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Improving roadside design to forgive human errors

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Abstract

Accidents involving roadsides are typically extremely "unforgiving". Even though the roadside design can affect only marginally the actual number of accidents occurring on a road, the severity of crashes can be considerably reduced if roadsides are designed to be more "forgiving".
Within the IRDES project a practical and uniform guideline that allows the road designer to improve the forgivingness of the roadside and a practical tool for assessing the effectiveness of applying a given roadside treatment have been produced for the following set of roadside features: barrier terminals; shoulder rumble strips; forgiving support structures for road equipment; shoulder width.

Keywords: Road safety; run-off road accidents; forgiving roadsides: barrier terminals; rumble strips; forgiving support structures

1. Introduction

Each year 43,000 persons are fatally injured in Europe due to road accidents. The RISER project has shown that even though 10 percent of all accidents are single vehicle accidents (typically run-off-road (ROR) accidents) the rate of these events increases to 45 percent when only fatal accidents are considered (Riser, 2006). One of the key issues of this high ROR fatality rate is to be found in the design of the roadsides that are often "unforgiving". A forgiving roadside design has a limited effect on reducing the total number of accidents (including property damage only events) but has a strong impact on crash severity thus reducing the number of fatal and injury crashes. The Conference of European Directors of Roads (CEDR) has identified the design of forgiving roads as

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one of the top priorities within the Strategic Work Plan. For this reason, a specific Team dealing with Forgiving Roadsides has been established within the Technical Group (TG) on Road Safety of CEDR.

According to the RISER project [1], a roadside is defined as the area beyond the edge line of the carriageway. There are different opinions and views in literature on which road elements are part of the roadside and which are not. Fig. 1 shows a typical roadway cross section (cut and embankment section) including some roadside elements. In this specific figure, the roadside can be seen as the area beyond the traffic lanes (or carriageway). The shoulders are thus part of the roadside, since the lane markings define the boundaries. The slopes, the clear zones (also called safety zones) and the tree are examples of roadside features that have to be considered by a road designer to make a roadside more "forgiving".

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

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

IRDES (Improving Roadside Design to Forgive Human Errors) is a research project of the cross-border funded joint research programme "ENR SRO1 – Safety at the Heart of Road Design", which is a trans-national joint research programme that was initiated by "ERA-NET ROAD – Coordination and Implementation of Road Research in Europe" (ENR), a Coordination Action in the 6th Framework Programme of the EC. The funding partners of this cross-border funded Joint Research Programme are the National Road Administrations (NRA) of Austria, Belgium, Finland, Hungary, Germany, Ireland, Netherlands, Norway, Slovenia, Sweden and United Kingdom. The aim of the IRDES project, completed in November 2011, was to produce a forgiving roadside design guideline and a practical tool for effectiveness assessment with specific reference to a well identified set of roadside features.

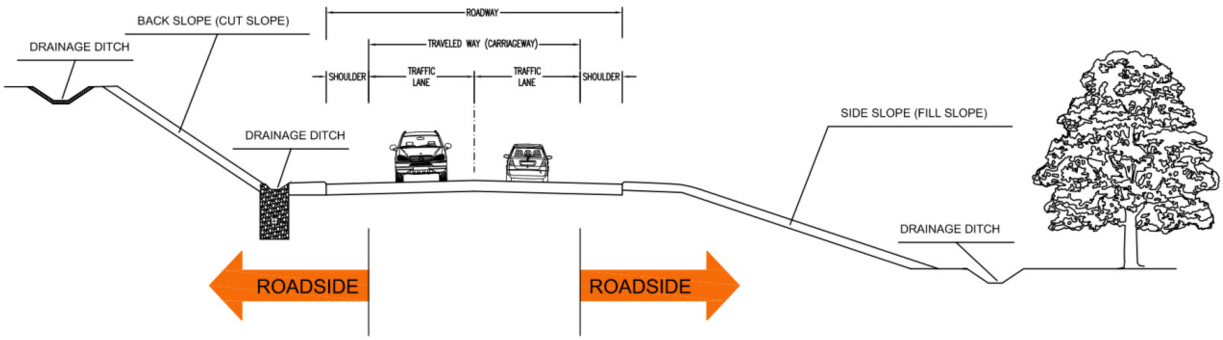

Fig. 1. Roadway cross section with examples for roadsides with clear zones

2. The Forgiving Roadside Design Guideline

2.1. Structure of the guideline

The forgiving roadside design guideline [2] has been developed as a practical handbook that can be easily used by designers 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/Examples;
- Key references.

