Co-funded by the
Erasmus+ Programme
of the European Union

EuroS@P
EUROPEAN ROAD SAFETY PARTNERSHIP

WP3. Teaching materials development related to the road infrastructure safety inspection

IO.17 Development of roadside safety management methodology

This project has been funded with the support of the European Commission. This publication reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

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INTRODUCTION

Obstacles in the roadside do not pose a direct hazard to road users while driving, but they become dangerous if they leave the road uncontrolled. To prevent such situations, roads are designed which, thanks to their geometry and horizontal and vertical markings, are easier to use and therefore safer. Descriptions of such solutions can be found in the guidelines on the idea of "forgiving roads". Nevertheless, human error is and will be present in car traffic as long as people drive vehicles. Therefore, road engineers have been researching the issue of hazards in the vicinity of roads for years, developing methods of reducing the hazards. Research conducted in based on the analysis of fatal accidents in which a vehicle hit an obstacle (data from the U.S. Department of Transportation's Fatality Analysis Reporting System (FARS)) shows which obstacles in the road environment are the most dangerous for road users. The results reveal that the most dangerous roadside element are trees, they occurred in almost half of the accidents.

A vehicle runs off the road when it loses stability or changes its direction rapidly (a result of excessive speed, loss of wheel grip, etc.). While the vehicle will occasionally return to the road, there are other secondary and very dangerous consequences as well: vehicle roll-over, driving into a ditch, hitting a slope or a roadside object such as striking a safety barrier, hitting a tree, utility pole or road sign.

The risk of becoming involved in an accident is the result of a malfunctioning element of the transport system (man – vehicle – road – environment). The road and its traffic layout and safety equipment have a critical impact on road user safety. Run-off-road accidents continue to be one of the biggest problems of road safety. They lead to secondary collisions when the vehicle rolls over or hits a roadside object. This type of accident represents more than 25% of rural accidents and nearly 20% of all road deaths in Poland. The likelihood and consequences of run-off-road accidents may be reduced where road measures are used to improve safety. This is to be achieved by developing and implementing the concept of “forgiving roads”, i.e. roads with no side obstacles causing a hazard or, if there are obstacles fitting them with passive safety devices. In addition, road signage should be comprehensible and user-friendly. Run-off-road accidents, which include hitting a tree, pole, sign or safety barrier, represent about 10% of all accidents in Poland and more than 19% of road deaths. On a national scale, these accidents are some of the most frequent. A detailed analysis shows that when a vehicle leaves the road it usually hits a tree (nearly 7% of all road accidents in Poland). Roadside trees are one of the most serious problems of road safety. One way to solve it is to use safety barriers. Barriers are used to reduce the consequences of an accident or collision (as opposed to striking a tree in a head-on collision). To that end barriers must be designed and built to respond adequately when struck by a car.

GLOSSARY OF TERMS

Barrier terminal. A device installed at the end of a safety barrier, designed to shield vehicles from collisions with an exposed barrier end.
Clearance. The lateral distance between a safety barrier and a roadside hazard.
Clear zone. The width of an area beside a road (measured at right angles from the edge line or the edge of the nearest lane) to be kept free of fixed roadside hazards and steep side slopes so errant vehicles can recover or stop before striking a hazard.
Crash cushion. A device that prevents an errant vehicle from impacting fixed objects by gradually decelerating the vehicle to a stop, or by redirecting the vehicle away from the fixed object. It is also known as an impact attenuator.
Critical slope. A side slope on which most errant vehicles are likely to overturn (roll over).
Deflection. The transverse displacement of a safety barrier during an impact by an errant vehicle.
Delineation. A general term for the signs and devices used to provide clear definition of the designated traffic path through a road work site.
Errant vehicle. A vehicle out of control (for any reason) and traveling (usually at speed) off the road.
Flexible barrier. A barrier made from wire rope and supported by frangible posts. These barriers deflect more than other barrier types; they are, therefore, often the best option for minimizing injuries to vehicles' occupants.
Frangible. The ability of a device, including structure supports, posts, and poles, to break away or be deformed upon impact by an errant vehicle without causing significant risk of serious injury to vehicles' occupants.
High-speed road. A road where vehicle speeds are typically greater than 60 kilometers per hour.
Length of need. The length of safety barrier system needed to prevent errant vehicles from colliding with a roadside hazard.
Longitudinal barrier. A safety barrier running generally parallel with the roadway. It is designed to prevent penetration and to safely redirect an errant vehicle away from a roadside hazard.
Low-speed road. A road where vehicle speeds are typically 60 kilometers per hour or less.
Median barrier. A longitudinal barrier located in a median of a divided road. It is designed to prevent an errant vehicle crossing from one carriageway to the other, or to shield roadside hazards within the median.
Nonrecoverable slope. A roadside slope that is traversable but on which an errant vehicle will not be able to recover and return to the roadway. The vehicle will continue to the bottom of the slope without significant risk of overturning.
Offset. Lateral distance from the traffic lane to a roadside hazard, including safety barriers.
Performance level. The degree to which a longitudinal barrier, including bridge barrier, is designed for containment and redirection of different types of vehicles.
Pocketing. An errant vehicle striking a barrier but directed by that barrier into a fixed object.
Recoverable slope. A side slope on which a driver can generally retain (or regain) control of an errant vehicle.
Rigid barrier. A barrier made of concrete designed not to deflect. They are used where there is no room for the deflections associated with semirigid or flexible barrier systems. Depending

