RESEARCH ON ROAD RESTRAINTS SYSTEM AND DESIGN METHODOLOGY

Phase 1: LITERATURE REVIEW

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SUBMITTED TO:

Road Traffic Management Corporation (RTMC)

Contact detail: Deon Roux

Research, Innovation and Engineering

Email: Deon.Roux@rtmc.co.za

SUBMITTED BY:

TSHEDEGA delivering infrastructure

Contact detail: Willem Joubert PrEng PrCPM

Email: willem@wiljou.co.za

Figures

EXECUTIVE SUMMARY

The literature review gives an overview of the sources and themes that are relevant for developing the National Design Guideline that details the requirements and criteria, giving guidance for the provision, design and layout of permanent and temporary safety barriers, vehicle parapets, terminals, transitions, crash cushions, pedestrian parapets, pedestrian guardrails, vehicle arrester beds and anti-glare screens. Safety policies, strategies and design guides that promote safety above operations are in line with international best practice, driven by the Safe System approach.

The literature review sets the framework for developing the proposed RTMC manual. It is accepted that the literature presented in this document may be elaborated on, expanded and augmented as the guideline is written up. The final literature study to be included in the RTMC manual will therefore contain more references.

Guidelines and manuals for the safe design of roadsides are crucial for this RTMC project. Design guidelines are mostly aligned with the AASHTO Guide for Design of Highways and Streets (AASHTO, 2018), and the SANRAL Geometric Design Guide(SANRAL, 2003). The outcome in terms of reference requires the consultant to ''Develop a National Design Guideline that details the requirements and criteria, giving guidance for the provision, design and layout of permanent and temporary safety barriers, vehicle parapets, terminals, transitions, crash cushions, pedestrian parapets, pedestrian guardrails, vehicle arrester beds and anti-glare screens''.

The literature on the testing methods and modelling reveal that all countries and states use the two current testing protocols, the European EN1317 series and the USA MASH test guide as the basis for setting standards of performance and approval of products. From the literature, it is clear that current research is into numerical modelling calibrated with full-scale testing, but once calibrated can be used to simulate any configuration and test variables. It is suggested that South Africa follow the latter path, as full-scale test facilities are expensive to construct, operate and manage with highly paid technicians and researchers.

A BACKGROUND

A1 INTRODUCTION

The Road Traffic Management Corporation appointed Tshepega as a suitably qualified and experienced company with individuals as experts/professional service providers to assist with Road Restraint Systems (RRS) Research and a Design Methodology in South Africa.

This literature review of pertinent literature forms the basis of the research into the design methodology for road restraint systems (RRS) for the RTMC Board. This version is complete with in-text citations and references. It is foreseen that new literature may be explored in the course of the project and will be incorporated in a post completion review.

A2 TERMS OF REFERENCE AND SCOPE OF WORK

The following sections on Problem Definition, Objectives and Scope are taken from the RTMC terms of reference and scope. They are repeated in this literature review (as a stand-alone document) so that the reader is informed of the project's background and context.

A2.1 Problem definition

Road Restraint Systems (RRS) are primarily used to protect vehicle occupants from impacting road furniture or hazards, and vehicles reaching opposing carriageways. They are also intended to protect pedestrians, and any other entity using a roadway such as motorcycles.

There is a worldwide movement towards a "*Safe System Thinking*" approach to road design, operations and safety in general and specifically in RRS design. This is based on the principle that life and health should not be compromised by the need to travel. No number of fatalities or serious injuries on road transport networks should be acceptable. Human fallibility and vulnerability need to be considered. The goal of safe systems is to ensure that mistakes do not lead to a crash; or, if a crash does occur, it is sufficiently controlled to not cause a death or a life-changing injury.

The terms of reference define road restrain systems by stating the two primary systems being used for vehicle and pedestrians and listing the various types, such as longitudinal barriers to pedestrian guardrails. It states that RRS need to be designed to specific standards that perform to specified containment or protection levels. The concepts of hazards and risk are incorporated and confirm that road will always present hazards to drivers and therefore, a risk exists. Risk must be eliminated, controlled or managed to acceptable levels. The cost to benefit must be considered as public funds compete for a wide range of societal needs, and the best solutions should be sought.

A2.2 Objectives

a) The main goal of the RTMC is to promote quality and safety in road traffic in general throughout the country in order to affect a decrease in road crashes, fatalities and injuries, as well as to coordinate road infrastructure audits and road traffic and safety engineering matters through the road safety engineering forums that report to the National Road Safety Steering Committee (NRSSC).

b) Specific objectives in this regard are to reduce fatalities by 50% by 2030, in support of the National Road Safety Strategy 2016-2030 which, is underpinned by interventions towards safer roads, including forgiving road infrastructure, among other things, research on Road Restraint Systems (RRS) and a sound (robust) restraint systems design methodology.

c) The project is linked to the following NRSSC Interventions that need to be implemented:

4D(ii)	VRU safety to be included as a key component of the Road Safety Manual.
1(vii)	Development of sector-specific implementation manuals to support participating industries.
2B(i)	Provision of self-explaining and forgiving road environment for all road users.

A2.3 Scope

Forgiving roadsides need to be designed to reduce the severity of crashes. The correct provision of RRS and the appropriate RRS for a specific location and traffic condition will contribute to a safer road environment. Since South Africa does not have a comprehensive design methodology and most local and national authorities use their own design guidelines, a South African Design Methodology that considers local conditions and challenges needs to be developed that will allow more consideration to be given to how RRS are designed.

Ensuring proper design, manufacture, installation and maintenance of RRS is an important element. Life cycle management from manufacture to maintenance is essential in ensuring that systems perform to the parameters for which they were certified.

These deliverables aim to inculcate a uniform approach to the assessment, evaluation, prioritisation and design of road restraint systems across all road networks by developing a design methodology tool. This tool should allow designers to develop a practical and readily understandable RRS guidance document and a user-friendly software tool that allows designers and road administrations to select the most appropriate solution in different road and traffic conditions.

In this way, road administrations can conduct risk assessments of specific situations and set priorities in upgrade programmes. The following deliverables are required:

a) A comparative review of existing (national and international) design standards and guidelines;

b) A National Design Guideline that details the requirements and criteria, giving guidance for the provision, design and layout of permanent and temporary safety barriers, vehicle parapets, terminals, transitions, crash cushions, pedestrian parapets, pedestrian guardrails, vehicle arrester beds and anti-glare screens;

c) A Design methodology;

d) A Risk Assessment Tool that calculates the level of risk. The tool must review the effect of various options on the associated risk level and, where appropriate, the B/C.

  - Must consider life cycle cost models

- Must consider bespoke solutions for retrofitting RRS on the legacy networks where constraints prevent compliant designs
- Cost-Benefit Analysis (CBA).

The service provider is encouraged to evaluate and adapt existing design methodologies and risk assessment tools such as the UK's Road Restraint Risk Assessment Process (RRRAP) and reconfigure the parameters and algorithms based on South African design guidelines and traffic conditions. Electronic worksheets/templates should be created where possible to calculate, e.g. cost-benefit analysis.

A2.4 Scope of road restraint systems

The scope of this project is RRS, and it is related to what is stated in the introduction to the EN1317 Road restraint systems Part 1: Terminology and general criteria for test methods (1998):

> *"In order to improve and maintain highway safety, the design of safer roads requires the installation, on certain sections of road and at particular locations, of devices to restrain vehicles and pedestrians from entering dangerous zones or areas. The road restraint systems designated in this standard are designed to specify containment performance levels, redirect errant vehicles, and guide pedestrians or other road users."*

A2.5 Contributing factors

The provision of RRS is a measure to reduce risk and improve safety. The absence of a barrier is may contribute to the severity of an accident, but it must be understood that it is not the cause of the accident. In a document titled Improving Pedestrian and Motorist Safety Along Light Rail Alignments (NASEM 2015) this is well described as:

> *Contributing factors influence the occurrence or severity of a collision but are not actually root causes and if eliminated would not have prevented the collision. Contributing factors provide a context for the collision. As an illustration, consider the case of a fatality on an interstate highway facility. The collision occurred on a straight portion of roadway in good driving conditions. Police determine that the driver was fatigued, fell asleep, and left the right-of-way. Driver fatigue was a causal factor. Police also determine that the vehicle was traveling at 70 mph when it left the right-*

of-way. The speed was a contributing factor. It did not on its own cause the collision, but would have reduced the time available for the driver to recover control upon leaving the pavement (e.g., if awoken by a rumble strip), and it affected the severity once the incident occurred. In the same case, the driver would not have left the roadway had there been barriers, but the lack of barriers did not cause the crash. The absence of barriers is a contributing factor.

A2.6 Summary

In law, it is accepted that a road authority must provide a reasonably safe road for the reasonable road user. This consideration should inform the designer of the good values of society that who expects an environment that is not detrimental to its health and well-being, as set out in the Bill of Rights in the South African Constitution. The overarching goal is to reduce crashes on South African roads to save lives, reduce transport costs and comply with local and international policies and treaties. The overall RRS project's specific objective is to ensure proper design, manufacture, and maintenance of RRS in the South African context to reduce the infrastructure's life cycle cost. "A South African Design Methodology needs to be developed, which considers local conditions and challenges which will allow more consideration to be given to the way RRS is designed." A design tool needs to ensure a uniform approach to assessing, evaluating, prioritising, designing, and maintaining RRS across all road networks. In designing RRS, it must be understood that the absence of RRS is not the cause of the accident but a contributing factor to the consequences.

A3 METHODOLOGY

A3.1 Evidence synthesis

A literature review or study is not only a process of collecting, collating, summarising and analysing what is written about a subject and its subcomponents in order to synthesise and draw conclusions of what the current body of knowledge is. It is a research methodology that has theoretical underpinnings and methods. There are many such research approaches and methods, mostly with systematic comprehensive in the title, of which the Evidence Synthesis approach suits the nature of this literature review.

Evidence synthesis is a type of research method that allows researchers to bring together all relevant information about a research question. This can help identify gaps in knowledge, establish an evidence base for best-practice guidance, or help inform policymakers and practitioners. There are many types of outputs that use evidence syntheses, such as policy briefs, systematic reviews, clinical practice guidelines, and many more (Centre for Evaluation, s.n.).

Synthesis methods range widely from "more aggregative (trying to bring together a set of experimental findings on one or more outcomes) to configurative (trying to bring together diverse evidence to provide an overall picture of what the literature looks like in a particular area; more akin to assembling a jigsaw puzzle" (Thomas et al., 2012). The configurative method describes the method that was followed in this research.

A3.2 Framework for literature review

Thomas's view of a jigsaw puzzle reminds of a two-dimensional area carrying the picture as a third dimension. The RRS topic is similarly multidimensional (or a matrix), and the approach is to orientate the type of source on one axis and the topics on the other. At the same time, each cell's content will be the description of the themes to varying degrees of detail, accuracy, reliability and appropriateness for this project.

A3.2.1 Sources:

The sources of information on RRS systems are:

- Road design manuals
- RRS design manuals
- RRS testing procedures
- RRS academic research
- Hazardous location manuals
- Road safety assessment, appraisal and audit manuals
- Legal documents and cases

A3.2.2 Themes

Themes relevant to RRS are (in alphabetical order):

- Anti-glare screens
- Breakaway support
- Crash cushions
- Crash modification factors CMFs
- Data collection, inventory and deficiency register
- Design Guide
- Fixed object and roadside furniture
- Flexible barriers
- Hazardous locations
- Legal issues
- Longitudinal barriers
- Low volume roads
- Motorcycles and rails
- Parapets and bridge balustrades
- Pedestrian rails
- Rigid barriers
- Risk assessment
- Semi-flexible barriers
- Side slopes
- Standards
- Temporary systems
- Terminals and transitions
- Terminology
- Tests, procedures, protection classes
- Training
- Vehicle arrester beds
- Warrants

B LITERATURE REVIEW

The literature review looks at the identified literature and discusses the contents under the sections of sources and topics. This will result in an overlap of some content, and if so, the detail will be discussed in the topic section. The sources are not in a specific order but aimed at listing local and significant sources first.

B1 Road design manuals

Road design manuals play an important role in road safety, as they provide the road designer with the design philosophy, controls and criteria that inform the elements of design that the designer must optimise for a road concerning its function, class, environment, topography and other constraints. Design manuals exist on national, state / provincial and local road authority / municipal levels. These manuals often range from the generic to the specific, where a municipality may insist on a specific manhole cover or kerb design to standardise and save cost in maintenance. Road design manuals give guidance on roadside design and often present warrants for installation of RRS. These warrants are typically outdated and based on specific products.

Not all road design manuals are of good quality, comprehensiveness or relevance concerning RRS. Robert Bartlett (2016) published Design Standards 6.1, a list of road design manuals, see https://www.researchgate.net/publication/305790405_Road_design_standards_61/link/57a1efa708aeb1604833d212/download, that evaluated road design manuals from many countries in terms of quality. Bartlett does not elaborate on the criteria and acknowledges that it is subjective, but it may indicate the value that road design manuals may have for this project. In his view the Australian and Austroads standards are GOOD, and the South African GDG and Red Book and SADC manual are USEFUL. Its evaluation of the USA and UK standards as LIMITED seems to be evidence of subjectiveness or a set of criteria that does not relate to our current understanding of the value of road design standards. It indicates that road standards of European counties should be included. The Abu Dhabi Urban Street Design Manual (2014) issued by the Abu Dhabi Planning Commission was listed as reflecting acceptable standards. This manual is more urban design oriented, and while the emphasis on multi-modal design is commendable, the manual has no references to RRS due to the low operating speeds in urban condition. This manual is, however, of no use to the RTMC project.

There is also a high degree of similarity in road design manuals concerning content and structure. This is very clear in manuals in the English-speaking countries or countries that followed the USA model. On a specific topic such as RRS, the content becomes repetitive and do not add much additional value. These secondary manuals are cited, but the primary source will be noted.

Design manuals are sometimes called guides or guidelines, to break the connotation that these "manuals" must be followed to the letter and the "standards" so established will result in safe roads. Hauer concluds that roads designed to published standards are neither safe nor unsafe, and the linkage between standards and safety is mostly unpremeditated (Hauer 2000) https://www.researchgate.net/publication/259969500. (Hauer, 2014).

B1.1 Geometric Design Guide (GDG) Sanral 2003

This manual (SANRAL, 2003) sets out the most traditional design approach used in South Africa. It gives an overview (Chapters 2 to 4) of the design philosophy, design context and design elements. Safety is held paramount in geometric road design. In the new philosophy, safety should be the prime consideration. Sacrificing safety in the interests of efficiency and economy is not an acceptable practice.

> ''A more holistic philosophy should thus be founded on the concept of reducing the probability of failure to the lowest possible level and should seek to minimise the consequences of those failures that do occur. To achieve these goals, designs must begin with a clear understanding of purpose and functionality. From this foundation comes selecting appropriate policies followed by integrating into the landform and its current and future use, design elements and design guidelines. The hallmark of professionalism in road design is the ability to foresee and optimise any project's conflicting objectives'' (SANRAL, 2003) (my underlining).

In Chapter 8, Roadside Safety, the manual addresses the issues affecting and determining RRS, starting with the safety objectives and the "Forgiving Roadside" approach, which links to the clear zone concept. The clear zone elements influencing the clear zone design domain, determine the clear zone's width. The need for roadside furniture (signs and light posts) and the design and location criteria for sign supports light posts are discussed. This leads to the need for safety barriers and looks at the longitudinal roadside and median barriers. It looks at the design and selection of impact attenuators for fixed objects. Lastly, it looks at criteria for provision of escape ramps, location of runaway-vehicle facilities and arrestor bed design features.

The GDG already primes the designer to look at the safe roadside design and broadly at RRS. It lacks detail and standards on RRS like most design manuals and will depend on an RRS design manual.

B1.2 Other South African road geometric design sources

It should be noted that the TRH 17, the UTG series of road design manuals for urban conditions and the Department of Housing Guide on Human Settlements Planning and Design (Red book), were all compiled by Keith Wolhuter Pr Eng when he worked at the CSIR. These manuals were based on the then-current American Association of State Highway and Transportation Officials (various dates), A Policy on Geometric Design of Highways and Streets (AASHTO, 2018) (to be discussed following) and use the same point of departure.

- TRH 17 Geometric Design of Rural Roads, 1988, Dept of Transport for CSRA .
- Province of Cape of Good Hope Roads and Traffic Administration Branch, 1984 reprint 1996, Geometric Design Manual. Guardrails (Section 2.219) and median barriers (Section 2.220) are typical for the time confined to W-beam guardrails with concrete guardrails for narrow medians. The manual gives warrants.
- Gauteng Department of Roads and Transport, Road Design Manual Volume 1: Geometrics (BB1).
- Department of Housing, 2000. Guide on Human Settlements Planning and Design (Red book). Typical of urban design guides, there is no mention of RRS .
- South African Road Safety Manual, 1999. Volume 7 Designing for Safety. This volume describes the role of safety in design and guides road designers and road safety auditors on principles and findings related to designing for safety. This volume is also a tool that can be used to evaluate or audit a design.

B1.3 American Association of State Highway and Transportation Officials (various dates, current 2018), A Policy on Geometric Design of Highways and Streets, 7th Edition

This is the most quoted road design manual and the basis of most design criteria used world-wide. Chapter 1 gives the design background, Chapter 2 the design control and criteria, Chapter 3 the design elements, and Chapter 4 cross-sections. However, traffic barriers receive limited attention (only six pages) in section 4.10, discussing:

- General Considerations

- Longitudinal Barriers
- Roadside Barriers
- Median Barriers
- Bridge Railings

The reader is referred to AASHTO Roadside Design Guide 2006 for design guidance on RRS.

Most US State Departments of Transport have their own Road Design Manuals or Guidelines highlighting some state-specific issues, such as snow and ice in the northern states. All have the AASHTO PGDHS as the base.

B1.4 Highways England, 2020. GG 000 Design Manual for Roads and Bridges index, 30-Dec-2020

The United Kingdom for many decades presented the Design Manual for Roads and Bridges as a series of documents preceded with the letter TD followed by Number/Date. In 2020 it migrated to a digital platform and revised the format and numbering of the manual. This manual applies in England, Wales, Scotland and Ireland, the latter with additional requirements. The following sections now comprise the manual:

Index of DMRB documents

- General Principles & Scheme Governance (G* 101-999)
- Sustainability & Environment (L* 101-999)
- Road Layout (C* 101-199)
- Pavement (C* 201-299)
- Highway Structures & Bridges (C* 301-499)
- Drainage (C* 501-599)
- Geotechnics (C* 601-699)
- Control & Communications Technology (T* 101-499)
- Road Lighting (T* 501-999)

The guidance in the road layout section still requires considering safety and operations of all modes of traffic. For example, section Road Layout Design CD 109 Highway links design (Highways England, no date a) states:

> The various geometrical elements detailed in this document need to be coordinated, together with a cross-section (CD 127 [Ref 1.N]) and junction layouts (CD 122 [Ref 3.N], CD 123 [Ref 2.N] and roundabouts CD 116 [Ref 4.N]), so the three-dimensional layout as a whole is appropriate in terms of traffic safety, operation and economic/environmental effects. (p5)

The use of RRS is not dealt with in detail as the section Highway Structures & Bridges Design CD 377 Requirements for road restraint systems deals with RRS. Note that the term Vehicle Restraint System (VRS) is used in the UK, and a VRS is defined as a safety system installed at the edges of the carriageway to provide vehicle restraint.

Section Road Layout Design CD 127 Cross-sections and headrooms (Highways England, no date b) deals with the setbacks of RRS (called Vehicle Restraint Systems (VRS) in the UK) from the road geometric elements in the cross-section. The actual RRS is in CD 377, as mentioned above.

> Vehicle restraint system setback E/3.15 The setback to a VRS shall be measured as the lateral distance between the traffic face of a safety barrier and:
>
> 1) nearside:
>   a) the back of the rigid nearside strip (when it is greater than 600mm) or hard shoulder;
>   b) the kerb face for roads without a nearside rigid strip (or a rigid strip less than 600mm) or hard shoulder;
>   c) the trafficked edge of the edge line for roads without a rigid strip (or hard strip less than 600mm), or without hard shoulder or kerb;
> 2) offside:
>   a) The edge line's trafficked edge or the kerb face where there is no edge line (Highways England, no date c).

The cross-section of a rural motorway below shows the location of RRS on the verges and median.

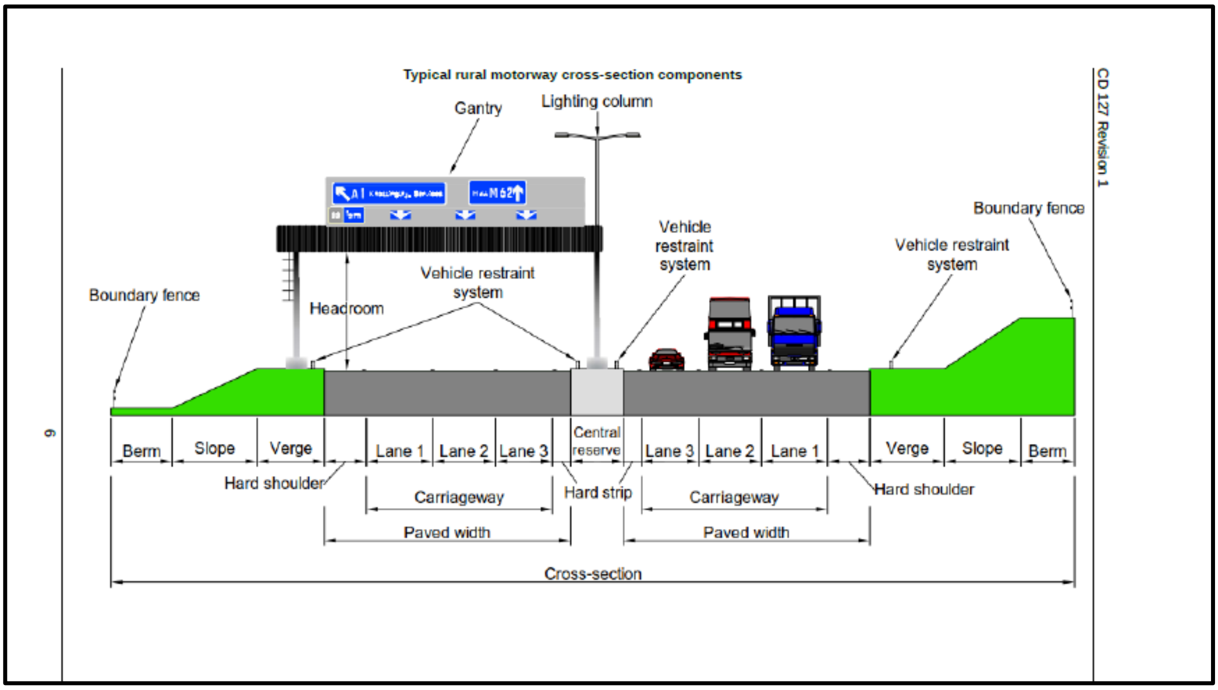


Figure 1: Rural motorway cross-section

B1.5 Austroads AGRD03-16 Guide to Road Design Part 3: Geometric Design

The Australian and New Zealand road authorities pool their research funds in Austroads. Austroads is responsible for overarching research and outputs in policies, roads design, operations and management, road safety and traffic accommodation at roadworks. The quality of their publications is of a high standard, and it has the benefit for South Africa that the drive side and environmental conditions are the same. The main differences are in law abidance, modal split (no minibus taxi industry), and vehicles' quality due to a younger vehicle fleet.

The design manual (Austroads, 2016) is extensive, and the chapters follow a logical order from design consideration and principles such as safety, fundamental considerations, speed, cross-section and then all the design elements. RRS are influenced by the cut and fill batters, a design choice that depends on road class, topography, geotechnical factors and economics. From this manual, Table 4.11 shows desirable maximum batter slopes for cut and fill situations. The table is shown in Figure 2.

Slopes flatter than the desired maximum should be used where possible to improve roadside safety for motorists, batter stability and erosion control. Where steeper slopes are unavoidable, and barriers are required, designers should consult the Guide to Road Design Part 6: Roadside Design, Safety and Barriers.

Table 4.11: Typical design batter slopes

	Cut		Fill	
	Desirable maximum	Maximum	Desirable maximum	Maximum
Earth batter	3:1	2:1	6:1	4:1(2)
Rock batter(3)	0.5:1	0.25:1(1)	–	–
Median	10:1	6:1(2)	10:1	6:1(2)

1 *May be steeper if geotechnical conditions permit.*
2 *Steeper slopes may be considered in combination with safety barriers to protect errant vehicles; however consideration should be given to safe maintenance practices and the surfacing treatment adopted.*
3 *Rock batter slopes shown (i.e. steeper than 2:1) should only be adopted if a geotechnical assessment/design is carried out and it is demonstrated that the batter would have a factor of safety of at least 1.6 against instability.*

Figure 2: Typical design batter slopes

B1.6 United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), 2017. Asian Highway Design Standard for Road Safety Design Guidelines in October 2017

The manual states: "Road infrastructure's fundamental safety aspects are primarily the highway engineering design domain covering alignment, cross-sections, forward visibility, and overtaking sections. Providing adequate road-users facilities to stop and rest is also crucial to road safety in the highway network. Self-explaining roads have a consistent design and visual appearance which match the expectation of all road-users. They foster appropriate speeds and behaviour naturally without resorting to excessive use of signs and deterrence measures. Therefore, self-explaining roads are more sustainable in safety performance and are often more compatible with urban design objectives". Chapter 4 of this road design manual deals with roadside safety. The following aspects are looked at:

PART 4 ROADSIDE SAFETY

1 OVERVIEW

2 FORGIVING ROADSIDE

2.1 General Requirements

2.2 Clear Zones

2.4 Diverge Gores

3 VEHICLE RESTRAINT SYSTEMS

3.1 General Requirements

3.2 Roadside Safety Barriers

3.3 Median Safety Barriers

3.4 Transitions

3.5 End Treatments

3.6 Crash Cushions

B1.7 Indian Roads Congress, 2013. Manual for Specifications and Standards for Expressways

The geometric design section states that the manual lays down the geometric design standards and available features for expressways. The application of geometric standards should aim at achieving safety, mobility and efficiency in traffic operation.

The clear zone is shown in Figure 2.3.

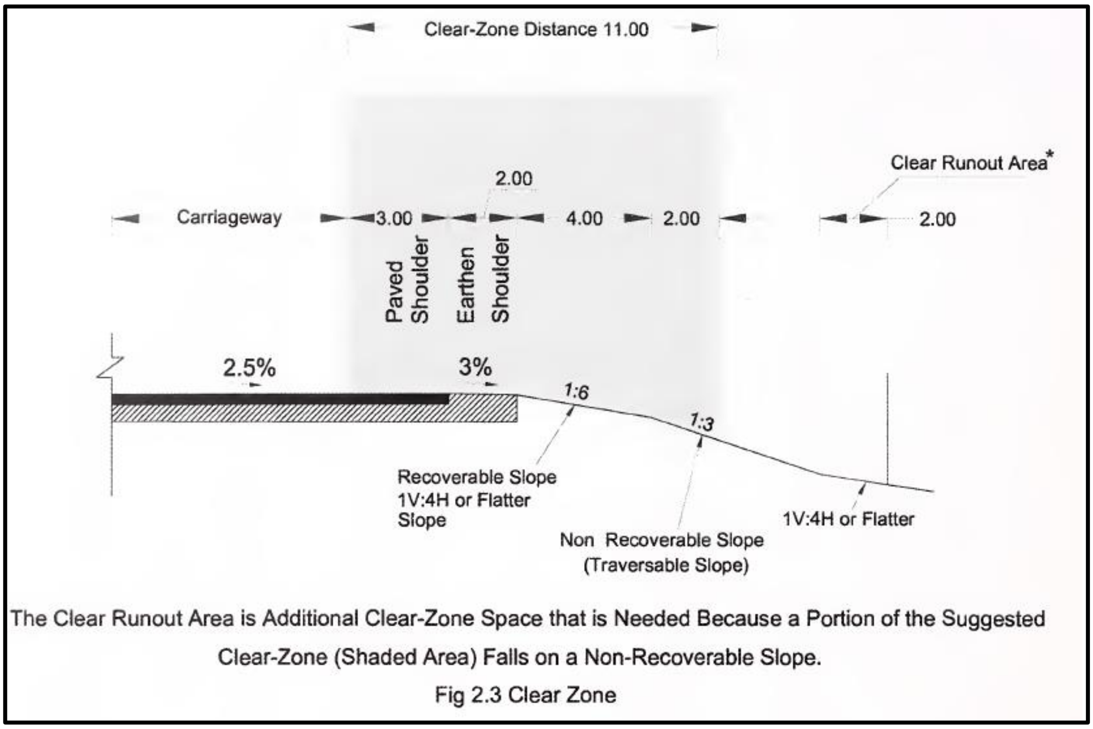


Figure 3: Clear zone

The warrants and barrier types are described in section 10.7.

B1.8 Conclusions on Road Design Manuals

Road design manuals all have safety, functionality, efficiency, economy and environmental impacts in mind when guiding the designer to provide infrastructure facilities for the access and mobility needs of all road users and considering all modes. The overall design of a road influences the roadside characteristics and in combination with traffic volumes, topography, geotechnical and economic factors, the need for RRS must be defined.

The listed road design manuals, which account for 99% of all design aspects affecting the roadside, show the range of design issues to be taken into account.

B2 Road restraint systems design/roadside design manuals

The pertinent manuals or chapters/sections of manuals dealing with RRS are summarised to give a short overview, and the indexes of the contents are presented to indicate the range of aspects and themes.

B2.1 South African Road Safety Manual, 1999. Volume 6 Road Side Hazard Management

Volume 6 aims to provide a best-practice guideline document concerning the roadside and median area management to reduce the severity of roadside accidents. Comparing the South African document (1999) to more recent international manuals, the South African document is an excellent compilation of roadside hazard management aspects, with comprehensive discrete subsections and examples of then-current technologies and products. The index to this manual is given below to illustrate the range of content. The full index with all subsections is included in Appendix D, with additional subjects identified from other manuals and guidelines.