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

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

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

The guideline is based on the results of an extensive literature review on forgiving roadsides conducted in the first part of the IRDES project [3], combined with an additional literature review focused on the specific safety treatments tackled in the guideline.

The different proposed interventions are linked to the potential effectiveness as evaluated in the specific IRDES activity [4] as well as in other relevant literature in order to allow the user to perform cost-effectiveness evaluations before planning a specific treatment. Case studies from [4] are synthesised in the guideline in order to provide examples of applications and best practices.

2.2. Barrier terminals

Safety barrier ends are usually considered hazardous when the termination is not properly anchored or ramped down in the ground or when it does not flare away from the carriageway. Crashes with “unprotected” safety barrier ends often “unforgiving” as they can result in a penetration of the passenger compartment with severe consequences (Fig. 2).

Crashworthy terminals provide a more forgiving barrier end (Fig. 3) and can be either flared or parallel, energy-absorbing or non-energy absorbing but in the latter case they have to be properly designed and flared to avoid front hits on the nose of the terminal. The advantage of using flared non-energy-absorbing terminals is that there are usually non-patented terminals that essentially can be installed as a termination of any W-beam steel barrier just by including the design drawings in the safety barriers detailed construction planning. The most commonly flared non-energy-absorbing terminals are the Eccentric Loader Terminal (ELT) and the Modified Eccentric Loader Terminal (MELT) (Fig. 4).

Fig. 2. Unprotected barrier terminals [2]

Fig. 3. Crashworthy barrier terminals ([5], left & [1] right)

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

If, for local constraints, the proper length of need cannot be guaranteed or if the terrain beyond the terminal and immediately behind the barrier is not safely traversable, an energy-absorbing terminal is recommended. Turn-down terminals, or flared-degraded terminals, which have been commonly used in the last years in several counties are now often replaced in new designs by flared terminals with no degradation as the longitudinal slide that arises from the degradation to the ground can lead to an overriding of the barrier.

Additional issues to be considered in the terminals design that are addressed in the IRDES Guideline are:

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

In terms of effectiveness there are no before-after studies available and a Crash Modification Factor (CMF) to account for the number of unprotected terminals on rural single carriageway roads has been developed in the IRDES Project and could be used as a reference [4]:

$$CMF = e^{0.02381 \times UT} \quad (1)$$

The CMF allows to estimate the potential number of crashes in a section with UT unprotected terminals per km of length by multiplying the CMF for the number of accidents expected in the base condition (CMF=1) that is a segment with no unprotected terminals with all the same characteristics as the analysed one.