on their height and other details, these provide the highest level of containment of heavy vehicles.
Roadside. The area between the boundary of the road reservation and the edge of the shoulder, or traffic lane in the absence of a shoulder. The median between carriageways of a divided road is also a part of the roadside.
Roadside hazard. Any feature located in the clear zone (along the roadside or within the median) that could cause significant injury to vehicles' occupants in an errant vehicle.
Road work. Any work on a road or a roadside that has potential to disturb traffic flow and/or safety.
Safety barrier. A physical barrier separating a hazard from the traveled way, designed to resist penetration by an out-of-control vehicle and, as far as practicable, to redirect the colliding vehicle back into the travelled path.
Safety barrier system (road restraint system). A device generally constructed of steel, concrete, or steel cables designed to contain and redirect errant vehicles by providing a physical restriction to penetration in a way that reduces the risk of injury to occupants of the errant vehicle and other traffic. A safety barrier system consists of end terminals and longitudinal safety barriers.
Semirigid barrier. A barrier usually made from steel beams or rails. Commonly called "guardrail," it deflects less than a flexible barrier and so can be located closer to a hazard when space is limited.
Slope. The relative steepness of the terrain expressed as a ratio or percentage. Slopes may be fill slopes or cut slopes, and parallel or cross slopes in relation to the direction of traffic
Transition. A section between two different barrier types which allows a gradual change in the properties of the barrier so there is no discontinuity that would be hazardous in the event of an impact (such as pocketing of a vehicle).
Traversable slope. A roadside slope which is relatively smooth, sufficiently compacted, and free of fixed objects, and which allows a driver to retain or regain control of a vehicle or stop safety.
Working width. The width that includes the barrier deflection plus the roll distance of an impacting high vehicle. It is a necessary consideration when designing barriers to shield hazards, such as bridge supporting piers on expressways from impacts by large trucks. For rigid barriers, this is also known as the zone of intrusion.

1 DIRECTIVE 2019/1936/EC

The safety performance of existing roads should be improved by targeting investment to the road sections with the highest accident concentration and the highest accident reduction potential.

According to the Safe System approach, death and serious injury in road accidents are largely preventable. It should be a shared responsibility at all levels to ensure that road accidents do not lead to serious or fatal injuries. In particular, well-designed, properly maintained and clearly marked and signed roads should reduce the probability of road accidents, whilst 'forgiving roads' (roads laid out in an intelligent way to ensure that driving errors do not immediately have serious or fatal consequences) should reduce the severity of accidents. The Commission should provide guidance for the provision and maintenance of 'forgiving roadsides', building on the experience of all Member States.

Indicative elements of targeted road safety inspections (roadside):

- roadside environment including vegetation;
- roadside hazards and distance from carriageway or cycle path edge;
- user-friendly adaptation of road restraint systems (central reservations and crash barriers to prevent hazards to vulnerable road users);
- end treatments of crash barriers;
- appropriate road restraint systems at bridges and culverts;
- fences (in roads with restricted access).

2 BACKGROUND

Over the past 50 years extensive research has been conducted into the relationship between clear zones and road safety (Elvik, Hoye et al. 2009, AASHTO 2011), much of this in the USA and focussed on establishing the relationship between clear zone width, speeds, vehicle penetration rates and crashes. The results of this research have been conflicting and by no means conclusive with regards to what constitutes an optimum as far as a safe clear zone width is concerned. Additionally there has been significant research into the effects of obstacles and objects near or adjacent to roads on crashes and crash outcomes (van Petegem 2012, Schermers and Van Petegem 2013, van Petegem and Louwerse 2015, Petegem, Louwerse, Louwerse and Petegem 2018) Since the mid-1960's road safety engineers have made significant progress improving the design of barriers, guardrails and other devices (such as frangible posts, crash attenuators etc.) which aim at reducing the risk of serious injury to road users if struck. This research has to a large extent been the foundation for the development of numerous (international) standards regulating and prescribing best practice when it comes to roadside design and in some cases maintenance.

