is factors such as the existence of special risks to third parties (for example railways lines) and obstructions posing a risk to vehicle occupants which are referenced most frequently.

Guidance on the need to install crash cushions is very limited; however it is the presence of a non-deformable hazard which occurs most common (perhaps unsurprisingly). With regard to determining the performance level of the crash cushion, this is limited to the actual speed limit of the road. This is perhaps also as expected as the standards for the testing of crash cushions identify impact speed as one of the defining parameters for performance.

It was also observed that, whilst the majority of the countries have guidelines and/or standards related to roadside and median barriers, there is generally limited guidance for other VRS systems such as crash cushions, transitions and MPS.

6.2 Conclusions from the Literature Review

The available literature on the placement of VRS focuses on safety barriers. Most of the studies make comparative analyses on accident rate and severity on road segments before and after the placement of safety barriers. Information on terminals, transitions and crash cushions is scarce.

The discussion on median barriers focuses on the effectiveness in reducing accident rate and severity against the option of wider central reserves. In fact, although 10 m wide central reserves do not eliminate cross-over hazard they do seem to cause a lower number of accidents than median barriers. However, in recent years in Europe economic and practical reasons have often led to a reduction in central reserve strip width up to 5 m. In these conditions numerous National Road Authorities have decided to erect barriers with higher containment capacities (level H2 or over) than those most commonly used (level N2). The same problem is starting to be acknowledged in the US.

As for roadside barriers their placement is influenced by the fact that although single vehicle ROR accidents are not the most common type of crashes, they contribute to a high number of fatal or severely injured casualties from road traffic accidents. As for central reserve several guidelines recommend thus dimensions for the width of the safety zone, often depending on traffic and local conditions. To prevent accidents, a small recuperation zone next to the carriageway is also recommended to allow drivers to correct their behaviour.

Available documents concerning ROR accidents generally consider only the safety of the traffic participants; however, ROR accidents can also have important consequences for the road environment when a vehicle that leaves the road ends up in an ecological fragile environment, in an industrial or urban environment, housings or other areas. Environment and pedestrian protection issues play a role also in the placement of roadside barriers in corridors and rural roads. In regard to this the need to protect public health by both increasing physical activity and reducing casualties has led to different outcomes in Europe and in North America. In Europe in fact some countries prefer minimizing interaction between different road users and between vehicles driving in different directions using central reserve and roadside barriers, while in US especially wide safety zone complemented by landscape and trees are preferred.

Another hot topic on roadside barriers research is the comparison on the effectiveness of rigid and flexible barriers on reducing accident severity. The containment level is almost never discussed while different kind of barriers: steel rope, steel w-beam and concrete barriers are assessed.

In terms of variables for the placement and choice of VRS, these are not generally indicated since, as already stated, most of the studies analyse a same road, for the same traffic and geometrical conditions, before and after a safety treatment. Risk analysis and safety management tools such as 'safety-barrier diagrams' are suggested for identifying the risks associated with the installation of safety barrier systems.

On the other side studies on Motorcyclist Protection Systems use traffic volume variables such as AADT and percentages of different road users and recommend the installation of MPS in roads with high exposure of PTWs. In terms of road geometry, accident statistics and in-depth analyses point out roads with bends between 50 m and 150 m as specific areas of higher risks.

In regard to the influence of cost on the placement of VRS although the literature provides limited information for European wide application, there are useful methodologies that can be exploited for a European economic assessment tool.

The main current and future difficulty is to find financial data covering all aspects of a VRS installation and valid beyond a region or national level. Different currencies, organization record keeping systems, and diverse product catalogues make it onerous to develop a generic European tool. However, the tool can be developed and distributed for use at the local level where specific data may be available.

7 Moving Forward to Work Package 2

The main aim of Work Package 1 was to develop a list of the most influential parameters in the installation and selection of vehicle restraint systems from a detailed analysis of National standard and guidelines, and from a thorough review of literature. From the completion of these two Tasks, the following parameters have been highlighted:

Parameters related to the consequences of an accident were used more often for the decision as to whether to install a VRS

Parameters related to the likelihood of a given type of accident were used more often to determine the level of performance required from the VRS

Roadside and median safety barriers:

Factors most frequently used to justify installation:

Risk to vehicle occupants;
Actual travelled speed;
Road geometry;
The distance between the roadside and the hazard;
The existence of risk to third parties and traffic;
The presence of embankments and cuttings (and their height and gradient);
The presence and proximity of vulnerable road users;
The presence railways;
The presence bodies of water;
The presence of non-deformable roadside obstacles;
The average annual daily traffic;
Width of median (for median barriers only);
Width of safety zone (roadside barriers only).

Factors most frequently used to specify performance:

Special risk to third parties;
Traffic and road alignment and/or geometry;
The presence of structures;
The presence railways;
The presence bodies of water;
The presence of non-deformable roadside obstacles;
The average annual daily traffic;
The average annual daily HGV traffic;
Actual travelled speed;
The presence of adverse road geometry

Bridge parapets:

Factors most frequently used to justify installation:

Risk to vehicle occupants, and
The height of the bridge.

Factors most frequently used to specify performance:

Special risks to third parties, and

Obstructions posing a risk to vehicle occupants.

Crash cushions:

Factor most frequently used to justify installation: presence of a non-deformable hazard

Factor most frequently used to specify performance: actual speed limit of the road

Motorcyclist Protection Systems

Factors most frequently used to justify installation:

Traffic flow, and

Percentage of motorcyclists on the road.

These parameters will therefore be taken forward into Work Package 2 for further evaluation and study, utilising crash data to observe their influence with regard to crash numbers.

It was also observed that, whilst the majority of the countries have guidelines and/or standards related to roadside and median barriers, there is generally limited guidance for other VRS systems such as crash cushions, transitions and MPS.

In regard to the influence of cost on the placement of VRS although the literature provides limited information for European wide application, there are useful methodologies that can be exploited for a European economic assessment tool. There is little information within the VRS-specific standards and guidelines.

The main current and future difficulty is to find financial data covering all aspects of a VRS installation and valid beyond a region or national level. Different currencies, organization record keeping systems, and diverse product catalogues make it onerous to develop a generic European tool. However, the tool can be developed and distributed for use at the local level where specific data may be available.

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9 References

ABNT. (2007). NBR 15486:2007. *Segurança no tráfego - Dispositivos de contenção viária – Diretrizes*. Brazil.

ACEM 2004. In-depth investigations of accidents involving powered two wheelers, Final Report 1.2. *In:* Report, M. (ed.).

AENOR 2008. UNE 135900:2008 - Standard on the evaluation of performance of the protection systems for motorcyclists on safety barriers and parapets.

Alberta Infrastructure and Transportation (2007) – *Roadseide Design Guide: Chapter H3 Roadside Design Process*. Available:http://www.transportation.alberta.ca/Content/docType233/Production/H3-Roadside-Design-Process.pdf, last access 22.10.13.

Alluri, p., k., h. & gan, a. 2012. *In-Service Performance Evaluation for G4(IS) Type Strong Post W-beam Guardrail Systems and Cable Median Barrier*, Lehman Center for Transportation Research, Florida International University.

American Association of State Highway and Transportation Officials. (2010). *Highway Safety Manual*. US: AASHTO.

American Association of State Highway and Transportation Officials. (2011). *Roadside Design Guide*. US: AASHTO.

Australian/New Zealand Standard. (1999). AS/NZS 3845:1999. *Road Safety Barrier Systems*. Sydney, Australia; Wellington, New Zealand: SAI Global.

Australian Transport Council. 2011. *The National Road Safety Strategy 2011-2020*. Australia.

Austroads. (2009). *Guide to Road Design Part 6 Roadside Design, Safety and Barriers*. Sydney, Australia.

Avenoso, A. & Beckmann, J. (eds.) 2005. *The Safety of Vulnerable Road Users in the Southern, Eastern and Central European Countries (The "SEC Belt"),* Brussels: European Transport Safety Council.

Banverket. (1998). BVF 586.20:1998. *Fritt utrymme utmed banan*. Stockholm, Sweden: BVF.

Barlow S., Pritchard R., Theodoropoulos A., Troutbeck R., 2009. *Barrier Between Road and Rail: Barrier Adjacent to rail Explaned.* Available:http://www.cmnzl.co.nz/assets/sm/3541/61/0018-E10Barlow.pdf, last access 23.10.13.

Belgian Standards. (2013). *Manual for Road Restraint systems – DRAFT*. Flanders, Belgium.

Belin, M.Å., Tillgren, P. & Vedung, E. 2011. Vision Zero – a road safety policy innovation. *International Journal of Injury Control and Safety Promotion,* 19**,** 171-179.

Berg, F. A., Rücker, P., König, J., Grzebieta, R. & Zou, R. 2005. *Motorcycle Impacts Into Roadside Barriers - real-world Accident studies, crash tests and simulations carried out in Germany and Australia*. *ESV.*

Bonneson J. A., Geedipally S., Pratt M. P., Lord D. *Safety prediction methodology and analysis tool for freeways and interchanges*. NCHRP Project 17-45, Final Report, May 2012

BS EN 12767:2007 *Passive safety of support structures for road equipment - Requirements and test methods*.

California Department Of Transportation 2002. California Highway Barrier Aesthetics. *In:* California Department Of Transportation (ed.).

Candappa, N., D'elia, A., Corben, B. & Newstead, S. 2009. Evaluation of the Effectiveness of Flexible Barriers along Victorian Roads. . Monash University Accident Research Centre.

Carlsson, A. 2009*. Uppföljning av mötesfria vägar – slutrapport* (Evaluation of 2+1 Roads – Final Report). *VTI Report.*

CEN, E. C. F. S. 2002. DD ENV 1317-4:2002 - Road restraint systems. *Performance classes, impact test acceptance criteria and test methods for terminals and transitions of safety barriers.* BSI.

CEN, E. C. F. S. 2010a. BS EN 1317-1:2010 - Road restraint systems. *Terminology and general criteria for test methods.* BSI.

CEN, E. C. F. S. 2010b. BS EN 1317-2:2010 - Road restraint systems. *Performance classes, impact test acceptance criteria and test methods for safety barriers including vehicle parapets* BSI.

CEN, E. C. F. S. 2010c. BS EN 1317-3:2010 - Road restraint systems. *Performance classes, impact test acceptance criteria and test methods for crash cushions.* BSI.

CEN, E. C. F. S. 2012a. EN1317-5:2007+A2:2012 - Road Restraint Systems. *Product requirements and evaluation of conformity for vehicle restraint systems.* BSI.

CEN, E. C. F. S. 2012b. EN1317-8:2012 - Road Restraint Systems. *Motorcycle road restraint systems which reduce the impact severity of motorcyclist collisions with safety barriers.* BSI.

Committee for Cultural Heritage and Landscape Cd-Patep. *Road Infrastructures: Tree avenues in the landscape*. 5th Council of Europe Conference on the European Landscape Convention, 30-31 March 2009 2009 Palais de l'Europe, Strasbourg.

Crossroads Software Inc. *Crossroads Software. www.crossroadssoftware.com*.

Crow 2004a. Handboek veilige inrichting van bermen. Niet-autosnelwegen buiten de bebouwde kom*.* Ede, Netherlands.

Davidse, R. 2011. Run-off-road crashes: characteristics, crash scenarios and possible interventions; Results of an in-depth study of run-off-road crashes on 60, 70, 80 and 100 km/h roads.

Davis, G. & PEI, J. 2005. Bayesian Reconstruction of Median-Crossing Crashes and Potential Effectiveness of Cable Barriers. Transportation Research Record.

Department of Infrastructure Energy Resources 2007. *Road Safety Barriers - Design Guide*. Available: http://www.transport.tas.gov.au/__data, last access 23.10.13.

Department of Transport and Regional Services Australian Transport Safety Bureau. 2000. *ATSB Annual Review 2000*. Australia.