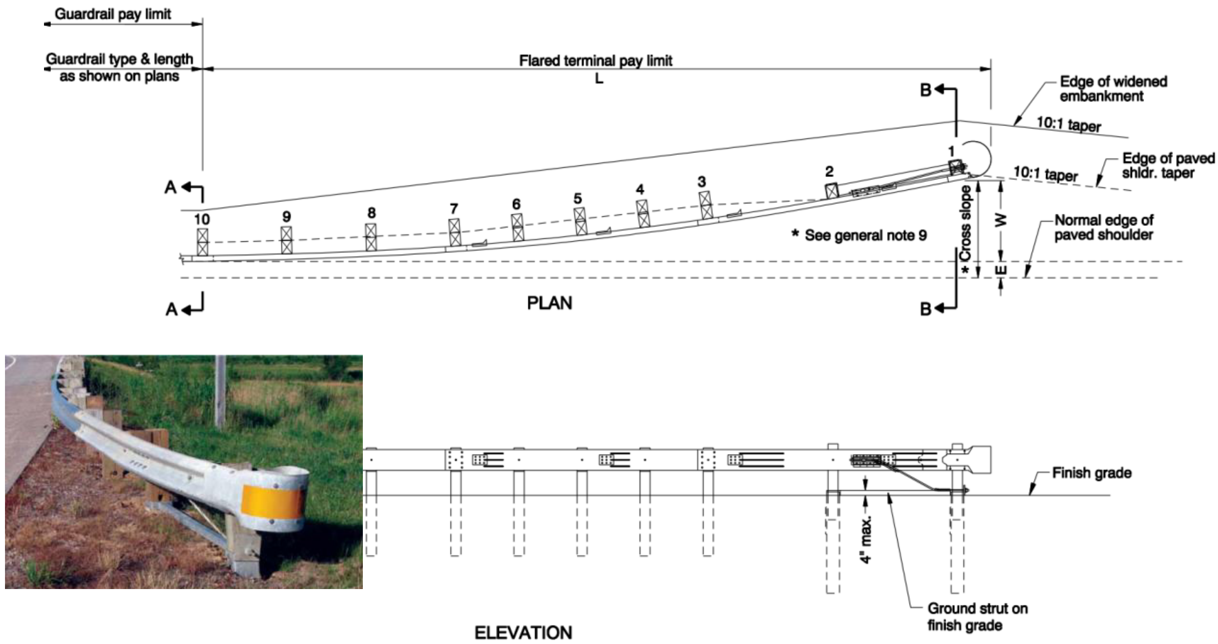

Fig. 4: Non patented crashworthy barrier terminal ([6], with photo from [7])

2.3. Shoulder rumble strips

Shoulder rumble strips have been proven to be a low cost and extremely effective treatment in reducing single vehicle run-off-road (SVROR) crashes and their severity.
For rural freeways the Crash Modification Factor (CMF) for the use of milled rumble strips has been estimated in [8] by combining different studies and resulted in:

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

For the use of milled rumble strips rural two lane roads the Crash Modification Factor (CMF) estimates are:

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

Given the standard errors below 1 - the predicted values the potential effect of milled shoulder rumble strips on these type of roads can be considered as definitely positive (with statistically limited risk of having an increase in accidents after the treatment).

For urban freeways and multilane divided highways the analysis data available do not yet allow for a statistically sound evaluation of the effectiveness. For multilane divided highways the following values can be used as a best estimate of the effects of milled shoulder rumble strips: SVROR crashes are expected to be reduced by 22% and SVROR fatal and injury crashes by 51% but more statistically sound research is needed.

Different design configurations have been proposed for milled rumble strips (Table 1):

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

Rumble strips on “non-controlled-access” highways should include periodic gaps of 3.7 m in length placed at periodic intervals of 12.2 m or 18.3 m to satisfy bicyclists’ need to cross the rumble strip pattern without causing them to enter the grooved area. This recommended length is sufficiently long to allow a typical bicyclist to cross without entering the grooved area, but not so long that a vehicle tire at a typical run-off-road angle of departure could cross the gap without entering the grooved area (Fig. 5).

Shoulder rumble strips should not be placed within 200 m of an urban area where, if needed, rolled rumble strips (with the typical design configuration of Table 1) could be considered as these produce less noise and do not affect bicycle handling.

Table 1. Rumble strips design configuration

		Typical configuration		Less aggressive configuration
	Parameter	Milled Rumble Strips	Rolled Rumble Strips	Milled Rumble Strips
A	Offset	0-760 mm	0-760 mm	0-760 mm
B	Length	400 mm	400 mm	152 mm
C	Width	180 mm	40 mm	127 mm
D	Depth	13 mm	32 mm	10 mm
E	Spacing	305 mm	170 mm	280-305 mm