8. SIGN CATEGORIES

9. SMALL ROADSIDE SIGNS

10. SUPPORTS FOR TRAFFIC SIGNALS AND MISCELLANEOUS TRAFFIC SERVICE DEVICES

11. UTILITY POLES

12. LARGE ROADSIDE SIGNS

13. OVERHEAD SIGNS

14. CONCLUSIONS

PART C: TRAFFIC BARRIERS

1. INTRODUCTION TO VOLUME 6: PART C

2. INTRODUCTION TO TRAFFIC BARRIERS

3. SAFETY CRITERIA FOR TRAFFIC BARRIERS

4. TECHNICAL CRITERIA FOR THE SELECTION OF TRAFFIC BARRIER SYSTEMS

5. VEHICLE DAMAGE AND ACCIDENT EXPERIENCE

6. CRASH TESTS: MEASURING THE EFFECTIVENESS OF TRAFFIC BARRIERS

7. IMPACT PERFORMANCE LIMITATIONS

8. SELECTION GUIDELINES

9. LONGITUDINAL BARRIERS

10. IMPACT ATTENUATING DEVICES

11. CONCLUSIONS

The manual gives the following criteria for the selection of a traffic barrier system.

Table C-1: Selection criteria for a traffic barrier system (1)

CRITERIA		COMMENTS
1.	Performance capability	The traffic barrier system should be structurally able to • contain the design vehicle • redirect the design vehicle
2.	Deflection	The available room to deflect should not be less than the expected traffic barrier deflection
3.	Site conditions	Conditions influencing the barrier type choice include: • Slope approaching the barrier system • Distance from traffic lane
4.	Compatibility	The system should be compatible with adjacent systems (like bridge railings) and end-treatments
5.	Cost	The full life cycle cost should be considered in the economic evaluation of alternative systems. A system with a relatively low installation cost typically requires significantly more maintenance following impacts.
6.	Maintenance	
6a.	Routine	Routine maintenance for W-guardrail systems for example, includes checking of bolts, posts and soil stability.
6b.	Collision	Flexible and semi-flexible systems requires in general significantly more maintenance than rigid systems
6c.	Materials storage	Storage includes inventory items and storage space
6d.	Simplicity	Simpler designs are more likely to be installed correctly by field personnel
7.	Field experience	Existing systems should be monitored in terms of performance and maintenance requirements to identify problems that can be reduced or eliminated by the use of a different barrier system.

Figure 4: Selection criteria for a barriers system

B2.2 American Association of State Highway and Transportation Officials. 2011. Roadside Design Guide. 4th Edition

This publication has evolved over several decades to this 4th Edition. The intention is to present information on the latest practices in roadside safety. It discusses concepts, designs and philosophies to justify and optimise RRS. It highlights that each project is unique and offer opportunities to enhance the roadside from a safety perspective. It acknowledges that monetary resources are limited, and the objective of design is to maximise roadside safety on a system-wide basis with given funds. This requires prioritisation of projects to get the best safety benefit and value for money.

The clear zone concept developed from studies in the 1960s and the width of clear sones were determined for speed, traffic volumes and side slopes using nomographs called clear-zone distance curves.

As this is the seminal publication on RRS, the index is presented to show its content in broad terms. Chapter 5 on roadside barriers is augmented with the subsection headings used in the other chapters where applicable.

Chapter 1—An Introduction to Roadside Safety

Chapter 2—Economic Evaluation of Roadside Safety

Chapter 3—Roadside Topography and Drainage Features including the Clear-Zone Concept

Chapter 4—Sign, Signal, and Luminaire Supports, Utility Poles, Trees, and Similar Roadside Features

Chapter 5—Roadside Barriers

1. *Overview*
2. *Performance requirements*
3. *Barrier recommendations*
4. *Test level selection factors*
5. *Structural and safety characteristics of roadside barriers*
6. *Placement recommendations*

7. *Upgrading systems*

Chapter 6—Median Barriers

Chapter 7—Bridge Railings and Transitions

Chapter 8—End Treatments

Chapter 9—Traffic Barriers, Traffic Control Devices, and other Safety

Chapter 10—Roadside Safety in Urban or Restricted Environments

Chapter 11—Erecting Mailboxes on Streets and Highways

Chapter 12—Roadside Safety on Low-Volume Roads and Streets

The performance requirements for each type of RRS are related to the then-applicable NCHRP 350 Recommended Procedures for the Safety Performance Evaluation of Highway Features, 1993, Transportation Research Board, National Research Council. This manual is used to determine the appropriate RRS for an identified hazard, based on performance criteria and risk analysis.

Like the road design manuals, most of the USA State Departments of Transport have issued their versions or complementary manuals. Some of these (Washington State, Texas) have detailed descriptions of design, installation and maintenance of specific products which applies to the state. These details will be captured under the themes.

B2.3 UK Highway Structures & Bridges Design CD 377 Requirements for road restraint systems

This subsection of the UK design manual focusses directly on the application of RRS. Road geometric design considerations are dealt with in the subsections CD 101 to 199.

The manual requires that the so-called Road Restraint Risk Assessment Process (RRRAP) be used. The RRRAP is a software tool to assist in assessing many situations, based on risk, as to whether a VRS (RRS) is warranted to prevent the occupants of a vehicle from hitting near side or offside hazards. The standards to which the performance of RRS is measured and the methods are based on BS EN 1317 – 1 and 1317-2. For comparison, the index to CD 377 is shown below to illustrate the content of the manual. The manual has an extensive list of definitions.

1. Scope

2. General requirements

3. Requirements for permanent safety barriers

4. Requirements for vehicle parapets

5. Requirements for terminals

6. Requirements for transitions

7. Requirements for crash cushions

8. Requirements for pedestrian restraint systems

9. Requirements for temporary safety barriers at roadworks

10. Legacy systems

11. Vehicle arrester beds

12. Anti-glare systems

13. Cattle grids

14. Normative references

15. Informative references

Appendix A. Guidance on the specification of vehicle restraint systems for low speed and/or low flow roads

Appendix B. Guidance on factors for ECPs and MCPs (emergencies and maintenance crossing points)

A separate design guide for the Republic of Ireland elaborates on specific local issues (Highways Ireland, 2019).

B2.4 Austroads AGRD06-20 Guide to Road Design Part 6: Roadside Design, Safety and Barriers

"Part 6 provides information to enable designers to understand the principles that lead to the design of safer roads, identify hazards, undertake a risk assessment process of roadside hazards, establish the need for treatment of hazards and determine the most appropriate treatment. Methods of evaluating the effectiveness of treatment options are summarised. A comprehensive design process, guidance and design considerations are provided to select a suitable barrier and the lateral and longitudinal placement of barrier systems. (Austroads, 2014)

<u>1. Introduction to Roadside Design</u>

1.1 Context Sensitive Designs

1.2 Purpose

1.3 Reading this Part in the Context of Part 1

1.4 Scope of this Part

1.5 Principles Considered in Roadside Design to Achieve the Safest System

1.6 Roadside Safety Design

1.7 Terminology

1.8 Overview of the Roadside Risk Assessment Process

1.9 Calculating a Risk Score

B2.5 Alberta Infrastructure and Transport Roadside Design Guide Section H, 2007

This document provides guidance for the cost-effective design of the roadside environment for highways in Alberta. Canada (Alberta Transportation, 2007).

- Section H1 outlines the general philosophy and principles of roadside design. Roadside design is not performed in isolation from other design activities. The relationship between roadside design and other design processes is presented along with a glossary of roadside design terms.
- Section H2 presents INFTRA's current practices and guidelines governing roadside design activities.
- Section H3 presents the design process for roadside design treatments. A set of decision charts is included to guide the designer through the design process to select the most appropriate design treatment for the specific situation under consideration.
- Sections H4 to H11 present the characteristics and design aspects of various roadside features in Alberta.

The Canadian roadside design practice, as taken from the Alberta documents, is based on AAHSTO guidance. It uses the NCHRP 350 – Recommended Procedures for the Safety Performance Evaluation of Highway, 1993. However, it refers to the current AASHTO Manual for Assessing Safety Hardware 2009 (AASHTOMASH 2009), indicating that new highway safety hardware not previously evaluated must utilise MASH for testing and evaluation.

B2.6 Norway, 2011. Vehicle Restraint Systems and roadside areas standard. Norwegian Public Roads Administration Manuals

This manual is based on the rules and regulations that the Construction Products Directive (86/106/EØF) gives. It was harmonised with the standard European guidelines for testing and approval of vehicle restraint systems – NS EN 1317, which was prepared under the auspices of CEN (Comité Européen de Normalisation) and set by Norwegian Standard, see section 1.6.

Guides have been prepared to supplement this handbook that describes standard road safety barriers in detail, including installation procedures, terminals, transitions, standard bridge parapets, guardrails for pedestrians and cyclists, crash cushions and overview lists for vehicle restraint systems, lighting columns and signposts for use by the Norwegian Public Roads Administration.

The purpose of the handbook is to provide regulations for the design and installation of vehicle restraint systems on public roads to reduce the number of incidents and limit the extent of damage and injury when incidents occur. Earth embankments are also addressed as an alternative solution to vehicle restraint systems. In addition to traffic safety, an assessment is provided of environmental aspects, maintenance-friendliness, and overall economics. The vehicle restraint systems standard is anchored in the Vision Zero goal of significantly reducing road traffic fatalities and severe casualties in road traffic.

This manual focusses on the more important and widely used subsystems. A separate manual is available for bridge parapets. The index to the manual is listed below.

1. *General*
2. *Calculations for safety zones and the need for safety barriers roads*
3. *Criteria for selection of safety barriers*
4. *Safety barrier lengths and terminals*
5. *Materials and design*
6. *Crash Cushions*

B2.7 Road ERA-Net, 2011. Forgiving Roadside Design Guide

IRDES (Improving Roadside Design to Forgive Human Errors) is a research project of cross border funded joint research programme'' ENR SR01 – Safety at the Heart of Road Design, initiated by ERA-NET ROAD – Coordination and Implementation of Road Research in Europe. Partners that funded the research were Austria, Belgium, Finland, Hungary, Germany, Ireland, Netherlands, Norway, Slovenia, Sweden and the United Kingdom. The project was supported by many countries with Roadside Design Manuals. Some countries had since published such a manual, instead of referring to a common guideline for the EU. The guide's value lies in the good illustrations and easy reading of the subject matter.

The Forgiving Roadside Design Guideline (la Torre, 2011) has been developed as a practical handbook that designers can easily use in road safety design projects. Based on the inputs by the potential stakeholders gathered during the IRDES webinars, the guideline has been structured with each feature analysed in a separate section providing:

- *Introduction,*
- *Design criteria,*
- *Assessment of effectiveness,*
- *Case studies and examples, and*
- *Key references.*

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

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

One of the issues tackled in the project has been harmonising different existing standards or identifying underlying reasons for different existing solutions for the same treatments to allow the user to select the optimal treatment and adequately assess its effectiveness.

B2.8 Asian Development Bank, 2018. Road Side Hazard Management

Carec Road Safety Engineering Manual 3. APRIL 2018. Mandaluyong City, 1550 Metro Manila, Philippines

DOI: http://dx.doi.org/10.22617/TIM179174-2

The content of this manual follows a similar pattern to the preceding manuals.

Purpose of this Manual

I. An Introduction to Roadside Hazard Management

A. Background to roadside hazard management

B. Safe design principles and the "forgiving roadside concept."

C. Engineers can make a difference

II. Identifying Roadside Hazards

A. What is a roadside hazard?

B. Clear zone concept

III. Investigating Roadside Hazards: A Roadside Safety Management Strategy

A. Investigating roadside hazards

B. Roadside hazard management strategy (a tool to assist decision making)

C. Keeping vehicles on the road

D. Remove the hazard

E. Relocate the hazard

F. Alter the hazard

G. Shield the hazard

IV. Treating (Eliminating or Reducing) Roadside Hazards

A. Case study 1: treating roadside hazards in hilly terrain

B. Case study 2: rehabilitation of a rural highway

C. Case study 3: reducing run-off-road crashes

D. Case study 4: upgrade of an urban interchange

V. Using Safety Barriers Correctly

A. Three groups of safety barriers

B. Selection of barriers

C. Design and installation considerations

VI. Other Roadside Safety Furniture

A. Frangible lighting columns

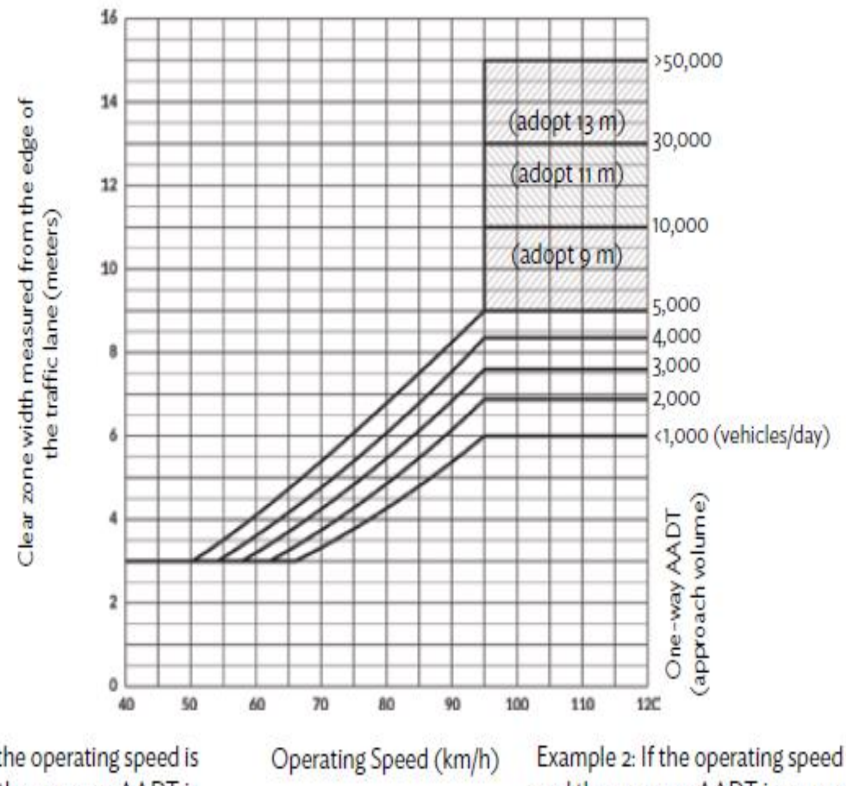
B. Drivable end walls

C. Impact attenuators (crash cushions)

D. Emergency crossings in medians

The warrant for longitudinal barriers is shown below.

Figure 1: Clear Zone for Straight Roads



Example 1: If the operating speed is 80 km/h and the one-way AADT is 4,000 vehicles/day, the clear zone width is 6 m.

Example 2: If the operating speed is 100km/h and the one-way AADT is 20,000 vehicles/day, the clear zone width is 11 m (adopt range 10,000–30,000 vehicles/day)

AADT = annual average daily traffic, km/h = kilometer per hour, m = meter.

Source: VicRoads. 2011. *Supplement to Austroads Guide to Road Design – Part 6 (Roadside Design, Safety and Barriers)*. Sydney, Australia.

Figure 5: Warrant for clear zone for straight roads

B2.9 Conclusions on Road Restraint System / Roadside Design Guides

The examples of roadside design guides all illustrate the design of RRS in various locations and for various functions. It was found that the South African Road Safety Manual Volume 6 Roadside Hazard Management 1999 provides a comprehensive and detailed framework for RRS design guidance. As it refers to products and technologies dating back more than 20 years and the then used NHCRP 350 test methodologies, it must be updated to current practice, standards and products.

In general, the Roadside Design Manuals subscribe to the same priority for dealing with identified roadside hazards:

- *remove the hazard;*
- *redesign the hazard so that it can be safely traversed or contacted;*
- *relocate the hazard to reduce the probability of it being traversed or contacted;*
- *reduce the severity of the hazard;*
- *shield the hazard; and*
- *delineate and increase the driver's awareness of the hazard when other mitigation measures cannot be made to work.*

The selection of Roadside Design Guides covers the primary contributing counties RSAS, USA, UK, Australia, Asia, Canada, Norway and a standard guide for the EU. These inputs will be collated with other manuals, and the contents will be evaluated for a synthesis document for the RTMC.

B3 RRS testing procedures

"The need for comprehensive testing procedures for roadside hardware to confirm how devices would function during a collision was recognised quite some time ago. Research conducted in the 1970s by the Transportation Research Board (TRB) in the United States yielded an early attempt to define how roadside hardware should perform during service conditions (in-service). The National Cooperative Highway Research Program (NCHRP) Report 350 – Recommended Procedures for the Safety Performance Evaluation of Highway Features (1993), presents the most current guidelines to evaluate the performance of roadside hardware" (Alberta Infrastructure and Transport Roadside Design Guide Section H, 2007).

Procedures for full-scale vehicle crash testing of guardrails were first published in Highway Research Correlation Services Circular 482 in 1962. This one-page document specified vehicle mass, impact speed, and approach angle for the crash tests. Although Circular 482 did bring a measure of uniformity to traffic barrier research then being performed at several research agencies, several questions arose that were not addressed. (NCHRP Report 350).

Two dominant sets of standard testing procedures developed: in the USA the NCHRP 350, which became MASH and in Europe the EN1317 series of standards.

B3.1 (NCHRP) Report 350 – Recommended Procedures for the Safety Performance Evaluation of Highway Features, 1993

This report was compiled by and based on research and experiments at the Texas Transport Institute at Texas A&M University. The first aim was to define standardised tests in terms of vehicle types, mass, speed and approach angles representing real-world situations, while the second aim was to test some products to see if the test procedures are reliable, repeatable and credible.

They conducted vehicle crash tests and in-service evaluation of roadside safety features or appurtenances. The features covered by these procedures include (1) longitudinal barriers such as bridge rails, guardrails, median barriers, transitions, and terminals; (2) crash cushions; (3) breakaway or yielding supports for signs and luminaries; (4) breakaway utility poles; (5) truck-mounted attenuators; and (6) work zone traffic control devices.

The tests conditions are prescribed, such as level surface, soil strength (standard soil) angle of approach and vehicle characteristics. The choice of vehicles in early 1990 in the USA is shown in the next table included as Figure 6. A small car's choice was made because these vehicles tended to perform worst in crashes than the more prevalent so-called Yank Tanks. The 2000 kg pickup truck was chosen as the vehicle type that sells most in the USA.

TABLE 2.1. Recommended properties of 700C, 820C, and 2000P test vehicles

Property	700C (Small Car)	820C (Small Car)	2000P (Pickup Truck)
MASS (kg)			
Test Inertial	700 ± 25	820 ± 25	2000 ± 45
Dummy	75	75	---
Max. Ballast	70	80	200
Gross Static	775 ± 25	895 ± 25	2000 ± 45
DIMENSIONS (cm)			
Wheelbase	230 ± 10	230 ± 10	335 ± 25
Front Overhang	75 ± 10	75 ± 10	80 ± 10
Overall Length	370 ± 20	370 ± 20	535 ± 25
Track Width[b]	135 ± 10	135 ± 10	165 ± 15
CENTER OF MASS LOCATION[a] (cm)			
Aft of Front Axle	80 ± 15	80 ± 15	140 ± 15
Above Ground	55 ± 5	55 ± 5	70 ± 5
LOCATION OF ENGINE	Front	Front	Front
LOCATION OF DRIVE AXLE	Front	Front	Rear
TYPE OF TRANSMISSION	Manual or Automatic	Manual or Automatic	Manual or Automatic

[a] For "test inertial" mass
[b] Average of front and rear axles

Figure 6: Recommended properties of 77C, 820C and 2000P test vehicles

The heavy vehicles chosen are shown in the next table shown as Figure 7.

TABLE 2.2 Recommended properties of 8000S, 36000V, and 36000T test vehicles

Property	8000S (Single-Unit Van Truck)	36000V (Tractor/Van Trailer)			36000T (Tractor/Tank Trailer)		
		Tractor[g]	Trailer[e]	Combination	Tractor[g]	Trailer[f]	Combination
Mass (kg)							
Curb	5,450 ± 450	N/S	N/S	13,200 ± 1,400	N/S	N/S	13,200 ± 1,400
Ballast[d]	As Needed	N/A	As Needed	N/A	N/A	As Needed	N/A
Test Inertial	8,000 ± 200	N/S	N/S	36,000 ± 500	N/S	N/S	36,000 ± 500
Dimensions (cm)							
Wheelbase	535 (max)	480 (max)	N/S	N/A	480 (max)	N/S	N/A
Overall Length	870 (max)	N/S	1,525 (max)	1,985 (max)	N/S	N/S	1,985 (max)
Trailer Overhang[a]	N/A	N/A	220 (max)[c]	N/A	N/A	185 (max)	N/A
Cargo Bed Height[b] (Above Ground)	130 ± 5	N/A	132 ± 5	N/A	N/A	N/A	N/A
Center of Mass Location (cm)							
Ballast[d] (Above Ground)	170 ± 5	N/A	185 ± 5	N/A	N/A	205 ± 10	N/S
Test Inertial (Above Ground)	125 ± 5	N/S	N/S	N/S	N/S	N/S	N/S

a. Distance from rearmost part of trailer to center of trailer tandems.
b. Without ballast
c. If trailer equipped with slide axies, they should be set at rearmost position.
d. See section 2.4.2.2 for recommended ballasting procedures.
e. It is preferable that the trailer structure be of the "semi-monoscope" type construction. It is preferable that a sliding undercarriage (slide axles) be used to attach the trailer tandems to the taller frame.
f. It is preferrable that a gasoline tank with an elliptical cross section be used.
g. Tractor should be a cab-behind-engine model, not a cab-over-engine model.
N/A – Not Applicable. N/S-Not Specified

Figure 7: Recommended properties for 8000S. 36000V and 36000 T-test vehicles

It will be noted that the maximum test mass for a laden truck was 36 000 kg. This is due to the USA's road freight legislation at that time leading to a prevalence of truck tractor with a single long trailer. This is different from the South African prevalence for the so-called interlink long haul truck consisting of a truck tractor and two trailers, typically designed for a 6 and 12 m container each and a maximum gross vehicle mass of 56 000 kg.

The *NCHRP Report 350* states that a performance goal is to provide hardware systems that will safely do one of the following:

- *contain or redirect an errant vehicle away from a hazardous area*
- *decelerate the vehicle to a stop over a relatively short distance*
- *readily break away, fracture, or yield*
- *allow a controlled penetration*

- *be traversed*

without causing severe injuries to the vehicle's occupants or other motorists, pedestrians, or work zone personnel.

The NCHRP Report 350 testing criteria considers two primary aspects of the longitudinal traffic barrier: Length of Need and transition. The Length of Need section is the portion of the longitudinal traffic barrier that is designed to redirect or contain an errant vehicle. The transition section is the portion at the end of the longitudinal traffic barrier that connects with features of varying rigidity.

The next table (marked Table 3.1 which is contained in Figure 8) shows the test matrix of procedures for longitudinal barriers for light vehicles, with different speeds and angles. Similar test matrices exist for crash cushions and temporary traffic barriers. Based on these test inputs, the outputs will be measured as shown in the table and the barrier's performance concerning displacement, working width, and deformation will become part of the product characteristics.

TABLE 3.1. Test matrix for longitudinal barriers

Test Level	Barrier Section	Test Designation	Impact Conditions[c] Vehicle	Impact Conditions[c] Nominal Speed (km/h)	Impact Conditions[c] Nominal Angle, θ (deg)	Impact Point	Evaluation Criteria[a] (See Table 5.1)
1	Length of Need	1-10	820C	50	20	(b)	A,D,F,H,I,(J),K,M
		S1-10[a]	700C	50	20	(b)	A,D,F,H,I,(J),K,M
		1-11	2000P	50	25	(b)	A,D,F,K,L,M
	Transition	1-20[d]	820C	50	20	(b)	A,D,F,H,I,(J),K,M
		S1-20[a]	700C	50	20	(b)	A,D,F,H,I,(J),K,M
		1-21	2000P	50	25	(b)	A,D,F,K,L,M
2	Length of Need	2-10	820C	70	20	(b)	A,D,F,H,I,(J),K,M
		S2-10[a]	700C	70	20	(b)	A,D,F,H,I,(J),K,M
		2-11	2000P	70	25	(b)	A,D,F,K,L,M
	Transition	2-20[d]	820C	70	20	(b)	A,D,F,H,I,(J),K,M
		S2-20[a]	700C	70	20	(b)	A,D,F,H,I,(J),K,M
		2-21	2000P	70	25	(b)	A,D,F,K,L,M
3 Basic Level	Length of Need	3-10	820C	100	20	(b)	A,D,F,H,I,(J),K,M
		S3-10[a]	700C	100	20	(b)	A,D,F,H,I,(J),K,M
		3-11	2000P	100	25	(b)	A,D,F,K,L,M
	Transition	3-20[d]	820C	100	20	(b)	A,D,F,H,I,(J),K,M
		S3-20[a]	700C	100	20	(b)	A,D,F,H,I,(J),K,M
		3-21	2000P	100	25	(b)	A,D,F,K,L,M
4	Length of Need	4-10	820C	100	20	(b)	A,D,F,H,I,(J),K,M
		S4-10[a]	700C	100	20	(b)	A,D,F,H,I,(J),K,M
		4-11[d]	2000P	100	25	(b)	A,D,F,K,L,M
		4-12	8000S	80	15	(b)	A,D,G,K,M
	Transition	4-20[d]	820C	100	20	(b)	A,D,F,H,I,(J),K,M
		S4-20[a]	700C	100	20	(b)	A,D,F,H,I,(J),K,M
		4-21[d]	2000P	100	25	(b)	A,D,F,K,L,M
		4-22	8000S	80	15	(b)	A,D,G,K,M
5	Length of Need	5-10	820C	100	20	(b)	A,D,F,H,I,(J),K,M
		S5-10[a]	700C	100	20	(b)	A,D,F,H,I,(J),K,M
		5-11[d]	2000P	100	25	(b)	A,D,F,K,L,M
		5-12	36000V	80	15	(b)	A,D,G,K,M
	Transition	5-20[d]	820C	100	20	(b)	A,D,F,H,I,(J),K,M
		S5-20[a]	700C	100	20	(b)	A,D,F,H,I,(J),K,M
		5-21[d]	2000P	100	25	(b)	A,D,F,K,L,M
		5-22	36000V	80	15	(b)	A,D,G,K,M
6	Length of Need	6-10	820C	100	20	(b)	A,D,F,H,I,(J),K,M
		S6-10[a]	700C	100	20	(b)	A,D,F,H,I,(J),K,M
		6-11[d]	2000P	100	25	(b)	A,D,F,K,L,M
		6-12	36000T	80	15	(b)	A,D,G,K,M
	Transition	6-20[d]	820C	100	20	(b)	A,D,F,H,I,(J),K,M
		S6-20[a]	700C	100	20	(b)	A,D,F,H,I,(J),K,M
		6-21[d]	2000P	100	25	(b)	A,D,F,K,L,M
		6-22	36000T	80	15	(b)	A,D,G,K,M

Figure 8: Test matrix for longitudinal barriers

Recommended safety performance evaluation criteria for safety features are given in Table 5.1. which is shown in Figure 9. Three dynamic performance evaluation factors are given together with recommended evaluation criteria and applicable tests. The factors are (1) structural adequacy, (2) occupant risk, and (3) post-impact vehicular response.

TABLE 5.1. Safety evaluation guidelines

Evaluation Factors	Evaluation Criteria	Applicable Tests[a]
Structural Adequacy	A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	10, 11, 12, 20, 21, 22, 35, 36, 37, 38
	B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	60, 61, 70, 71, 80, 81
	C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	30, 31, 32, 33, 34, 39, 40, 41, 42, 43, 44, 50, 51, 52, 53

TABLE 5.1. ***(Continued)***

Evaluation Factors	Evaluation Criteria	Applicable Tests[a]
Occupant Risk	D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted. See discussion in Section 5.3 and Appendix E.	All
	E. Detached elements, fragments or other debris from the test article, or vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.	70, 71
	F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	All except those listed in Criterion G.
	G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	12, 22, 30[b], 31[b], 32[b], 33[b], 34[b], 35[b], 36[b], 37[b], 38[b], 39[b], 40[b], 41[b], 42[b], 43[b], 44[b]

	H. Occupant impact velocities (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following:			
	Occupant Impact Velocity Limits (m/s)			
	Component	Preferred	Maximum	
	Longitudinal and Lateral	9	12	10, 20, 30, 31, 32, 33, 34, 36, 40, 41, 42, 43, 50, 51, 52, 53, 80, 81
	Longitudinal	3	5	60, 61, 70, 71
	I. Occupant ridedown accelerations (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following:			
	Occupant Ridedown Acceleration Limits (G's)			
	Component	Preferred	Maximum	
	Longitudinal and Lateral	15	20	10, 20, 30, 31, 32, 33, 34, 36, 40, 41, 42, 43, 50, 51, 52, 53, 60, 61, 70, 71, 80, 81
	J. (Optional) Hybrid III dummy. Response should conform to evaluation criteria of Part 571.208, Title 49 of Code of Federal Regulation, Chapter V (10-1-88 Edition). See Section 5.3 for limitations of Hybrid III dummy.			10, 20, 30, 31, 32, 33, 34, 36, 40, 41, 42, 43, 50, 51, 52, 53, 60, 61, 70, 71, 80, 81

TABLE 5.1. ***(Continued)***

Evaluation Factors	Evaluation Criteria	Applicable Tests[a]
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	All
	L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec and the occupant ridedown acceleration in the longitudinal direction (see Appendix A, Section A5.3 for calculation procedure) should not exceed 20 G's.	11, 21, 35, 37, 38, 39
	M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	10, 11, 12, 20, 21, 22, 35, 36, 37, 38, 39
	N. Vehicle trajectory behind the test article is acceptable.	30, 31, 32, 33, 34, 39, 42, 43, 44, 60, 61, 70, 71, 80, 81

[a] Test numbers refer to last two digits in Test Designation for each Test Level unless otherwise noted.