Dirección General de Carreteras. (2009). Orden Circular 28/2009. *Criterios de aplicación de barreras de seguridad metálicas*. Madrid, Spain: Gobierno de España.

Domenichini L., La Torre F., Giordano G. 2004. *Safety Analysis of Multimodal Transportation Corridors*, SIIV II International Congress, Italy, Florence.

Donnell, E., Harwood, D., Bauer, K., Mason Jr, J. & Pietrucha, M. 2002. Cross-Median Collisions on Pennsylvania Interstates and Expressways. . Transportation Research Record.

Donnell, E., K. & Mason Jr, J. 2004. *Predicting the Severity of Median-Related Crashes in Pennsylvania by Using Logistic Regression*. Transportation Research Record.

Dreznes, M. Implementation of CEN and U.S. Procedures on a Global Basis: the United States. Transportation Research Circular, No. 451. TRB, Washington. 1995.

Duijm, N. J. 2009. Safety-barrier diagrams as a safety management tool. *Journal of Reliability Engineering and Safety System,* 94**,** 332-341.

Duncan, C., Corben, B., Truedsson, N. & Tingvall, C. 2000. Motorcycle and Safety Barrier Crash-Testing - Feasibility Study. *In:* BUREAU, D. O. T. A. R. S. A. T. S. (ed.). Accident Research Centre - Monash University.

Duprè G., Bisson O., 2006 *Roadside Infrastructure for safer European Roads "RISER" – D05 – Summary of European design guideline for roadside infrastructure.*

Edl, T., Bares, A., Barnas, A. & Bittner, P. 2010. Passenger Safety on Modern Vehicle Restraint Systems. *16th IRF World Road Meeting.*

Edl T., 2009. *Containment level H4b Restraint System on The Huge German Siegtal-Bridge*, A Project Report Delta Bloc Europa GmbH, Precast Concrete Barrier Systems. Available: http://www.deltabloc.com, last access 23.10.13.

Edquist, J. 2008. *The Effects of Visual Clutter on Driving Performance.* Monash University.

Elvebakk, B. 2007. Vision Zero: Remaking Road Safety. *Mobilities,* 2**,** 425-441.

Elvik, R. 1995. The safety value of guardrails and crash cushions: A Meta-Analysis of Evidence From Evaluation Studies. *Journal of Accident Analysis and Prevention* 27**,** 523-549.

Elvik, R., Høye, A., Vaa, T. & Sørenson, M. 2009. *Handbook of Road Safety Measures*, Emerald Group Publishing Limited.

European Transport Safety Council - Etsc 1998. Forgiving Roadsides. *In:* European Transport Safety Council - Etsc (ed.);

Fagerlind, H., Martinsson, J., Nitsche, P., Saleh, P., Goyat, Y., La Torre, F., Grossi, A., 2011. *Guide for the Assessment of Treatment Effectiveness*. ENR SRO1 – ERANET Project IRDES – Deliverable N. 2

FGSV. (2009). RPS 2009. *Guidelines for passive protection on roads by vehicle restraint systems*. Germany.

Gabauer, D. & Gabler, H. 2010. The Effects of Airbags and Seatbelts on Occupant Injury in Longitudinal Barrier Crashes. *Journal of Safety Research* 41**,** 9-15.

Gabauer, D. & Thomson, R. 2005. Correlation of Vehicle and Roadside Crash Test Injury Criteria. Transportation Research Board 84th Annual Meeting.

Grzebieta, R., Zou, R., Jlang, T. & Carey, A. 2005. Roadside Hazard and Barrier Crashworthiness Issues Confronting Vehicle and Barrier Manufactures and Government Regulators. *Transportation Research Board 84th Annual Meeting.*

Hakkert, S., Gitelman, V. *Guidelines for Selection and Installation of Crash Cushions*. Ministry of Transport, Israel. 2004.

Hakkert, S., Gitelman, V. *Guidelines for Selection and Installation of Permanent Safety Barriers on Rural Roads*. Ministry of Transport, Israel. 2004.

Hakkert, S., Guttmann, L., Livney, M. *A Proposal of Guidelines for the Use of Safety Barriers in Israel: a Platform for Discussion*. Report 92-184. Transportation Research Institute, Techion, Haifa. 1992.

Hamilton-Baillie, B. 2004. Urban design: Why don't we do it in the road? Modifying traffic behavior through legible urban design. *Journal of Urban Technology,* 11**,** 43-62.

Harkey, D. L. & Zegeer, C. V. 2004. PEDSAFE: Pedestrian safety guide and countermeasure selection system. *In:* Department Of Transportation.Washington, D. U. S. (ed.).

His Majesty's Government of Nepal. (1997). *Road Safety Notes 6. Safety Barriers*. Nepal: Traffic Engineering and Safety Unit Design Branch, Department of Roads Ministry of Works and transport.

IDIADA 2012. Innovative concepts for smart road restraint systems to provide greater safety for vulnerable road users. D 2.4 Final Report *SmartRRS.*

Italferr (1999). *Linee guida per la sicurezza nell'affiancamento strada-ferrovia*.

Jama, H. H., Grzebieta, R. H., Friswell, R. & Mcintosh, A. S. 2011. Characteristics of fatal motorcycle crashes into roadside safety barriers in Australia and New Zealand. *Accident Analysis and Prevention,* 43**,** 652-660.

Karayolları Genel Müdürlüğü. (2005). *Karayolu Tasarim El Kitabi*. T.C. Bayindirlik Ve Iskan Bakanligi.

Karim, H. & Magnusson, R. 2008. Road Design for Future Maintenance Problems and Possibilities. *Journal of Transportation Engineering,* 134**,** 523-531.

Koornstra, M., Mathijssen, M. P. M., J.A.G., M., Roszback, R. & Wegman, F. C. M. 1990. Naar een duurzaam veilig wegverkeer - Nationale verkeersveiligheidsverkenning voor de jaren 1990 / 2010. SWOV Stichting Wetenschappelijk Onderzoek Verkeersveiligheid.

Kuebler J., 2013. *Improvement of Safety Barriers on German Bridges: result of impact test with heavy lorries*. Federal Highway Reseacrh Institute (BASt), Bergisch Gladbach, Germany.

Le Lier Laboratoire D'essais Inrets Equipements De La Route. 1995. *Lier test protocol;* [Online].

Liikennevirasto. 2013. Liikenneviraston ohjeita 27/2013. *Tiekaiteiden suunnittelu.* Helsinki, Finland.

Liikennevirasto. 2013. Liikenneviraston ohjeita 29/2013. *Tien poikkileikkauksen suunnittelu.* Helsinki, Finland.

Livneh, M., Krauss, J., Frisher, B. *Rural Road Geometry Design Guide*. Public Works Department, Ministry of Construction and Housing, Jerusalem, 1994.

Lynam, D. 2005. The travel of errant vehicles after leaving the carriageway.

Martin, J.-L. & Quincy, R. 2001. Crossover Crashes at Median Strips Equipped with Barriers on a French Motorway Network. Transportation Research Record.

Matijošaitienė, I. & Navickaitė, K. 2013. Aesthetics and Safety of Road Landscape: are they Related? *Journal of Sustainable Architecture and Civil Engineering,* 1**,** 20-25.

Miaou, S.-P., Bligh, R. P. & Lord, D. 2005. Developing Median Barrier Installation Guidelines: A Benefit/Cost Analysis using Texas Data. . *In:* Record, T. R. (ed.).

Ministerstvo dopravy Odbor silniční infrastruktury. (2010). TP114:2010. S*vodidla Na Pozemních Komunikacích*. Brno, Czech Republic.

Ministarstvo Mora, Turizma, Prometa I Razvitka. (2011). *Pravilnik O Prometnim Znakovima, Signalizaciji I Opremi Na Cestama*. Croatia.

Ministère de l'écologie, de l'énergie, du développement durable et de l'aménagement du territoire. (2009). DEVS0904864A:2009. *Arrêté du 2 mars 2009 relatif aux performances et aux règles de mise en service des dispositifs de retenue routiers soumis à l'obligation de marquage CE*. France: Journal Officiel De La République Française.

Ministerie van Infrastructuur en Milieu. (2012). *Componentspecificatie Voertuigkering*. Netherlands: Rijkswaterstaat.

Ministero dei Lavori Pubblici. (1992). Ministry Decree No. 223 of 18.02.1992. *Istruzioni Tecniche sulla Progettazione, Omologazione ed Impiego delle Barriere di Sicurezza Stradale*. Italy: Gazzetta Ufficiale.

Ministero delle Infrastrutture e dei Trasporti. (2004). *Ministry Decree No. 2367 of 21.06.2004. Aggiornamento del decreto 18 febbraio 1992, n. 223 e successive modificazioni*. Italy: Gazzetta Ufficiale.

Ministero delle Infrastrutture e dei Trasporti. (2011). Decree 28.06.2011. *Disposizioni sull'uso e l'installazione dei dispositivi di ritenuta stradale*. Italy: Gazzetta Ufficiale.

Ministry of Communications and Works, Public Works Department. (1997). *Geometric Design Standards for Inter-Urban and Rural Roads in Cyprus*. Cyprus.

Ministery of Transport. (2005). *Traffic and Safety Devices Approved for Installation on Roads*. 4th Edition. Jerusalem.

Mok, J.-H., Landphair, H. C. & Naderi, J. R. 2006. Landscape improvement impacts on roadside safety in Texas. *Landscape and Urban Planning,* 78**,** 263-274.

Mok, J.-H. & Landphair, H. C. 2003. Parkways and freeways: safety performance linked to corridor landscape type. . *Transportation Research Board 82nd Annual Meeting.*

Molinero, A. 2006. SP4 Report on accident scenarios for motorcycle-mororcyclist-infrastructure interaction. State-of-the art. Future research guidelines. *Aprosys Advanced PROtection SYStems (6th Framework Programme).*

Motorcyclists`Associations, F. F. O. E. 2012. *New Standards for road - restraint systems for motorcyclists*.

Naderi, J. R. 2003. Landscape design in clear zone - Effect of landscape variables on pedestrian health and driver safety. *Transportation Research Record: Journal of the Transportation Research Board***,** 119-130.

Naing, C. L., Hill, J., Thomson, R., Fagerlind, H., Kelkka, M., Klootwijk, C., Dupre, G. & Bisson, O. 2008. Single-vehicle collisions in Europe: analysis using real-world and crash-test data. *International Journal Of Crashworthiness,* 13**,** 219-229.

National Cooperative Highway Research Program. NCHRP 2000. Implementation of the AASHTO Strategic Highway Plan, Initial Draft of a Compendium of Strategies. *In:* 17-18(3), P. (ed.).

National Road Authority. (2013). DMRB Volume 2 Section 2 Part 8A (TD 19/13). *Safety Barrier.* Dublin, Ireland: NRA.

National Road Authority. (2013). DMRB Volume 2 Section 3 (TD 52/13). *The Design of Vehicle and Pedestrian Parapets.* Dublin, Ireland: NRA.

New Jersey Department of Transportation (2013). Design Manual - Roadway Section 9: *Guideline for the selection and Design Criteria of Crash Cushions*. Available: http://www.state.nj.us/transportation/eng/documents/RDM/ last access 22.10.13.

Ngo H., Lake N., Kotze R., Powers N., ARRB Australia (2012). *Risk-based approachto selecting bridge barrier performance levels*. 25th ARRB Conference: Shaping the future: Linking policy, research and outcomes, Australia, Perth.

Norma Oficial Mexicana. (2012). NOM-037-SCT2-2012. *Barreras de Proteccion en Carreteras y Vialidades Urbanas*. Mexico: Diario Oficial de la Dederacion.

Noyce, D. 2008. The Operational and Safety Impacts of Run-Off-Road Crashes in Wisconsin: Object Hits and Ramp Terminals. Madison.

NSW Government – Transport Roads and Maritime Service (2013). *Union Bridge Albury Proposed Safety Barriers, review of environmental factors* – Report DC 12098 Available: http://www.rms.nsw.gov.au/roadprojects, last access 23.10.13.