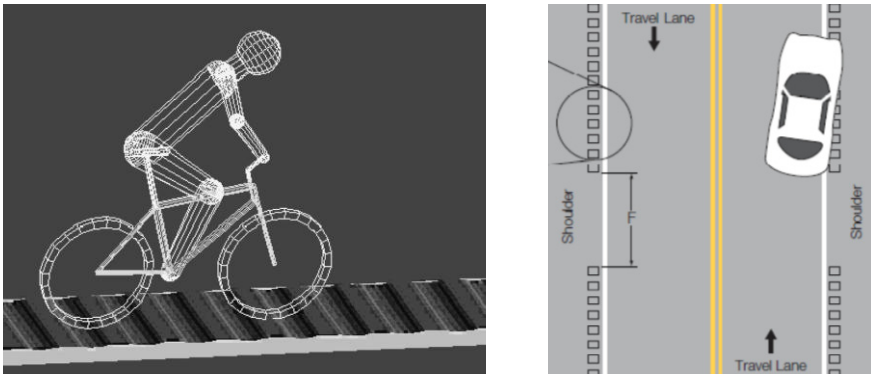

Fig. 5: Bicycle riding over rumble strips ([9], left) and typical shoulder scheme with bicycle gaps ([10], right)

Within the IRDES project a specific study was conducted in Sweden to evaluate the effectiveness of milled shoulder rumble strips in rural dual carriageway freeways [4]. Over a 200 km long segment milled shoulder rumble strips with the typical configuration described in Table 1 have been realized in the period June-October 2007 (Fig). Information from all single vehicle accidents occurred between the 1st of January 2004 and the 31st of December 2010 from the STRADA (Swedish Traffic Accident Data Acquisition) database, allowing for the development of a before-after analysis. The results show an overall estimate of a 27.3% reduction of single vehicle crashes (CMF = 0.727). Within a 95% confidence interval the potential reduction in accidents was estimated between 8.6% and 45.7% showing a definitely positive effect even though there is still a large variability to be explained.

Fig. 6: Case study to evaluate the effectiveness of rumble strips on motorways in Sweden [4]

2.4. Forgiving support structures for road equipment

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

In the IRDES Guideline the procedure developed in the RISER Project has been proposed and implemented. This requires identifying if the obstacle can be considered an hazard, which means if it is within the clear zone and if it has structural characteristics that can lead to injuries to the occupants of an errant vehicle impacting against the obstacle. As a matter of fact not all the structures placed within the clear zone are an “hazard” for an errant vehicle. Amongst the different criteria to define an hazard available in the literature the approach proposed by SETRA [11] has been selected as it allows to define the potential dangerousness based on the stiffness of the structure and not on its shape. According to this approach a structure can be considered as an hazard, if the resistant moment is above 5.7 kN*m and if the structure is not “passively safe”.

Support structures that have been tested according to EN12767 standard (Fig. 7) are considered to be “passively safe” or “forgiving” but different performance classes are given in the EN standard and guidelines for selecting the most appropriate performance class in different situations are given in the IRDES Guideline based on the UK selection procedure [12].

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

A risk assessment of the potential effect of using passively safe lighting columns and signposts has been performed in the UK [13] by combining the likelihood of occurrence of different events that can lead to passenger injuries. The risk associated with the use of “passively safe” o “forgiving” lighting columns resulted almost 8 times lower than the risk associated to conventional unprotected columns. The solution of protecting the column with a safety barrier leads to a risk that is still 2 times higher than the risk associated to using “passively safe” columns.

Fig. 7: Passively safe support structures [2]

2.5. Shoulder width

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

For rural single carriageway two lane roads and for multilane divided and undivided highways consolidated CMF functions can be found in the recently published Highway Safety Manual [14] while for motorways in open air the effect of the shoulder width is often not found as these road type have usually an outer shoulder width of 2.50-3.0 m that has been shown to be the value above which no effect can be seen in crash reduction. For motorways in tunnels, where shoulders are often more narrow and the confinement affects the drivers behaviour, a specific Safety Performance Function is given to estimate the effect of having a reduced shoulder width.