Figure 9: Safety evaluation guidelines

The NCHRP 350 test was used from 1993 to 2009 when it was replaced by the American Association of State Highway and Transportation Officials, Manual for Assessing Safety Hardware 2009 (AASHTOMASH 2009)

B3.2 American Association of State Highway and Transportation Officials, Manual for Assessing Safety Hardware 2009 (AASHTOMASH 2009)

To evaluate new safety hardware devices, the AASHTO - MASH 2009 supersedes NCHRP Report 350. MASH was developed through NCHRP Project 22-14(02). It contains revised criteria for impact performance evaluation highway safety features. Updates include an increase in several test vehicles' size to match the current vehicle fleet better, changes to the test matrices' number and impact conditions, and more objective, quantitative evaluation criteria.

The major differences between NCHRP 350 and MASH can be summarised as follows (Transportation Research Board, 2013):

- *Test vehicles are updated to reflect the 85th percentile of the United States' passenger vehicle fleet.*
- *Impact condition criteria were modified to correct inconsistencies and to identify needed conditions.*
- *Evaluation criteria were modified to correct subjective criteria and to better define other criteria.*

<u>CHANGES IN TEST VEHICLES</u>

- The sizes and weights of test vehicles are increased to reflect the increase in US passenger vehicle fleet size:

– The 820C test vehicle is replaced by the 1100C;

– The 2000P test vehicle is replaced by the 2270P;

– The single-unit truck mass is increased from 8,000 to 9,000 kg; and

– The light truck test vehicle must have a minimum centre of gravity height of 71 cm (28 in.).

- The option for using passenger car test vehicles older than six years is removed.
- Truck box attachments on test vehicles are required to meet published guidelines.
- External vehicle crush must be documented using National Automotive Sampling System procedures.
- A new crushable nose needs to be developed for use on surrogate test vehicles.
- TMA designers are required to select maximum and minimum support truck weight ratings.

CHANGES IN EVALUATION CRITERIA

- Windshield damage evaluation uses quantitative, instead of qualitative criteria.
- Windshield damage criteria are applied to permanent support structures in addition to work zone traffic control devices.
- The occupant compartment damage evaluation uses quantitative, instead of qualitative, criteria.
- All evaluation criteria will be pass or fail, eliminating the "marginal pass."
- All longitudinal barrier tests are required to meet flail space criteria.
- Maximum roll and pitch angles are set at 75°.
- The subjective criteria for evaluating exit conditions are eliminated; reporting the exit box evaluation criterion is required.
- Documentation on vehicle rebound in crash cushion tests is required.

CHANGES IN TEST DOCUMENTATION

- Computer-assisted drafting drawings of the test device and test installation are required.
- Additional documentation of the test and evaluation results is required.

Quoted from Dresnez in the chapter MASH Compared to NCHRP 350, published in TRB Roadside Safety Design and Devices. International Workshop, 17 July 2012. Transportation Research Circular E-C172, Milan Italy (Transportation Research Board, 2013),

B3.3 EN1317 Road Restraint Systems

This European Standard has been prepared by the Technical Committee CEN/TC 226, Road equipment, the Secretariat held by AFNOR. This European Standard consists of the following parts under the general title Road restraint systems.

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

EN1317 Part 1 sets out the terms and definitions which are used in the EU. It clarifies the use of RRS versus Vehicle (VRS) and Pedestrian Restraint Systems (PRS) as shown in Figure 10.

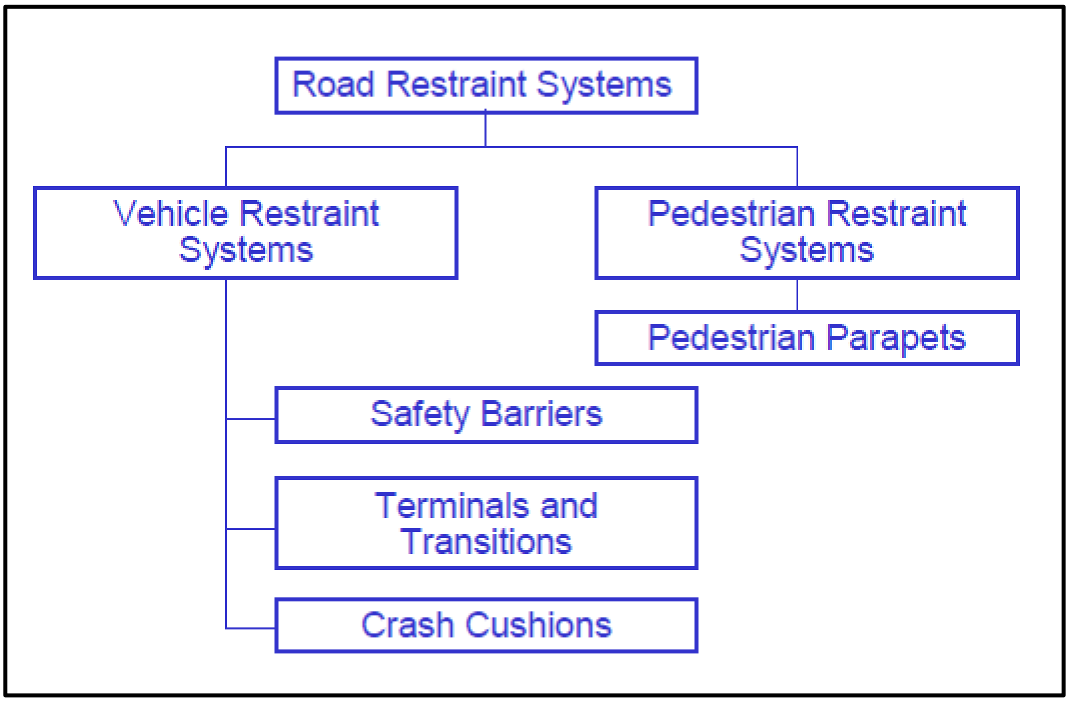


Figure 10: Classes of road restraint systems

The vehicle types and mass specifications differ from the USA (NCHRP 350 and MASH) as the typical light vehicles used in the EU are smaller and lighter, and the use of pickup trucks as personal passenger vehicles is limited. It remains to be seen if the world-wide shift to Sports Utility Vehicles (SUVs) will soon impact the EU road safety environment. See the following table marked Table 1 in Figure 11.

Table 1 — Vehicle specifications

Mass kg									
Vehicle mass (1)	825 ± 40	1 300 ±65	1 500 ±75	10 000 ± 300	13 000 ± 400	16 000 ± 500	30 000 ± 900	38 000 ± 1 100
Including maximum ballast (2)	100	160	180	—	—	—	—	—
Dummy	75	—	—	—	—	—	—	—
Total test mass	900 ± 40	1 300 ± 65	1 500 ± 75	10 000 ± 300	13 000 ± 400	16 000 ± 500	30 000 ± 900	38 000 ± 1 100
Dimensions m (limit deviation ±15%)								
Wheel track (front and rear)	1,35	1,40	1,50	2,00	2,00	2,00	2,00	2,00
Wheel radius (unloaded)	—	—	—	0,46	0,52	0,52	0,55	0,55
Wheel base (between extreme axles)	—	—	—	4,60	6,50	5,90	6,70	11,25
Number of axles	1S + 1 (3)	1S + 1	1S + 1	1S + 1	1S + 1	1S + 1/2	2S + 2	1S + 3/4
Ground clearance of the front bumper measured at the corner	—	—	—	0,58	—	0,58	0,58	0,58
Centre of gravity location m (limit deviation ±10%)								
Longitudinal distance (4) from front axle (CGX) ±10 %	0,90	1,10	1,24	2,70	3,80	3,10	4,14	6,20
Lateral distance from vehicle centre line (CGY)	±0,07	±0,07	±0,08	±0,10	±0,10	±0,10	±0,10	±0,10
Height above ground (CGZ):								
Vehicle mass (±10 %)	0,49	0,53	0,53	—	—	—	—	—
Load (+15 % −5 %)	—	—	—	1,50	1,40	1,60	1,90	1,90
Type of vehicle	Car	Car	Car	Rigid HGV	Bus	Rigid HGV	Rigid	Articulated HGV

(1) Including load for heavy goods vehicles (HGV).
(2) Including measuring and recording equipment.
(3) S: steering axle.
(4) Vehicle mass.

Figure 11: EN1317 vehicle specifications

The EN1317 uses ten levels of containment that is related to specific tests. These are listed in the following table shown in Figure 12.

Containment	Level	Tests
Low angle	T1 T2 T3	TB 21 TB 22 TB 41+ TB 21
Normal	N1 N2	TB31 TB 32 + TB 11
High	H1 H2 H3	TB 42 + TB 11 TB 51 + TB11 TB 61 + TB 11
Very high	H4a H4b	TB 71 + TB 11 TB 81 + TB 11

Figure 12: EN1317 containment levels

These tests are set out with the vehicle type and specifications in the following table shown as Figure 13.

Test	Type of vehicle	Mass (kg)	Speed (km/h)	Angle (°)
TB 11	Car	900	100	20
TB 21	Car	1300	80	8
TB 22	Car	1300	80	15
TB 31	Car	1500	80	20
TB 32	Car	1500	110	20
TB 41	Rigid truck	10 000	70	8
TB 42	Rigid truck	10 000	70	15
TB 51	Bus	13 000	70	20
TB 61	Rigid truck	16 000	80	20
TB 71	Rigid truck	30 000	65	20
TB 81	Articulated truck	30 000	65	20

Figure 13: EN1317 vehicle specifications

The kinetic energy involved in the test (as a function of speed and mass) linked to the traffic face deflection then indicates the average force acting in the test, as shown in the Figure 14 as Table B1.

Table B.1 — Containment levels

Containment level	Kinetic energy kJ	Traffic face deflection m					
		0,1	0,4	0,8	1,2	1,6	2,0
		Average force $\overline{F}$ kN					
T1	6,2	16,8	9,3	5,8	4,2	3,3	2,7
T2	21,5	36,5	24,2	16,7	12,7	10,3	8,6
T3	36,6	46,7	33,8	24,7	19,4	16,0	13,6
N1	43,3	59,2	42,0	30,3	23,7	19,4	16,5
N2	81,9	112,0	79,4	57,2	44,7	36,7	31,1
H1	126,6	93,6	76,6	61,7	51,6	44,4	38,9
H2	287,5	133,0	116,8	100,4	88,1	78,5	70,8
H3	462,1	266,4	227,1	189,8	163,0	142,9	127,1
H4a	572,0	311,3	267,6	225,4	194,7	171,4	153,1
H4b	724,6	269,1	242,1	213,6	191,1	172,8	157,8

Figure 14: EN1317 Containment levels with traffic face deflection

The other criteria relate to impact severity class in the range A to C, where the acceleration severity index ranges from 1 to 1.9. It is a requirement that the Theoretical Head Impact Velocity (THIV) be less than 33 km/h and the Post Impact Head Deceleration below 20g. This latter requirement may be taken away in future revisions of the EN1317. See the table in Figure 15.

Impact severity class	ASI		Other criteria
A	≤ 1,0	and	THIV ≤ 33 km/h PHD ≤ 20g
B	≤ 1,4		
C	≤ 1,9		

ASI = acceleration severity index
THIV = theoretical head impact velocity
PHD = post-impact head deceleration

Figure 15: EN1317 Impact severity class criteria

A significant performance indicator of longitudinal barrier performance is the working width which will determine where certain types and models of products can be used. The working width classes are shown in Figure 16 and the definition is illustrated in the Figure 17.

W classes	W
W1	≤ 0,6 m
W2	≤ 0,8 m
W3	≤ 1,0 m
W4	≤ 1,3 m
W5	≤ 1,7 m
W6	≤ 2,1 m
W7	≤ 2,5 m
W8	≤ 3,5 m

Figure 16: EN1317 Working width classes

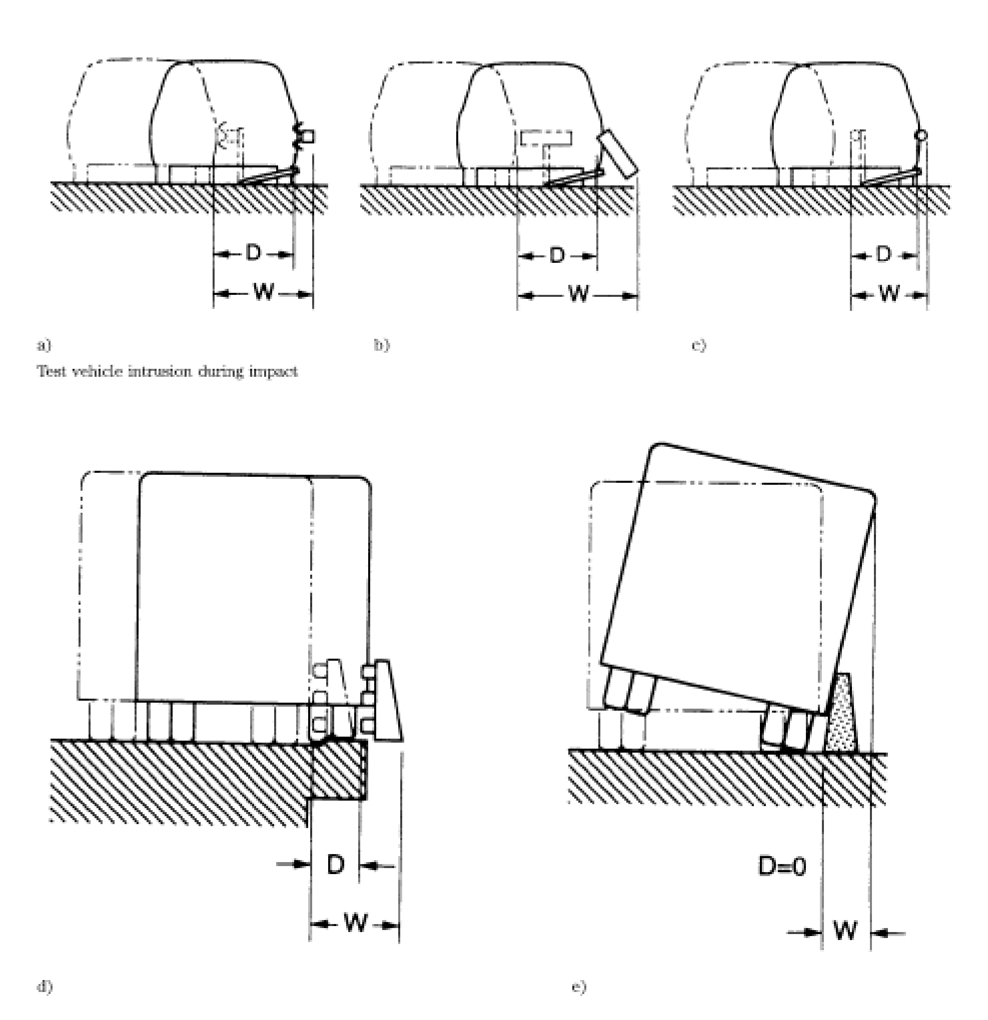


Figure 1 — Dynamic deflection (*D*) and working width (*W*)

Figure 17: EN1317 Dynamic deflection and working width

Other criteria that apply to testing are

- No ejection of parts
- No roll-over
- VCDI (Vehicle Cockpit Deformation Index)
- Exit trajectory (CEN box)

B3.4 Conclusions on RRS testing procedures.

Two dominant sets of RRS testing procedures developed, the first in the USA since testing started in the 1960s and the second in Europe in the 1980s in response to the different vehicle populations and road environments. The USA NCHRP 350 standard for testing published in 1993 remained in place until 2009 when research indicated that changes to vehicle specifications and other aspects were required. This lead to the MASH specifications. The first two parts of EN 1317 was published in 1998 and developed from the European Directive on Construction Products (CE marking) December 1988 CEN/ TC226/ WG1 Crash barriers, safety fences, guard rails and bridge parapets.

MARCO ANGHILERI (2012) in a paper on the Current Status of EN 1317 and US–Europe Test Result Mutual Recognition at the International Workshop, 17 July 2012. Transportation Research Circular E-C172, Milan Italy, came to the following conclusions:

1. EN 1317 and MASH are too different from being used as a single standard, but the technology to perform the tests, acquire data, and evaluate performances is the same.

2. EN TMA standard probably will accept NCHRP 350 or MASH tests. Will MASH accept EN 1317 European tests?

3. Test house accreditation is a passport to export results between the United States and Europe.

4. This passport could be accepted and tests performed in the United States, according to EN 1317 could also be accepted for CE markings.

Michael Dreznes, when he was an Executive of the International Road Federation in 2020, presented the IRF Road Safety Audit Team Leader accreditation course. Dreznes concludes the benefits of specifying a product with known performance, are more significant than being concerned about the specific test. In the real world, the variable's number is much more than what is tested, and the differences in the EN1317 versus MASH tests are less than the variance in parameters in real crashes.

B4 RRS academic research

Research can be divided into applied research and academic research. For example, applied research is the development of procedures, specifying and testing RRS at the Texas Transport Institute at Texas A&M University. This research is funded by federal and state road authorities grants that lead to NCHRP 350 and NCHRP 20-07 published by AASHTO as the MASH guideline. Academic research is where universities and students research aspects of RRS or analyse crash data to comment on, recommend or verify the use of RRS. These papers and theses vary widely in nature, content and focus. For this executive summary, some papers were selected to illustrate the usefulness of these research projects that result in conference papers and journal articles. The abstracts of the selected articles are presented below.

B4.1 Tso-Liang Teng, Cho-Chung Liang and Thanh-Tung Tran, 2015. Effect of various W-beam guardrail post spacings and rail heights on safety performance

Abstract: W-beam guardrails are the most widely used road safety barriers world-wide. They are used for protecting vehicle occupants on dangerous areas of roadways. All road safety barriers used on European highways are designed according to the European standard EN 1317. Conventionally, such road safety barriers have the following dimensions: a 750-mm height from the top of the W-beam to the ground and a 1.33-, 2-, or 4-m post spacing. This study applied the finite element code LS-DYNA for evaluating the safety performance of an AG04-2.0 A-type barrier, which was designed using three post spacings and various rail heights when impacted by a 900-kg small passenger car. Eight crash test simulations were conducted for evaluating the crashworthiness of the AG04-2.0 barrier, according to the European Standard EN 1317. A baseline model was developed and validated against the existing crash test models. The results showed that the various post spacings (1.33, 2, and 4 m) and rail heights (600, 650, 700, 750 and 800 mm) enabled the AG04-2.0 barrier to withstand the impact of the 900-kg car, satisfying the EN 1317 criteria (i.e. TB11 test). The 2000-mm post spacing and 700-mm rail height were considered the optimal dimensions for AG04-2.0 road safety barriers (Teng, Liang and Tran, 2015).

B4.2 Fernandez MA, Garcıa-Escudero LA, Molinero A (2019) Analysis of real crashes against metal roadside barriers

https://doi.org/10.1371/journal.pone.0211674.

Abstract: Metal Road Safety Barriers (MRSB) are one of the devices implemented in roadsides to mitigate the consequences of run-off crashes. In Europe, they have to meet the requirements of the European Standard EN-1317-2. This article analyses a set of run-off crashes against MRSB, for which an in-depth investigation has been performed, comparing them with the standard tests. It has been observed that in many of these real crashes, the barriers have not appropriately worked despite having passed these standard tests. This paper demonstrates which variables may be responsible for this to improve the current test standard through the analysis of new test variables. Multidimensional Scaling, a dimension reduction multivariate statistical technique, has been used to understand better how real crashes compare to standard tests, using several impact variables simultaneously. A statistical analysis has then been developed to show the influence of the "Relative orientation impact angle" on the performance of the MRSB. Most of the real crashes analysed are close to "TB11" and "TB32" standard tests. In many of these real crashes, the "Relative orientation impact angle" is very different from the "Impact angle", and in these situations, the vehicle is not safely redirected to the road concerning the so-called "Exit-Box". MRSB is not working correctly in some situations that are not far from the standard tests. To handle this, it could be interesting to include the "Relative orientation impact angle" as a control variable in new versions of the EN-1317-2 tests to guarantee the behaviour of the MRSB. These results can help to adapt some test variables from the EN-1317-2 to what is happening in crashes.

B4.3 Schmidt, JD, Rosenbaugh, SK, Bielenberg, RW, Faller, RK, Reid, JD and Schmidt, TL, 2016. MASH TL-4 Design and Evaluation of A Restorable Energy-Absorbing Concrete Barrier

Transportation Research Board 95th Annual Meeting. January 10-14, 2016. Washington, DC.

Abstract: A new, high-containment longitudinal barrier was designed to reduce the accelerations imparted to passenger vehicles during impacts and restorable and reusable. Elastomer support posts were designed to translate laterally and absorb energy when impacted and restore to their initial position after impact events. A hybrid concrete beam and steel tube combination rail was optimised to minimise weight, provide sufficient structural capacity, maintain a height to contain and redirect single-unit trucks, and prevent passenger vehicles from snagging on the posts. Three full-scale vehicle crash tests were conducted according to Manual for Assessing Safety Hardware (MASH) Test Level (TL-4) safety performance requirements on a 240-ft long barrier with a nominal height of 38⅝ in. In test SFH-1, a 5,021-lb pickup truck was redirected with minimal damage to the barrier. The peak lateral acceleration was reduced by 47% as compared to similar impacts on rigid barriers. In test SFH-2, a 2,406-lb small car was redirected by the barrier, and the peak lateral acceleration was reduced by 21% compared to similar impacts on rigid barriers. In test SFH-3, a 21,746-lb single-unit truck was successfully contained and redirected, resulting in only minor damage to the concrete rail. Therefore, the barrier met all MASH TL-4 safety performance criteria. Recommendations about the performance, future design refinements, and installation requirements of the barrier where provided.

B4.4 La Torre F, Erginbas C, Thomson R, Amato G, Pengal B, Stefan C, Hemmings G. 2016. Selection of the most appropriate roadside vehicle restraint system – the SAVeRS project

Transportation Research Procedia 14 (2016) 4237 – 4246.

Abstract: Run Off Road (ROR) crashes are road accidents that often result in severe injuries or fatalities. To reduce the severity of ROR crashes, "forgiving roadsides" need to be designed and this includes identifying situations where there is a need for a Vehicle Restraint System (VRS) and what appropriate VRS should be selected for a specific location and traffic condition. Whilst there are standards covering testing, evaluation and classification of VRS within Europe (EN1317 parts 1 to 8), their selection, location and

installation requirements are typically 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. The European SAVeRS project, funded within the 2012 CEDR Transnational Research Programme "Safety", has developed a practical and readily understandable VRS guidance document and a user-friendly software tool which allow designers and road administrations to select the most appropriate solution in different road and traffic conditions. This paper describes the project's primary outcomes, the process to select the most appropriate roadside barrier, and the user-friendly SAVeRS tool.

B4.5 National Academies of Sciences, Engineering, and Medicine 2019. Performance of Longitudinal Barriers on Curved, Superelevated Roadway Sections

Washington, DC: The National Academies Press. https://doi.org/10.17226/25290. NCHRP RESEARCH REPORT 894.

Abstract: NCHRP Project 22-29, "Performance of Longitudinal Barriers on Curved, Superelevated Roadway Sections," and Project 22-29A, "Evaluating the Performance of Longitudinal Barriers on Curved, Superelevated Roadway Sections," were initiated to develop a better understanding of the safety performance (i.e., crashworthiness) for barriers used on curved, superelevated roadway sections (CSRS) and to suggest options and guidance for improving barrier selection, design, and deployment in pursuit of enhanced highway safety. CSRS is most commonly found on major interstate-type highways, and they exist on both tight and gentle curves (see Figure 1). The most critical CSRS situations occur on the tight curves associated with interchanges. This research involved a four-phase effort to systematically and comprehensively consider safety for varying CSRS situations. The research (1) reviewed the practices and available knowledge of barriers on curves and their safety performance; (2) analysed issues associated with vehicle-to-barrier interfaces; (3) simulated crashes with various types of barriers for varying curvature, shoulder configurations, and superelevation conditions; and (4) conducted crash tests to confirm the simulation results. The project resulted in the development of proposed enhancements to barrier design, selection, and deployment for varying CSRS situations.

B4.6 Gates TJ, Noyce DA, and Stine PH, 2005. The Safety and Cost-Effectiveness of Approach Guardrail for Bridges on Low Volume Roads. TRB

Abstract: Bridge approach guardrail is a commonly used safety feature designed to prevent collision with bridge components, such as the blunt end of the bridge rail, and other types of a run-off-the-road crash occurring on the bridge approach. This research's primary objective was to determine the ADT threshold at which installation of bridge approach guardrail on low volume roads, such as county roads and secondary state highways, is cost-effective based on reductions in crash severity. A survey of US state transportation agencies found that 26 of 35 responding agencies have policies or guidelines requiring placement of approach guardrail on all state-funded bridges, regardless of Average Daily Traffic (ADT) or roadway classification. Other states require a bridge approach guardrail on state-funded local facilities only if a specified ADT threshold is exceeded. The authors used logistic regression and chi-square tests to analyse the characteristics of 96 run-off-the-road crashes that occurred on the approach or departure to 68county state-aid highway bridges in 10 Minnesota counties over 15 years. Crashes that occurred at bridges with approach guardrail were found to be much less severe than crashes that occurred at bridges where no guardrail was present. None of the 33 crashes with approach guardrail resulted in fatalities or severe injuries, while roughly one-quarter of the 63 crashes with the roadside or bridge rail end resulted in fatalities or severe injuries. Crashes with the approach guardrail were much more likely to result in no injury than crashes with the roadside or bridge rail end. The subsequent benefit/cost analysis showed that overall, bridge approach guardrail has a benefit/cost ratio of 3.12 to 4.35 and is cost-effective (i.e., benefit/cost > 1) at ADTs greater than or equal to 400. Based on the benefit/cost analysis, the authors recommended that the ADT threshold for installation of bridge approach guardrail on low volume roads be set at 400, consistent with current AASHTO very low-volume local road guidelines for roadside clear zones.

B4.7 Budzynski M, Wilde K, Jamroz K, Chroscielewski J, Witkowski W, Burzynski S, Bruski D, Jelenski L and Pachocki L. 2019. Effects of vehicle restraint systems on road safety

MATEC Web of Conferences 262, 05003 (2019).

Abstract: To identify the hazards and sources of hazards cause by wrong or improper use of road safety devices and identify errors in design, structure, construction and operation of safety devices.

B4.8 Budzynski M, Jamroz K, Wilde K, Witkowski W, , Jelenski L and Bruski D. 2020. The role of numerical tests in assessing road restraint system functionality

Budzynski et al. European Transport Research Review (2020) 12:30 https://doi.org/10.1186/s12544-020-00424-8

Abstract: Key to understanding the needs and building road infrastructure management tools to prevent and mitigate run-off-road accidents is to identify hazards and their sources which are a result of wrong design, construction, and installation of road restraint systems. Building such tools requires advanced studies with field tests, simulations and models to demonstrate the effects of selected parameters on road user safety. The research work included numerical building models which were validated with crash tests and mathematical models to assess the effects of selected parameters on the safety and functionality of devices. Twenty-five field tests were the basis for conducting 670 numerical tests. Preliminary results of numerical tests are also presented looking at selected problems such as barriers on curves, presence of kerbs and obstacles within barrier working width. The methodology will help with an optimal selection of parameters leading to improved safety as regards errant vehicles.

B4.9 Budzynski M, Gobis A, Jamroz K, Jelinski L, and Ostrowski K. 2019. Road Restraint Systems as a Basis for Roadside Safety Improvement

IOP Conf. Series: Materials Science and Engineering 471 (2019) 062029 IOP Publishing doi:10.1088/1757-899X/471/6/062029

Abstract. Roadside-related crashes occur when vehicles run off the road. The majority of the crashes have severe outcomes, especially when an object is hit (tree, pole, supports, front wall of a culvert, barrier). These accidents represent app. 19% of all of Poland's road deaths. Roadside crashes involve: hitting a tree, hitting a barrier, hitting a sign or utility pole, vehicle roll-over on the roadside, vehicle roll-over on a slope and vehicle roll-over into a ditch. Understanding the effects of roadside factors on road safety requires in-depth research. The problem was partly addressed at the WMCAUS conference in 2017 [1]. Key to understanding road infrastructure management's needs and tools for preventing run-off-road crashes or minimising their consequences is to identify the hazards and sources of hazards caused by wrong or improper use of road safety devices. It is also important to identify errors in road safety devices' design, structure, construction, and operation. Studying such an extended scope of the problem required fieldwork. Site tests had to be conducted such as hitting a wire rope barrier and a steel barrier on a curve (test TB32), light and heavy vehicles hitting a bridge parapet (tests TB11 and TB51), hitting a transition between a steel and wire rope barrier (TB32) and crashes into a lighting column placed within the barrier's working width. Besides, the project includes numerical tests validated based on-site tests. This helps to assess the behaviour of road restraint systems when selected parameters are changed. The work is part of the RID Programme (Development of Road Innovation) and the RoSE project (Road Safety Equipment). In the article, the authors present the effects of building a road restraint system database for a selected test site (about 3,000 km of Poland's national roads). An outline of new road restraint system guidelines could only be developed after understanding the effects of restraint systems, the design, additional elements, type of road and safety barrier location on a road or engineering structure and the road and traffic conditions on their functionality and safety. The paper will present the preliminary results of this research. Once complete, the research will offer tools to help with the implementation of road restraint systems. The tools will ensure that road infrastructure is safer and that the most common mistakes are eliminated.

B4.10 Jamaa HH, Grzebietaa RH, Friswella R, and Andrew S. McIntosh A S, 2010. Characteristics of fatal motorcycle crashes into roadside safety barriers in Australia and New Zealand

Accident Analysis and Prevention 43 (2011) 652–660

This paper reports on the findings of a retrospective case series study of fatal motorcyclist–roadside barrier collisions. Cases were retrieved from the National Coroners Information System (NCIS), the coronial case files of Australian jurisdictions, and the Crash Analysis System (CAS) of the New Zealand Transport Agency. Seventy seven (77) motorcycle fatalities involving a roadside barrier in Australia and New Zealand were examined. The fatalities usually involved a single-vehicle crash and young men. The roadside barriers predominantly involved were steel W-beams, typically on a bend in the road's horizontal alignment. A majority of fatalities occurred on the weekend, during daylight hours, on clear days with dry road surface conditions indicating predominantly recreational riding. Speeding and driving with a blood-alcohol level higher than the legal limit contributed to a significant number of these fatalities.