NYSDOT 2009. Work zone traffic control Manual. Revised version. *In:* Mobility, N. N. Y. S. D. O. T.-O. O. T. S. A. (ed.).

NZ Transport Agency. (2002). *State Highway Geometric Design Manual*. New Zealand.

OSDG1.06.51(01) D.112:2006. *Le choix des dispositifs de retenue à placer sur le réseau routier régional wallon*. Belgium.

Österreichische Forschungsgesellschaft. (2005). RVS 08.23.05:2005. *Rückhaltesysteme Leitschienen Aus Stahl*. Vienna, Austria: FSV.

Österreichische Forschungsgesellschaft. (2005). RVS 08.23.06:2005. *Rückhaltesysteme Leitschienen Aus Stahl*. Vienna, Austria: FSV.

Österreichische Forschungsgesellschaft. (2009). RVS 09.01.25:2009. *Vorportalbereich*. Vienna, Austria: FSV.

Österreichische Forschungsgesellschaft. (2011). RVS 05.02.31:2011. *Anforderungen Und Aufstellung*. Vienna, Austria:FSV.

Österreichische Forschungsgesellschaft. (2012). RVS 05.05.41:2012. *Gemeinsame Bestimmungen Für Alle Strassen*. Vienna, Austria: FSV.

Österreichische Forschungsgesellschaft. (2010). RVS 15.04.71:2010. *Fahrzeugrückhaltesysteme*. Vienna, Austria: FSV.

Österreichische Forschungsgesellschaft. (2010). RVS 02.02.42:2010. *Empfehlungen Zur Verbesserung Der Sicherheit Für Den Motorradverkehr*. Vienna, Austria: FSV.

Pardillo-Mayora, J. 2010. Empirical calibration of a roadside hazardousness index for Spanish two-lane. *Accident Analysis and Prevention*.

PHRTA Design Manual. Chapter 8: Traffic Barriers and Fencing. Department of transportation and main road. Available: http://www.deq.state.ne.us, last access 22.10.13.

Queensland Government, D. O. M. R. 1997. Road Landscape Manual.

Queensland Government – Department of main Road 2009. *Design and Selection Criteria for Rail/Road Interface Barriers*. Technical Specification QR MCE-SR-007. Available: http://www.tmr.qld.gov.au, last access 23.10.13.

Raford, N. & Ragland, D. R. 2003. Space Syntax: An Innovative Pedestrian Volume Modeling Tool for Pedestrian Safety. Institute of Transportation Studies, UC Berkeley.

Raford, N. & Ragland, D. R. 2005. Pedestrian Volume Modeling for Traffic Safety and Exposure Analysis. Institute of Transportation Studies, UC Berkeley.

Ragland, D. R., Markowitz, F. & Macleod, K. E. 2003. An Intensive Pedestrian Safety Engineering Study Using Computerized Crash Analysis. Institute of Transportation Studies, UC Berkeley.

RANKERS Ranking for European Road Safety TREN-04-FP6TR-S07.36996/001678,. Sixth Framework Programme Specific Targeted Research or Innovation Project.

Ray, M. H., Carrigan, C. E., Plaxico, C. A., Miaou, S.-P. & Johnson, T. O. 2012. NHCRP 22-27: Roadside Safety Analysis Program (RSAP) Update.

Ray, M.H., Weir J. and Hopp J., 2003. *In-Service Performance of Traffic Barriers*. NCHRP Report 490, Transportation Research Board Washington

Republic of the Philippines, Department of Public Works and Highways. (2012). *Highway Safety Design Standards*. Part 1: Road Safety Design Manual. Philippines.

Rizzi, M., Strandroth, J., Sternlund, S., Tingvall, C. & Brian, F. 2012. Motorcycle Crashes into Road Barriers: the Role of Stability and Different Types of Barriers for Injury Outcome. *IRCOBI Conference 2012.* Dublin, Ireland.

Roadside Safety Manual (2013). Chapter 4: Roadside Safety. Available: http://www.dot.state.fl.us/rddesign/ppmmanual/2013/Volume1/Chap04.pdf, last access 22.10.13.

Roque, C. & Cardoso, J. L. 2013. Observations on the Relationship between European Standards for Safety Barrier Impact Severity and the Degree of Injury Sustained. IATSS Research.

Rosenblatt, J. & Bahar, G. 1998. An Integrated Approach to Environmental Impact Mitigation and Safety Management: Case Studies in the Municipality of Metropolitan Toronto. *XIIIth World Meeting of the International Road Federation, Roads/Transportation and the Environment Session.* Toronto, Ontario, Canada.

Ross, H.E., Sicking, R.A., Zimmer, R.A., and Michie, J.D. *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. NCHRP Report 350. TRB, Washington, 1993.

Safety Trailers INC. Towable Trailer Mounted Attenuator TTMA-100.

SafetyNet. 2007. *European Road Safety Observatory* [Online]. Available: http://www.dacota-project.eu/Links/erso/index-2.html.

Saleh, P. 2010. Interaction between Powered Two-Wheeler Accidents and Infrastructure. *In:* FP7, E.-. (ed.) *Project 2-Wheeler Behaviour and Safety, 2-BE-SAFE D1.2.*

Schneider Iv, W., Savolainen, P. & Zimmerman, K. 2009. Driver Injury Severity Resulting from Single-Vehicle Crashes Along Horizontal Curves on Rural Two-Lane Highways. T. Transportation Research Record.

Schrum, K. D., Sicking, D. L., Faller, De Albuquerque F. D. B., Lechtenberg, K.A., Reid, J.D. 2012. *Syntesis of crash cushions guidance*. MwRSF Research Report No. TRP-03-252-12 University of Nebraska, Lincoln. Available: http://mwrsf.unl.edu/researchhub last access 23.10.13.

Sétra. 2002. *Handling lateral obstacles on main roads in open country*. France.

Sétra. 2002. *Traitement des obstacles latéraux sur les routes principales hors agglomération*. France.

Sétra. 2008. *L'accotement revêtu. Savoirs et savoir-faire*. France.

Shankar V. N., Albin R. B., Milton J. C., Nebergall M (2000) *In-Service, Performnce-Based Roadside Design Policy, Preliminary Insight from Washington State's Bridge Rail Study* Transportation Research Record 1720, Paper No. 00-1184, p. 72-79.

Shojaati, M. 2003. Correlation between injury risk and impact severity index ASI. *3rd Swiss Transport Research Conference.* Monte Verita/Ascona.

Sicking, D. L., Lechtenberg, K.A., Peterson, S., 2009. NCHRP Report 638 - Guidelines for Guardrail Implementation. *NCHRP Report.*

Sistemas De Seguridad Vial. Motorcycle Impact Attenuator BASYC. sistemasdeseguridadvial.com.

Speer, D., Rich, P., White, M. & Jewell, J. 2002. Crash testing of various textured barriers. *In:* State Of California Department Of Transportation (ed.).

Statens Vegvesen. (2011). Manual 231 E:2011. *Vehicle Restraint Systems and Roadside Areas*. Norway.

Steele, D. A. & Vavrik, W. R. 2009. Improving the safety of moving lane closures. . Applied Research Associates, Inc., Illinois Center for Transportation.

Stonecipher, C. (2012). *Instructional Bulletin No. 12-03 Regardin Crash Cushion Design*. Department of Transportation Design Division, State of Tennessee.

Tarko, A., Villwock, N. & Blond, N. Effect of Median Design on Rural Freeway Safety: Flush Medians with Concrete Barriers and Depressed Medians. Transportation Research Record.

Task Force For Roadside Safety Of The Standing Committee On Highways Subcommittee On Design 1996. Roadside Design Guide. Washington, D.C. : American Association of State Highway and Transportation Officials.

Tehnicna Specifikacija, Za Javne Ceste. (2010). TSC 02.210:2010. *Varnostne Ograje Pogoji In Nacin Postavitve*. Republika Slovenija, Ministrstvo Za Promet.

The Highways Agency. (2006). TD 19/06. *Requirement for Road Restraint Systems*. UK:HA.

Thomson, R. 2002. Vehicle Impacts in V-Ditches. *Transportation Research Record*, 82-88.

Tomasch, E., Sinz, W., Hoschopf, H., Gobald, M., Steffan, H., Nadler, B., Nadler, F., Strnad, B. & Schneider, F. 2011. Required Length of Guardrails Before Hazards. . *Accident Analysis and Prevention* 43 2122-2120.

Trafikverket. (2011). TRV 2011:085. *TRVK Bro 11 Trafikverkets tekniska krav*. Stockholm, Sweden: TRV.

Trafikverket. (2011). TRV 2011:086. *TRVR Bro 11 Trafikverkets tekniska råd Bro*. Stockholm, Sweden: TRV.

Trafikverket. (2012). TRV 2012:179. *Krav för Vägars och gators utformning*. Stockholm, Sweden: TRV.

Trafikverket. (2012). TRV 2012:180. *Råd för Vägars och gators utformning*. Stockholm, Sweden: TRV.

Transportation Association of Canada. (2011). *Geometric Design Guide for Canadian Roads*. Canada.

Transportation Research Institute. (2006). *New guidelines for the approval of barriers and crash cushions* .Israel.

Trinity Highway Products Commercial/advertising brochure.

TxDOT 2001. Landscape and Aesthetic Design Manual. Texas Department of Transportation (TxDOT).

Vegagerdin. (2010). *Veghönnunarreglur*. Iceland.

Vejregelrådet. (2007). *Autoværn - Opsætning af vejautoværn og påkørselsdæmpere i åbent land*. Denmark.

Venkataraman, S., Albin, R., Milton, J. & Nebergall, M. 2000. In-Service, Performance-Based Roadside Design Policy: Preliminary Insights from Washington State's Bridge Rail Study. Transportation Research Record.

Vereinigung Schweizerischer Strassenfachleute. (1995). Swiss Norm 640 566:1995. *Passiver Schutz im Strassenraum*. Zurich, Switzerland: VSS.

Vieira, C. M., Almeida, H. A., Ferreira, I. S., Vasco, J. O., Bártolo, P. J., Ruben, R. B. & Santos, S. P. 2008. Development of an impact absorber for roadside barriers. *LS-DYNA Anwenderforum.* Bamberg.

Volksgezondheid, N. K. 2004-2009. Verkeersongevallen en -slachtoffers. Belgium.

Washington State Department Of Transportation 2012. WSDOT Design Manual - Impact Attenuator Systems.

Wijen, W., Mesken, J. & Vis, M. A. 2010. Effectiviteit en kosten van verkeersveiligheidsmaatregelen [Effectiveness and costs of road safety measures]. SWOV report.

Zeigler, A. J. 1986. Guide to Management of Roadside Trees. . *In:* FHWA, U. S. D. O. T. (ed.).

Zeigler, A. J. 1987. Risk of Vehicle-Tree Accidents and Management of Roadside Trees. *Transportation Research Record* 37-43.

Annex A: Glossary

Term	Definition
A-pillar	The first pillar of the passenger compartment, usually surrounding the windscreen. A-pillars protect the vehicle occupants in roll-over crash, but could increase the size of blind spots in the driver's vision.
Bridge abutment	The end support of a bridge deck or tunnel, usually retaining an embankment.
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.
Arterial	An arterial road, or arterial thoroughfare, is a high-capacity urban road. The primary function of an arterial road is to deliver traffic from collector roads to motorways, and between urban centres at the highest level of service possible. As such, many arteries are limited-access roads, or feature restrictions on private access.
Back slope	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	See "Passively safe support".
Carriageway	The part of the roadway constructed for use by vehicular traffic. 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.
CCTV Masts	A mast on which a closed circuit television camera is mounted for the purpose of traffic surveillance.
Central reserve	An area separating the carriageways of a dual carriageway road.
Clear zone	See "Safety zone".