Given the fact the national standards usually set the criteria for defining the minimum or standard outer shoulder width, a “uniform” value was not proposed but the requirements given for rural roads in Austria, France, Italy and Sweden have been compared showing that the these are very similar for Motorways with speed limits of 130 km/h (2.50-3.00 m) while more variability is found in the secondary road network with a speed limit of 90-100 km/h.

To evaluate the effectiveness of the outer shoulder width and shoulder type (paved/unpaved) a specific procedure based on PC Crash simulations of black spots (with variable roadside features) was developed in the IRDES project ([4], Nitsche et al., 2011, Nitsche et al., 2012) to assess the potential reduction in the MAIS (Maximum Abbreviated Injury Scale) value when different roadside treatments are applied. The two examples presented in (Fig. 8) show that the most effective treatment is the implementation of a hard shoulder that result to be more effective than placing a safety barrier. The implementation of a soft shoulder, on the other hand, is less effective than placing a safety barrier.

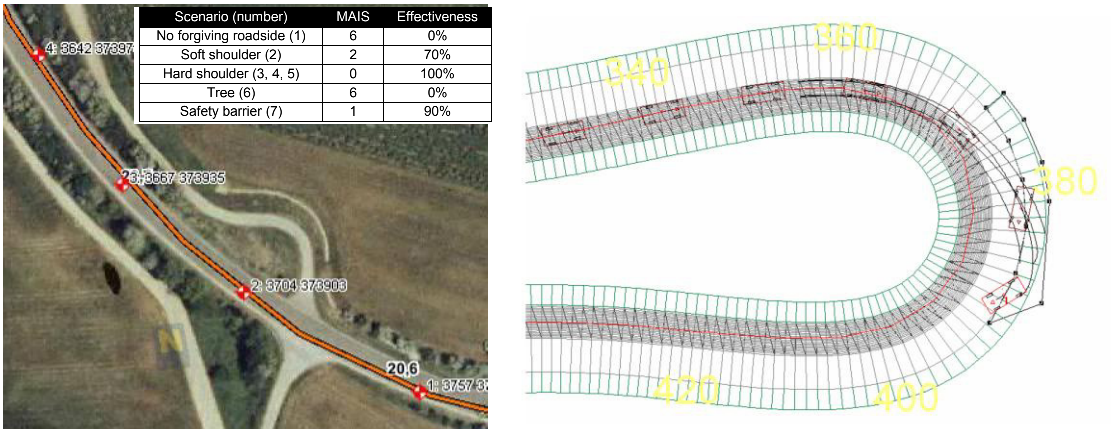

Fig. 8: PC Crash procedure for black spot analysis and for the evaluation of shoulder type effectiveness based on measured road geometry ([4], [15], [16])

3. Conclusions

Within the ERANET Funded project IRDES a practical and uniform guideline that allows the road designer to improve the forgivingness of the roadside and a practical tool for assessing the effectiveness of applying a given roadside treatment has been produced with specific reference to the following set of roadside features:

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

The study conducted allowed to define sound and practical guidelines to design “forgiving” barriers terminals but, on the other hand, there is still a need for extensive effectiveness studies to evaluate the effect of replacing “unprotected” (unforgiving) barrier terminals with crashworthy terminals.

Similarly the use of forgiving support structures for road equipment tested according to EN12767 standard, needs practical guidelines for selecting the proper performance classes that only few countries have already implemented. In addition there is a lack of data to provide an estimate of the effect of using this type of structures even though a risk assessment has shown that the potential benefit is higher than protecting the support structure with a safety barrier.

Shoulder rumble strips, on the other side, are proven to be a highly cost-effective intervention that, with proper design, can be suitable also if bicycle traffic is allowed on the road but within 200 m of the urban areas milled rumble strips (more effective but more noisy and disturbing for the bicycle riding) should be avoided and, if necessary, only rolled rumble strips should be considered.

Finally the effect of the outer shoulder width on road safety has a well defined effect but this should be used to assess the effect of having a shoulder narrower than the national design standard for a given road type. The effect of wider shoulder should be evaluated by means of a specific risk assessment as it might encourage wrong drivers' behaviours. Unpaved shoulders effect on safety can be limited, especially in bends.

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