B4.11 Hagighi and others, 2018. Impact of roadway geometric features on crash severity on rural two-lane highways (Haghighi *et al.*, 2018)

The authors developed a regression model to predict the impact of geometric road features on crash severity. The conclusions from the modelling confirmed that the known elements that impact on roadside crashes such as curve radius and clear zone have the most significant influence.

B4.12 Claude C and Lyon N. 2015. Vehicle restraint system crash test modelling – Application to steel-wood structures

This paper looked at composite barriers of steel attached to wood structure other than posts. (Claude and Lyon, 2015)

B4.13 Georgiades and Mouskos, 2020. Black spots identification through a Bayesian Networks quantification of accident risk index

(Gregoriades and Mouskos, 2020)

The improvement of methods for identification of black spots remains a favourite subject for academics and the latest research links this to risk index. The data used in calibrating the models highlight the risk index of curves and narrow clear zones and confirms the role of RRS in the treatment of high-risk locations.

B4.15 Abraham, N., Ghosh, B., Simms, C., Thomson, R., & Amato, G. (2016). Assessment of the impact speed and angle conditions for the EN1317 barrier tests

International Journal of Crashworthiness. https://doi.org/10.1080/13588265.2016.1164444

Abstract

Roadside safety barriers designs are tested with passenger cars in Europe using standard EN1317 in which the impact angle for normal, high and very high containment level tests is 20°. In comparison to EN1317, the US standard MASH has higher impact angles for cars and pickups (25°) and different vehicle masses. Studies in Europe (RISER) and the US have shown values for the 90th percentile impact angle of 30-34°. Thus the limited evidence available suggests that the 20° angle applied in EN 1317 may be too low.

The first goal of this paper is to use the US NCHRP database (Project NCHRP 17-22) to assess the distribution of impact angle and collision speed in recent ROR accidents. Secondly, based on the statistical analysis findings and analysis of impact angles and speeds in the literature, and LS-DYNA Finite Element analysis was carried out to evaluate the normal containment level of concrete barriers in non-standard collisions. The FE model was validated against a crash test of a portable concrete barrier carried out at the UK Transport Research Laboratory (TRL).

The accident data analysis for run-off-road accidents indicates that a substantial proportion of accidents have an impact angle in excess of 20°. The baseline LS-DYNA model showed a good comparison with experimental Acceleration Severity Index (ASI) data, and the parametric analysis indicates a very significant influence of impact angle on ASI. Accordingly, a review of European run-off-road accidents and the configuration of EN 1317 should be performed.

B4.14 Lynam and Kennedy, 2005. The travel of errant vehicles after leaving the carriageway. TRL

The TRL researchers Lynam and Kennedy undertook a Safety and Information Division project, Highways Agency, using an extensive database in the UK. They determined the risk of running off the road and developed software Roadside and RSAP (Lynam and Kennedy, 2005).

B4.15 Conclusions on academic and research articles

Research into barrier systems was mostly focussed on application and verification of designs in experimental settings. There is also a body of research into numerical and finite element modelling of vehicles' interaction with the barriers to model more variables than is possible in physical experimental settings at a very high cost of infrastructure and vehicles. The more recent research such as in Poland (Budzynski and others) looks at the effects of RRS on safety to improve application guidelines. The calibration of finite element analysis and models of interaction between vehicles and RRS, as well as the criteria for the acceleration of the crash test dummy variables, makes it easy to extend the range of test parameters such as the angle of approach, the height of barriers, stiffness etc., that increases the knowledge of crash performance and forensic examination of crashes. This eliminates costly experimental tests with real vehicles and barriers.

B5 Hazardous location manuals

Manuals for the identification and treatment of hazardous locations on the road have been developed over decades. Earlier versions were paper-based and guided how to collate and present data. The management of Haz-Loc became software-driven with the development of analysis software and integration with Graphic Information Systems (GIS). The value of such hazardous location manuals in this project is to determine how such a manual or software identifies run-off-road and hit object crashes for which the proposed solutions could include RRS. The following is a selection of the available literature. The contents tend to be similar, and not all the sources are described in detail.

- The South African Road Safety Manual, 1999. Volume 5 Remedial measures and evaluation. Volume 5 provides guidelines for accident investigation and road-engineering elements that can be modified or implemented to reduce the number and severity of accidents. The economic benefit and evaluation of the remedial measures form an essential part of the document.
- Transportation Research Board (TRB) (2009) Highway Safety Manual, First edition. Transportation Research Board, 500 Fifth St. NW, Washington, DC. The Highway Safety Manual 2010 was developed (Hughes *et al.*, 2004) to provide the framework and processes to assess networks, sections and locations by developing prediction models (Safety Prediction Functions (SPF)) and crash modification factors (CMF).
- The Road Safety Toolkit (http://www.toolkit.irap.org/default.asp) provides free information on the causes and prevention of road crashes that cause death and injury. Building on decades of road safety research, the Toolkit helps engineers, planners and policymakers develop safety plans for car occupants, motorcyclists, pedestrians, bicyclists, heavy vehicle occupants and public transport users. The Road Safety Toolkit resulted from the collaboration between the International Road Assessment Programme (iRAP), the Global Transport Knowledge Partnership (gTKP) and the World Bank Global Road Safety Facility. ARRB Group provided expert advice during the Toolkit's development.
- Austroads 2015. Guide to Road Safety Part 8: Treatment of Crash Locations. This manual contains practical, hands-on advice to help practitioners in road agencies investigate and treat locations on the road system experiencing crashes. By effectively treating these locations, the number and severity of crashes can be reduced through effective engineering solutions. The treatment of crash locations and the process of road safety audit involve applying road safety engineering knowledge

and experience to make roads safer – one after crashes occur and the other beforehand. Treatment of Crash Locations explains the step-by-step process of identifying crash locations, diagnosing the crash problem and its causes, selecting a countermeasure that targets the problem, designing a safe remedial treatment, and establishing its cost-effectiveness. The guide also provides information on road crash data sources and how engineering improvements fit into an overall road safety strategy. Treatment of Crash Locations complements the Austroads Guide to Road Safety Part 6: Road Safety Audit, and Part 7: Road Network Crash Risk Assessment and Management.

- Other manuals and handbooks:
  - Tasmania Department of Infrastructure, Energy and Resources, s.n. Road Hazard Management Guide, ARRB Transport Research.
  - Elvik, R., Høye, A., Vaa, T., and Sørensen, M. (2009) *The Handbook of Road Safety Measures*, Second edition, Emerald Group Publishing Limited, Howard House, Wagon Lane, Bingley BD16 1WA, UK.
  - Elvik, R. (2008) Comparative analysis of techniques for identifying locations of hazardous roads. *Transportation Research Record*, No. 2083, Transportation Research Board of the National Academies, Washington, DC.
  - Elvik, R, Sørensen, M, 20058 Black Spot Management and Safety Analysis of Road Networks – Best practice Guidelines and Implementation Steps. Ripcord.
  - Land Transport New Zealand (LTNZ) (2004) *A New Zealand Guide to The Treatment of Crash Locations*. Land Transport New Zealand 2004, ISBN 0–478–24199–2.
  - Kentucky Transportation Center, College of Engineering, 2015. Development of procedures for Identifying High-Crash Locations and Prioritising Safety Improvements.

B6 Road safety assessment, appraisal and audit manuals

Manuals on road safety assessment (network-wide investigations), appraisals (existing road investigations) and audits (new or rehabilitation projects) do not give direct input into the investigation, design and implementation decisions on RRS. However, they provide a frame of reference on how road safety hazards are identified, analysed, and remedial measures proposed. The following is a selection of current manuals.

- RTMC, 2012. South African Road Safety Audit Manual 2012.
- Austroads 2015. Guide to Road Safety Part 6: Managing Road Safety Audits.
- Austroads 2015. Guide to Road Safety Part 6A: Implementation of Road Safety Audits. I
- Asian Development Bank, 2003. Road Safety Audit for Projects - An Operational Toolkit. Manila: Asian Development Bank.
- African Development Bank. 2014. Road Safety Manuals for Africa: New Roads and Schemes: Road Safety Audit
- African Development Bank. 2014. Road Safety Manuals for Africa: Existing Roads: Proactive Approaches
- African Development Bank. 2014. Road Safety Manuals for Africa: Existing Roads: Reactive Approaches

C: ANALYSIS OF PERTINENT THEMES

The following themes are discussed:

1. Anti-glare screens
2. Breakaway supports
3. Crash cushions
4. Crash modification factors CMFs
5. Data collection, inventory and deficiency register
6. Design Guide
7. Fixed object and roadside furniture
8. Flexible barriers
9. Hazardous locations
10. Legal issues
11. Longitudinal barriers
12. Low volume roads
13. Motorcycles and rails
14. Parapets and bridge balustrades
15. Pedestrian rails
16. Rigid barriers
17. Risk assessment
18. Semi-flexible barriers
19. Side slopes
20. Standards
21. Terminals and transitions
22. Terminology
23. Tests, procedures, protection classes
24. Training
25. Vehicle Arrestor beds
26. Warrants

C1 Anti-glare screens

Anti-glare screens are most relevant on median islands where high vehicle volumes justify the cost. In South Africa, most freeways are designed with wide earth medians, and vegetation was used as an anti-glare measure. As urban freeways were widened to the inside, concrete barriers were used to separate the carriageways, and these barriers up to one meter high are adequate. This is not always true in vertical sag curves. Anti-glare screens were erected on some freeways with a dual purpose of preventing pedestrians from crossing the freeways, but vandalism is a problem. In South Africa, there was an unfortunate decision taken to allow toll roads on the N1 (Kroonstad Vaal section) and N3 (Heidelberg Warden) to develop these Class 1 roads as a single carriageway, high-speed four-lane roads. Glare is an excellent problem there, and the accident rates on these sections are significantly higher than on freeways.

Research in anti-glare screens was undertaken as long ago as 1965 by Michigan State Highways (Hewitt and Nunn, 1965). Of interest is that the AASHTO design guide for roadside safety does not mention anti-glare screens.

In 2011, TRB Geometric Design Committee (AFB10) drafted research needs statement to complete an updated synthesis of the practice to the 1979 Glare Screen Guidelines, Synthesis of Highway Practice. This study completes the efforts of the 2011 research needs statement on glare screens and their use in road design. The research identifies the uses and types of glare screen in road design, examines national-level glare screen guidance, and summarises the findings from 30 transportation agencies in the United States. Glare Screen Use in Road Design: A Synthesis of the Practice (Johnson and Mcdonald, 2019). Recent research focuses on height and economic value of anti-glare screes in sag curves (Bagui and Ghosh, 2012).

C2 Breakaway support

Breakaway support is the subject of the SARSM 1999 Volume 2 Part A. Signs are necessary to provide information (regulatory, warning, guidance and direction) to drivers. The poles and posts to mount them on are essential roadside furniture. Wooden poles are mostly used in South Africa. Wooden poles may seem to be less hazardous than steel, but this is only true for small diameter poles. The practice in South Africa to drill two large diameter (50 mm) holes near the pole base to facilitate breaking seems to have been forgotten. High mast lighting, large gantry signs and billboard signs have strong steel columns, and these should be protected utilising barriers or crash cushions.

"The term breakaway support refers to all types of sign, luminaire, and traffic signal supports that are safely displaced under vehicle impact, whether the release mechanism is a slip plane, plastic hinges, fracture elements, or a combination of these."

Breakaway support, in contrast to a rigid support that forms a fixed object that can be hit when running off the road, yields on impact and reduces the deceleration of the vehicle and its occupants. Therefore, the use of breakaway support for all sign, luminaire and traffic signal supports aims to reduce the severity of accidents.

C3 Crash Cushions

Crash cushions can be re-directive or non-directive. Crash cushions are routinely provided at toll booth islands and can be provided at bridge piers, billboard columns, the start of concrete barrier RRS and primary fixed objects in the clear zones. The tests can be head-on or from different angles and offsets.

The test matrix below comes from EN1317 Road Restraint Systems Part 1.

Table 1 - Vehicle impact test criteria for crash cushions

Test[1]	Approach	Total vehicle mass kg	Velocity km/h	Figure 1 Test N°
TC 1.1.50	Head-on centre	900	50	1
TC 1.1.80		900	80	
TC 1.1.100		900	100	
TC 1.2.80		1 300	80	1
TC 1.2.100			100	
TC 1.3.110		1 500	110	1
TC 2.1.80	Head-on, ¼ vehicle offset	900[2]	80	2
TC 2.1.100			100	
TC 3.2.80	Nose (centre), at 15°	1 300	80	3
TC 3.2.100		1 300	100	
TC 3.3.110		1 500	110	
TC 4.2.50	Side impact at 15°	1 300	50	4
TC 4.2.80		1 300	80	
TC 4.2.100		1 300	100	
TC 4.3.110		1 500	110	
TC 5.2.80	Side impact at 165°	1 300	80	5
TC 5.2.100		1 300	100	
TC 5.3.110		1 500	110	

[1] Test notation is as follows:

TC	**1**	**2**	**80**
Test of crash cushion	Approach	Test vehicle mass	Impact speed

[2] For this test condition, the dummy is to be located at the more distant location from the centre line of crash cushion.

NOTE 1 Vehicle specifications and tolerances are specified in EN 1317-1.

NOTE 2 Test 5 will not be run for a crash cushion of non-parallel form when, at the relevant impact point, the angle (α) of the vehicle path to the traffic face of the crash cushion is less than 5°.

: EN1317 Vehicle impact test criteria for crash cushions

C4 Crash modification factors CMFs

Definition: A crash modification factor (CMF) measures the safety effectiveness of a particular treatment or design element. The concept of Safety Prediction Function (SPF) and CMF developed over time and was consolidated in the AASHTO Highway Safety Manual 2010 (Ray *et al.*, 2010). Application CMFs are applied to the estimated crashes without treatment to compute the estimated crashes with treatment, as shown by the following equation:

Estimated Crashes WITH Treatment = CMF*Estimated Crashes WITHOUT Treatment

A CMF less than 1.0 indicates that treatment has the potential to reduce crashes. Example: A CMF for total crashes for installing centerline rumble strips on rural major collector roads has been estimated to be 0.86 (1). This CMF indicates that the frequency of total crashes with the treatment is estimated to be 86% of the estimated crash frequency without the treatment. In other words, the CMF indicates that there will be a 14% reduction in total estimated crash frequency.

CMFs for RRS applications to illustrate: (iRAP Toolkit)

- Roadside Barriers: Medium cost, treatment life 10 to 20 year, effectiveness 40 to 60%, CMF = 0.6 to 0.4) http://www.toolkit.irap.org/default.asp?page=treatment&id=28
- Median Barriers: Medium to high cost, treatment life 10 to 20 year, effectiveness 60% or more, CMF = 0.4 or less. http://www.toolkit.irap.org/default.asp?page=treatment&id=13
- Hazard removal: Low to medium cost, treatment life 5 to 10 years. Effectiveness 25 to 40%, CMF = 0.75 to 0.6. http://www.toolkit.irap.org/default.asp?page=treatment&id=29

References:

American Association of State Highway and Transportation Officials (AASHTO). Highway Safety Manual, 1st Edition, Washington, DC, 2010. 4.

Crash Modification Factors (CMF) Clearinghouse. Federal Highway Administration. Available online at: www.cmfclearinghouse.org (Federal Highway Administration, no date)

IRAP Road Safety Toolkit. www.toolkit.irap.org (Federation, no date)

C5 Data collection, inventory and deficiency (exception) register

The quality, timeliness and completeness of South African Accident data have been a bone of contention among traffic authorities, the South African Police Services and RTMC on the one side as responsible for collecting and processing data, and researchers and engineers on the other side. The only data that seems reliable are fatalities on the day of the accident, as the SAPS must report these fatalities directly to the RTMC as a quick response system. The international definition of a fatality is within 30 days of the accident, but the SAPS does not follow up on severe crashes unless there is a case of culpable homicide or reckless driving. Calibration with the National Injury Mortality Surveillance System (NIMSS) (a unit under the South African Medical Research Council (MRC)) is often proposed to augment the fatality data. However, the NIMSS data is challenging to obtain due to confidentiality and lack of cooperation. Its published information is outdated: its website displays as most recent reports two provincial reports of 2011(Gauteng and Mpumalanga). Good data is available from the Metropolitan Municipalities of Cape Town and Ethekwini (Durban) and Western Cape Province, SANRAL has a good database on the national roads system.

Not only is the poor quality of the data problematic: the detail to which data is captured is often insufficient to determine where the accidents happened. To properly investigate roadside accidents, such as run-off-the-road or hit-a-fixed-object types, the distance reference must be accurate.

SARSM 1999. Volume 5: Remedial Measures and Evaluation. Colto.

The accident data analysis enables the professional to identify the target accident type and severity, i.e. the accident type or severity that can effectively be reduced by a specific remedial measure.

The study of a specific site/ route should focus on the identification of a target accident type which is dominant. Not only can the target accident type be used to identify the appropriate remedial measure(s) or alternative(s), but it can also be utilised effectively as an indication of future accidents that will occur at the site/ en route if an effective remedial measure is not implemented.

In addition to the identification of a target accident type, the following analysis can also assist the professional in identifying an appropriate remedial measure (African Development Bank, 2014):

- Lighting condition: Day/ night/ twilight etc. to identify potential visibility problems
- Road condition: Wet/ dry to identify possible skidding or drainage problems
- Time of accident: AM peak, PM peak, off-peak etc. to identify particular problems with specific traffic movements
- Day of week: Weekdays, Saturday, and Sunday, to identify potential problems with specific road user groups such as Saturday night partygoers.

Importance of Data

Crash data are essential for:

- Assessing and communicating the scale of the road crash problem, and making a case for increased investment in road safety
- Identifying the most important road safety issues that need to be tackled as a priority
- Making a business case for road safety engineering treatments at a location, route or area
- Targeting treatments at the 'real' issues
- Monitoring road safety performance
- Evaluating the impact of individual measures, whole schemes and strategies
- Determining what works and what does not work.

A variety of crash data sources is used to support the development and monitoring of road safety programmes internationally. The quality of crash data and other sources such as medical information on road casualties tend to be poor, especially in LMICs. The poor quality and availability of the range of crash and injury data in many countries remains a major impediment to obtaining significant and measured improvements in Africa's road safety levels - and across the world.

In Highways England. GG 101, 'Introduction to the Design Manual for Roads and Bridges', the concept of a design strategy record is introduced. It is more than just an accident data system or a design exception record (Highways England, 2020).

Design strategy record

- E/2.4 When applying this document's requirements, a design strategy record (DSR) shall be developed as part of the design process.
- E/2.5 The DSR shall be updated and maintained during each HE PCF [Ref 14.N] stage.
- E/2.6 The DSR shall record key design decisions, constraints and assessments, in support of using the relaxations within this document or cross-referenced documents.
- E/2.7 The DSR shall be used to record:

1) a causal analysis of the local collision history to identify any performance issues or trends, comprising the most recently available 36 months of collision data;

2) all safety control review group (SCRG) acceptance and rejections;

3) the strategy for determining traffic flows to be used in the design (including data source and design year);

4) all items to be recorded as required in this document;

5) the decisions made with regards to the design and its associated specification for high quality primary resources;

6) the decisions made with regards to the design and its re-use of material generated within the scheme works;

7) the decisions made with regards to the design and the sourcing of secondary materials from other public-sector projects;

8) the contribution that schemes are seeking to make against the Overseeing Organisation's performance measures;

9) the steps are taken to comply with GD 304 [Ref 3.N] and Raising the Bar 26 RtB 26 [Ref 7.I].

C6 Design Guides

See section B1 for descriptions of the pertinent manuals.

Most of the design manuals converge on the following steps to design a safe road environment. The following diagram comes from the SARSM Vol 6 (Committee for Land Transport, 1999), shown as Figure 18.

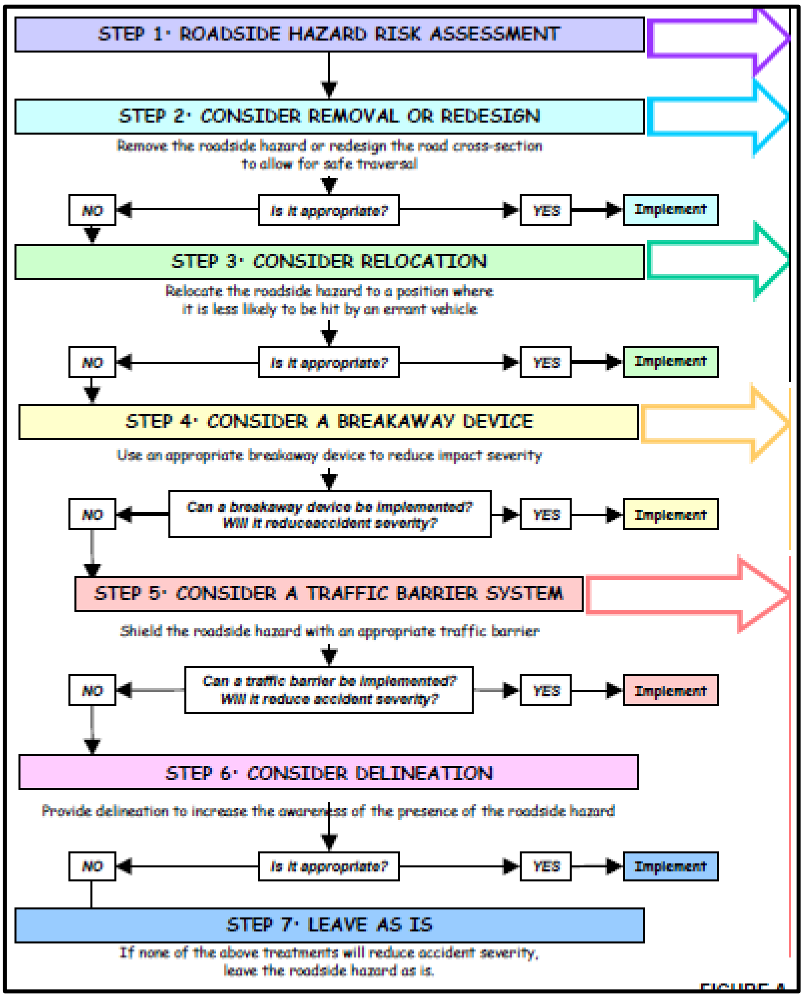


Figure 18: Steps in road hazards assessment

These steps can be viewed against the more generic systems safety design of the US Department of Defence (Department of Defence, 2000):

''System safety design order of precedence: The ultimate goal of a system safety program is to design systems that contain no hazards. However, since the nature of most complex systems makes it impossible or impractical to design them completely hazard free, a successful system safety program often provides a system design where there exist no hazards resulting in an unacceptable level of mishap risk. As hazard analyses are performed, hazards will be identified that will require resolution. The system safety design order of precedence defines the order to be followed for satisfying system safety requirements and reducing risks. The alternatives for eliminating the specific hazard or controlling its associated risk are evaluated so that an acceptable method for mishap risk reduction can be agreed to''.

C7 Fixed objects and roadside furniture

In general, the Roadside Design Manuals subscribe to the same priority for dealing with identified roadside hazards:

- *remove the hazard;*
- *redesign the hazard so that it can be safely traversed or contacted;*
- *relocate the hazard to reduce the probability of it being traversed or contacted;*
- *reduce the severity of the hazard;*
- *shield the hazard; and*
- *delineate and increase the driver's awareness of the hazard when other mitigation measures cannot be made to work.*

AASHTO recommends the following guidelines for context sensitive roadside design:

• Avoid establishing unrealistically low target and design speeds;

• Apply a consistent roadside treatment approach for any given project;

• Avoid establishing an arbitrary clear-zone width;

• Remove or relocate signs, utility poles and other fixed objects to improve safety and aesthetics; and

• Encourage safe landscaping that, even when mature, maintains proper sight triangles and stays beyond desired clear-zones.

C8 Flexible barriers

SARSM 1996 Vol 6 Part C

Longitudinal cable (also called wire rope) barriers are the most used flexible barriers. When a vehicle impacts a cable system, tension develops in the cable. After sufficient tension has developed, the vehicle is redirected.

At impact, the "cables wrap around the bumper and front fender of the vehicle. Lateral resistance is developed as the cables, which are restrained by end anchors, are deflected. As they deflect and stretch, large tensile forces develop in the cables, and lateral components of those tensile forces redirect the vehicle''.

C9 Hazardous locations

See also: B4 for list of manuals on identifying, analysis and treatment of hazardous locations.

C4 for data collection.

In the SARSM 1999 Vol 5 Remedial measures and evaluation, the criteria for the selection of remedial measures are as follows:

The remedial measure should be:

- *Technically feasible, i.e. providing a technology-based solution*

- *Economically efficient, i.e. cost-effective (having a benefit-cost ratio (BCR) exceeding one)*
- *Appropriate, being able to be implemented within the current budget (if not, an interim alternative or longer-term implementation programme is necessary)*
- *Acceptable, targeting the identified accident type and severity*
- *Practical, ensuring that the solution does not rely too heavily on excessive levels of enforcement.*
- *Acceptable politically and institutionally, ensuring that the measure will be supported by management or the body responsible for the construction and maintenance thereof*
- *Legal, conforming to the laws of the country*
- *Compatible with strategies used at similar sites*
- *Selected based on the target accident type.*

The following lists give typical hazards associated with roadside encroachments. Guide to Road Safety Part 8: Treatment of Crash Locations lists under section 1.9.2 Description of Significant Hazards (Austroads, 2015):

The risk evaluation process, described in Appendix B, uses a 'Trauma Index' to define collisions' likely outcome with hazards. Collisions with hazards with a higher Trauma Index are more severe. Significant hazards for the purpose of evaluating the NRRIT have a Trauma Index of approximately six and higher and include:

- *tree-lined edges*
- *isolated trees*
- *utility poles (excluding slip base poles and energy-absorbing poles)*
- *fixed base lighting columns*
- *traffic signal poles*
- *rocks protruding more than 300 mm above the ground surface*
- *ruts in the ground surface more than 300 mm deep*
- *rock cuttings*
- *2:1 fill batters more than 5 m high*

- *1.5:1 fill batters more than 2 m high*
- *vertical drops of more than 2 m*
- *watercourses more than 2 m deep*
- *down slopes, parallel to the road, higher than 5 m and with a slope of 4:1 or steeper*
- *down slopes, parallel to the road, between than 2 m and 5 m high and with a slope of 2:1 or steeper*
- *up slopes, parallel to the road, 1.5:1 or steeper significant drainage structures, exposed culvert headwall and wing walls, with vertical height drops of more than 2 m or a watercourse more than 2 m deep.*

The SARSM 1999 Vol 6 Roadside Hazard Management Part A, lists reasons for accidents that can be considered risk factors:

The transportation system consists of the road environment, the road user (pedestrians, drivers, cyclists etc.) and the vehicle. Generally, a variety of road environment conditions, road users and vehicle types interact with each other in the transportation system without any negative consequences. An accident occurs when one or a combination of these elements causes a failure of the system. One example of such a failure will be a vehicle leaving the roadway for reasons that may include any of the following:

- *· Poor visibility*
- *· Loss of vehicle control*
- *· Roadway-weather conditions such as ice or rain or poor drainage and other*
- *design problems*
- *· Vehicle component failure such as tyre burst, brake failure etc.*
- *· Excessive speed*
- *· Accident avoidance*
- *· Driving under the influence of alcohol or drugs (2)*
- *· Secondary collision*

Research has shown that in 50% of all run off-the-road accidents, the vehicle leaves the roadway in a skidding manner (3). This has a significant impact on vehicle behaviour when confronted with roadside features and hazards. Roadside hazards can increase the severity of these accidents, and it is, therefore the goal of Roadside Hazard Management is to manage roadside hazards to reduce the severity of these accidents. Typical roadside hazards include:

- *· Trees*
- *· Supports and poles (for lighting, utilities, signage)*
- *· Drainage structures such as culverts, drains, drop inlets*
- *· Bridge abutments/ piers*
- *· Side slopes such as embankments*
- *· Ends of traffic barriers, bridge railings*
- *· Incorrectly positioned traffic barriers, i.e. >3m off the roadway*
- *· Obsolete roadside furniture (4)*
- *· SOS call boxes*

C10 Legal issues

The following is from Roodt, 2016. Maintenance engineering standards to fulfil the legal duty of road authorities towards safe roads. Stellenbosch University PhD Thesis https://scholar.sun.ac.za/handle/10019.1/98720

Road authorities are the only institutions empowered to own public roads, and it follows that they are obliged to build, operate and maintain them in functional condition for reasonable use. Road users expect that roads can be used with safety. Legal duty describes the way an engineer executes his/her duties without being negligent.

Policy on the engineering discipline states that government is aware of the need to apply sound engineering in the quest to improve traffic safety. This should be balanced with education and enforcement functions. Transport, traffic engineering and road traffic quality will have an emphasis on safety. National guidelines and standards for the provision of road infrastructure, in the planning, design, construction, in-service and evaluation phases will be developed (Department of Transport, 1996).

Following the 1996 White Paper on National Transport Policy, a strategy for implementation under the theme *Moving South Africa* was developed. The *Moving South Africa* project was designed to produce a strategic action programme that extends the *policy* in the Transport White Paper into a long-term strategy.

Provide safe, reliable, effective, efficient and fully integrated transport operations and infrastructure which will best meet the needs of freight and passenger customers at improving levels of service and cost that supports government strategies for economic and social development whilst being environmentally and economically sustainable (Department of Transport, 1998).

For the engineering function, the strategy proposed was to be aware of high-accident risk areas and to effectively reduce the hazards by providing simple remedial measures such as signs, fences, and traffic calming. Roads should provide a forgiving environment that allows for reasonable levels of human error.

All share responsibility for road safety. While individual road users are expected to be responsible for complying with traffic laws and behaving in a safe manner, it can no longer be assumed that the burden of road safety responsibility rests with the individual road user. Many organisations - the 'system managers' - have a primary responsibility to provide a safe operating environment for road users. They include the government and industry organisations that design, build, maintain and regulate roads and vehicles. These and a range of other parties involved in the road transport system's performance, and the way roads and roadsides are used, all have responsibility for ensuring that the system is forgiving when people make mistakes.