Clearance	The unobstructed horizontal dimension between the front side of safety barrier (closest edge to road) and the traffic face of the of the protected object.
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 impacting 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 device that absorbs the energy of an impacting vehicle. It can be redirective or non-redirective.
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.
Deformable safety barrier	A safety barrier that deforms during a vehicle impact and may suffer permanent deformation.
Design Speed	The speed which determines the layout of a new road in plan, being the speed for which the road is designed. It is the maximum safe speed that can be maintained over a specified section.
Distributed hazards	Also known as 'continuous obstacles', distributed hazards are hazards which extend along a length of the roadside, such as embankments, slopes, ditches, rock face cuttings, retaining walls, lighting, 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	See "Dual carriageway".

Double-sided safety barrier	A safety barrier designed to be impacted on both sides.
Drainage gully	A structure to collect water running off the roadway.
Drop-off	The vertical thickness of the asphalt edge.
Dual carriageway	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.
Dynamic deflection	Is the maximum lateral dynamic displacement of the front edge of a restraint system during a collision.
Edge line	Road marking indicating where the carriageway ends and the roadside or median begins. If a shoulder or emergency lane is present, these are located in the roadside beyond the edge line.
Embankment	A general term for all sloping roadsides, including cut (upward) slopes and fill (downward) slopes (see also "Cut slope" and "Fill slope").
Encroachment	A term used to describe the situation when the vehicle leaves the carriageway and enters the roadside area.
End terminal	See "Terminal".
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.
Flared barrier end	A barrier end that is angled away from the road to prevent errant vehicles to drive behind the barrier and to avoid direct impact with the extremity of the barrier.
Fore slope	The fore slope is a part of the ditch and refers to the slope closest to 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.
Frangible support	A sign, traffic signal or luminaire support designed to break when struck by a vehicle.
Guardrail	A guardrail is another name for a metal post and rail safety barrier.
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.
Hard 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.
Highsider (PTW crash type)	A highsider or highside is a type of motorcycle accident characterized by sudden and violent rotation of the bike around its long axis. This generally happens when the rear wheel loses traction, skids, and then suddenly regains traction, creating a large torque which flips the rider head first off the road. The initial traction loss may be caused by a rear locked wheel due to excessive braking or by applying too much throttle when exiting a corner or by oversteering the bike in the turn or by any loss of traction to the rear wheel.
Highway	See "Motorway"
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 device which helps to reduce the severity of a vehicle impact with a fixed object by absorbing energy and by transferring energy to another medium. Impact attenuators include crash cushions and arrester beds.
Kerb (noun)	A border or row of joined stones elements intended to separate areas of different surfaces often on different level and to provide physical delineation or containment.
Lane line	See "Lane marking".
Lane marking	The road marking between the travel lanes.
Link road	a road used to link two cities or two more major hubs of road transport.
Leading terminal	See "Upstream terminal".
Length of need	The total length of a longitudinal safety barrier needed to shield an area of concern.
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.
Lowsider (PTW crash type)	The lowsider or lowside is a type of motorcycle crash usually occurring in a turn and caused by a loss of grip between the tires and the road surface. It is most often caused by either locking a wheel due to excessive braking or application of excessive power out of or through the turn. It may also be caused by slippery or loose material (such as oil, water, dirt or gravel) on the road surface.
Median	See "Central reserve".
Median barrier	A longitudinal safety barrier that is used to prevent vehicles from going across a median and colliding with vehicles in the opposing traffic lanes.

Motorcyclist Protection System (MPS)	A vehicle restraint system designed to protect crashed PTW riders from severe injuries.
Motorways	A dual carriageway road intended solely for motorized vehicles, and which 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).
Unpaved roadside	A roadside which contains very little or no paved surface immediately beyond the edge line.
Unpaved surface	A surface type that is not asphalt or concrete (e.g. grass, gravel, soil..).
Offside	A term used when discussing right and left hand traffic infrastructure. The side of the roadway closest to opposing traffic or a median.
Parapet	A longitudinal safety barrier whose primary function is to prevent an errant vehicle or pedestrians from going over the side of the bridge structure.
Paved shoulder	See "Hard shoulder".
Pedestrian guardrail	A restraint system for pedestrians or other road users intended to restrain pedestrians or other road users from stepping onto or crossing a road or other area likely to be hazardous including headwalls and wingwalls remote from the road. Note: "other road users" includes cyclists, equestrians, road maintenance personnel, emergency services personnel and cattle.
Pedestrian parapet	A restraint system for pedestrians or other road users along a bridge or on top of a retaining wall or similar structure which is used to avoid falling and is not intended to act as a road vehicle restraint system. Note: "other road users" includes cyclists, equestrians, road maintenance personnel, emergency services personnel and cattle.

Pedestrian restraint system	A road restraint system installed to provide restraint for pedestrians.
Permanent safety barrier	A safety barrier installed permanently on the road.
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.
Rebounded vehicle	A vehicle that has struck a road restraint system and then returns to the main carriageway.
Recovery zone	The recovery zone is a small strip immediately adjacent to the carriageway that allows drivers of errant vehicles to correct their behaviour and to continue their journey without consequences. No objects are allowed in the recovery zone. The surface should be sufficiently resistant to allow manoeuvring.
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.
Rigid safety barrier	A safety barrier that has negligible deflection during a vehicle impact.
Road equipment	The general name for structures related to the operation of the road and located in the roadside.
Road furniture	See "Road equipment".
Road restraint system (RRS)	The general name for all vehicle and pedestrian restraint systems used on the road (EN 1317).
Roadside	The area beyond the edge line of the carriageway. The central reserve may also be considered roadside.
Roadside Barrier	A road vehicle restraint system installed alongside of roads.
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 paved area of the road including shoulders, for vehicular use.
Rock face cuttings	A rock face cutting is created for roads constructed through hard, rocky outcrops or hills.
Rumble strip	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	The safety zone is the zone adjacent to the carriageway for which measures should be taken to avoid severe consequences for drivers and passengers of vehicles that accidentally leave the road and enter into this zone. In general the zone consists of a small recovery zone and a larger strip which should be free of fixed and potentially aggressive objects, non-recoverable slopes and other installations that represent a hazard when impacted by an errant vehicle. The safety zone allows a controlled or uncontrolled slowdown and stop without severe injuries. The desired width depends on traffic volume, speed and road geometry.
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.

Set-back	Lateral distance between the way and an object in the roadside for clearance.
Shoulder	The portion of the roadway contiguous with the travel lane, primarily for accommodation of stopped vehicles, emergency use, lateral support of the carriageway.
Single carriageway	A carriageway with no physical separation between lanes.
Single-sided safety barrier	safety barrier designed to be impacted on one side only
Slope	See "Embankment".
Soft strip	A narrow strip of gravel surface located in the roadside, beyond the roadway (normally beyond a hard strip/shoulder).
Soft 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.
Temporary safety barrier	safety barrier which is readily removable and used at road works, emergencies or similar situations.
Terminal	The end treatment for a safety barrier. It can be energy absorbing structure or designed to protect the vehicle from going behind the barrier.
Termination	See "Terminal".
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 that is travelled on by motor vehicles. A carriageway can include one or more travel lanes.
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 (underride barriers)	A type of MPS, a closed surface on steel barriers to avoid the sliding of a rider under the barrier system.
Undivided roadway	See "Single carriageway".
Unpaved shoulder	See "Soft shoulder".
Upstream terminal	A terminal placed at the upstream end of a safety barrier.
Vehicle parapet	A longitudinal safety barrier whose primary function is to prevent an errant vehicle from going over the side of the bridge structure.
Vehicle Restraint System (VRS)	A system installed on the road to prevent an errant vehicle from colliding with objects located beside the road. This includes for example a safety barrier, a crash cushion, etc.
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.

Annex B: Data Matrices

The following pages contain the data matrices developed through the analysis of National guidelines. For a detailed explanation of how these matrices are prepared and how they should be interpreted, please see Section 4.2 -The Data Matrix & Identified Parameters.

General (Cumulative Sum of All Types of VRS)