In Europe, numerous standards have been produced aimed at making roads in particular, and roadsides specifically, more forgiving. However, many of these are aimed at the harmonisation of measures based on primarily theoretical (scientific) considerations. Consequently, the measures have not been widely implemented nor have pilot applications been researched and published. Furthermore, there are various measures aimed at essentially the same problem without it being clear what the merits of each measure are when compared to the others. The CEDR funded project IRDES aimed to fill the identified gap by providing practical guidance for the implementation of forgiving roads (La Torre et.al., 2011). IRDES provides the means with which users could select the optimal treatment but with the clear ambition to also monitor the efficacy of this once implemented. The IRDES design guide brought together best practice design guidance on roadside safety. However, IRDES has not been implemented widely and the reasons for this need to be established to prevent re-occurrence. In addition to IRDES, the EU funded RISER and CEDR funded SAVeRS have also researched roadside safety and similarly the results have only been implemented on a limited scale (La Torre, 2013). Although comprehensive, the research efforts have been predominantly focussed on establishing which roadside elements and criteria are essential for providing optimal (state of the art) roadside design. These efforts are generally classic in their approach and concentrate on specifying best practice and giving guidance for remedial treatments. The decision support algorithm developed in RISER is an example of such a traditional approach (Thomson; Fagerlind; et al. 2006). This promotes evaluation, followed by removal, modification and ultimately protection. However, a more fundamental approach may be to assess the merits of adopting a roadside safety strategy based on a clear roadside area versus for example, the extensive application of barriers. Cost-effectiveness is an aspect that may need to be included in such warrants or decision support algorithms, a feature that was included in the roadside assessment procedure developed under the Portuguese funded SAFESIDE research project (Roque and Cardoso 2013, Roque and Cardoso 2015).

Furthermore, research on safe roadside design paid limited attention to aspects such as maintenance and safety during maintenance. Consequently, the procedures in standards focus very much on the design of new elements (and roadsides) and seemingly make inadequate provision for ongoing safety compliance through the road life cycle. Maintenance and inspections of roadsides and roadside elements are seen as supplemental and are not part of the current standards leading to potential discord between the setting of standards for new roads and maintaining them for the duration of the roads' life (Progress, 2019).

3 ROADSIDE HAZARD

Roadside hazards o According to a report issued by CEDR (Conference of European Directors of Roads), roadside hazards can be divided into 3 groups:

- Single, stationary obstacles;
- Longitudinal, continuous obstacles;
- Dynamic obstacles.

3.1 Single, stationary obstacles.

3.1.1 Trees and other plants.

Trees and other plants in roadside areas are the most dangerous obstacles that claim the greatest number of lives compared to other roadside obstacles. The study in showed that tree accidents, compared to all other accidents, result in the greatest number of injured people. The chart is shown below (Fig. 3.1).

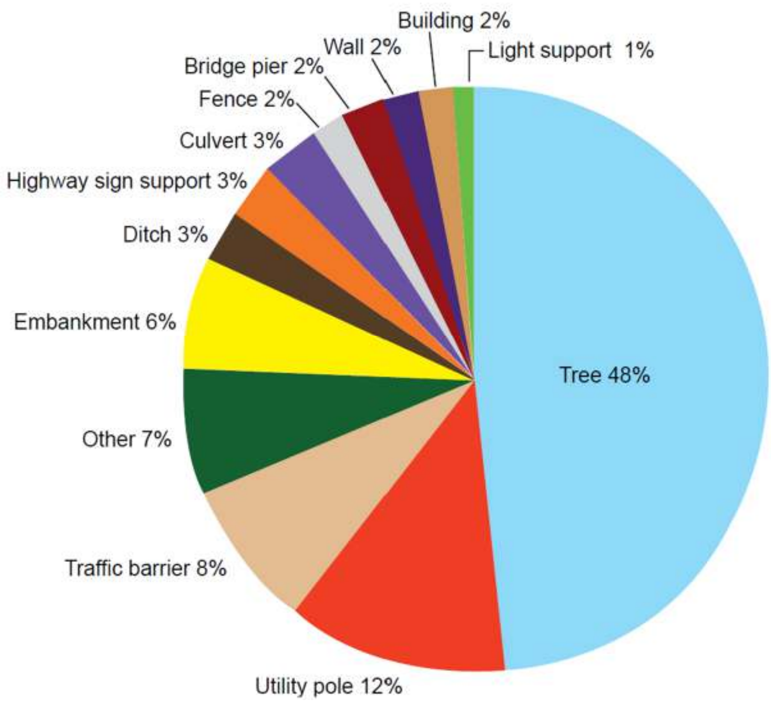


Fig. 3.1 Percent Distribution of Fixed-Object Fatalities by Object Struck (source: AASHTO, 2011)

A guide from the (NCHRP, 2003) contains an interesting analysis of the relationship between the average distance of trees to the travel lane and tree crashes. It shows that shorter distances result in more crashes. The example pictures in Fig. 3.2 shows trees that are located too close to the road without delineation or shielding.