Road engineers (a specialisation within Civil Engineering) are knowledgeable, experienced and skilled employees who have to perform in accordance with legislation and common law, as well as according to an ethical code. If a person takes on a position that requires special skills such as a road engineer, he/she is expected to be able to perform the tasks. The registered professional transportation engineer must have due regard for and give priority to the health, safety and interest of the public, and avoid or minimise adverse impact on the environment. He/she must execute work with integrity and in accordance with accepted norms of professional conduct.

From FHWA 2006. Good Practices: Incorporating Safety into Resurfacing and Restoration Projects

The spectre of tort liability looms over every transportation agency. The influence of tort claims on resurfacing project decisions varies substantially among the agencies visited and is mostly a result of the prevailing legal climate (e.g., statutory limits on the nature and magnitude of agency liability). In general, agency procedures and project-level documentation were an integral part of the agency's tort management strategy.

Numerous transportation agency personnel indicated concern about litigation and expressed the opinion that a litigious environment contravenes public interest. Several engineers expressed reluctance to make any geometric improvements unless all applicable criteria were attained. Several engineers expressed the opinion that simple resurfacing involves less tort exposure than projects that alter infrastructure but do not result in attainment of all applicable criteria. Even well-informed, well-considered, and well-documented deviations (e.g., design exceptions) are considered risky. Tort concerns were expressed most strongly in New York and Washington State.

C11 Longitudinal barriers

From Austroads AGRD06-20 Road restraint systems (Austroads, 2020):

> 5.3.19 Minimum Length of Barrier (Step B12)
>
> In order to perform satisfactorily, barrier systems must have sufficient length to enable the strength to be developed through the system and into the posts as impact occurs.
>
> MASH requires the minimum tested barrier length to be at least three times the length in which deformation is predicted, but not less than 30 m for steel beam systems and 180 m for WRSBs.
>
> While shorter lengths than the tested length are possible, the designer must consider how this will affect other performance values (e.g. deflection).
>
> The lengths to be considered in the design of barriers are the:
>
> - terminal length

• transition length

• minimum length

• development length.

The development length applies to unanchored barriers and is the length in advance of the point of redirection that is necessary to provide sufficient mass for the barrier within the length of the need to perform in accordance with its design parameters.

C12 Low volume roads

Low volume roads in rural areas are often gravel roads where accident data is even more unreliable. The economic benefit of designing low volume roads to high standards or additional safety features is often low, but the road is needed for access to communities and interaction with social and health services. Accidents are rare and the accident rates and indices cannot compete with that of high volume class 2 and 3 roads.

For example, rural mountain passes in the Eastern Cape have no roadside barriers. Naude's Neck Pass, in the Eastern Cape, South Africa, connects Maclear to Rhodes. With its summit at 2 587 m above sea level, the pass is the second highest dirt road in South Africa. This pass is based on the route taken by the intrepid Naudé brothers in the 1890s. Wikipedia. This pass is hazardous to the extreme, but will never justify roadside barriers.

C13 Motorcycles and rails

A motorcycle rider is not only riding an inherently unstable inverted pendulum but is also not protected by the vehicle body. Runoff the road accidents where motorcycle riders hit the RRS have resulted in severe injuries, which could have been minimised with more friendly design of the systems. The increased use of wire rope barriers in the '90s resulted in outcries of cheese cutters. Investigations and research into motorcycle crashes into RRS.

Federation of European Motorcyclists' Associations 2012 New Standards Restraint Systems for Motorcyclists Designing safer roadsides for motorcyclists.

Crash barriers are designed with only cars and heavy vehicles in mind. The European testing standard has made no mention of motorcycles for the last decades even though hitting a road restraint system is a factor in 8-17 per cent of rider deaths. In collisions with crash barriers, riders are 15 times more likely to be killed than a car occupant. Lately, the European Parliament has identified standard guardrails as a "death trap" for motorcyclists. Barrier posts are particularly aggressive, irrespective of the barriers' other components, causing a five-fold increase in injury severity compared to the average motorcycle crash. Motorcycle-friendly systems have been shown to halve the fatalities and offer high return rates (Federation of European Motorcyclists' Association, 2012).

The use of wire rope barriers was investigated in New Zealand by Jamaa HH, Grzebietaa RH, Friswella R, and Andrew S. McIntosh A S, 2010. Characteristics of fatal motorcycle crashes into roadside safety barriers in Australia and New Zealand. Accident Analysis and Prevention 43 (2011) 652–660. They found that:

Overall, the research notes that whilst WRSBs have the potential to cause serious injury to errant riders, so do all road safety barriers. Indeed, "there is no reliable evidence to indicate that WRSBs present a greater or less risk than other barrier types, or indeed, no barrier at all."3 It is important to note that road safety barriers should only be installed where necessary in order to protect road users from hazards, for instance at the edge of a large drop-off or on-coming vehicles, where the risk of incurring more severe and life-threatening injuries exist without the barrier being installed. This was also discussed by (Selby, no date), indicating opposition to further use.

The provision of underrun protection for W-type barriers, mostly used, to protect motorcycle riders from crashing into the barrier posts was investigated by (Atahan *et al.*, 2018).

C14 Parapets and bridge balustrades

A **parapet** is a low retaining wall while **balustrade** is (architecture) a row of **balusters** topped by a rail, serving as an open **parapet**, as along the edge of a bridge.

South African bridge RRS varies dramatically, with SANRAL new bridges having F shaped parapets and many older bridges being upgraded to the same. Provincial bridges have mostly balustrades of varying formats, with some bridge having no RRS.

To analyse South African bridges, a survey will have to be done to determine each type's types and operational adequacy and then each bridge. After the change from NCHRP 350 to MASH as test standard, a study was done in the USA to determine which systems would comply with the MAASH standards. The report:

National Cooperative Research Program Transportation Research Board Project No. 20-07 / Task 395, 2017, TTI Project 607141 Mash Equivalency of NCHRP Report 350-Approved Bridge Railings Final Report, National Research Council, serves as an example. In this report, a total of 34 survey responses were collected, including 33 DOT Agencies and FHWA Federal Lands. The following bridge rail categories and sub-categories were defined:

Concrete Only

- *Vertical profile*
- *Vertical profile, post and beams*
- *New Jersey profile*
- *Single Slope profile*
- *F-Shape profile*

Metal Only

- *Deck-Mounted*
- *Side-Mounted*

Concrete-Metal Combined (Traffic Only)

With Curb

- *3 metal members*
- *2 metal members*
- *1 metal member*

With Parapet

- *3 metal members*
- *2 metal members*
- *1 metal member*

Combination Traffic-Pedestrian

- *With Sidewalk*
- *Without Sidewalk*

Out of the 22 bridge rail systems analysed, 13 were given a satisfactory overall assessment. To receive an overall assessment of satisfactory, a bridge rail system must receive a satisfactory designation for each of the three evaluation criteria: stability, rail geometrics, and strength. Other bridge rail systems that were similar or less critical than the 13 systems with a satisfactory overall assessment are also considered satisfactory. This resulted in a total of 50 bridge rail systems found to be MASH compliant.

From Austroads AGRD06-20 Roadside Design, Safety and Barriers, the following:

> *F.2 Treatments for Bridges*
>
> *F.2.1 General*
>
> *The structural limitations of old bridges often prevent the upgrade of their barriers to current standards. Engineering expertise and judgment must design the best possible upgrade if a risk assessment shows that the existing barrier has an unacceptable risk. The reasons for not meeting current standards need to be well documented and justified. If the bridge and its barriers present a very high risk, and upgrade is not structurally possible, it may be necessary to program the replacement of the bridge (Austroads, 2020).*

F.2.2 Treatments for Bridge Piers, Abutments, End Posts and Tunnel Portals

Bridge ends should be designed to prevent vehicles from running into end support posts, being speared by any horizontal bridge members or simply crashing through any approach barrier and being exposed to a hazard (e.g. rollover, railway track, watercourse).

Stiffening needs to be provided on the transition from the semi-rigid approach barrier to the rigid bridge structure, otherwise, the excessive local deformation will cause errant vehicles to snag on the end of the bridge barrier.

A crash cushion or barrier should shield the piers of bridges over roads (at overpasses). It may be necessary to provide a barrier that can shield piers from heavy vehicle crashes, involving a two-stage shielding system.

C15 Pedestrian rails

The design, application and testing of pedestrian rails are described in various general design as well as pedestrian specific manual. The current focus on Non-Motorised Transport in combination with the Safe System approach puts the human body with its frailty as design vehicle on the foreground.

The EN1317 Road Restraint Systems Part 6: Pedestrian Restraint System - Pedestrian Parapets (British Standards Institute, 2012) provides the testing procedures and criteria. The performance of the pedestrian parapet (or rail) is relative to the human body hitting the parapet or rail. Two tests are shown for a large diameter soft body and a rigid body as shown in Figures 19 and 20.

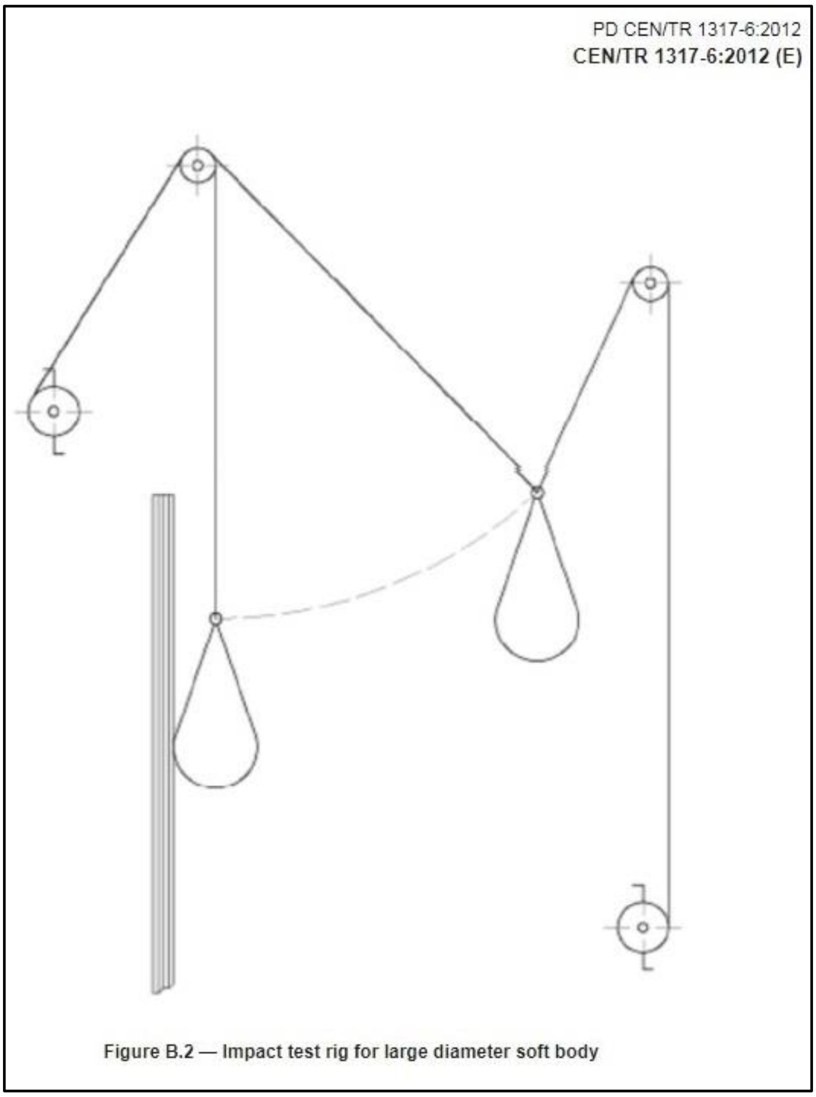


Figure B.2 — Impact test rig for large diameter soft body

Figure 19: Impact test rig for large diameter soft body

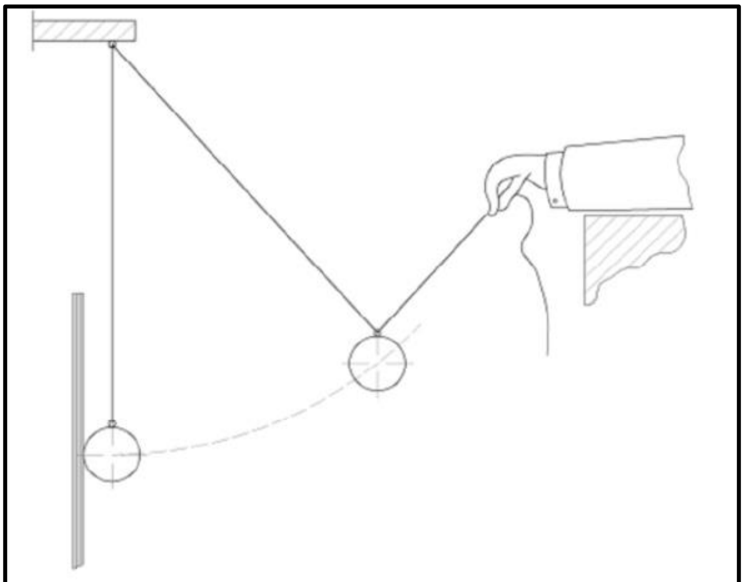


Figure 20: Impact test rig for hard body

The EN 1317 test on parapets is to ensure that the parapet does not break or yield in an unexpected manner. This test is not for performance if a vehicle hits the parapet or rail. The vehicular interaction reverts back to the tests for vehicles.

The Irish National Roads Authority in Volume 2 Section 3 Design Manual for Roads and Bridges Part 3 NRA BD 52/16 January 2016 11 5. SPECIFIC REQUIREMENTS FOR PEDESTRIAN PARAPETS AND GUARDRAILS widens the ambit of design subject to include cyclists and horse riders.

This Chapter gives requirements and guidance on parapets for pedestrians, cyclists and equestrians on bridges without vehicular traffic and also on pedestrian guardrails to provide pedestrian restraint at structures. It does not provide guidance on the use of pedestrian guardrails at locations away from structures

From AGRD06-20 Roadside Design Safety and Barriers (Austroads, 2020):

Pedestrians or cyclists may require shielding by a road safety barrier in situations where they are considered to be exposed to a higher than normal risk of being struck by an errant vehicle. A pedestrian/cyclist facility either exists or is proposed for an existing site with a run-off-road crash history, an assessment of pedestrian, cyclist, and bystander exposure should be undertaken so that crash reductions for alternative treatments can be considered.

For new works, pedestrians and cyclists' protection from passing traffic may also be considered and should be investigated by undertaking a risk assessment to assess the likelihood of the encroachment of errant vehicles into proposed pedestrian/cyclist facilities. Consideration also needs to be given to providing protection for the pedestrians and cyclists from the barrier as they travel along the path.

When considering the need to protect pedestrians and cyclists, the designer should consider the combination of factors including the:

- *number and type of path users (e.g. whether large numbers of people congregate in or pass through the area, the presence of primary school children)*
- *factors that make the site more hazardous than other sites along the road (e.g. road geometry and characteristics that would increase the risk of run-off-road events)*
- *type of traffic that may cause a run-off-road event to be particularly severe (e.g. high numbers of heavily laden freight vehicles).*

Situations, where a road safety barrier may be appropriate, are:

- *intermediate and high-speed roads (i.e. posted speed limit of > 60 km/h) where a pedestrian or bicycle path is close to the road*
- *shared-use paths separated by less than 4 m from an adjacent heavily trafficked lane, especially if the geometry is substandard. However, designers should refer to Section 5.3.4 for discussion on lateral location issues.*

• sites where there is expected to be large numbers of bystanders congregated adjacent to the road (e.g. schoolyard, sporting facilities) and the consequences of a crash are expected to be high.

Treatment options

Where practicable, the preferred options for treatment are:

• design and management of the road to minimise the likelihood of encroachment into the roadside by motor vehicles

• location (or relocation for existing facilities) of the pedestrian/bicycle facility away from the road where it has a low probability of encroachment by errant vehicles

• provision of a road safety barrier. The deflection of the barrier should be taken into account, and the barrier should be placed as close as practical to the vehicle travelled way.

Cyclists and pedestrians may require a barrier to prevent them from inadvertently running onto a traffic lane from an adjacent shared path (e.g. footpath on a bridge with high numbers of young pedestrians/cyclists). In cases where there is no need to protect path users from errant vehicles, or errant vehicles from roadside hazards, a pedestrian fence of a suitable height for cyclists should be adequate.

Institute of Transportation Engineers had the Context Sensitive Solutions in Designing Major Urban Thoroughfares for Walkable Communities (Bochner *et al.*, 2006) compiled. It is states:

The buffering of the roadside from traffic in the travelled way is one of the most important factors in providing pedestrian comfort along major urban thoroughfares. The effectiveness of buffers is largely dependent on width (see the section in this chapter on roadside width and functional requirements) and the contributing buffer elements, such as street furniture and landscaping that can create a visual barrier between the pedestrian and moving traffic (Figure 8.9).

On-street parking and edge and furnishings zones combine to provide buffering from traffic. Guidelines include:

• On-street parking should provide a buffer between pedestrians on the sidewalk and moving traffic; especially in areas with ground floor commercial uses and/or where high-volumes of pedestrian activity are expected. Texturing parking lanes or bays with the same material as the sidewalk can visually reduce the width of the roadway when the parking lane is empty.

• For thoroughfares without on-street parking and travel speeds of 30 mph or less, the width of the furnishings zone as a buffer for pedestrians should be at least 6-ft. wide.

• Consider reducing the frontage zone to its minimum or eliminating it so that an appropriately wide pedestrian buffer can be achieved within the furnishings zone.

• Bicycle lanes can serve as a buffer if desired roadside widths cannot be achieved, or if roadside

widths can only be achieved at the lower end of the ranges shown in Table 8.1.

C16 Rigid barriers

SARSM 1999 Vol 6 Part C (Committee for Land Transport, 1999)

At low angle impacts with a concrete barrier, the wheels absorb the impact force. The compression of the suspension system is used at higher impact angles. As the impact angle and speed increase, so does the movement of the vehicle on the barrier. When a vehicle impacts a concrete barrier at an angle of less than 15 degrees, the vehicle tyre and the barrier make contact. The tyre deforms and absorbs energy. At an increase in the impact speed, the front wheel will climb up the barrier face. By lifting the vehicle, further kinetic energy is absorbed. The re-directional force perpendicular to the barrier is now applied to the suspension system. Depending on the speed, the wheel will continue the climbing movement to the barrier's upper section. At this section, the wheels are turned parallel to the longitudinal axis of the barrier. This redirects the vehicle. If the impact speed is very high, the vehicle will continue the climbing movement on the face before returning to the roadway (24).

C17 Risk assessment (See also Appendix C)

The analysis of safety has developed from qualitative expert opinions to risk assessments based on criteria and quantified dimensions. The risk assessments start at network level by calculating network indices that set intervention thresholds. The hazardous locations are then assessed for a risk score, and if it exceeds the threshold, remedial action must be taken. The following diagram in Figure 21 from Austroads AGRD06-20 Roadside Design, Safety and Barriers, shows the process.

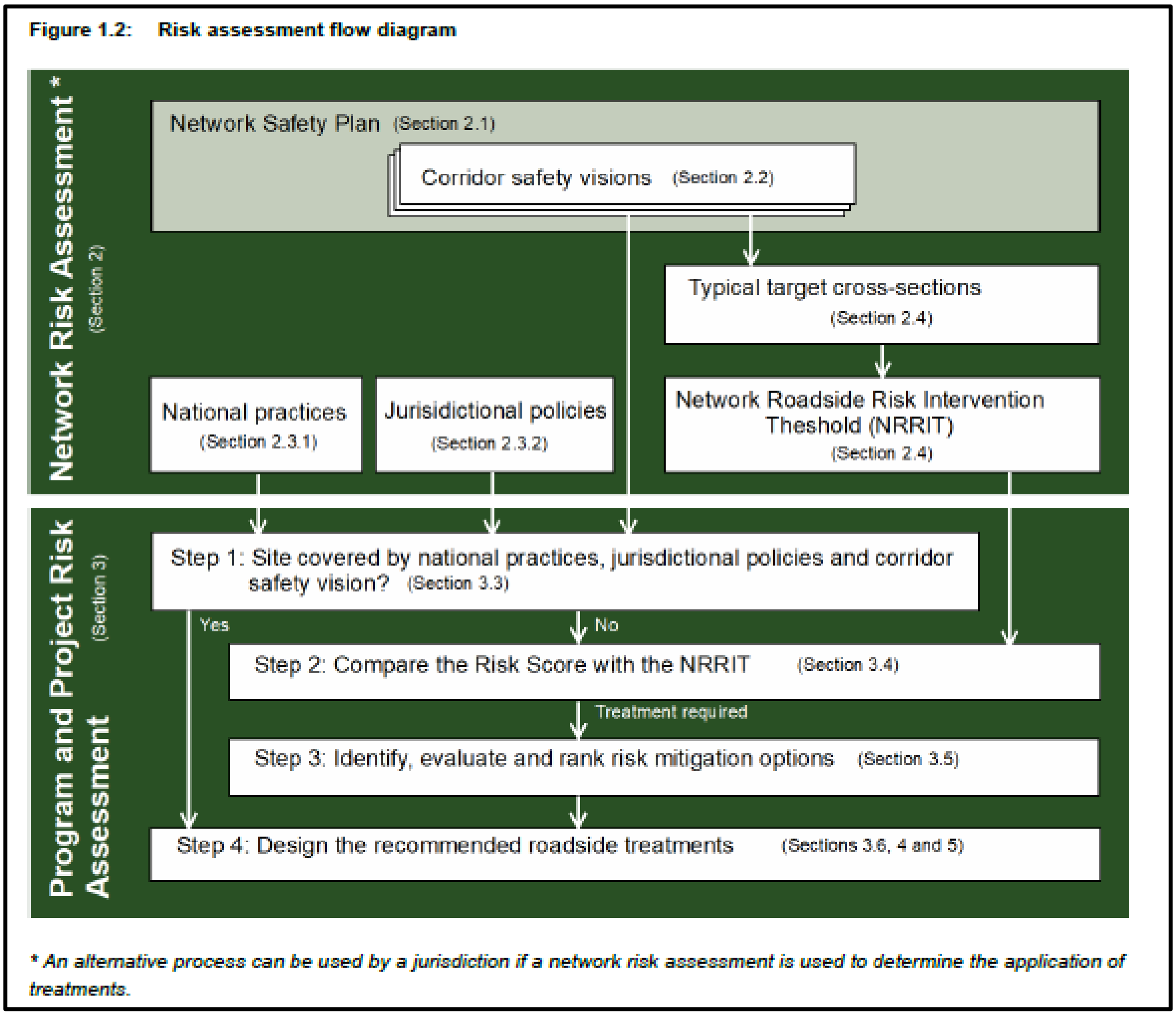


Figure 21: Risk assessment flow diagram

At a project level, the site is assessed by a set-out procedure or using the software. The manual then states:

1.9 Calculating a Risk Score

The Risk Score is used to inform the NRRIT covered in Section 2, and the risk evaluation of roadsides at road program and project segments is covered in Section 3.

The Risk Score is based on the road's geometry and the cross-section of the roadside or median. The procedure for calculating the Risk Score is aligned with the Safe System Risk Assessment Framework (Austroads 2016c). However, rather than using qualitative indices, quantitative risk values are utilised in the Risk Score procedure.

For a particular cross-section, the procedure evaluates the collective risk of run-off-the-road crashes on the roadside using an assessment of:

- *Exposure: The frequency of vehicles leaving the traffic lane and encroaching onto the shoulder. The exposure is dependent on the carriageway AADT, the number of lanes, the lane width, terrain type, grade and curve radii.*
- *Likelihood: The proportion of drivers that leave the traffic lane and then collide with a roadside hazard. The likelihood is dependent on the operating speed and the lateral distance to a hazard.*
- *Severity: The expected severity of a collision measured by a Trauma Index (refer to Appendix B). Different hazards have different Trauma Indices.*

Related to risk assessment is safety systems. The US Department of Defence sets the following requirements for a holistic assessments of what they call mishaps.

System safety requirements consist of the following:

4.1 Documentation of the system safety approach. Document the developer's and program manager's approved system safety engineering approach. This documentation shall: a. Describe the program’s implementation using the requirements herein. Include identification of each hazard analysis and mishap risk assessment process used. b. Include information on system safety integration into the overall program structure. c. Define how hazards and residual mishap risk are communicated to and accepted by the appropriate risk acceptance authority (see 4.7) and how hazards and residual mishap risk will be tracked (see 4.8).

4.2 Identification of hazards. Identify hazards through a systematic hazard analysis process encompassing detailed analysis of system hardware and software, the environment (in which the system will exist), and the intended use or application. Consider and use historical hazard and mishap data, including lessons learned from other systems. Identification of hazards is a responsibility of all program members. During hazard identification, consider hazards that could occur over the system life cycle.

4.3 Assessment of mishap risk. Assess the severity and probability of the mishap risk associated with each identified hazard, i.e., determine the potential negative impact of the hazard on personnel, facilities, equipment, operations, the public, and the environment, as well as on the system itself. The tables in Appendix A are to be used unless otherwise specified.

4.4 Identification of mishap risk mitigation measures. Identify potential mishap risk mitigation alternatives and the expected effectiveness of each alternative or method. Mishap risk mitigation is an iterative process that culminates when the residual mishap risk has been reduced to a level acceptable to the appropriate authority. The system safety design order of precedence for mitigating identified hazards is:

a. Eliminate hazards through design selection. If unable to eliminate an identified hazard, reduce the associated mishap risk to an acceptable level through design selection.

b. Incorporate safety devices. If unable to eliminate the hazard through design selection, reduce the mishap risk to an acceptable level using protective safety features or devices.

c. Provide warning devices. If safety devices do not adequately lower the mishap risk of the hazard, include a detection and warning system to alert personnel to the particular hazard.

d. Develop procedures and training. Where it is impractical to eliminate hazards through design selection or to reduce the associated risk to an acceptable level with safety and warning devices, incorporate special procedures and training. Procedures may include the use of personal protective equipment. For hazards assigned Catastrophic or Critical mishap severity categories, avoid using warning, caution, or other written advisory as the only risk reduction method.

4.5 Reduction of mishap risk to an acceptable level. Reduce the mishap risk through a mitigation approach mutually agreed to by both the developer and the program manager. Communicate residual mishap risk and hazards to the associated test effort for verification.

4.6 Verification of mishap risk reduction. Verify the mishap risk reduction and mitigation through appropriate analysis, testing, or inspection. Document the determined residual mishap risk. Report all new hazards identified during testing to the program manager and the developer.

4.7 Review of hazards and acceptance of residual mishap risk by the appropriate authority. Notify the program manager of identified hazards and residual mishap risk. Unless otherwise specified, the suggested tables A-I through A-III of the appendix will be used to rank residual risk. The program manager shall ensure that remaining hazards and residual mishap risk are reviewed and accepted by the appropriate risk acceptance authority (ref. table A-IV). The appropriate risk acceptance authority will include the system user in the mishap risk review. The appropriate risk acceptance authority shall formally acknowledge and document acceptance of hazards and residual mishap risk.

4.8 Tracking of hazards, their closures, and residual mishap risk. Track hazards, their closure actions, and the residual mishap risk. Maintain a tracking system that includes hazards, their closure actions, and residual mishap risk throughout the system life cycle. The program manager shall keep the system user advised of the hazards and residual mishap risk.

C18 Semi-flexible barriers

The semi-flexible RRS in the form of the W- beam (better known under the historical supplier name of ARMCO), is mostly used in South Africa. This profile's general use has led to most road authorities standardising on this for ease of maintenance and inventory cost. It functions as follows:

SARSM 1996 Vol 6 Part C

When a vehicle makes contact with a guardrail, the W-beam forms a wide tension band by bending and flattening to contain the vehicle. The posts rotate and bend to the ground line as the passive pressure of the soil fails. During the contact, a restraining force acts on the side of the vehicle. The line of action of this force is lifted and dropped as the posts and spacers deflect. By changing the direction of the force, vaulting, rollover and snagging are reduced. Further restraint for the vehicle develops as the posts yield and the metal of the barrier tears away from of the bolt heads (15). Kinetic energy is absorbed by the barrier system through friction, deformation and the breaking of posts.

C19 Side slopes

Side slopes (fore slopes and back slopes) has a significant influence on the ability of a vehicle to recover in the clear zone. The slopes are too steep (usually linked to fill height, geotechnical, topographical and drainage) barriers to contain the vehicles on the road shoulders. These decisions are made with reference to warrants or better, risk assessments. The side slope conditions between too steep and flat need to be considered. The terms are illustrated in Figure 22 from the SARSM 1999 Vol 6.

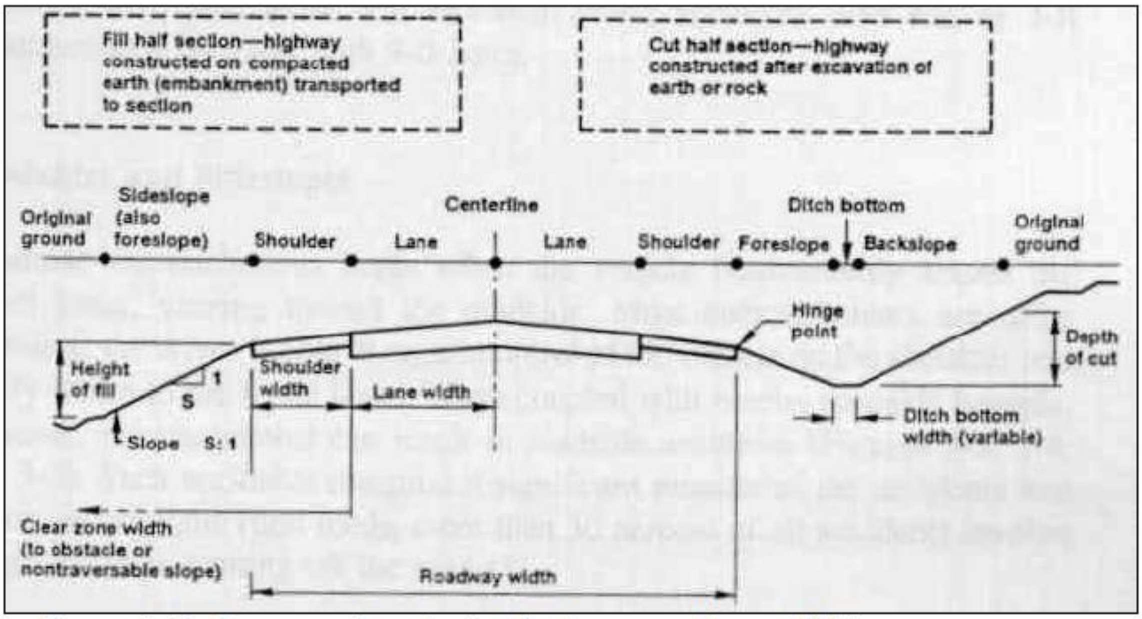


Figure A-8: Cross-section design features and terms (17)

Figure 22: Cross-section design features and terms

From Austroads AGRD06-20:

C4.1 Embankment Slopes

Some steep embankment slopes may not constitute a direct hazard but prevent errant vehicles from recovering when they leave the road and run onto the embankment. The condition of the ground surface may increase the hazardousness of an embankment. The propensity for a vehicle to rollover is increased on steeper embankments.