	1- Barrier Needed or Not 2- Type of VRS	Austria	Belgium	Brazil	Bulgaria	Canada	Croatia	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Iceland	Ireland	Israel	Italy	Latvia	Lithuania	Luxembourg	Mexico	Nepal	Netherlands	Norway	Philippines	Poland	Portugal	Slovenia	Spain	Sweden	Switzerland	Turkey	UK	USA	LITERATURE
LEVEL OF RISK – Consequences	A - Existence of Special Risk to 3rd parties	1,2	1,2	1,2	1,2	1,2		1	1,2	1,2	1,2	1,2	2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2		1,2	1,2	1,2	1,2	1,2	1,2	1	1,2	1,2	1,2	1,2	1,2	1
	Chemical Plants				1,2					1	1,2		2	1,2	1,2	1,2			1	1,2	1,2	1,2				1,2		1,2	1,2	1,2	1	1,2	1,2		1,2		
	Structures at risk of collapse, support and load bearing			2	1,2	2		1			1,2	1,2		1,2	1,2	1,2	1	1,2	1	1,2	1,2	1,2	2			1,2	2	1,2	1,2	1,2	1	1,2		2		2	
	Heavily used walkways, public areas with frequent pedestrian activity	1,2		1	1,2	1		1	1,2	1,2	1,2	1	2	1,2	1,2	1	1	1,2	1	1,2	1,2	1,2	1			1	1	1,2	1,2	1,2	1	1,2	1,2	1	1,2	1	1
	Volume of Pedestrian Traffic / Average number of people exposed to risk			1		1				1													1				1							1	1,2	1	1
	Average time each person is exposed to risk (hours per year)																																		1,2		
	Heavily used bicycle paths	1		1	1,2	1				1	1,2	1		1,2	1,2	1	1		1	1,2	1,2	1,2	1			1	1	1,2	1,2					1		1	1
	AADT of bicycles in the bicycle path									1																											1
	Environmental Concern such as Source of drinking water			2		2			1,2	1,2		2	2			1,2			1				2			1,2	2			1,2	1	1,2	1,2	2	1,2	2	
	Adjacent rail lines	1,2			1,2				1,2	1	1,2	1	2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2				1,2		1,2	1,2	1,2	1	1,2	1,2		1,2		
	Distance to the Rail line																		1,2											1	1	1,2			1,2		
	Number of trains per day, Per week or per hour				1,2						1,2			1,2	1,2					1,2	1,2	1,2						1,2	1,2	2	1		1,2				
	Rail line at the foot of an embankment																														1				1,2		
	Number of Tracks																																		1,2		
	Permissible Speed on rail line																																1,2		1,2		
	Adjacent Roads				1,2				1,2		1,2	1,2	2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2				1,2		1,2	1,2	1,2	1				1,2		
	AADT on adjacent road				1,2						1,2	1,2		1,2	1,2	1	2		1,2	1,2	1,2	1,2				1		1,2	1,2						1,2		
	Speed on adjacent road				1,2						1,2			1,2	1,2	1	2			1,2	1,2	1,2				1		1,2	1,2						1,2		
	Distance to the adjacent road							1								1			1,2							1					1				1,2		
	Road at the foot of an embankment							1											1,2											1,2	1						
	Object which can cause severe traffic disruptions if damaged											1																					1,2		1		
	B - Obstructions with a special risk to vehicle occupants	1	1,2	1	1,2	1	1	1,2	1,2	1	1,2	1,2	1	1,2	1,2	1,2	1,2	1	1	1,2	1,2	1,2	1	1	1	1,2	1	1,2	1,2	1,2	1	1	1,2	1	1,2	1	1
	Non-deformable extensive obstacles parallel to direction of travel	1	1,2	1	1,2	1	1	1		1	1,2	1,2	1	1,2	1,2	1	1,2	1	1	1,2	1,2	1,2	1	1	1	1	1	1,2	1,2	1,2	1	1,2	1,2	1	1,2	1	1
	Retaining walls with non smooth traffic face up to 1.5m above traffic level			1		1		1		1			1			1,2	1,2	1					1			1,2	1				1			1	1,2	1	
	Noise barriers	1			1,2			1	1,2	1	1,2	1,2		1,2	1,2	1				1,2	1,2	1,2			1	1		1,2	1,2	1,2	1		1,2				
	Height/Depth of the Hazard															1,2										1,2									1,2		
	Fencing (Stone wall, wooden fence, concrete wall, etc.)												1																				1,2		1,2		
	Non-deformable select individual obstacles	1	1,2	1	1,2	1	1	1,2		1	1,2	1		1,2	1,2	1,2	1,2	1	1	1,2	1,2	1,2	1	1	1	1,2	1	1,2	1,2	1	1	1,2	1,2	1	1,2	1	1
	Bridge Piers, abutments, railing ends									1		1	1					1															1,2			1	
	Above ground equipment other than emergency telephones (e.g. CCTV masts, communication control cabinets, pillars, stores for signs)							1		1		1	1			1									1	1				1	1	1	1,2		1,2		1
	Boulders			1		1				1		1				1		1					1			1	1					1		1		1	
	Intersecting /Transverse Ditches			1	1,2	1		1		1	1,2			1,2	1,2	1	1,2			1,2	1,2	1,2	1		1	1	1	1,2	1,2			1		1	1,2	1	1
	Culverts, Pipes, Headwalls			1		1										1,2	1,2	1					1		1	1,2	1					1		1	1,2	1	
	Ends of concrete barriers, retaining walls, etc.											1	1			1		1								1											1
	Trees			1		1		1		1		1	1			1	1,2	1					1		1	1	1			1	1	1	1,2	1	1,2	1	1
	Trunk girth of a single tree							1		1		1	1			1	1,2									1				1	1		1,2		1,2		1
	High Mast lighting poles			1		1		1,2		1		1	1			1	1,2	1					1		1	1	1					1	1,2	1	1,2	1	1
	Sign/signal gantry supports			1		1		1,2		1		1	1			1	1,2	1	1				1		1	1	1			1	1	1	1,2	1	1,2	1	1
	Diameter of support posts							1		1		1					1,2	1												1	1				1,2		1
	Height of gantry							1,2																											1,2		
	Fall Height (Height from lower surface for bridges, retaining walls etc.)	1			1					1	1		2	1	1	2	1,2			1	1	1				2		1	1	1,2		1			1,2		1
	Falling Slopes (Embankments)		1			1	1	1	1,2	1	1,2	1,2	1,2	1,2	1,2	1	1,2	1	1	1,2	1,2	1,2		1	1	1	1	1,2	1,2	1,2	1	1	1,2	1	1,2	1	1
	Slope	1	1	1	1,2	1		1	1,2	1	1,2	1,2	1,2	1,2	1,2	1	1,2	1	1	1,2	1,2	1,2	1	1	1	1	1	1,2	1,2	1,2	1	1	1,2	1	1,2	1	1
	Height	1		1	1,2	1	1	1	1,2	1	1,2	1,2	1	1,2	1,2	1		1	1	1,2	1,2	1,2	1	1	1	1	1	1,2	1,2	1,2	1	1	1	1	1,2	1	1
	Surface of the slope (short grass, long grass, bush, etc.)																																		1,2		1
	Rising (Cutting) Slopes		1			1				1	1,2	1	1	1,2	1,2	1	1,2	1		1,2	1,2	1,2	1		1	1	1	1,2	1,2		1	1	1,2	1	1,2		1
	Slope	1	1	1	1,2	1				1	1,2	1	1	1,2	1,2	1	1,2	1		1,2	1,2	1,2	1		1	1	1	1,2	1,2		1	1	1,2	1	1,2	1	1
	Height		1		1					1	1	1	1	1	1		1,2			1	1	1			1			1	1			1	1		1,2		
	Surface of the slope (short grass, long grass, bush, etc.)																																		1,2		
	Permanent bodies or streams of water	1		1		1		1	1,2	1	1,2	1		1,2	1,2	1,2	1,2	1		1,2	1,2	1,2	1		1	1,2	1	1,2	1,2	1,2	1	1	1,2	1	1,2	1	
	Water depth			1	1,2	1			1,2		1,2	1		1,2	1,2	1,2	1,2			1,2	1,2	1,2	1			1,2	1	1,2	1,2	1,2	1	1	1,2	1	1,2	1	
	Distance to water from the edge of carriageway			1		1				1													1				1			1	1		1,2	1	1,2	1	
LEVEL OF RISK – Likelihood	A - Traffic	2	1	1,2	1,2	1,2		2	2	1,2	1,2	1,2	2	1,2	1,2	1,2	1	1,2	2	1,2	1,2	1,2	1,2	1		1,2	1,2	1,2	1,2	1,2	1	1,2		1,2	1,2	1,2	1
	Average annual daily traffic (AADT)		1	1,2	1,2	1,2		2	2	1,2	1,2	1,2		1,2	1,2	1,2	1	1		1,2	1,2	1,2	1,2	1		1,2	1,2	1,2	1,2	1,2	1	1,2		1,2	1,2	1,2	1
	Average annual daily HGV traffic ($AADT_{HGV}$)	2		1,2	2	1,2		2	2	1,2	2	2	2	2	2	2	1	2	2	2	2	2	1,2			2	1,2	2	2	2	1	1,2		1,2	1,2	1,2	
	Percentage of Motorcycle Traffic															1										1						1,2					1
	B - Speed	1,2	1,2	1,2	1,2	1,2		1,2	2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1	1,2	1,2	1,2	1,2	1,2	1	1	1,2	1,2	1,2	1,2	1,2	1	1,2	1	1,2	1,2	1,2	1
	Local Speed Limits	1,2	1,2	1,2	1,2	1,2		1,2	2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2		1,2	1,2	1,2	1,2	1,2	1	1,2	1,2	1,2	1,2	1,2	1,2		1,2	1	1,2	1,2	1,2	1
	Design Speed			1,2		1,2		1											1				1,2		1,2		1,2				1	1,2		1,2		1,2	1
	C - Road Alignment / Geometry	2	1,2	1,2	1,2	1,2		1	1,2	1	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1	1,2	1,2	1,2	1,2	1,2		1	1,2	1,2	1,2	1,2	1,2	1	1	1,2	1,2	1,2	1,2	1
	Distance between the edge of traffic and hazard		1,2	1	1	1		1		1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1,2	1	1,2	1	1
	Width of median	2	1,2	1	2	1		1			2	1,2	2	2	2	1,2	1,2			2	2	2	1		1	1,2	1	2	2	1,2		1	2	1	1	1	1
	Vertical Alignment (Slope)	2	1	2		2			1,2								1,2						2		1		2			1,2				2		2	1
	Bridge Length	2											2			2			2							2							2				
	Geometry of diverge (parallel, trapezoid, etc.)				1,2						1,2			1,2	1,2					1,2	1,2	1,2						1,2	1,2								
	Radius of curvature			2	1,2	2		1	1,2	1	1,2			1,2	1,2	1	1,2			1,2	1,2	1,2	2			1	2	1,2	1,2	1,2	1			2		2	1
	Kerb Height									1			1						1											1	1				1,2		
	Roadside Topography (in terms of likelihood of reaching hazard)												2			1,2										1,2									1,2		1
	Adverse Geometrics	2	1	1,2	1,2	1,2			2		1,2	2		1,2	1,2	1,2		1		1,2	1,2	1,2	1,2	1		1,2	1,2	1,2	1,2		1	1		1,2	1,2	1,2	
	Stopping Sight Distance not up to the standard																																		1,2		
	Curve Radius Shorter than allowed design value		1	2	1,2	2			2		1,2			1,2	1,2	1				1,2	1,2	1,2	2	1		1	2	1,2	1,2		1	1		2		2	
	Several successive curves with radii smaller than permitted			2	1,2	2					1,2			1,2	1,2					1,2	1,2	1,2	2				2	1,2	1,2		1			2		2	1
	non-typically large directional changes	2		2	1,2	2					1,2			1,2	1,2					1,2	1,2	1,2	2				2	1,2	1,2					2		2	
	Sleep related problematic design (featureless rural roads, etc.)																																		1,2		
	D - Road Layout	1,2	1,2		1		2	1,2	2	2	1		1	1	1	2	1,2	1,2	1,2	1	1	1			1	2		1	1	1,2	1	1,2	1,2		1,2		1
	Road Type (Single or Dual Carriageway)		1,2		1				2		1		1	1	1		1,2	1,2	2	1	1	1			1			1	1	1,2	1	1,2	1,2		1,2		
	Road Class (Public Roads or Local Roads)	1,2					2	1,2	2				1			2	1,2		1							2				1,2		1			1,2		
	One-way or two way traffic?		1,2							2									1						1							1,2			2		
	Number of Lanes		1,2										2																						1,2		
	E - Accident History / Frequency			1,2	1,2	1,2				1	1,2			1,2	1,2		1			1,2	1,2	1,2	1,2	1			1,2	1,2	1,2		1	1,2		1,2	1	1,2	1
	Accident Frequency				1,2						1,2			1,2	1,2		1			1,2	1,2	1,2		1				1,2	1,2		1	1,2					1
	Accident History			1,2	1,2	1,2				1	1,2			1,2	1,2		1			1,2	1,2	1,2	1,2	1			1,2	1,2	1,2			1,2		1,2	1	1,2	1
Other	Other			2		2										2	1						2			2	2			2		2		2	1	2	
	Aesthetics			2		2										2	1						2			2	2			2		2		2	1	2	1
	Maintenance costs			2		2											1						2				2							2		2	1
	Life-cycle costs			2		2											1						2				2							2	1	2	1

Barriers (Roadside & Median)

1- Barrier Needed or Not
2- Type of VRS

LEVEL OF RISK – Consequences / Likelihood

Barriers (Roadside & Median)	Austria		Belgium		Brazil		Bulgaria		Canada		Croatia		Cyprus		Czech Republic		Denmark		Estonia		Finland		France		Germany		Greece		Iceland		Ireland		Israel		Italy	
Location on the road (median, verge)	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median
Consequences																																				
A - Existence of Special Risk to 3rd parties	1		1,2		1,2	2	1,2	2	1,2	2			1		1,2	1,2	1,2		1,2	2	1,2				1,2	2	1,2	2	1,2		1,2	1	1,2		1,2	
Chemical Plants							1,2										1		1,2						1,2		1,2		1,2						1	
Structures at risk of collapse, support and load bearing					2		1,2	2	2				1						1,2	2	1,2				1,2	2	1,2	2	1,2		1	1	1,2		1	
Heavily used walkways, public areas with frequent pedestrian activity	1				1		1,2		1				1		1,2	1,2	1,2		1,2		1				1,2		1,2		1		1		1,2		1	
Volume of Pedestrian Traffic / Average number of people exposed to risk					1				1								1																			
Average time each person is exposed to risk (hours per year)																																				
Heavily used bicycle paths	1				1		1,2		1								1		1,2		1				1,2		1,2		1		1				1	
AADT of bicycles in the bicycle path																	1																			
Environmental Concern such as Source of drinking water					2				2						1,2	1,2	1,2				2								1,2						1	
Adjacent rail lines	1						1,2								1,2		1		1,2		1				1,2		1,2		1,2		1,2		1,2		1,2	
Distance to the Rail line																																			1,2	
Number of trains per day, Per week or per hour							1,2												1,2						1,2		1,2									
Rail line at the foot of an embankment																																				
Number of Tracks																																				
Permissible Speed on rail line																																				
Adjacent Roads							1,2						1		1,2				1,2		1,2				1,2		1,2		1		1,2		1,2		1,2	
AADT on adjacent road							1,2												1,2		1,2				1,2		1,2		1							
Speed on adjacent road							1,2												1,2						1,2		1,2		1							
Distance to the adjacent road													1																1							
Road at the foot of an embankment													1																							
Object which can cause severe traffic disruptions if damaged																					1															
B - Obstructions with a special risk to vehicle occupants	1		1,2	1,2	1		1,2		1		1		1,2	1,2	1,2	1,2	1		1,2		1,2		1		1,2		1,2		1,2		1,2	1,2	1			
Non-deformable extensive obstacles parallel to direction of travel	1		1,2		1		1,2		1		1		1		1,2	1,2	1		1,2		1,2		1		1,2		1,2		1,2		1,2	1,2	1			
Retaining walls with non smooth traffic face up to 1.5m above traffic level					1				1				1				1						1						1,2		1,2	1,2	1			
Noise barriers	1						1,2						1		1,2	1,2	1		1,2		1,2				1,2		1,2		1							
Height/Depth of the Hazard																													1,2							
Fencing (Stone wall, wooden fence, concrete wall, etc.)																							1													
Non-deformable select individual obstacles	1		1,2	1,2	1		1,2		1		1		1,2	1,2			1		1,2		1				1,2		1,2		1,2		1,2	1,2	1			
Bridge Piers, abutments, railing ends																	1				1		1										1			
Above ground equipment other than emergency telephones (e.g. CCTV masts, communication control cabinets, pillars, stores for signs)													1				1				1		1						1							
Boulders					1				1								1				1								1				1			
Intersecting /Transverse Ditches					1		1,2		1				1				1		1,2						1,2		1,2		1		1,2					
Culverts, Pipes, Headwalls					1				1																				1,2		1,2		1			
Ends of concrete barriers, retaining walls, etc.																					1		1													
Trees					1				1				1				1				1		1						1		1,2	1,2	1			
Trunk girth of a single tree													1				1				1		1						1		1,2	1,2				
High Mast lighting poles					1				1				1,2				1				1		1						1		1,2	1,2	1			
Sign/signal gantry supports					1				1				1	1,2			1				1		1						1		1,2	1,2	1			
Diameter of support posts													1				1				1										1,2	1,2				
Height of gantry													1,2																							
Fall Height (Height from lower surface for bridges, retaining walls etc.)																	1												2		1,2					
Falling Slopes (Embankments)	1		1		1		1,2		1		1		1		1,2		1		1,2		1,2		1		1,2		1,2		1		1,2		1			
Slope	1		1		1		1,2		1				1		1,2		1		1,2		1,2		1		1,2		1,2		1		1,2		1			
Height					1		1,2		1		1		1		1,2		1		1,2		1,2		1		1,2		1,2		1				1			
Surface of the slope (short grass, long grass, bush, etc.)																																				
Rising (Cutting) Slopes	1		1		1		1,2		1								1		1,2		1		1		1,2		1,2		1		1,2		1			
Slope	1		1		1		1,2		1								1		1,2		1		1		1,2		1,2		1		1,2		1			
Height	1		1				1										1		1		1		1		1		1				1,2					
Surface of the slope (short grass, long grass, bush, etc.)																																				
Permanent bodies or streams of water	1				1		1,2		1				1		1,2	1,2	1		1,2		1				1,2		1,2		1,2		1,2		1			
Water depth					1		1,2		1						1,2	1,2			1,2		1				1,2		1,2		1,2		1,2					
Distance to water from the edge of carriageway					1				1								1																			
Likelihood																																				
A - Traffic	2	2	1	1	1,2	1,2	1,2	2	1,2	1,2		1	2	2	2	2	1,2	1,2	1,2	2	1,2	1,2			1,2	2	1,2	2	1,2		1	1	1,2		2	2
Average annual daily traffic (AADT)			1	1	1,2	1	1,2	2	1,2	1			2	2	2	2	1,2	1,2	1,2	2	1	1,2			1,2	2	1,2	2	1,2		1	1	1			
Average annual daily HGV traffic ($AADT_{HGV}$)	2	2			2	1,2	2	2	2	1,2			2	2	2	2	2	1,2	2	2	2				2	2	2	2	2		1	1	2	2	2	2
Percentage of Motorcycle Traffic																																				
B - Speed	1,2	1,2	1,2	1,2	1,2		1,2	1	1,2				1,2	1,2	1,2	1,2	1,2	1,2	1	1	1,2	1,2	1,2		1	1	1	1	1,2		1	1			1	1
Local Speed Limits	1,2	1,2	1,2	1,2	1,2		1	1	1,2				1,2	1,2	2	2	1,2	1,2	1	1	1,2	1,2	1,2		1	1	1	1	1,2		1	1				
Design Speed					1,2				1,2				1	1																					1	1
C - Road Alignment / Geometry		2	1,2	1,2	1,2	1	1,2	2	1,2	1,2			1	1	1,2	1,2	1		1,2	2	1,2	1,2	1	2	1,2	2	1,2	2	1,2	1,2	1,2	1,2	1		1	
Distance between the edge of traffic and hazard			1,2	1,2	1		1		1				1				1		1		1		1		1		1		1		1		1		1	
Width of median		2		1,2		1		2		1				1				2		2		1,2		2		2		2		1,2		1,2				
Vertical Alignment (Slope)			1		2				2						1,2	1,2															1,2	1,2				
Bridge Length																																				
Geometry of diverge (parallel, trapezoid, etc.)							1												1						1		1									
Radius of curvature					2		1,2	2	2				1		1,2	1,2	1		1,2	2					1,2	2	1,2	2	1							
Kerb Height																	1						1												1	
Roadside Topography (in terms of likelihood of reaching hazard)																													1,2							
Adverse Geometrics			1	1	2	1,2	1,2	2	2	1,2					2	2			1,2	2		2			1,2	2	1,2	2	1,2							
Stopping Sight Distance not up to the standard																																				
Curve Radius Shorter than allowed design value			1	1	2		1,2	2	2						2	2			1,2	2					1,2	2	1,2	2	1							
Several successive curves with radii smaller than permitted					2		1,2	2	2										1,2	2					1,2	2	1,2	2								
non-typically large directional changes					2		1,2	2	2										1,2	2					1,2	2	1,2	2								
Sleep related problematic design (featureless rural roads, etc.)																																				
D - Road Layout	1		1,2	1,2				1			2	2	1	1,2	2	2				1			1	2		1		1	2				1,2		1,2	1,2
Road Type (Single or Dual Carriageway)			1,2	1,2				1							2	2				1			1			1		1					1,2		2	2
Road Class (Public Roads or Local Roads)	1										2	2	1	1,2	2	2							1						2						1	1
One-way or two way traffic?			1,2	1,2																																
Number of Lanes			1,2	1,2																				2												
E - Accident History / Frequency					2	1	1,2	2	2	1							1	1	1,2	2					1,2	2	1,2	2			1	1				
Accident Frequency							1,2	2											1,2	2					1,2	2	1,2	2			1	1				
Accident History					2	1	1,2	2	2	1							1	1	1,2	2					1,2	2	1,2	2			1	1				
Other																															1	1				
Aesthetics					2				2																				2		1	1				
Maintenance costs					2				2																						1	1				
Life-cycle costs					2				2																						1	1				

Barriers (Roadside & Median)	Latvia		Lithuania		Luxembourg		Mexico		Nepal		Netherlands		Norway		Philippines		Poland		Portugal		Slovenia		Spain		Sweden		Switzerland		Turkey		UK		USA		LITERATURE
Location on the road (median, verge)	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	
Consequences																																			
A - Existence of Special Risk to 3rd parties	1,2	2	1,2	2	1,2	2	1,2	2			1,2	1,2	1,2		1,2	2	1,2	2	1,2	2	1,2		1		1,2	1,2	1,2		1,2	2	1,2		1,2	2	
Chemical Plants	1,2		1,2		1,2								1,2				1,2		1,2		1,2		1		1,2	1,2	1,2				1,2				
Structures at risk of collapse, support and load bearing	1,2	2	1,2	2	1,2	2	2						1,2		2		1,2	2	1,2	2	1,2		1		1,2	1,2			2				2		
Heavily used walkways, public areas with frequent pedestrian activity	1,2		1,2		1,2		1						1		1		1,2		1,2		1,2		1		1,2	1,2	1,2		1		1,2		1		1
Volume of Pedestrian Traffic / Average number of people exposed to risk							1								1														1		1,2		1		1
Average time each person is exposed to risk (hours per year)																															1,2				
Heavily used bicycle paths	1,2		1,2		1,2		1						1		1		1,2		1,2							1,2			1				1		1
AADT of bicycles in the bicycle path																																			1
Environmental Concern such as Source of drinking water							2						1,2		2						1,2		1		1,2	1,2	1,2		2		1,2		2		
Adjacent rail lines	1,2		1,2		1,2								1,2				1,2		1,2		1,2		1		1,2	1,2	1,2				1,2				
Distance to the Rail line																					1		1		1,2	1,2					1,2				
Number of trains per day, Per week or per hour	1,2		1,2		1,2												1,2		1,2		2		1				1,2								
Rail line at the foot of an embankment																							1								1,2				
Number of Tracks																															1,2				
Permissible Speed on rail line																											1,2				1,2				
Adjacent Roads	1,2		1,2		1,2								1						1,2		1,2		1								1,2				
AADT on adjacent road	1,2		1,2		1,2								1				1,2		1,2												1,2				
Speed on adjacent road	1,2		1,2		1,2								1				1,2		1,2												1,2				
Distance to the adjacent road													1										1								1,2				
Road at the foot of an embankment																					1,2		1												
Object which can cause severe traffic disruptions if damaged																											1,2								
B - Obstructions with a special risk to vehicle occupants	1,2		1,2		1,2		1		1		1		1,2		1		1,2		1,2		1,2		1		1	1	1,2		1		1,2		1	1	1
Non-deformable extensive obstacles parallel to direction of travel	1,2		1,2		1,2		1		1				1,2		1		1,2		1,2		1,2		1		1	1	1,2		1		1,2		1		1
Retaining walls with non smooth traffic face up to 1.5m above traffic level							1						1,2		1								1						1		1,2		1		
Noise barriers	1,2		1,2		1,2						1		1				1,2		1,2		1,2		1				1,2								
Height/Depth of the Hazard													1,2																		1,2				
Fencing (Stone wall, wooden fence, concrete wall, etc.)																											1,2				1,2				
Non-deformable select individual obstacles	1,2		1,2		1,2		1		1		1	1	1,2		1		1,2		1,2		1		1		1	1	1,2		1		1,2	1	1	1	1
Bridge Piers, abutments, railing ends																											1,2						1	1	
Above ground equipment other than emergency telephones (e.g. CCTV masts, communication control cabinets, pillars, stores for signs)											1	1	1								1		1		1	1	1,2				1,2				1
Boulders							1						1		1										1	1			1				1		
Intersecting /Transverse Ditches	1,2		1,2		1,2		1				1	1	1		1		1,2		1,2						1	1			1		1,2		1		1
Culverts, Pipes, Headwalls							1				1		1,2		1										1	1			1		1,2		1		
Ends of concrete barriers, retaining walls, etc.																																			1
Trees							1				1		1		1						1		1		1	1	1,2		1		1,2		1		1
Trunk girth of a single tree													1								1		1				1,2				1,2				1
High Mast lighting poles							1				1	1	1		1										1	1	1,2		1		1,2		1		1
Sign/signal gantry supports							1				1		1		1						1		1		1	1	1,2		1		1,2		1		1
Diameter of support posts																					1		1								1,2				1
Height of gantry																															1,2				
Fall Height (Height from lower surface for bridges, retaining walls etc.)													2												1	1					1,2				1
Falling Slopes (Embankments)	1,2		1,2		1,2		1		1		1	1	1		1		1,2		1,2		1,2		1		1	1	1,2		1		1,2		1		1
Slope	1,2		1,2		1,2		1		1		1	1	1		1		1,2		1,2		1,2		1		1	1	1,2		1		1,2		1		1
Height	1,2		1,2		1,2		1		1				1		1		1,2		1,2		1,2		1		1	1	1		1		1,2		1		1
Surface of the slope (short grass, long grass, bush, etc.)																															1,2				1
Rising (Cutting) Slopes	1,2		1,2		1,2		1				1	1	1		1		1,2		1,2				1		1	1	1,2		1		1,2		1		1
Slope	1,2		1,2		1,2		1				1	1	1		1		1,2		1,2				1		1	1	1,2		1		1,2		1		1
Height	1		1		1						1	1					1		1						1	1	1				1,2				
Surface of the slope (short grass, long grass, bush, etc.)																															1,2				
Permanent bodies or streams of water	1,2		1,2		1,2		1						1,2		1		1,2		1,2		1,2		1		1	1	1,2		1		1,2		1		
Water depth	1,2		1,2		1,2		1						1,2		1		1,2		1,2		1,2		1		1	1	1,2		1		1,2		1		
Distance to water from the edge of carriageway							1								1						1		1				1,2		1		1,2		1		
Likelihood																																			
A - Traffic	1,2	2	1,2	2	1,2	2	1,2	1,2	1				1,2		1,2	1,2	1,2	2	1,2	2	2	1,2	1		1,2	1,2			1,2	1,2	1,2	2	1,2	1,2	1
Average annual daily traffic (AADT)	1,2	2	1,2	2	1,2	2	1,2	1	1				1,2		1,2	1	1,2	2	1,2	2	2	1,2	1		1	1			1,2	1	1,2	2	1,2	1	1
Average annual daily HGV traffic ($AADT_{HGV}$)	2	2	2	2	2	2	2	1,2					2		2	1,2	2	2	2	2	2	2	1		1,2	1,2			2	1,2	1,2		2	1,2	
Percentage of Motorcycle Traffic																									1,2	1,2									1
B - Speed	1	1	1	1	1	1	1,2		1		1,2	1,2	1,2		1,2		1	1	1	1	1,2		1		1	1	1		1,2		1,2		1,2		1
Local Speed Limits	1	1	1	1	1	1	1,2		1		1,2	1,2	1,2		1,2		1	1	1	1	1,2				1	1	1		1,2		1,2		1,2		1
Design Speed							1,2				1,2	1,2			1,2								1		1	1			1,2				1,2		1
C - Road Alignment / Geometry	1,2	1,2	1,2	2	1,2	2	1,2	1,2			1	1	1,2	1,2	1,2	1,2	1,2	2	1,2	2	1,2	1,2	1		1	1	1,2	2	1,2	1	1,2	1	1,2	1,2	1
Distance between the edge of traffic and hazard	1		1		1		1				1	1	1		1		1		1		1		1		1	1	1,2		1		1,2		1		1
Width of median		2		2		2		1				1		1,2		1		2		2		1,2				1		2		1		1		1	1
Vertical Alignment (Slope)							2				1	1			2						2								2				2		1
Bridge Length																																			
Geometry of diverge (parallel, trapezoid, etc.)	1		1		1												1		1																
Radius of curvature	1,2	2	1,2	2	1,2	2	2						1		2		1,2	2	1,2	2	1,2		1						2				2		
Kerb Height																					1		1								1,2				
Roadside Topography (in terms of likelihood of reaching hazard)													1,2																		1,2				1
Adverse Geometrics	1,2	2	1,2	2	1,2	2	2	1,2	1				1,2		2	1,2	1,2	2	1,2	2			1		1	1			2	1,2	1,2		2	1,2	
Stopping Sight Distance not up to the standard																															1,2				
Curve Radius Shorter than allowed design value	1,2	2	1,2	2	1,2	2	2		1				1		2		1,2	2	1,2	2			1		1	1			2				2		
Several successive curves with radii smaller than permitted	1,2	2	1,2	2	1,2	2	2								2		1,2	2	1,2	2			1						2				2		
non-typically large directional changes	1,2	2	1,2	2	1,2	2	2								2		1,2	2	1,2	2									2				2		
Sleep related problematic design (featureless rural roads, etc.)																															1,2				
D - Road Layout		1		1		1					1	1	2					1		1	1,2	1,2	1		1	1	1,2				1,2	1,2			1
Road Type (Single or Dual Carriageway)		1		1		1					1	1						1		1	1,2	2	1		1	1	1,2				1,2	1			
Road Class (Public Roads or Local Roads)													2								1,2	1			1	1					1,2	2			
One-way or two way traffic?																									1	1									
Number of Lanes																															1,2				
E - Accident History / Frequency	1,2	2	1,2		1,2	2	2	1	1	1					2	1	1,2	2	1,2	2			1		1,2	1,2			2	1			2	1	1
Accident Frequency	1,2	2	1,2	2	1,2	2			1								1,2	2	1,2	2			1		1,2	1,2									1
Accident History	1,2	2	1,2	2	1,2	2	2	1	1	1					2	1	1,2	2	1,2	2					1,2	1,2			2	1			2	1	1
Other																																			
Aesthetics							2						2		2						2				2	2			2				2		1
Maintenance costs							2								2														2				2		1
Life-cycle costs							2								2														2				2		1