Thomson and Valtonen (2002) describe the results of some crash testing of drain shapes which indicates that, depending on the angle of departure of the vehicle from the road, shapes outside of those shaded in Figure 4.18 and Figure 4.19 in AGRD Part 3 (Austroads 2016a) are traversable.

Thomson and Valtonen (2002) reported that the collision severity of vehicles travelling in a V-shaped ditch was not appreciably worse than the loading measured in standardised testing of load restraint systems, as long as a rollover did not occur. The rollovers observed tended to be quite violent even for the lowest speed tests (80 km/h).

The impact severity of a V-shaped ditch is dependent on the change of slope at the V. Vehicles will plough into the back slope if this change in slope is too great.

A significant risk not measured in these (or similar) tests was the consequence of a vehicle travelling over the backslope and continuing into the roadside terrain. The backslope used in these tests was 1 m higher than the road, which was not sufficient to contain vehicles to the ditch. The speed was observed to be not significantly reduced as the vehicle exited the ditch. Often the vehicle was airborne as the backslope acted as a ramp. Subsequent impact with a pole, tree, or rock located beyond the ditch could have severe consequences for the vehicle trajectories observed in the tests.

Transverse embankments with relatively flat side slopes may cause vehicular vaulting with the vehicle and becoming airborne. For steeper slopes, the vehicle bumper may 'catch' in the slope resulting in an abrupt stop and high occupant decelerations. For these reasons, transverse slopes should be as flat as practical.

A preferred option may be to flatten the slope to 6:1 to make it 'recoverable'. An economic evaluation of flattening the embankment, compared to installing a barrier, may inform the *designer. This evaluation should include the costs associated with crashes, maintenance and installation or construction for each option.*

C20 Standards

The most used RRS in South Africa is the W- section and a South African standard was approved by National Committee StanSA TC 5120.36, Safety equipment used on public roads, in accordance with procedures of Standards South Africa, the first edition being (SABS 1350:1982). The current edition is SANS 1350:2005 SOUTH AFRICAN NATIONAL STANDARD Guardrails for roads (W-section).

A new National Standard for testing any systems was approved in 2009: SANS 51317 –parts 1 & 2. These are basically copies of EN 1317 of 1998 and require that any South Africa system be a CRASH TESTED system.

C21 Temporary Systems

RSS for roadworks and temporary traffic accommodation is a critical issue to be considered in this project. The current requirement for safe passage of traffic and protection for workers can be found in Road Traffic Signs Manual Volume 2 Chapter 13 –Section 13.5.4

"Barriers must be sufficiently fixed to give physical protection to traffic and workers alike. Typical barriers are moveable/portable steel or concrete section systems mounted following prevailing SANS requirements."

The SANS requirements are under review, and the aim is to align with the EN1317 requirements.

C22 Terminals and transitions

From Austroads AGRD 06-20

5.3.21 Terminal Treatments (Step B14)

General

Once the barrier has been located longitudinally (points of redirection) and laterally to accommodate dynamic deflection and sight distance, suitable leading and trailing terminal treatments must be selected for use. Crashworthy terminals are used on safety barriers located in areas where they may be hit by an errant vehicle.

Terminal treatments and crash cushions or impact attenuators are used to terminate a barrier. These devices are designed to ensure that the ends of barriers provide safe conditions for occupants of vehicles that may impact this area of a barrier. They must be used on all rigid and semi-rigid barrier systems. Flexible barriers have an end anchorage and when impacted head-on the posts and cables collapse as the vehicle decelerates.

A barrier terminal treatment may fulfil its function by:

- *permitting controlled penetration by the vehicle into an area behind the device*
- *decelerating a vehicle to a safe stop within a relatively short distance*
- *containing and redirecting the vehicle*
- *a combination of the above.*

Road safety barrier terminals are generally classified as either a gating/non-gating terminal or as a crash cushion/impact attenuator (refer to paragraph Gating and non-gating terminals).

Selection factors for terminal treatments

The selection of the most appropriate crashworthy terminal treatment for a barrier should take into account the:

- *need for gating or non-gating characteristics*
- *need for redirective or non-redirective characteristics*
- *speed environment*
- *space available for installation and deformation of the terminal*
- *need for a run-out area behind the barrier*

- *width required for accommodation and deformation of the terminal*
- *capacity to absorb nuisance crashes*
- *compatibility with barrier type*
- *cost and maintenance factors.*

5.3.22 Transitions between Barriers (Step B15)

General

Wherever it is necessary to change from one type of barrier to another, or to physically join them together (e.g. a bridge barrier to a road barrier), the interface must be designed to ensure that the overall system will perform safely when impacted by a design vehicle.

Interfaces are designed to provide a smooth, snag-free transition between different types of barriers where they meet, such as at bridge parapets. Inappropriate, incorrectly installed or missing interfaces present a hazard to vehicles impacting the barriers at or near the interface point (i.e. the end of the concrete or steel bridge barrier).

Different profiles of semi-rigid steel barrier and different profiles of rigid barrier can all be interfaced with a properly designed continuous transition, whereas interfaces between flexible barriers and more rigid systems can only be effected by overlapping the different systems. The overlap should be designed on the basis that the terminating system will overlap in front of a system that is beginning, irrespective of the system type. The barriers should be separated by a clearance at least equivalent to the dynamic deflection of the terminating system.

Bridge approaches

Transitions from approach barriers to bridge barriers should conform to the following requirements (AS 5100.1-2017):

• A transition barrier should be provided on the approach to all bridge safety barriers.

• The strength and stiffness of the approach barrier should vary to provide a transition from the flexible barrier to the rigid or semi-rigid bridge barrier.

• A smooth face and tensile continuity should be maintained throughout, for example, exposed rail ends, kerbs, posts and sharp changes in the geometry of the barrier components and kerbs, should be avoided or transitioned out with a taper that reflects the change to flare rates in Table 5.5.

C23 Terminology

The RRS is a subsystem within the road safety engineering field, which also overlaps with safety and risk management in general. A set of definitions of safety and systems was sourced from the USA Department of Defence Standard Practice for System Safety MIL-STD-882D dated 10 February 2000

- Safety. Freedom from those conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment.
- Subsystem. A grouping of items satisfying a logical group of functions within a particular system.
- System. An integrated composite of people, products, and processes that provide a capability to satisfy a stated need or objective.
- System safety. The application of engineering and management principles, criteria, and techniques to achieve acceptable mishap risk, within the constraints of operational effectiveness and suitability, time, and cost, throughout all phases of the system life cycle.
- System safety engineering. An engineering discipline that employs specialized professional knowledge and skills in applying scientific and engineering principles, criteria, and techniques to identify and eliminate hazards, in order to reduce the associated mishap risk.

Two RRS sources of terminology are listed here, as they represent the terminology from the test environment and the design environment. Other sources may yield single or limited additional information which will be added without referencing as terminology is in the public domain and not subject to plagiarism.

The EN1317 Road Restraint Systems, for the purposes of this standard, apply the following definitions:

1. ***Road restraint system:*** *general name for vehicle restraint system and pedestrian restraint system used on the road*
2. ***Vehicle restraint system:*** *system installed on the road to provide a level of containment for an errant vehicle*

3. ***Safety barrier:*** *road vehicle restraint system installed alongside, or on the central reserve, of a road.*
4. ***Permanent safety barrier:*** *safety barrier installed permanently on the road*
5. ***Temporary safety barrier:*** *safety barrier which is readily removable and used at road works, emergencies or similar situations*
6. ***Deformable safety barrier:*** *safety barrier that deforms during a vehicle impact and may suffer permanent deformation*
7. ***Rigid safety barrier:*** *safety barrier that has negligible deflection during a vehicle impact*
8. ***Single-sided safety barrier:*** *safety barrier designed to be impacted on one side only*
9. ***Double-sided safety barrier:*** *safety barrier designed to be impacted on both sides*
10. ***Terminal:*** *the end treatment of a safety barrier*
11. ***Leading terminal:*** *terminal placed at the upstream end of a safety barrier*
12. ***Trailing terminal:*** *terminal placed at the downstream end of a safety barrier*
13. ***Transition:*** *connection of two safety barriers of different designs and/or performances*
14. ***Vehicle parapet:*** *safety barrier installed on the edge of a bridge or on a retaining wall or similar structure where there is a vertical drop, and which may include additional protection and restraint for pedestrians and other road users*
15. ***Crash cushion:*** *road vehicle energy absorption device installed in front of a rigid object to reduce the severity of impact*
16. ***Redirective crash cushion:*** *crash cushion designed to contain and redirect an impacting vehicle*
17. ***Non-redirective crash cushion:*** *crash cushion designed to contain and capture an impacting vehicle*
18. ***Arrester bed:*** *area of land adjacent to the road filled with a particular material to decelerate and arrest errant vehicles*
19. ***Pedestrian restraint system:*** *system installed to restrain and to provide guidance for pedestrians*
20. ***Pedestrian parapet:*** *pedestrian or ''other users'' restraint system along a bridge or on top of a retaining wall or similar structure which is not intended to act as a road vehicle restraint system*
21. ***Pedestrian guardrail:*** *pedestrian or "other user" restraint system along the edge of a footway or footpath intended to restrain pedestrians and ''other users'' from stepping onto or crossing a road or other area likely to be hazardous NOTE. ''Other users'' includes provision for equestrians, cyclists*

From the Austroads AGRD06-20 Guide to Road Design Part 6: Roadside Design, Safety and Barriers. Appendix A Road Safety Barrier Terminology, extracted from Table A2 the design terminology. The AGRD Figures A2 and A3 are shown as Figures 23 and 24 following the definitions.

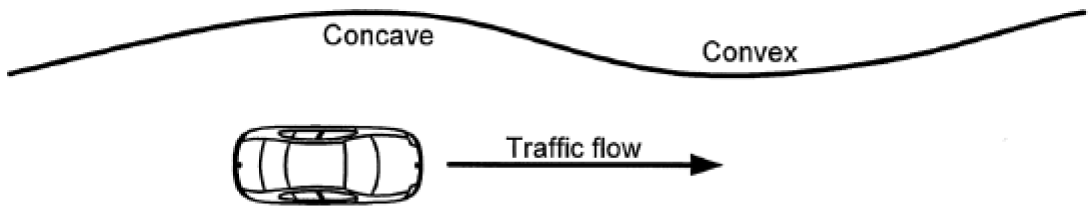
1. ***Concave Barrier:*** *curvature away from the adjacent traffic lane, i.e. inside the curve (Figure A.2).*
2. ***Containment****: The maximum tested vehicle mass used in a set of standard crash tests.*
3. ***Convex Barrier:*** *curvature towards the adjacent traffic lane, i.e. outside the curve. Figure A.2*
4. ***Crash attenuator:*** *Devices that prevent an errant vehicle from impacting hazardous objects by gradually decelerating the vehicle to a safe stop or by directing the vehicle away from the hazard. They are often used as the end treatment on the leading end of a barrier system.*
5. ***Crash cushion:*** *An energy absorption device installed in front of a rigid object to reduce the severity of impact.*
6. ***Departure angle:*** *The angle at which the vehicle leaves the barrier after initial impact (Figure A.3).*
7. ***Development length:*** *A length of unanchored barrier, in advance of the point of redirection, that is necessary to provide sufficient mass for the barrier within the length of need to perform in accordance with its design parameters.*
8. ***Double-sided barrier:*** *A barrier designed for impact on both sides.*
9. ***Dynamic deflection:*** *The largest transverse deflection of a barrier system during a crash or during a full-scale impact test (i.e. the amount the barrier deflects from its initial position during impact (Figure A.3).*
10. ***Exit trajectory:*** *The path followed by the vehicle after last impact with the barrier (Figure A.3).*
11. ***Flare:*** *The change in the offset of a barrier to move it further from the travelled way or closer to the travelled way.*
12. ***Flare rate:*** *The curvature applied near the end of a barrier installation (Figure 5.5). Expressed as the ratio of the longitudinal distance to the transverse offset, by which a barrier flares away from, or towards, the edge of the travelled way.*
13. ***Flexible barrier:*** *A barrier system where the barrier elements under an impact respond and absorb kinetic energy, by substantial movement, deformation and deflection.*
14. ***Gating terminal:*** *A barrier terminal designed to allow an impacting vehicle to pass through the device. Terminals that are designed to break away, pivot or hinge, and allow a vehicle to pass through when impacted at an angle to the end, or at a point upstream of the beginning of the length of the associated barrier system.*

15. ***Impact angle:*** *The minimum angle at which a vehicle at speed leaves the road (Figure A.3).*
16. ***Initial lateral position:*** *The lateral position of the vehicle prior to initial change of direction (Figure A.3).*
17. ***Interface:*** *The length of barrier system used to connect systems with different operating characteristics, commonly used to connect a non-rigid barrier system to a rigid barrier system, such as a bridge safety barrier.*
18. ***Lateral redirection:*** *The lateral position of the vehicle after impact (Figure A.3).*
19. ***Leading point of need:*** *In relation to a roadside hazard, the first point at which the barrier is needed to prevent an errant vehicle from striking the hazard (Figure A.4 and Figure A.5).*
20. ***Leading terminal:*** *The terminal treatment at the end of a barrier that faces vehicles approaching in the adjacent traffic lane (Figure A.4 and Figure A.5).*
21. ***Length of need:*** *The length of a barrier system, needed to prevent errant vehicles from impacting a hazard, representing the length over which a barrier will redirect an impacting vehicle. It is the distance between the leading and trailing points of need (Figure A.4 and Figure A.5).*
22. ***Median application:*** *A barrier system when it is installed in a median location. Can be impacted from both sides.*
23. ***Nearside:*** *The side of a vehicle closest to the kerb on the left-hand side of the road when the vehicle is travelling in the normal direction of travel.*
24. ***Non-gating terminal:*** *A barrier terminal that is designed to redirect or contain an impacting vehicle and absorb part of the energy of the impacting vehicle at any point along the terminal without allowing it to pass through the device.*
25. ***Non-redirective crash cushion:*** *A crash cushion designed to contain and capture an impacting vehicle.*
26. ***Non-rigid barrier system:*** *A barrier system where elements are designed to move substantially in a crash, and where energy is absorbed by movement of the barrier system and deformation of the vehicle.*
27. ***Offside:*** *The side of a vehicle furthest away from the kerb on the left side of the road when the vehicle is travelling in the normal direction of travel (i.e. it corresponds to the driver side of the vehicle).*
28. ***Permanent deformation:*** *The permanent deformation of the barrier that remains after impact (Figure A.3).*
29. ***Permanent barrier:*** *A barrier that is installed permanently at the roadside.*

30. ***Point of impact:*** *The point where the vehicle first impacts a barrier (Figure A.3).*
31. ***Point of need:*** *The start or end of the length of need, defining the length over which an errant vehicle needs to be redirected by the barrier and would otherwise strike the hazard if a barrier was not provided.*
32. ***Post-impact speed:*** *The speed of the vehicle following impact (Figure A.3).*
33. ***Pre-impact speed:*** *The speed of the vehicle before a change of direction (Figure A.3).*
34. ***Proprietary system:*** *A barrier system that is the subject of patent or other intellectual property rights within Australia and New Zealand.*
35. ***Public domain system:*** *A barrier system that is not the subject of patent or other intellectual property rights within Australia and New Zealand.*
36. ***Redirective crash cushion:*** *A crash cushion designed to contain and redirect an impacting vehicle.*
37. ***Rigid barrier system:*** *A barrier where there is no observable dynamic deflection during a vehicle impact. The deformation is contained within the impacting vehicle.*
38. ***Risk Score:*** *The product of exposure, likelihood and crash severity (defined by the Trauma Index).*
39. ***Road safety barrier system:*** *A roadside device that provides a physical restriction to penetration of a vehicle in a way that reduces the risk to vehicle occupants and other traffic. Its purpose is to redirect or contain an errant vehicle. It is used to shield roadside obstacles or non-traversable terrain features. Occasionally, it may be used to protect people from vehicular traffic.*
40. ***Secondary impact angle:*** *The angle at which the vehicle impacts the barrier for the second time (Figure A.3).*
41. ***Semi rigid barrier:*** *A barrier where the barrier elements under an impact, manage and absorb kinetic energy by limited movement, yielding deformation and deflection.*
42. ***Single-sided barrier*** *A barrier designed for impact on one side only.*
43. ***System width:*** *The front-to-back dimension of the barrier including its supporting posts, etc. (Figure A.3). This dimension should be less than the working width so that the system will not impact the hazard.*
44. ***Temporary barrier:*** *A barrier that is readily removable and used at roadworks, emergencies or similar situations.*
45. ***Terminal A:*** *device designed to treat the end of a barrier. The terminal may function by decelerating a vehicle to a safe stop within a relatively short distance, or permit controlled penetration of the vehicle behind the device, or contain and redirect the vehicle, or a combination of these performance characteristics.*

46. ***Test level (TL):*** *A set of conditions, defined in terms of vehicular type and mass, vehicular impact speed and vehicular impact angle that quantifies the impact severity of a matrix of tests.*
47. ***Three-beam:*** *A triple-corrugated steel-rail barrier supported on steel posts.*
48. ***Trailing point of need:*** *In relation to a roadside hazard, the last point at which the barrier is needed to prevent an errant vehicle from striking the hazard (Figure A.4 and Figure A.5).*
49. ***Trailing terminal:*** *The terminal treatment at the departure end of a barrier in the direction of travel in the adjacent traffic lane (Figure A.4 and Figure A.5).*
50. ***Transition:*** *The connection of two barriers of different designs and/or performances.*
51. ***Vehicle roll allowance:*** *The lateral distance between the deflected face of a barrier and the maximum extent of vehicle body roll during impact.*
52. ***W-beam:*** *A double-corrugated steel rail barrier supported on steel posts.*
53. ***Wire rope barrier:*** *A barrier system consisting of wire rope cables under high tension that are supported on posts and anchored at the ends.*
54. ***Working width***: The minimum width that is required to prevent an impacting design vehicle from colliding with an object behind a barrier system. This includes both the dynamic deflection of the barrier (if any) and the extra width to allow for an impacting vehicle's roll (vertical rotation). This ensures that the system width can be accommodated between the deformed barrier and the hazard during impact (Figure A.3 = Figure 24) and that the top of a high heavy vehicle will not impact a high hazard during impact.

Figure A.2: Road safety barrier terminology – curvature

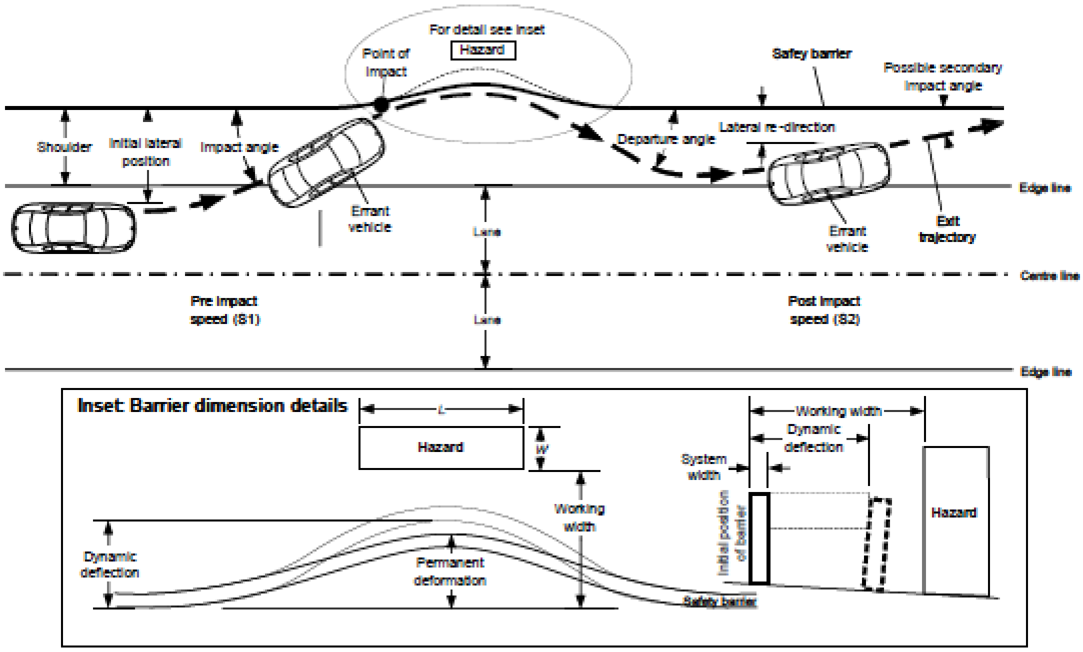


Source: Roads and Maritime Services (2016).

Figure 23: Road safety barrier terminology - curvature

The terminology associated with barrier impact is shown in Figure A.3.

Figure A.3: Road safety barrier terminology – impact



Source: Roads and Maritime Services (2016).

Figure 24: Terminology associated with barrier impacts

C24 Tests, procedures, protection classes

See B3 Testing procedures.

From SARSM 1999 Vol 6 Part C:

Traffic barriers should conform to the following safety criteria:

- *It should be able to have sufficient strength and stability to absorb the impacting energy of an errant vehicle*
- *It should redirect a vehicle parallel to traffic flow to prevent secondary collisions*
- *It should reduce the severity of injuries by reducing the impact forces on occupants*
- *During impact it should suffer as little as possible damage and cause as little as possible damage to the impacting vehicle*

- *It should keep an impacting vehicle upright during and after impact It should not cause any debris or fragments that could penetrate or have a potential to penetrate the passenger compartment or cause danger to other vehicles travelling on the roadway.*

Budzynski et al. The role of numerical tests in assessing road restraint system functionality. European Transport Research Review (2020) https://doi.org/10.1186/s12544-020-00424-8:

The main objective of safety barrier modelling and simulation tests is to develop numerical models of crash tests. The work conducted in 2016 included an extensive review of the literature, adjusting vehicle numerical models to the needs of the project and preliminary numerical tests. Building on these results in 2017 further research included simulations of virtual crash tests using a commercial system of the FEM, the LS-Dyna.

Based on the Finite Element Method, numerical simulations of crash tests can be a reliable source of information about road safety devices, vehicle behaviour and the overloads affecting vehicle occupants. If correctly verified, numerical tests can significantly aid the design and modification of existing safety barriers. The benefit they offer is the ability to analyse many different configurations of the devices, their locations and different driving conditions where real tests would be very difficult or impossible. Numerical simulations give a unique insight into the mechanisms that occur during the dynamic and fast changing process which is a vehicle striking a road safety device.

The results of the tests have helped to build mathematical models making analysis of safety barriers possible under different and non-normative conditions.

C25 Training

This project's findings will be presented at a conference on road safety and combined with a workshop to obtain input from the industry before finalising the project. The project then requires that training be given to road engineers, traffic officers and safety officers. The typical mode of delivery of practical training would be lecturing at regional centres, taking the lecturer to the learners is more cost-effective. Given the Covid Pandemic, consideration must be given for online delivery of the course.

Further research will be done into online delivery for different interest groups, as well as registration for Continued Professional Development credits for registered persons.

C26 Vehicle Arrestor Beds

South Africa has less than ten vehicle arrestor beds, most on national roads and one on the R37 road in the mountainous area under the Mpumalanga Roads and Transport. The GDG has a section 8.6 on runaway vehicle facilities (escape ramps on arrestor beds), and there are specific manuals on the design thereof.

The purpose of escape ramps and arrestor beds is to stop, without severe injury or serious damage to vehicles, to adjacent property or to other road users, those vehicles that become out-of-control on long downhill gradients. A full-width level arrestor bed obtains deceleration rates of between 5 m/s2 and 6 m/s2 without the use of vehicle brakes. (A 10 per cent down gradient on the bed surface can reduce the deceleration by about 1 m/s^2). It should be noted that, under high deceleration, inadequately restrained vehicle occupants, or insecurely attached cargo may not be safely contained (SANRAL, 2003).

The factors are taken into account

- Gradient;
- Driver error such as failure to downshift gears;
- Equipment failure such as defective brakes;
- Inexperience with the vehicle;
- Unfamiliarity with the specific location;
- Driver impairment due to fatigue or alcohol; and
- The inadequate signing of a downgrade.

Many old research papers were done for USA state departments of transportation such as Performance of a Gravel-Bed Truck-Arrester System by Joseph R. Allison, Kenneth C. Hahn, and James E. Bryden, New

York State Department of Transportation, Albany. Recent research seems to be from China(Qin, 2019) and the European East Block countries, which are now developing modern roads. Numerical modelling (Ambrož, Trajkovski and R, no date) is also researched as computing power increases.

The South African design guidelines are sufficient, based on the successful performance of current installations, provided that rounded gravel is selected and maintenance (airing or fluffing) of the gravel is done.

C27: Warrants

Warrants were used to direct the road designer concerning where and when specific measures that generally would add to a design's cost may be used. The more current approach is to do a risk assessment and benefit-cost analysis to justify specific measures.

Most warrants are based on variables such as traffic volume, design speed, roadside slope, fill height and shoulder width. The following shows how warrants are presented in a selection of road design manuals.

C27.1 SANRAL GDG:

This manual considers filling height and batters slope. The manual applies typically to a national road which is mainly Classes 1, 2 and 3 roads which carry significant traffic. See Figure 25.

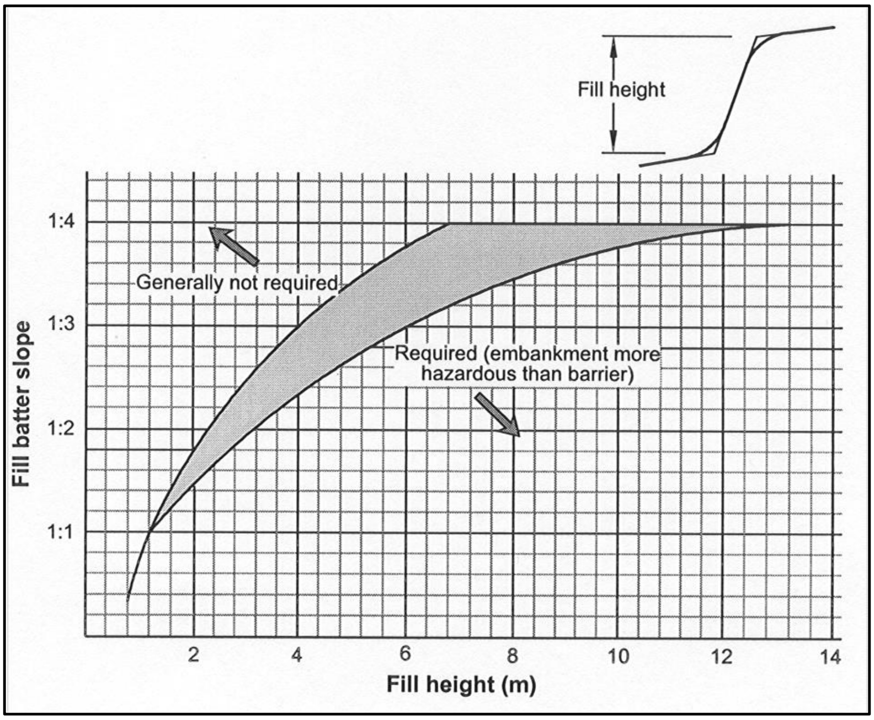


Figure 25: Warrants for the use of roadside barriers

The SANRAL GDG 2003 also list the typical roadside obstacles to be shielded with RRS. Table 8.3 is shown here as Figure 26.

Table 8.3: Roadside obstacles normally considered for shielding	
Terrain or Obstacle	Comment
Bridge piers, abutments, railing ends	Shielding analysis required
Boulders	Judgement: nature of object: likelihood of impact
Culverts, pipes (smooth)	Judgement: based on size, shape, location
Cut slopes (smooth)	Shielding analysis not generally required

Cut slopes (rough)	Judgement: based on likelihood or impact
Ditches (parallel)	Analysis generally required
Embankments	Judgement: based on fill height and slope
Retaining walls	Judgement: based on wall smoothness and angle of impact
Sign and luminaire supports	Shielding analysis for isolated signals in the clear zone on high speed (80 km/h or greater) facility
SOS telephones	Shielding analysis required
Traffic signal supports	Shielding analysis for isolated signals in the clear zone on high speed (80 km/h or greater) facility
Trees	Judgement: site specific
Utility poles	Judgement: case by case basis
Permanent bodies of water	Judgement: depth of water, likelihood of encroachment

Figure 26: Typical roadside obstacles to be shielded with RRS

C27.2 AASHTO Roadside Design Guide.

This manual uses the same criteria of fill height and batter slope as the SANRAL GDG. The warrant values differ. The criteria for road obstacles are the same as SANRAL GDG as it served as a source. See Figures 27 and 28.