Bridge Barriers & Parapets

Level of risk	1- VRS needed or not 2-VRS type	Austria	Belgium	Brazil	Bulgaria	Canada	Croatia	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Iceland	Ireland	Israel	Italy	Latvia	Lithuania	Luxembourg	Mexico	Nepal	Netherlands	Norway	Poland	Portugal	Slovenia	Spain	Sweden	Switzerland	Turkey	UK	USA
LEVEL OF RISK – Consequences	**A - Existence of Special Risk to 3rd parties**	2			2			1,2	1,2		2		2	2	2	2	2		1,2	2	2	2				2	2	2	1,2			2		2	
	Chemical Plants				2			1,2			2		2	2	2				1	2	2	2					2	2	1,2						
	Structures at risk of collapse, support and load bearing				2				1,2		2			2	2				1	2	2	2					2	2	1,2						
	Heavily used walkways, public areas with frequent pedestrian activity				2			1,2	1,2		2		2	2	2				1	2	2	2					2	2	1,2			2		2	
	Volume of Pedestrian Traffic / Average number of people exposed to risk																																		
	Average time each person is exposed to risk (hours per year)																																		
	Heavily used bicycle paths				2						2			2	2				1	2	2	2					2	2							
	AADT of bicycles in the bicycle path																																		
	Environmental Concern such as Source of drinking water								1,2				2						1										1,2						
	Adjacent rail lines	2			2				1,2		2		2	2	2	2	2		1,2	2	2	2				2	2	2	1,2					2	
	Distance to the Rail line																																		
	Number of trains per day, Per week or per hour				2						2			2	2					2	2	2					2	2							
	Rail line at the foot of an embankment																																		
	Number of Tracks																																		
	Permissible Speed on rail line																																		
	Adjacent Roads				2				1,2		2		2	2	2	2	2		1,2	2	2	2				2	2	2						2	
	AADT on adjacent road				2						2			2	2		2		1,2	2	2	2					2	2							
	Speed on adjacent road				2						2			2	2		2			2	2	2					2	2							
	Distance to the adjacent road																		1,2																
	Road at the foot of an embankment																		1,2																
	Object which can cause severe traffic disruptions if damaged																																		
	B - Obstructions with a special risk to vehicle occupants	1			1,2				1,2		1,2		2	1,2	1,2	2	2		1	1,2	1,2	1,2				2	1,2	1,2	1,2			2		2	
	Non-deformable extensive obstacles parallel to direction of travel				2				1,2		2			2	2				1	2	2	2					2	2	1,2						
	Retaining walls with non smooth traffic face up to 1.5m above traffic level																																		
	Noise barriers				2				1,2		2			2	2					2	2	2					2	2	1,2						
	Height/Depth of the Hazard																																		
	Fencing (Stone wall, wooden fence, concrete wall, etc.)																																		
	Non-deformable select individual obstacles				2						2			2	2				1	2	2	2					2	2						2	
	Bridge Piers, abutments, railing ends																																		
	Above ground equipment other than emergency telephones (e.g. CCTV masts, communication control cabinets, pillars, stores for signs)																																		
	Boulders																																		
	Intersecting /Transverse Ditches				2						2			2	2					2	2	2					2	2						2	
	Culverts, Pipes, Headwalls																																	2	
	Ends of concrete barriers, retaining walls, etc.																																		
	Trees																																		
	Trunk girth of a single tree																																		
	High Mast lighting poles																																		
	Sign/signal gantry supports																		1																
	Diameter of support posts																																		
	Height of gantry																																		
	Fall Height (Height from lower surface for bridges, retaining walls etc.)	1			1						1		2	1	1	2	2			1	1	1				2	1	1	1,2						
	Falling Slopes (Embankments)				2						2		2	2	2		2		1	2	2	2					2	2							
	Slope				2						2		2	2	2				1	2	2	2					2	2							
	Height																2		1																
	Surface of the slope (short grass, long grass, bush, etc.)																																		
	Rising (Cutting) Slopes				2						2			2	2					2	2	2					2	2							
	Slope				2						2			2	2					2	2	2					2	2							
	Height																																		
	Surface of the slope (short grass, long grass, bush, etc.)																																		
	Permanent bodies or streams of water				2						2			2	2					2	2	2					2	2	1,2					2	
	Water depth				2						2			2	2					2	2	2					2	2	1,2						
	Distance to water from the edge of carriageway																																		
LEVEL OF RISK – Likelihood	**A - Traffic**				2				2		2		2	2	2				2	2	2	2					2	2						2	
	Average annual daily traffic (AADT)								2																									2	
	Average annual daily HGV traffic ($AADT_{HGV}$)				2				2		2		2	2	2				2	2	2	2					2	2						2	
	Percentage of Motorcycle Traffic																																		
	B - Speed	2			2			1,2	2		2			2	2		2		1	2	2	2					2	2	1,2			2		2	
	Local Speed Limits	2			2			1,2	2		2			2	2		2			2	2	2					2	2	1,2			2		2	
	Design Speed							1											1																
	C - Road Alignment / Geometry	2							1,2				2			2	2		2							2			1,2			2		2	
	Distance between the edge of traffic and hazard																																	2	
	Width of median																												1,2						
	Vertical Alignment (Slope)	2							1,2																				1,2						
	Bridge Length	2											2			2			2							2						2			
	Geometry of diverge (parallel, trapezoid, etc.)																																		
	Radius of curvature								1,2								2												1,2						
	Kerb Height																															2			
	Roadside Topography (in terms of likelihood of reaching hazard)												2																						
	Adverse Geometrics	2							1,2																									2	
	Stopping Sight Distance not up to the standard																																	2	
	Curve Radius Shorter than allowed design value								1,2																										
	Several successive curves with radii smaller than permitted																																		
	non-typically large directional changes	2																																	
	Sleep related problematic design (featureless rural roads, etc.)																																	2	
	D - Road Layout	2					2	1	2								2		1,2													2		2	
	Road Type (Single or Dual Carriageway)								2								2		2															2	
	Road Class (Public Roads or Local Roads)	2					2	1	2								2		1													2		2	
	One-way or two way traffic?																																		
	Number of Lanes																																		
	E - Accident History / Frequency																																		
	Accident Frequency																																		
	Accident History																																		
	Other																												2					2	
	Aesthetics																												2					2	
	Maintenance costs																																		
	Life-cycle costs																																		