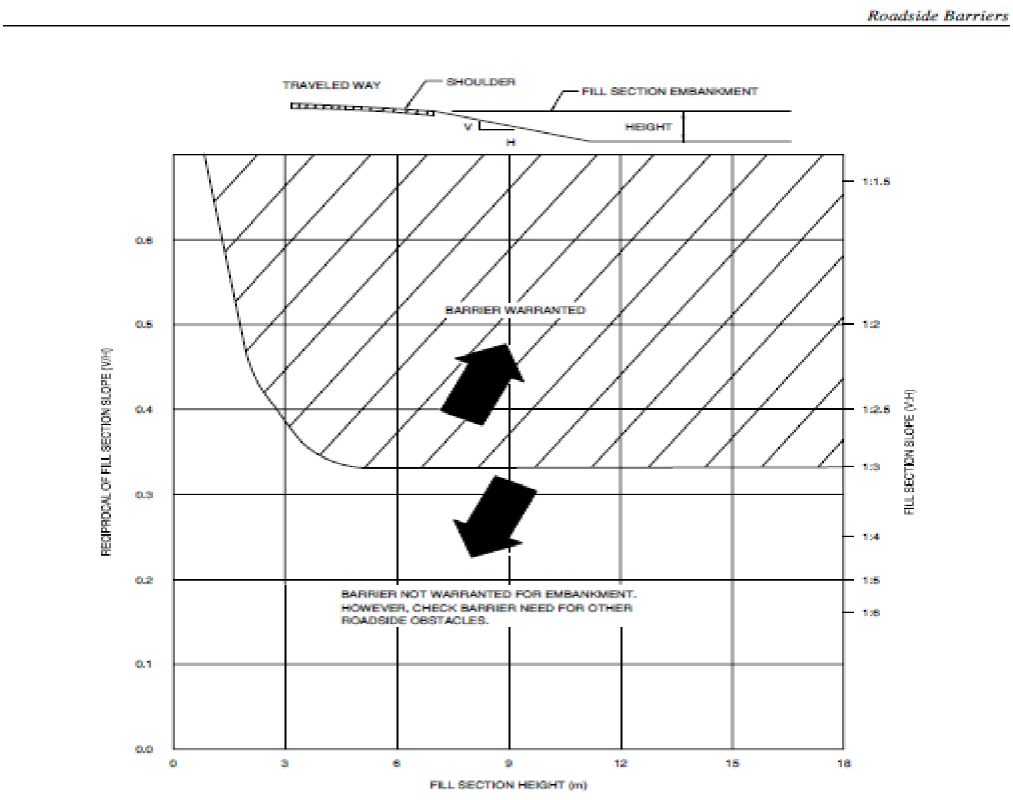


FIGURE 5.1a Comparative risk warrants for embankments (metric units)

Figure 27: Comparative risk warrants for embankments

Roadside Barriers

TABLE 5.1 Barrier warrants for non-traversable terrain and roadside obstacles[1,2]

Obstacle	Warrants
Bridge piers, abutments, and railing ends	Shielding generally required
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
Cut & fill slopes (smooth)	Shielding not generally required
Cut & fill slopes (rough)	Judgment decision based on likelihood of impact
Ditches (parallel)	Refer to Figures 3.6 and 3.7
Ditches (transverse)	Shielding generally required if likelihood of head-on impact is high
Embankment	Judgment decision based on fill height and slope (see Figure 5.1)
Retaining walls	Judgment decision based on relative smoothness of wall and anticipated maximum angle of impact
Sign/luminaire supports[3]	Shielding generally required for non-breakaway supports
Traffic signal supports[4]	Isolated traffic signals within clear zone on high-speed rural facilities may warrant shielding
Trees	Judgment decision based on site-specific circumstances
Utility poles	Shielding may be warranted on a case-by-case basis
Permanent bodies of water	Judgment decision based on location and depth of water and likelihood of encroachment

Notes:

Figure 28: Barrier warrants for non-traversable terrain and roadside obstacles

C27.3 UNESCAP, 2017. Asian Highway Design Standard for Road Safety Design Guidelines October 2017

This Asian Highway Design Standard for Road Safety Design Guidelines (United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), 2017) combine fill height and side slope but allow areas where the side slope can be steeper for low-speed, low-volume roads. See Figure 29.

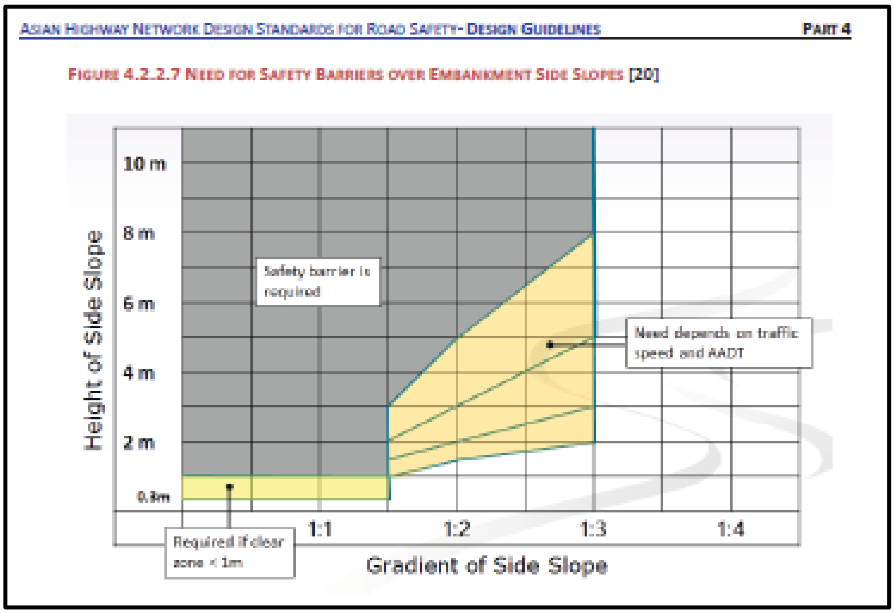


Figure 29: Need for safety barriers over embankment side slopes

C27.4 Indian Roads Congress, 2013. Manual for Specifications and Standards for Expressways.

The Indian manual (Indian Roads Congress, 2013) is more descriptive in some ways and gives good guidance to design considerations.

6.13 Safety Barriers

1. *Reinforced Cement Concrete crash barriers shall be provided on the edges of all slab/box type culverts bridges and grade-separated structures.*
2. *The design loading for the crash barriers shall be as per Clause 209.7 of IRC:6.*
3. *The type design for the crash barriers may be adopted as per IRC:5. High containment type crash barrier shall be provided on the Road Over Bridges, and the Vehicle crash barrier type shall be provided on all other structures.*

   (The sketches of concrete crash barriers extracted from IRC:5 are given in Figs. 6.6a and 6.6b for the Vehicular crash barrier and High Containment type Crash barriers respectively.)

4. *Crash barriers on the structures shall be suitably continued and connected with safety barriers on approaches on either side of the structures to have a smooth transition as per guidelines given in Section-10 of this Manual.*

10.7 Crash Barriers

There are three types of crash barriers viz., rigid (concrete), semi-rigid (metal beam -"W" beam and three-beam type) and flexible (wire rope safety barrier). Crash barriers shall be provided on the roadside and median side as per requirements given hereunder. The specification of various types of crash barriers shall be as per Section 800 of MORTH Specifications unless specified in this Section.

10.7.1 Roadside safety barriers

i. *Warrants: The longitudinal roadside barriers are basically meant to shield two types of roadside hazards i.e. embankments and roadside obstacles and also for preventing the* *vehicles veering off the sharp curves. Roadside safety barriers shall be provided at the following locations:*

a) On embankments where recoverable slope up to a distance of clear zone applicable for the design speed (refer para 2.17 of this Manual) is not available.

b) On the retaining/reinforced earth wall abutting the paved/earthen shoulder.

c) Along all horizontal curves having radii up to 2000 m for the complete length of curves including transitions and 20 m further before and after the curve.

d) In front of roadside obstacles like bridge piers, abutments and railing ends, roadside rock mass, culverts, pipes and headwalls, cut slopes, retaining walls, lighting supports, traffic signs and signal supports, trees and utility poles.

ii. *Normally on the shoulder side, the lateral distance of at least 0.75 to 1 .0 m width from the edge of the paved portion (i.e. carriageway + paved shoulder) should be available without any obstacles. Wherever a permanent object cannot be removed for some reasons, provision of tandems viz. W-beam metal crash barriers and hazard markers with reflectors must be made. Further, frangible lighting columns and signposts need to be used for minimizing the severity in case of collision.*

iii. *Irrespective of the type of barrier being used, the slope in front of the crash barrier shall be near to a flat gradient so that the safety barrier performs best: When impacted by a vehicle and the slope of ground in front of the barrier shall not be steeper than 10:1.*

10.7.2 Median barriers

Warrants: Median barriers shall be provided at the following locations:

a) At the centre of flush type medians;

b) At both ends of bridges, Road Over Bridges and grade separated structures in continuation of crash barriers on structures;

c) To shield fixed objects. If necessary, median barriers shall be flared to encompass a fixed object, which may be a light post, foundation of overhead signs, bridge pier etc.;

d) In the depressed medians having width less than 15 m.

10.7.3 Crash barrier acceptance standards

- a. *The barrier shall be capable of restraining a vehicle from penetrating, vaulting over or wedging under the installation;*
- b. *Unless otherwise designed, the barrier must also remain intact so that detached elements and debris will not create hazards for vehicle occupants or other traffic;*
- c. *The system must be designed and installed so that spearing does not occur,*
- d. *The vehicle/barrier collision should result in smooth redirection of the vehicle at an angle so that the vehicle will not create a hazard to trailing or oncoming vehicles;*
- e. *The collision must not result in excessive damage to the vehicle occupants.*
- f. *On mainline expressway; places affecting other railways, important highway and important utility lines and places; adjacent to water bodies the crash barrier shall comply with test level TL-3, TL-4 and TL-5 performance in accordance with NCHRP Report 350, or containment Levels N1 , N2, HI and H2 as per EN 1317-2.*
- g. *For all other places such as interchange ramps, connection to local roads, protection of bridge piers on median and roadside, etc., the crash barrier shall comply with at least Test Level TL-2 in accordance with NCHRP Report 350 or containment level N1, N2 as per EN 1317*

C27.5 UK PART 8 TD 19/06 Requirement for Road Restraint Systems.

The following section contains the full text of Section 3, a comprehensive treatment of the Criteria and Guidance for the provision of permanent safety barriers. This is considered a sound basis to include in the RTMC manual, with the necessary acknowledgement and paraphrasing.

3. CRITERIA AND GUIDANCE FOR THE PROVISION OF PERMANENT SAFETY BARRIERS

Performance Class Requirements

General

3.1 All safety barriers installed must be compliant with the Test Acceptance Criteria requirements of BS EN 1317-2 and the following criteria.

3.2 The Design Organisation must specify the required Performance Class for each safety barrier installation in terms of Containment Level (e.g. N1, N2, H1, H2 or H4a), Impact Severity Level (ISL) (e.g. ISL Class B) and the Working Width Class (W1 to W8).

3.3 The Design Organisation must identify any special requirements with regard to the provision of safety barriers which may affect the choice of system by the Contractor, such as the maximum height of safety barrier that allows sufficient visibility. Examples are given in Paragraph 3.110.

Containment Levels

3.4 The containment levels requirements for safety barrier are:

Permanent Deformable and Rigid Safety Barriers:

(i) **On roads with a speed limit of 50 mph or more:**

(a) Normal Containment Level = N2

(b) Higher Containment Level = H1 or H2

(c) Very High Containment Level = H4a

(ii) **On roads with a speed limit of less than 50 mph:**

(a) Normal Containment Level = N1

3.5 Where the Road Restraint Risk Assessment Process (RRRAP) or the requirements below indicate a containment level that is higher than the minimum, as indicated in Paragraphs 3.4(i)(a) or (ii)(a), is required, the higher containment level must be specified.

Impact Severity Levels (ISL)

3.6 The ISL for safety barriers must not normally exceed Class B as stipulated in BS EN 1317-2.

3.7 At specific locations where the containment of an errant vehicle (such as a heavy goods vehicle) is the prime consideration, or where there is limited space available, a Vehicle Restraint System (VRS) may need to be installed with an ISL greater than Class B. The use of VRS with an ISL greater than Class B must be with the agreement of the Overseeing Organisation and justified by the RRRAP. Where an ISL level greater than Class B is to be used, the limits ASI ≤ 1.9 and THIV ≤ 33 km/h shall apply.

Working Width Class

3.8 The Working Width Class for each safety barrier installation must be the same as or less than that specified by the Design Organisation.

3.9 The Design Organisation must specify the greatest Working Width Class that the local highway geometry will allow. (See Paragraph 3.93 for Guidance).

3.10 Where the Working Width Class for a proposed System is based on an update to EN 1317:1998, a check must be carried out to ensure that there is sufficient clearance between the hazard being protected and the restraint system that is proposed, to ensure that the hazard will not be hit by a vehicle intruding beyond the restraint system (see Chapter 1 Paragraph 1.49 et seq.).

General Requirements

General

3.11 Permanent Deformable or Rigid Safety Barriers must be provided where the outcome of the RRRAP indicates that a VRS is necessary.

3.12 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.

The following is a list of hazards that must be identified within the RRRAP. This list is not exhaustive and other hazards should be considered.

(i) Above ground structural supports, bases or foundations which are positioned less than 3 m above the adjacent paved carriageway. The chance of reaching a hazard that is greater than 3 m above the paved carriageway is thought to be very low, but if there are any reasons or conditions at the site that the Designer believes will make it possible for the hazard to be reached, the hazard should also be identified.

(ii) Drainage culvert headwall.

(iii) Restricted headroom at a Structure or part of a structure (See Figure 3-10 and **TD 27 [DMRB 6.1.2]**).

(iv) 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. A 'smooth' face may include a surface that may have an irregular surface finish subject to the maximum amplitude of the steps and undulations in the surface not exceeding 30 mm when measured with respect to a plane through the peaks. The plane must be broadly parallel to the road alignment. A structure that has a 25 mm wide chamfered construction joint in its surface would be regarded as smooth.

(v) An exposed rock faced cutting slope, rock filled gabions, crib walling or similar structures (See **BD 68 [DMRB 2.1.3]**).

(vi) Soil cutting slopes and earth bunds greater than 1 m high and with a side slope gradient of 1:1 or steeper.

(vii) Embankments and vertical drops.

(viii) Strengthened or geotextile reinforced slopes.

(ix) Environmental noise barriers or screens.

(x) Highway boundary fences and walls.

(xi) Dwarf retaining walls surrounding hazards such as drainage access manholes and communication cabinets.

(xii) 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.

(xiii) Road lighting columns, though see further guidance in Paragraphs 3.123 to 3.125 below.

(xiv) High mast road lighting columns.

(xv) Sign and signal gantry supports.

(xvi) 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.

(xvii) Large signs (typically those higher than 2 m) located in a position where the fascia could be struck by an errant vehicle.

(xviii) Above ground communications control cabinets, pillars and equipment (other than emergency telephones), CCTV Masts (See **BD 83 [DMRB 2.2.1]**, Telephone Masts (See **TA 77 [DMRB 9.5.1]**).

(xix) Stores for emergency/diversion signs and similar permanent structures.

(xx) A tree or trees having, or expected to have, trunk girths of 250 mm or more (measured at a height of 0.3 m above ground level) at maturity (see Guidance Paragraph 3.130 et seq.).

Hazards where Others could be affected:

(i) Non-motorised User (NMU) subway entrance or agricultural underbridge passing under the highway.

(ii) A railway, canal or separate road or carriageway.

(iii) Public meeting places where a number of people would be present for some time such as schools, hospitals, recreational, retail facilities or factories.

(iv) Chemical works, petroleum storage tanks or depots, facilities manufacturing or storing hazardous materials in bulk.

3.13 The RRRAP must be used to determine if a safety barrier is required to protect each single hazard identified or, where there are a number of hazards that are in close proximity, the group; and, if a safety barrier is required, then to determine the Length of Need for the single hazard, or group thereof to produce a risk that is 'broadly acceptable'. Note that some safety barrier systems may require additional lengths to function as intended.

3.14 Road furniture and equipment must not be positioned in front (i.e. within the set-back) of a new or existing Road Restraint System (RRS) and, in general, it should not be placed immediately in advance of nor within the available Working Width of a new or existing RRS (as it can affect the way the RRS performs) unless the road furniture or equipment has been designed to be passively safe and, if hit, will not be displaced into the adjacent carriageway or give rise to a secondary event, and the circumstances outlined in Paragraphs 3.66 to 3.69 dealing with Relaxations and Departures are met.

Visibility

3.19 The requirements stipulated in **TD 9 [DMRB 6.1.1]** in respect of visibility, sightlines over and in front of safety barriers and Stopping Sight Distances must be complied with.

3.20 In difficult situations where the horizontal and/or the vertical alignments or other physical features prevent the establishment of the appropriate Stopping Sight Distance requirements stated in **TD 9**, the Design Organisation must apply to the Overseeing Organisation for a Departure from **TD 9**.

Set-Back

3.21 Set-back at permanent systems must be in accordance with **TD 27.** The relationship between set-back and Working Width at hazards in verge and central reserve is given in Figure 3-4.

3.22 Any proposal to reduce set-back from the values required in **TD 27** must be accompanied by a Risk Assessment identifying the factors considered, their likely combined effects and justification for the proposal and be included in an application for a Departure from Standard to the Overseeing Organisation.

3.23 Some terminals protrude proud of the traffic face of the general run of the VRS and, therefore, set-back should be measured to the part of the VRS closest to the traffic face. Further guidance is given in Paragraph 3.96.

3.24 On central reserves where there are no hazards and there is only one double-sided deformable safety barrier, or rigid safety barrier between the carriageways, the set-backs on both sides of the safety barrier must not be less than as stipulated in **TD 27** nor less than the Working Width Class of the safety barrier minus the actual width of the safety barrier (See also Figure 3-3). This is to ensure that the safety barrier will not encroach into the opposing carriageway if hit.

3.25 Set-back greater than the minimum values stipulated in **TD 27** should be provided where space allows and as described in that document.

3.15 The safety barrier layout must be carefully planned to minimise the number of approach ends of safety barriers, as the ends themselves are a hazard. Where new safety barriers are required and gaps of 50 m or less arise between two separate safety barrier installations, where practicable, the gap must be closed and the safety barrier made continuous. Further Guidance is given in Paragraph 3.107 and 3.108.

3.16 The treatment and positioning of the ends of safety barriers must also be carefully considered to minimise the risk they impose. For further guidance on the end treatment of safety barriers, see Chapter 5, Guidance on Terminals.

3.17 The Design Organisation must ensure that the site is inspected prior to carrying out the RRRAP.

3.18 The Design Organisation must ensure that during construction works the original design assumptions are valid. If the original design assumptions are not valid, the Design Organisation must carry out the RRRAP again and ensure that the new requirements are provided. This is particularly important at embankment side slopes, at the transitions between cut and embankment or start of sidelong ground, at locations where there are hazards present that may affect Others, and on curves where there may be subtle details present that are not apparent from drawings and which are difficult to model in the RRRAP.

Minimum Lengths of Safety Barrier

3.26 If the Length of Need determined using the RRRAP is less than the minimum length of "full height" safety barrier in advance given in Table 3-1, then the minimum length must be provided. In addition, at least the corresponding minimum length of "full height" safety barrier beyond the single hazard, or group thereof, given in Table 3-1 must also be provided.

3.27 Where the traffic can travel in both directions along the same carriageway, either under normal conditions or under temporary traffic management such as contraflow (either now or at some future time), the RRRAP must be used to determine whether the minimum Length of Need of safety barrier beyond that given in Table 3-1 is sufficient under these conditions. The greatest of the lengths of need so determined must be used; however, where the Length of Need for the temporary situation is longer than the Length of Need for normal conditions, the extra Length of Need may be provided only for the period that the temporary situation is operative, or it may be provided as a permanent solution.

3.28 The safety barrier provided to protect a single hazard, or group thereof, must be a continuous length that may or may not be made from one type of product (e.g. a metal safety barrier – concrete safety barrier – metal safety barrier would constitute a continuous length).

Safety Barrier Containment Level	MINIMUM "full height" lengths of safety barrier[1]	
	In advance of hazard	Beyond hazard
Normal (N2 or N2)	30 m	7.5 m
Higher (H1 or H2)	30 m	10.5 m
Very High (H4a)	45 m	18 m

TABLE 3-1

Notes: 1. These are minimum lengths. Manufacturers may require longer lengths than specified above. (Refer to Chapter 1 Paragraph 1.42 Length of Need.)

3.29 Where the constraints of the site make it physically impossible to install the required lengths of safety barrier, the maximum achievable lengths must be recorded together with the results of the RRRAP relating to the actual situation and full details of the alternatives examined together with the justification for the proposed lengths, must be forwarded to the Overseeing Organisation for their consideration as a Departure from Standard.

Provision at Vehicle Parapets

3.30 Where a vehicle parapet is required, a safety barrier must be provided to prevent direct impact with each approach end of the vehicle parapet. The Performance Class of the parapet and VRS may differ. At each approach end of the vehicle parapet, the safety barrier must be full height for at least the minimum length in advance for the Containment Level of the safety barrier stated in Table 3-1 and must continue the line of the traffic face of the vehicle parapet. The minimum length may include the length of any transition between the parapet and safety barrier.

3.31 Where traffic can travel in both directions, either under normal conditions or under temporary traffic management such as contraflow, a safety barrier must be provided at each end of the parapet in accordance with Paragraph 3.30. If traffic can only flow in both directions under temporary traffic management, then the safety barrier provided at the end that is normally the departure end of the parapet may either be permanent or only installed for the duration of the Works. When the temporary situation ceases, the minimum length beyond the hazard specified in Table 3-1 shall remain.

3.32 A transition must be provided between the safety barrier and the vehicle parapet. The parapet must be capable of resisting forces applied from the safety barrier or transition. Refer to Chapter 6 for details of requirements for transitions.

3.33 The RRRAP must be used to determine whether the minimum Length of Need of safety barrier in advance given in Table 3-1 is sufficient under the conditions stated in Paragraphs 3.30 and 3.31. If the Length of Need determined from the RRRAP is greater than the minimum length given, then the Length of Need from the RRRAP must be provided. See also Chapter 4 Paragraph 4.37 relating to provision at railways.

3.39 It should be noted that, unless there is a very significant risk, for instance, at a point where large numbers may congregate regularly for significant periods of time, it is not normally the case that a safety barrier is provided for protection of pedestrians and other NMUs. Whilst it is preferable for NMU routes to be located completely beyond the Working Width of the safety barrier, it will often be the case that there is insufficient space available. The NMU route should, therefore, be located as far from the rear of the safety barrier as is reasonably practicable.

3.40 Where there is a significant pedestrian movement and the need to channel the movements has been established, consideration should be given to the provision of a separate pedestrian guardrail behind the safety barrier (See Chapter 9 and **TA 91**).

Motorcyclists

3.41 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.

3.42 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.

Drainage and Kerbs

3.43 Consideration must be given to the form and design of the carriageway, verge and central reserve drainage and its maintenance and to the interaction of the drainage with the safety barrier systems to ensure satisfactory performance of both.

3.44 When considering the use of surface water drainage channels and or kerbing, the Design Organisation must evaluate the safety aspect in relation to the position of any safety barriers and the relevant set-backs (see **HA 37 [DMRB 4.2]**, **HA 83 [DMRB 4.2.4]** and **HA 119 [DMRB 4.2.9]**and **MCHW-3 Series B and F**). Consideration must be given to their placement in terms of the safety of two-wheeled powered vehicles (see **HA 83**).

Verges and Central Reserves

Provision in Verges and Central Reserves – General

3.45 The verge and central reserve below and immediately adjacent to the safety barrier should be nominally flat.

Provision in Verges – General

3.46 Figures 3-4 to 3-10 show the general layout of safety barriers adjacent to hazards.

3.47 Figure 3-12 shows the minimum taper lengths required at changes of horizontal alignment of verge and central reserve safety barriers. Advice should be sought from the VRS manufacturer about the particular systems to confirm that these lengths are adequate.

3.48 Figure 3-10 shows the requirements where there is restricted headroom at a structure. (See **TD 27 [DMRB 6.1.2]**)

3.49 Where the RRRAP indicates that a safety barrier will be required and the safety barrier will be placed adjacent to a slope, reference should be made to Figures 3-1 and 3-2 which show the relationship of the safety barrier to the top of embankments and sidelong ground and toe of cuttings in verge and central reserve situations.

> 3.50 On carriageways that are divided/separated (e.g. when one carriageway has been constructed a distance from the other to take advantage of the ground profile to minimise cut/fill or to improve alignment) 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.

3.51 Any safety barrier installation in the vicinity of a Motorway Police Observation Platform should be in accordance with the requirements of **TA 66 [DMRB 6.3.2]**. Where the Police have agreed that the Observation Platform is no longer required it should be removed.

3.52 At exposed rock faced cuttings slopes, additional rock netting may be required behind a safety barrier to prevent falling rocks from reaching the hardstrip, hardshoulder and or carriageway, see Paragraph 3.104 et seq. of the Guidance section.

Provision at Nosings

3.53 Nosings, where one carriageway diverges from another, are areas that are particularly prone to runoff accidents. There is always a balance to be struck between (a) the need to place signs, lighting columns or other street furniture in the vicinity of a nosing and protect them from errant vehicles, (b) keeping the area free of all hazards (including safety fencing), whilst discouraging deliberate overrunning of the nosing area, and (c) keeping within the physical horizontal and vertical constraints of the location.

3.54 A flat area, ideally free of all hazards, of around 10m length should be maintained at the back of nosing. (See **TD 22 [DMRB 6.2.1]** and Figure 3-13).

3.55 Where it is necessary to install street furniture or other hazards, these should be kept to a minimum and ideally be passively safe in accordance with **TA 89 [DMRB 8.2.2]**. They should be placed as far from the point of the physical nose as practicable. Where passive safety is not possible and safety barrier protection is required to protect the hazards (including the level difference between the adjacent carriageways), sufficient space along and across the nosing area should be allowed for any safety barriers, terminals and the required Working Widths and set-back.

D ANALYSIS

The literature review gives an overview of the sources and themes that are relevant for developing the National Design Guideline that details the requirements and criteria, giving guidance for the provision, design and layout of permanent and temporary safety barriers, vehicle parapets, terminals, transitions, crash cushions, pedestrian parapets, pedestrian guardrails, vehicle arrester beds and anti-glare screens. Safety policies, strategies and design guides promoting safety above operations are in line with international best practice, driven by the Safe System approach.

The literature review was compiled to set the framework for developing the proposed RTMC manual, and it is accepted that the literature presented may be elaborated, expanded and augmented as the topic is written up. The final literature study to be included in the RTMC manual will therefore contain more references.

Design guidelines are mostly aligned with AASTO Guide for Design of Highways and Streets (AASHTO, 2018), and the SANRAL Geometric Design Guide(SANRAL, 2003) is sufficient. It also includes chapters on roadside safety and arrestor beds.

Guidelines and manuals for the safe design of roadsides are crucial for this RTMC project. The outcome in terms of reference requires the consultant to ''Develop a National Design Guideline that details the requirements and criteria, giving guidance for the provision, design and layout of permanent and temporary safety barriers, vehicle parapets, terminals, transitions, crash cushions, pedestrian parapets, pedestrian guardrails, vehicle arrester beds and anti-glare screens''.

The South African Road Safety Manual, 1999. Volume 6 Road Side Hazard Management (Committee for Land Transport, 1999) is a comprehensive source of all the aspects and topics that the proposed manual needs to synthesise. This publication's index is presented in Appendix D in a table with the additional topic identified in the literature review.

The overview of topics contains the descriptions and definitions of the subject matter and can be referred to when elaborating in the proposed manual. This will not limit the manual's content, as further research into the topic may include more literature.

The literature on the testing methods and modelling reveals that all countries and states use the two current testing protocols, the European EN1317 series and the USA MASH test guide as the basis for setting standards of performance and approval of products. The European Union has a lighter vehicle fleet for passenger vehicles, and the difference in test vehicles is justified. The USA's dominant vehicle is the light truck and Sports Utility Vehicles often based on the light truck platforms, and these vehicles are not represented in Europe. There is an acceptance that these two tests standards are sufficient and can be adapted for new vehicle types over time, but the variables such as tolerance of the human body are well defined. The IRF proposes that it does not matter which test was used, but the critical issue is the only tested products should be used on the road, with designers taking responsibility to specify the correct level of containment for the traffic operations and road geometry. The test should be done by independent research institutions such as the Texas Transportation Institute at Texas A&M University, Midwest Roadside Safety Facility (MwRSF) at the Nebraska Transportation Center, Transport Research Laboratory and the French test facilities. Test facilities run by suppliers of products such as Holmes in New Zealand should be used with strict independent monitoring.

From the literature, it is clear that current research is into numerical modelling calibrated with full-scale testing, but once calibrated can be used to simulate any configuration and test variables. It is suggested that South Africa follow the latter path, as full-scale test facilities are expensive to construct, operate and manage with highly paid technicians and researchers.

E INSTITUTIONAL ANALYSIS

The institutional analysis attempts to identify from the literature where the capacity to design, test, certify and do quality control on products and installations lies.

The actual testing of barriers, terminals, crash cushions and parapets in the USA has been mainly done at the Texas Transport Institute at the Texas Agriculture and Mechanical University Crash: TTI Proving Ground 3100 SH 47, Building 7091 Bryan, TX 77807. An example of a report of tests done by Nauman M. Sheikh, Roger P. Bligh, Wanda L. Menges, Darrell L. Kuhn, and Glenn E. Schroeder. 2019, is MASH TL-4 Testing and Evaluation of Free-Standing Single Slope Concrete Barrier with Cross-Bolt Connection (Sheikh *et al.*, 2019).

The other facility is Midwest Roadside Safety Facility (MwRSF) Nebraska Transportation Center University of Nebraska-Lincoln 130 Whittier Research Center 2200 Vine Street Lincoln, Nebraska 68583-0853. An example of a report of tests done Bielenberg, R.W., Lingenfelter, J.L., Kohtz, J.E., Faller, R.K., and Reid, J.D. 2017 is Testing and Evaluation of MASH TL-3 Transition Between Guardrail and Portable Concrete Barriers.

UK Transport Research Laboratory (TRL). Crowthorne, UK is a well-known research institution that has the capacity to do tests with test dummies. They are well known for testing crashes with fixed objects and the New Car Assessment Program (NCAP).
https://www.securityworldmarket.com/na/Newsarchive/jamps-franklin-completes-test-of-vehicle-barrier-system-with-trl

The suggestion is for South Africa not to construct its own facilities, but to create the capacity to do numerical modelling. The South African Bureau of Standards is the statutory body that certifies products and standards. The subcommittee on-road restraint systems have opted to adopt the European EN1317 series of test procedures. This subcommittee is currently updating the specifications, which are based on existing standards, in order to control products used in South Africa.

A company Holmes Solutions in Christchurch New Zealand does tests for clients, typically suppliers. A video can be seen on their website for a test requested by ArcelorMittal Global R&D, CRM Group and

Gregory Industries for a MASH Test Level 5 test for their new Guardian 5 (G5) longitudinal barrier (the world's first MASH TL5, high-containment steel safety barrier) https://www.holmessolutions.com/mash-test-level-5/.

GDTech commits to deliver an integrated service covering the entire product development process: from the development of the plans to the crash test's realisation. GDTech can model and simulate all types of road equipment: from safety barriers installed in ground to motorcycle protections, including temporary barriers, cable barriers or shock attenuators.

https://www.gdtech.eu/en/services/crash-dynamic-and-traffic/road-vehicle-restraint-systems/

The Austrian and New Zealand approach seems to be that the control over products rest with Austroads the federal organisation of road transport and traffic agencies in Australia and New Zealand. "It publishes guidelines, codes of practice and research reports that promote best practice for road management organisations in Australasia. Austroads is based in Sydney and funded by the federal Australian government. Operations of Austroads are primarily administrative, with all research and engineering work contracted out, such as to produce the Australian standards for construction, planning and design in roads. (https://en.wikipedia.org/wiki/Austroads)

Since its introduction in 1999, Australian/New Zealand Standard AS/NZS 3845 (the Standard) has utilised the National Cooperative Highway Research Program Report 350 (NCHRP 350) guidelines as the basis for testing protocols to assess safety barrier related hardware and devices.

Stan Robb, Chair of the Austroads Safety Barrier Assessment Panel wrote a letter under Austroads letterhead dated 23 April 2018 (Rob, 2018):

> *Previously submissions to the Panel were based on NCHRP 350 in line with the Standard. In 2017, Part 1 :2015 and Part 2:2017 of the Standard recognised the introduction of the American Association of State Highway and Transportation Officials (AASHTO) 2009 Manual for Assessing Safety Hardware (MASH) guidelines. In an effort to encourage the installation of MASH crash-tested devices, and in line with the changes to the Standard, the Panel has updated its product*

submission criteria. Effective immediately, all submissions received by the Panel must be in accordance with AASHTO's MASH guidelines or an equivalence rating to MASH in accordance with AS/NZS3845 Parts 1 and 2. The Panel will transition the current suite of accepted road safety barrier systems and devices within the Australasian market to MASH guidelines in line with the timeframes.

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APPENDICES

Appendix A: How does a Systematic Review Differ from a Traditional Literature Review?

Source: Cornell University Library, s.n

URL: https://guides.library.cornell.edu/evidence-synthesis

One commonly used form of evidence synthesis is a systematic review. This table compares a traditional literature review with a systematic review.

	Traditional Literature Review	Systematic Review
Review Question/Topic	Topics may be broad in scope; the goal of the review may be to place one's own research within the existing body of knowledge, or to gather information that supports a particular viewpoint.	Starts with a well-defined research question to be answered by the review. Reviews are conducted with the aim of finding all existing evidence in an unbiased, transparent, and reproducible way.
Searching for Studies	Searches may be ad hoc and based on what the author is already familiar with. Searches are not exhaustive or fully comprehensive.	Attempts are made to find all existing published and unpublished literature on the research question. The process is well-documented and reported.
Study Selection	Often lack clear reasons for why studies were included or excluded from the review.	Reasons for including or excluding studies are explicit and informed by the research question.
Assessing the Quality of Included Studies	Often do not consider study quality or potential biases in study design.	Systematically assesses risk of bias of individual studies and overall quality of the evidence, including

		sources of heterogeneity between study results.
Synthesis of Existing Research	Conclusions are more qualitative and may not be based on study quality.	Bases conclusion on quality of the studies and provide recommendations for practice or to address knowledge gaps.

Appendix B: Bartlett's evaluation of road design standards

Table 1: Subjective evaluation of some country standards

Good	Useful	Limited	Minimum / none
Abu Dhabi Emirate	Argentina	Afghanistan	American Samoa
Australia	Bangladesh	Albania	Anguilla
Austria	Chile	Algeria	Antigua and Barbuda
Finland	Ecuador	Bhutan	Armenia
Germany	Ethiopia	Bolivia	Belgium
Netherlands	France	Bosnia and Herzeg	Botswana
Norway	Hungary	Brazil.	Croatia
Russia	Iceland	Colombia	Cyprus
Sweden	Ireland	Costa Rica	French Guiana
Switzerland	Kenya	Czech Republic	Ghana
	Nepal	Estonia	Libya
	Paraguay	Georgia (Caucasus)	Mozambique
	Peru	Greece	Samoa
	Qatar	Honduras	Zambia
	Singapore	Hong Kong	
	South Africa	India	
	Spain	Indonesia	
	Tanzania	Italy	
	Uganda	Nigeria	
		Portugal	
		Puerto Rico	
		Romania	
		Saudi Arabia	
		Serbia	
		Slovenia	
		Turkey	
		UK	
		USA	

Table 2: Subjective evaluation of some multi-country standards

Good	Useful	Limited	Minimum / none
Austroads	SADC	Arab Mashreq	
		ASEAN	
		Asian Highway Standards	
		TEM	

Appendix C: Software Developed for Risk Assessment and Selection of Road Restraint Systems

(This appendix was extracted from a project report compiled by engineering interns at the SANRAL Academy in Port Elizabeth, and supplied to this project by Mr Andrew van Gruting).

1 THE ROAD RESTRAINT RISK ASSESSMENT PROCESS (RRRAP)

The software based RRRAP forms part of a risk management framework that will allow the level of risk from a hazard, in or beyond, the verge, or in the central reserve, to be calculated. The RRRAP will allow a review of the effect of various options on the associated risk level and, where appropriate, the B/C.

The RRRAP acknowledges that RRS have an inherent element of risk, and that this risk must be balanced by the cost benefit afforded by a RRS in mitigating the severity and implications of accidents.

The RRRAP software has two main elements: risk analysis, and risk assessment. Risk analysis enables the designer to enter information about a site (such as: location and hazard; traffic speed; alignment), and the risk that each hazard may pose, to be presented in terms of the probability of an accident/year/km and benefit/cost ratio. The software then enables various control measures to be reviewed and their effect on the risk level and relative benefit/cost assessed.

An important function of the RRRAP is that of providing an audit trail for the Designer and Overseeing Organisation by formally recording all the factors which were considered in the design process. The RRRAP forms an integral part of the TD 19/06 Standard as it is the vehicle through which this procedure is undertaken, and the decisions are recorded.

The RRRAP is currently based on an MS Excel spreadsheet and uses 'drop downs' to facilitate data entry, and macros to assist in calculating and recording risk and cost benefit information for each of the options investigated.

The RRRAP also requires the Designer to input information that is ancillary to the process of hazard identification and risk mitigation that provides background details for the audit trail.

The RRRAP has not been developed to assess the risk from roadside hazards at speeds of less than 50 mph and/ or for traffic flows of less than 5,000 AADT. If the risk from roadside hazards, therefore, needs to be assessed at speeds of less than 50 mph or traffic flow of less than 5,000 AADT, then the following may be considered:

(i) Use the RRRAP at 50 mph and the higher of the AADT for the road and 5,000 AADT but use all other information from the site to aid any decision making about those road side hazards. It is recommended that a site inspection is carried out to ensure local hazards are considered that might fall outside the hazards included within the RRRAP.

(ii) Carry out a separate risk assessment without the aid of the RRRAP and use the guidance and technical requirements to aid in the decision-making process.

In the UK the results of the RRRAP for each design must be included as part of the Health and Safety documentation.

ASSESSING RISK USING THR RRRAP

The RRRAP uses a simple formula. It assesses risk as:

- The *Likelihood* of an errant vehicle hitting a roadside hazard multiplied by the resulting *Consequence*.
    - The Likelihood of an errant vehicle hitting a hazard is based on the likelihood of it leaving the road, the distance of the hazard from the running lane, the nature of the ground the errant vehicle would have to cross, etc.
    - The Consequences are based on the speed of the errant vehicle and the aggressiveness of the hazard (i.e. the ability to do harm).

The RRRAP will highlight if the risk is 'broadly acceptable', 'tolerable', or 'unacceptable'. The RRRAP must be used to determine if a safety barrier is required to protect each single hazard identified or, where there are a few hazards that are near, the group. If a safety barrier is required, RRRAP will determine the Length of Need for the single hazard, or group thereof to produce a risk that is 'broadly acceptable'.

The RRRAP aims to:

(iii) Identify the hazards - location and hazard; traffic speed; alignment etc

(iv) Identify the risk that each hazard may pose, decide who might be harmed and how

(v) Evaluate the risks, and decide on precaution/mitigation in terms of the probability of an accident/year/km and benefit/cost

(vi) Eliminate/control or mitigate identified risks by:

- removing and relocating obstacles (Clear Zone Concept)
- modifying roadside elements to make them less aggressive (incl. safety barrier terminals and transitions)
- shielding obstacles (rigid, semi-rigid, flexible and temporary barriers)
- change in road geometry to reduce the probability of vehicle runoff and/or consequences
- increasing the length of the VRS
- a combination of these to maximise the B/C ratio

It will not state how the risk should be mitigated but will allow options to eliminate or control the hazards, and/or to mitigate the risk to be tested and their impact on the risk level assessed and recorded. Options might include: removing or relocating the hazard; a change in, or redesign of, a hazard to make it less aggressive (e.g. making it passively safe, or smooth-faced); a change to the highway geometry or cross-section to reduce the probability of vehicle runoff and/or consequences; increasing the length of VRS; or a combination of these in order to maximise the B/C ratio.

The cost of crashes data base must be checked for local application to ensure that the RTMC Cost of Crashes values are used and escalated to year of investigation.

GENERAL INFORMATION REQUIRED FOR THE RRRAP TOOL

Key to the process is that:

- the decision must be taken and recorded. It must not be allowed to happen by default
- the decision must be taken at the correct level in the organisation
- the decision taker must not be afraid of doing nothing, if to do nothing is the proper conclusion from following the Road Restraint Risk Assessment Process (RRRAP)

The RRRAP is split into several worksheets grouped into the following categories:

- Basic Details: This section records key details such as: Project name; Designer and company name; reason why the works are being done.

- Features Listing: This section is used to identify whether any hazard listed in each category of hazard is present in the length of road verge (or central reserve) being assessed.
- Hazard Data Entry worksheets: Details of the type of hazard, e.g. street sign, its start chainage, length and width, offset and other relevant information is entered. The offset of each hazard and safety barrier is referenced relative to a standard point, called 'Psb'
- Option Evaluation: The risk and cost benefit calculations in the RRRAP are based on where the traffic and the hazard are relative to Psb.
- Recording Results: The RRRAP can be used to record the various Options looked at and the chosen Option for each hazard. In some cases, this might mean no Vehicle Restraint provision.

For any site where it is not possible to propose a solution that produces an 'acceptable' level of risk, the Design Organisation must consider if a Relaxation can be used. If a Relaxation cannot be used, a Departure from Standard must be applied.

Road Safety Audits must be undertaken on all highway schemes involving removal, provision or improvement of RRS.

CHALLENGES AND LIMITATIONS OF RRRAP

This risk estimation tool has been developed using British collision records for roads with speeds of 50 mph or greater, and with traffic flows of more than 5,000 vehicles of any classification (AADT). Experience of using the TD 19 risk-based approach to low speed and low flow roads found it likely to result in over application of RRS's, and it may not represent best use of limited resources.

There are several reasons why the use of the RRRAP risk model is not suitable for direct application to low speed or low-flow roads:

- The RRRAP data is from many routes that share a large number of common features;
- Local authority roads are much more diverse and a huge variety of risk-related circumstances exist;
- RRRAP data is from routes that have substantially better road geometry;

- RRRAP data is from routes that have other safety features that would not typically be present on local highway authority routes, e.g., hard shoulders or strips, motorway incident detection, and automatic signalling;

Further challenges include:

- The tool parameters can be viewed as being too black and white – real world has shades of grey
- Designers often forget the "Do nothing" scenarios
- "RRRAP is theoretically a good concept. However, the current system is not flexible enough and overly complex. It needs to be stripped back to a more basic and fundamental process that gives the designer control and more input into the specific requirements of safety barrier
- Needs common-sense approach
- RRRAP does not make provision for pedestrian restraint systems
- The RRRAP is not capable, at present, of assessing the risk to motorcyclists

2 ROADSIDE SAFETY ANALYSIS PROGRAM (RSAP) V3

The 1988 and 1996 American Association of State Highway and Transportation Officials (AASHTO) Roadside Design Guide includes general warrants for the use of traffic barriers and other roadside safety features. However, these warrants do not address the cost-effectiveness of such installations. The Roadside Design Guide also includes information on a computer program, ROADSIDE, which was developed for cost-effectiveness analysis. However, agencies using the ROADSIDE program experienced difficulties, and some found the results questionable.

The Federal Highway Administration (FHWA) adopted the National Cooperative Highway Research Program (NCHRP) Report 350, R*ecommended Procedures for the Safety Performance Evaluation of Highway Features*, as the official guidelines for safety performance evaluation of highway features.

The Roadside Safety Analysis Program (RSAP) was developed to provide improved software for cost-effectiveness analysis of roadside features and to formulate procedures to provide roadside safety features that are better tailored to the specific conditions of a site

RSAP is an encroachment-based computer software tool for cost-effectiveness evaluation of roadside safety improvements originally developed under the NCHRP Project. Subsequently, some improvements were made, bugs corrected, and patches installed under another NCHRP project. A third NCHRP project, was initiated but never completed. Various releases of RSAP have been distributed with the AASHTO Roadside Design Guide (RDG) since the 2002 edition. This research effort updated RSAP to the third version (i.e., RSAPv3). Version 3 of RSAP (RSAPv3) is available electronically at no charge from AASHTO to purchasers of the Roadside Design Guide.

RSAPv3 is comprised of a series of data entry and data storage Excel worksheets which assists in performing roadside safety economic analyses and serves as an alternative to the warranting approach. The program starts with the Project Information Worksheet. When all the information is entered in each worksheet a button will appear that takes you to the next appropriate worksheet. The tabs on the controls dialog box and the associated Worksheets are:

- Project - Project Information Worksheet
- Traffic - Traffic Information Worksheet
- Highway - Road Segments Worksheet
- Alternatives - Alternatives Worksheet
- X-Section - Cross-Section Worksheet
- Analyze - There is no worksheet associated with the Analyze tab
- Results - Results Worksheet
- Settings - There is no worksheet associated with the Settings tab
- Hazards - Severity Worksheet

RSAPv3 incorporates substantive advances in roadside safety and divides collisions into three independent events:

- The encroachment, when the vehicle first leaves the road;
- The traversal of the roadside, where hazards may be located;

- The severity of the crash when a vehicle intersects a roadside hazard.

RSAPv3 performs this series of calculations many times, simulating tens of thousands of encroachments for a typical roadway segment and estimating the crash costs of each possible encroachment. After generating all the encroachments and the estimated crash costs, the program produces an estimate of the total crash cost for the segment.

RSAPv3 incorporates data on vehicle trajectories during an encroachment. The trajectories are superimposed on the user-entered data for roadside terrain, and the program assesses all possible interactions of trajectories with user-entered hazards. RSAPv3 replaces the subjective severity index with an objective fatal crash cost ratio based on observed, police-reported crash data. RSAPv3 also accounts for unreported crashes—which can be considered roadside safety successes. The program includes a preloaded selection of crash severity models for many common roadside hazards, such as trees, utility poles, guardrails, and bridge piers.

A benefit/cost report then compares one alternative to another and determines which alternative is the most cost-beneficial to implement.

3 SAVeRS PROJECT

SAVeRS (Selection of Appropriate Vehicle Restraint Systems) is a Research Project funded within the 2012 Call "Safety" of the Transnational Road Research Programme of CEDR (Conference of European Directors of Roads) by Belgium/Flanders, Germany, Ireland, Norway, Sweden, and the United Kingdom to produce a practical and readily understandable Vehicle Restraint System (VRS) guidance document and a user-friendly software tool that would allow users (designers and road administrations) to select the most appropriate solution in different road configurations and traffic conditions.

Within the SAVeRS project a guideline for the selection of the most appropriate vehicle restraint system class and type has been developed and a public tool has been made available.

The Guideline aims at:

- identifying the need for a VRS (barrier placement guidance) and the minimum length of barrier to be placed prior to the hazard ("length of need");

- selecting the most appropriate VRS performance class for safety barriers (including bridge parapets);
- selecting the most appropriate VRS performance class for crash cushions;
- selecting the most appropriate VRS performance class for terminals;
- identifying the need for motorcycle protection systems (MPS).

All the performance classes are given according to EN1317.

Whilst there are standards covering testing, evaluation and classification of VRS within Europe (EN1317 parts 1 to 8), the selection, location and installation requirements are typically based upon national guidelines and standards, produced by National Road Authorities (NRA) and/or overseeing organisations. Due to local conditions, these national guidelines vary across Europe.

In Europe, although the German standard stands out as the most widely adopted, most of the countries have their own dedicated guidelines and standards. However, many approaches, decision processes, tables and graphs are shared or similar among several countries.

The “forgiving roadside” approach is an inherent part of all the standards reviewed within the SAVeRS Project and should always be kept in mind as the main guideline in deciding if a VRS is required or not.

Based on the risk assessment principle described earlier, the procedure developed in the SAVeRS project to select the most appropriate safety barrier performance class and type consists of the following steps:

- define the likelihood of having an impact with a barrier for both a passenger car or a Heavy Goods Vehicle (HGV) by developing a set of Run Off Road (ROR) models
- define the probability that the crash will be contained by the given barrier by comparing the specific crash impact energy (IKE) with the barrier containment lever (VRSCL)
- evaluate the potential consequences of a crash for road users depending on weather the vehicle is contained or not and depending on the hazard the barrier is shielding or protecting from
- a suitable VRS and conduct a Whole Life Cost (WLC) analysis
- evaluate third party risk (based on the chart included in the Guideline).

Each model in the SAVeRS procedure is designed to allow the user to change the calculation parameters. Where possible, different default parameter sets are given for different conditions to allow the user to select the one that best fits the specific case being analysed.

The SAVeRS tool is a free of charge public tool developed as an Excel Spreadsheet (downloadable at www.saversproject.com) that can be used by National Road Authorities, designers road administrations directly involved in road management and researchers for setting VRS requirements, or for site specific risk assessments.

The SAVeRS tool can be applied at a national level in the definition of national standards allowing the different National Road Authorities to identify:

- the minimum return time of a penetration per km that can be deemed acceptable in the design phase;
- the minimum return time of a fatal crash per km that can be deemed acceptable in the design phase;
- the default parameters that should be used in the design phase;
- the minimum VRS class for different traffic conditions and infrastructure layouts to be included in the national standard. This would be used in preliminary design phases and where a site specific analysis is not conducted;
- the situations where a maximum VRS class should be set unless special circumstances justify a higher VRS class.

This tool will allow designers to conduct risk assessments of specific situations and road administration directly involved in road management to set priorities in upgrade programmes. It will also support National Road Authorities to set new standards for minimum performance requirements.

The main innovation of the SAVeRS tool is that the likelihood of having a Run Off Road (ROR) crash can be calculated based on several models implemented in the tool as well as with locally derived models.

The implementation of the SAVeRS Guideline and tool could provide a sounder risk-based selection of vehicle restraint system.

Appendix D: Comparison of the table of content from SARSM 1999 Volume 6 Roadside Hazard Management with others to augment

	AGRS03-16	Guide.	UK C127	Ireland	Indian
MANAGEMENT				All aspects covered	Purpose of this Manual
1. INTRODUCTION	1. Introduction to Roadside Design (2.1)	Chapter 1—An Introduction to Roadside Safety (2.1)	1. Scope	1 Introduction	I. An Introduction to Roadside Hazard Management
1.1 Purpose	1.1 Context Sensitive Designs	Chapter 2—Economic Evaluation of Roadside Safety (2.5)	2. General requirements	2 Roadside Hazards	A. Background to roadside hazard management
1.2 Scope	1.2 Purpose (1.1)	Chapter 3—Roadside Topography and Drainage Features including the Clear-Zone Concept (2.2, 2.6 and 2.14)	3. Requirements for permanent safety barriers	3 Permanent Safety Barriers	B. Safe design principles and the "forgiving roadside concept"
1.7 Terminology AGRS	1.3 Reading this Part in the Context of Part 1 (N/A)	Chapter 4—Sign, Signal, and Luminaire Supports, Utility Poles, Trees, and Similar Roadside Features (10 and 11)	4. Requirements for vehicle parapets	4 Temporary Safety Barriers	C. Engineers can make a difference
1.3 Contents	1.4 Scope of this Part (1.2)	Chapter 5—Roadside Barriers	5. Requirements for terminals	5 Terminals	II. Identifying Roadside Hazards
2. MANAGING ROADSIDE HAZARDS	1.5 Principles Considered in Roadside Design to Achieve the Safest System	1. Overview	6. Requirements for transitions	6 Transitions	A. What is a roadside hazard?
2.1 Introduction	1.6 Roadside Safety Design (2.2 and 2.6)	2. Performance requirements	7. Requirements for crash cushions	7 Crash Cushions	B. Clear zone concept
1.5 Principles Considered in Roadside Design to Achieve the Safest System	1.7 Terminology	3. Barrier recommendations	8. Requirements for pedestrian restraint systems	8 Vehicle Parapets	III. Investigating Roadside Hazards: A Roadside Safety Management Strategy
2.2 The Forgiving Roadside Concept (Clear zone concept)	1.8 Overview of the Roadside Risk Assessment Process	4. Test level selection factors	9. Requirements for temporary safety barriers at roadworks	9 Bespoke Parapets	A. Investigating roadside hazards
1.1 Context Sensitive Designs	1.9 Calculating a Risk Score	5. Structural and safety characteristics of roadside barriers	10. Legacy systems	10 Pedestrian Parapets and Guardrails	B. Roadside hazard management strategy (a tool to assist decision making)
2.3 The Objective of Roadside Hazard Management	2. Network Risk Assessment	6. Placement recommendations	11. Vehicle arrester beds	11 Requirements for Parapet Anchors and Supports	C. Keeping vehicles on the road
2.4 The Key Elements of Roadside Hazard Management	2.1 General	7. Upgrading systems	12. Anti-glare systems	12 References	D. Remove the hazard
1.8 Overview of the Roadside Risk Assessment Process	2.2 Corridor Safety Visions	Chapter 6—Median Barriers (2.13.2)	13. Cattle grids N/A		E. Relocate the hazard
1.9 Calculating a Risk Score	2.3 Treatment of Roads Based on Policies and Practices	Chapter 7—Bridge Railings and Transitions (2.15)	14. Normative references	Examples of Safety Barrier Parameters	F. Alter the hazard
2. Network Risk Assessment	2.4 The Network Roadside Risk Intervention Threshold (NRRIT)	Chapter 8—End Treatments (9.8)	15. Informative references		G. Shield the hazard
2.1 General	2.5 Example of Setting a NRRIT	Chapter 9—Traffic Barriers, Traffic Control Devices, and other Safety (2.16 and 10))	Appendix A. Guidance on the specification of vehicle restraint systems for low speed and/or low flow roads	Lengths of Flared Barriers	IV. Treating (Eliminating or Reducing) Roadside Hazards
2.2 Corridor Safety Visions	3. Program and Project Risk Assessment	Chapter 10—Roadside Safety in Urban or Restricted Environments	Appendix B. Guidance on factors		A. Case study 1: treating roadside hazards in hilly terrain
2.3 Treatment of Roads Based on Policies and Practices	3.1 Overview of the Risk Evaluation Process	Chapter 11—Erecting Mailboxes on Streets and Highways N/A		VRS Justification Sheet	B. Case study 2: rehabilitation of a rural highway
2.4 The Network Roadside Risk Intervention Threshold (NRRIT)	3.2 Concepts Used in Evaluating the Risk at Particular Sites	Chapter 12—Roadside Safety on Low-Volume Roads and Streets			C. Case study 3: reducing run-off-road crashes
2.5 Example of Setting a NRRIT	3.3 Step 1: Assess Against National Practices, Jurisdictional Policies and Corridor Visions				D. Case study 4: upgrade of an urban interchange

3. Program and Project Risk Assessment	3.4 Step 2: Compare the Risk Score with the NRRIT		V. Using Safety Barriers Correctly
3.1 Overview of the Risk Evaluation Process	3.5 Step 3: Identify, Evaluate and Rank Risk Mitigation Options		A. Three groups of safety barriers
3.2 Concepts Used in Evaluating the Risk at Particular Sites	3.6 Step 4: Design the Recommended Roadside Treatments		B. Selection of barriers
3.3 Step 1: Assess Against National Practices, Jurisdictional Policies and Corridor Visions	4. Treatment Options		C. Design and installation considerations
3.4 Step 2: Compare the Risk Score with the NRRIT	4.1 General		VI. Other Roadside Safety Furniture
3.5 Step 3: Identify, Evaluate and Rank Risk Mitigation Options	4.2 Summary of Treatment Options		A. Frangible lighting columns
3.6 Step 4: Design the Recommended Roadside Treatments	4.3 Effectiveness of Treatment Options		B. Drivable end walls
2.5 Economic Evaluation of Roadside Hazard Management Features	4.4 Types of Treatments		C. Impact attenuators (crash cushions)
4. Treatment Options	5. Road Safety Barriers		D. Emergency crossings in medians
4.1 General	5.1 Introduction		
4.2 Summary of Treatment Options	5.2 Factors Considered in Barrier Selection		
4.3 Effectiveness of Treatment Options	5.3 Road Safety Barrier Design Process		
4.4 Types of Treatments	5.4 General Access Through Road Safety Barriers		
2.6 Roadside Clear Zones	5.5 Aesthetic Road Safety Barriers		
2.6.1 Introduction	5.6 Other Road Safety Barrier Design Considerations		
2.6.2 Definition of a clear zone	5.6.1 Barriers at Intersections		
2.7 Rollover Accidents and the Roadside	5.6.2 Stepped Offset		
2.8 Principles of Roadside Safety	5.6.3 Excessive Offset		
2.9 Limited Budgets	5.6.4 Delineation		
2.10 Roadside Safety and the Vehicle	5.6.5 System Height		
2.11 Treatment of Roadside Hazards	6. Roadside Design for Steep Downgrades		
2.12 Severity Indices of Roadside Features (see Risk as well)	6.1 Purpose and Need		
2.13 Roadside Cross-Section	6.2 Containment Facilities		
2.13.1 Introduction	6.3 Warrants for Investigation		
2.13.2 Medians	6.4 Location and Spacing		
2.13.2.1 Median width	6.5 Key Design Considerations		
2.13.2.2 Median slope and design	6.6 Design Process		
2.13.3 Shoulders	7. Work Zone Safety Barrier Systems		
Items 2.13.4 TO 2.16.4 - Not Applicable			
12. Anti-glare systems			
Chapter 10—Roadside Safety in Urban or Restricted Environments			
Chapter 12—Roadside Safety on Low-Volume Roads and Streets			
Appendix A. Guidance on the specification of vehicle restraint systems for low speed and/or low flow roads			
8. Requirements for pedestrian restraint systems			
7. Upgrading systems			
10. Legacy systems			
Part B 1 to 12.5 - Not Applicable			
13. OVERHEAD SIGNS	5. Road Safety Barriers	Chapter 5—Roadside Barriers	
13.1 A Strategy for the Overhead Sign Hazard	5.1 Introduction	1. Overview	
14. CONCLUSIONS	5.2 Factors Considered in Barrier Selection	2. Performance requirements (3 and 6)	
PART C: TRAFFIC BARRIERS	5.3 Road Safety Barrier Design Process	3. Barrier recommendations	
1. INTRODUCTION TO VOLUME 6: PART C	5.4 General Access Through Road Safety Barriers	4. Test level selection factors	
1.1 Scope	5.5 Aesthetic Road Safety Barriers	5. Structural and safety characteristics of roadside barriers	

1.2 Overview	5.6 Other Road Safety Barrier Design Considerations	6. Placement recommendations
2. INTRODUCTION TO TRAFFIC BARRIERS	5.6.1 Barriers at Intersections	7. Upgrading systems
2.1 Background	5.6.2 Stepped Offset	
5.1 Introduction	5.6.3 Excessive Offset	
5.2 Factors Considered in Barrier Selection	5.6.4 Delineation	
5.3 Road Safety Barrier Design Process	5.6.5 System Height	
2. Performance requirements (3 and 6)		
3. Barrier recommendations		
4. Test level selection factors		
5. Structural and safety characteristics of roadside barriers		
6. Placement recommendations		
5.4 General Access Through Road Safety Barriers		
5.5 Aesthetic Road Safety Barriers		
5.6 Other Road Safety Barrier Design Considerations		
5.6.1 Barriers at Intersections		
5.6.2 Stepped Offset		
5.6.3 Excessive Offset		
5.6.4 Delineation		
5.6.5 System Height		
Item 2.2 to 9.5.6 - Not Applicable		
9.5.7 Recommended practice	7. Work Zone Safety Barrier Systems	
Item 9.5.7.1 to 10.8.3 - Not Applicable		
6. Roadside Design for Steep Downgrades / arrestor beds		
6.1 Purpose and Need		
6.2 Containment Facilities		
6.3 Warrants for Investigation		
6.4 Location and Spacing		
6.5 Key Design Considerations		
6.6 Design Process		
11. CONCLUSIONS		
A. Case study 1: treating roadside hazards in hilly terrain		
B. Case study 2: rehabilitation of a rural highway		
C. Case study 3: reducing run-off-road crashes		
D. Case study 4: upgrade of an urban interchange		