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

Crash Cushions

1- Crash Cushion Needed or Not
2- Type of Crash Cushion

		Austria		Belgium		Brazil		Bulgaria		Canada		Croatia		Cyprus		Czech Republic		Denmark		Estonia		Finland		France		Germany		
	Location on the road (median, external shoulder, bridge)	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Info
LEVEL OF RISK – Consequences	A - Existence of Special Risk to 3rd parties																											
	Chemical Plants																											
	Structures at risk of collapse, support and load bearing																											
	Heavily used walkways, public areas with frequent pedestrian activity																											
	Volume of Pedestrian Traffic / Average number of people exposed to risk																											
	Average time each person is exposed to risk (hours per year)																											
	Heavily used bicycle paths																											
	AADT of bicycles in the bicycle path																											
	Environmental Concern such as Source of drinking water																											
	Adjacent rail lines																											
	Distance to the Rail line																											
	Number of trains per day, Per week or per hour																											
	Rail line at the foot of an embankment																											
	Number of Tracks																											
	Permissible Speed on rail line																											
	Adjacent Roads																											
	AADT on adjacent road																											
	Speed on adjacent road																											
	Distance to the adjacent road																											
	Road at the foot of an embankment																											
	Object which can cause severe traffic disruptions if damaged																											
	B - Obstructions with a special risk to vehicle occupants					1	1			1	1							1				1						
	Non-deformable extensive obstacles parallel to direction of travel																	1										
	Retaining walls with non smooth traffic face up to 1.5m above traffic level																											
	Noise barriers																											
	Height/Depth of the Hazard																											
	Fencing (Stone wall, wooden fence, concrete wall, etc.)																											
	Non-deformable select individual obstacles					1	1			1	1							1				1						
	Bridge Piers, abutments, railing ends					1	1			1	1											1						
	Above ground equipment other than emergency telephones (e.g. CCTV masts, communication control cabinets, pillars, stores for signs)																											
	Boulders					1	1			1	1																	
	Intersecting /Transverse Ditches																											
	Culverts, Pipes, Headwalls					1	1			1	1																	
	Ends of concrete barriers, retaining walls, etc.					1	1			1	1											1						
	Trees					1	1			1	1																	
	Trunk girth of a single tree																											
	High Mast lighting poles					1	1			1	1																	
	Sign/signal gantry supports					1	1			1	1																	
	Diameter of support posts																											
	Height of gantry																											
	Fall Height (Height from lower surface for bridges, retaining walls etc.)																											
	Falling Slopes (Embankments)																											
	Slope																											
	Height																											
	Surface of the slope (short grass, long grass, bush, etc.)																											
	Rising (Cutting) Slopes																											
	Slope																											
	Height																											
	Surface of the slope (short grass, long grass, bush, etc.)																											
	Permanent bodies or streams of water																											
	Water depth																											
	Distance to water from the edge of carriageway																											
Likelihood	A - Traffic																											
	Average annual daily traffic (AADT)																											
	Average annual daily HGV traffic ($AADT_{HGV}$)																											
	Percentage of Motorcycle Traffic																											
	B - Speed	2	2					2	1,2									1	1	2	1,2	2		2		2	1,2	
	Local Speed Limits	2	2					2	1,2									1	1	2	1,2	2		2		2	1,2	
	Design Speed																											
	C - Road Alignment / Geometry							2	2											2	2					2	2	
	Distance between the edge of traffic and hazard																											
	Width of median								2												2						2	
	Vertical Alignment (Slope)																											
	Bridge Length																											
	Geometry of diverge (parallel, trapezoid, etc.)							2	2											2	2					2	2	
	Radius of curvature																											
	Kerb Height																											
	Roadside Topography (in terms of likelihood of reaching hazard)																											
	Adverse Geometrics																											
	Stopping Sight Distance not up to the standard																											
	Curve Radius Shorter than allowed design value																											
	Several successive curves with radii smaller than permitted																											
	non-typically large directional changes																											
	Sleep related problematic design (featureless rural roads, etc.)																											
	D - Road Layout								1												1						1	
	Road Type (Single or Dual Carriageway)								1												1						1	
	Road Class (Public Roads or Local Roads)																											
	One-way or two way traffic?																											
	Number of Lanes																											
	E - Accident History / Frequency																											
	Accident Frequency																											
	Accident History																											
	Other																											
	Aesthetics																											
	Maintenance costs																											
	Life-cycle costs																											

	Greece		Iceland		Ireland		Israel		Italy		Latvia		Lithuania		Luxembourg		Mexico		Nepal		Netherlands		Norway	
Location on the road (median, external shoulder, bridge)	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median
A - Existence of Special Risk to 3rd parties																								
Chemical Plants																								
Structures at risk of collapse, support and load bearing																								
Heavily used walkways, public areas with frequent pedestrian activity																								
Volume of Pedestrian Traffic / Average number of people exposed to risk																								
Average time each person is exposed to risk (hours per year)																								
Heavily used bicycle paths																								
AADT of bicycles in the bicycle path																								
Environmental Concern such as Source of drinking water																								
Adjacent rail lines																								
Distance to the Rail line																								
Number of trains per day, Per week or per hour																								
Rail line at the foot of an embankment																								
Number of Tracks																								
Permissible Speed on rail line																								
Adjacent Roads																								
AADT on adjacent road																								
Speed on adjacent road																								
Distance to the adjacent road																								
Road at the foot of an embankment																								
Object which can cause severe traffic disruptions if damaged																								
B - Obstructions with a special risk to vehicle occupants			1	1			1	1									1	1					1	1
Non-deformable extensive obstacles parallel to direction of travel			1																				1	
Retaining walls with non smooth traffic face up to 1.5m above traffic level																								
Noise barriers																								
Height/Depth of the Hazard																								
Fencing (Stone wall, wooden fence, concrete wall, etc.)																								
Non-deformable select individual obstacles			1	1			1	1									1	1					1	1
Bridge Piers, abutments, railing ends			1	1			1	1									1	1					1	1
Above ground equipment other than emergency telephones (e.g. CCTV masts, communication control cabinets, pillars, stores for signs)																								
Boulders																	1	1						
Intersecting /Transverse Ditches																								
Culverts, Pipes, Headwalls																	1	1						
Ends of concrete barriers, retaining walls, etc.			1	1			1	1									1	1					1	1
Trees							1										1	1						
Trunk girth of a single tree							1																	
High Mast lighting poles							1	1									1	1						
Sign/signal gantry supports			1	1			1	1									1	1					1	1
Diameter of support posts							1																	
Height of gantry																								
Fall Height (Height from lower surface for bridges, retaining walls etc.)																								
Falling Slopes (Embankments)																								
Slope																								
Height																								
Surface of the slope (short grass, long grass, bush, etc.)																								
Rising (Cutting) Slopes																								
Slope																								
Height																								
Surface of the slope (short grass, long grass, bush, etc.)																								
Permanent bodies or streams of water																								
Water depth																								
Distance to water from the edge of carriageway																								
A - Traffic																								
Average annual daily traffic (AADT)																								
Average annual daily HGV traffic ($AADT_{HGV}$)																								
Percentage of Motorcycle Traffic																								
B - Speed	2	1,2	2	2			1	1	1,2		2	1,2	2	1,2	2	1,2					2	2	2	2
Local Speed Limits	2	1,2	2	2					1,2		2	1,2	2	1,2	2	1,2					2	2	2	2
Design Speed																					2	2		
C - Road Alignment / Geometry	2	2					1				2	2	2	2	2	2								
Distance between the edge of traffic and hazard																								
Width of median		2										2		2		2								
Vertical Alignment (Slope)																								
Bridge Length																								
Geometry of diverge (parallel, trapezoid, etc.)	2	2									2	2	2	2	2	2								
Radius of curvature																								
Kerb Height																								
Roadside Topography (in terms of likelihood of reaching hazard)																								
Adverse Geometrics							1																	
Stopping Sight Distance not up to the standard																								
Curve Radius Shorter than allowed design value																								
Several successive curves with radii smaller than permitted																								
non-typically large directional changes																								
Sleep related problematic design (featureless rural roads, etc.)																								
D - Road Layout		1					1,2					1		1		1								
Road Type (Single or Dual Carriageway)		1					1,2					1		1		1								
Road Class (Public Roads or Local Roads)																								
One-way or two way traffic?																								
Number of Lanes																								
E - Accident History / Frequency																								
Accident Frequency																								
Accident History																								
Other																								
Aesthetics																								
Maintenance costs																								
Life-cycle costs																								

	Philippines		Poland		Portugal		Slovenia		Spain		Sweden		Switzerland		Turkey		UK		USA		LITERATURE
Location on the road (median, external shoulder, bridge)	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	Verge	Median	
A - Existence of Special Risk to 3rd parties																	1				1
Chemical Plants																					
Structures at risk of collapse, support and load bearing																					
Heavily used walkways, public areas with frequent pedestrian activity																					1
Volume of Pedestrian Traffic / Average number of people exposed to risk																					1
Average time each person is exposed to risk (hours per year)																					
Heavily used bicycle paths																					1
AADT of bicycles in the bicycle path																					1
Environmental Concern such as Source of drinking water																					
Adjacent rail lines																					
Distance to the Rail line																					
Number of trains per day, Per week or per hour																					
Rail line at the foot of an embankment																					
Number of Tracks																					
Permissible Speed on rail line																					
Adjacent Roads																					
AADT on adjacent road																					
Speed on adjacent road																					
Distance to the adjacent road																					
Road at the foot of an embankment																					
Object which can cause severe traffic disruptions if damaged																	1				
B - Obstructions with a special risk to vehicle occupants	1	1									1,2	1,2			1	1			1	1	1
Non-deformable extensive obstacles parallel to direction of travel											1,2	1,2									1
Retaining walls with non smooth traffic face up to 1.5m above traffic level																					
Noise barriers																					
Height/Depth of the Hazard																					
Fencing (Stone wall, wooden fence, concrete wall, etc.)																					
Non-deformable select individual obstacles	1	1									1,2	1,2			1	1			1	1	1
Bridge Piers, abutments, railing ends	1	1													1	1			1	1	
Above ground equipment other than emergency telephones (e.g. CCTV masts, communication control cabinets, pillars, stores for signs)																					1
Boulders	1	1													1	1			1	1	
Intersecting /Transverse Ditches																					1
Culverts, Pipes, Headwalls	1	1													1	1			1	1	
Ends of concrete barriers, retaining walls, etc.	1	1													1	1			1	1	1
Trees	1	1													1	1			1	1	1
Trunk girth of a single tree																					1
High Mast lighting poles	1	1													1	1			1	1	1
Sign/signal gantry supports	1	1													1	1			1	1	1
Diameter of support posts																					1
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Fall Height (Height from lower surface for bridges, retaining walls etc.)																					1
Falling Slopes (Embankments)																					1
Slope																					1
Height																					1
Surface of the slope (short grass, long grass, bush, etc.)																					1
Rising (Cutting) Slopes																					1
Slope																					1
Height																					
Surface of the slope (short grass, long grass, bush, etc.)																					
Permanent bodies or streams of water																					
Water depth																					
Distance to water from the edge of carriageway																					
A - Traffic											2	2					1				1
Average annual daily traffic (AADT)											2	2									1
Average annual daily HGV traffic ($AADT_{HGV}$)											2	2									
Percentage of Motorcycle Traffic																					1
B - Speed			2	1,2	1,2	1,2					2	2					1,2				1
Local Speed Limits			2	1,2	2	1,2					2	2					1,2				1
Design Speed											2										1
C - Road Alignment / Geometry			2	2	2	2											1				1
Distance between the edge of traffic and hazard																					1
Width of median				2		2															1
Vertical Alignment (Slope)																					1
Bridge Length																					
Geometry of diverge (parallel, trapezoid, etc.)			2	2	2	2															
Radius of curvature																					
Kerb Height																					
Roadside Topography (in terms of likelihood of reaching hazard)																					1
Adverse Geometrics																	1				
Stopping Sight Distance not up to the standard																					
Curve Radius Shorter than allowed design value																					
Several successive curves with radii smaller than permitted																					
non-typically large directional changes																					
Sleep related problematic design (featureless rural roads, etc.)																					
D - Road Layout				1		1					2	2									1
Road Type (Single or Dual Carriageway)				1		1					2	2									
Road Class (Public Roads or Local Roads)																					
One-way or two way traffic?											2	2									
Number of Lanes																					
E - Accident History / Frequency																	1				1
Accident Frequency																					1
Accident History																	1				1
Other																	1				
Aesthetics																					1
Maintenance costs																					1
Life-cycle costs																	1				1