Rys. 3.2 Examples of hazardous trees located on the roadside

3.1.2 Utility poles.

Roadside utility poles are typically used to carry power lines. They are made of various materials: metal, wood, reinforced concrete. They are the second most dangerous roadside obstacle in terms of fatal accidents. In both photos below (Fig.3.3), the poles are placed at a distance of up to 1 m from the road, they are not secured with road safety devices or properly marked, and they pose a significant hazard to road traffic.

Rys. 3.3 Electric poles not placed safety (source: CEDR, 2013)

3.1.3 Road sign posts and lighting poles

Compared to utility poles and trees, these are elements that must be located near the road. They cannot be moved and are dangerous, so they must be made in a way that will reduce the effects of impact. The photos below (Fig. 3.4) show poles that do not meet safety requirements.

Fig. 3.4 Road sign post (source: CEDR, 2013)

3.1.4 Bridge abutments and piers

Abutments, tunnel entrance walls, viaducts and bridge piers are usually made of concrete. According to the RISER project (Thomson; Fagerlind; et al. 2006), these objects are dangerous when: they are not protected by road safety elements, the pillar diameter is greater than 1 m and when they are located too close to the road. Nevertheless, these elements are involved in a relatively small number of fatal accidents compared to other roadside obstacles. The photo below (Fig. 3.5) shows a dangerous pillar of the viaduct.

Fig. 3.5 Examples of a hazardous bridge abutment and overpass (source: CEDR, 2013)

3.1.5 Ends of road barriers and transitions

Road barriers are used on roads all over the world and are of strategic importance to the "forgiving roadside" concept. Barriers protect dangerous objects and prevent vehicles from leaving the road. On the other hand, barrier connections and their ends may be dangerous for road traffic. The end of a barrier becomes dangerous when it is improperly anchored or when it is not horizontally angled towards the roadside. Accidents involving poorly constructed barriers often result in penetration of the vehicle from the passenger side. The photo below (Fig. 3.6) shows an incorrectly completed barrier.

Fig. 3.6 Dangerous end of the road barrier.

3.1.6 Stones and boulders

When they are too close to the road, they pose a serious threat to vehicles. They are mainly found along roads in rocky surroundings, sometimes they are also used as decoration. In the event of a collision, the vehicle and passengers are exposed to great danger. The photos below (Figure 3.7) show stones placed dangerously close to the road. An additional hazard in the case of roads cut in rocks are boulders falling on the road.

Fig. 3.7 Stones and boulders placed too close to the road (source: CEDR, 2013)

3.1.7 Drainage elements

If a car leaves the road uncontrolled, water drainage elements such as culverts may be dangerous. They are usually made of steel, concrete or other hard materials, and if they are not properly protected, they can cause major damage in the event of a collision. Driveways, which usually connect a property to a road or are entrances to minor roads, can be dangerous if they are perpendicular to the ditch and are incorrectly shaped. The photos below (Fig. 3.8) show incorrectly designed road culverts.

Fig. 3.8 Vertical concrete walls of road culverts

3.1.8 Other single obstacles

In addition to the objects described above, there may also be other threats in roadside areas, such as: buildings located too close to the road, sculptures, hydrants, etc., which must be properly secured. In the past, sculptures and other large monuments were placed in the middle of roundabouts, which may prove dangerous to road traffic.

3.2 Longitudinal, continuous obstacles

Longitudinal, continuous obstacles are of considerable length, making their relocation or removal impractical or impossible.

3.2.1 Ditches

The ditches are responsible for road drainage and are usually laid parallel to the road. They consist of an internal and external slope. A ditch deeper than 1 m and with an internal slope with a slope greater than 1:4 is considered dangerous and should be properly secured. The photos below (Fig. 3.9) show incorrectly constructed ditches, as a hazard.

Fig. 3.9 Dangerous ditches (source: CEDR, 2013)

3.2.2 Slopes

To avoid constant changes in the road's height level, it is usually placed on an embankment, which is made of compacted material. Excavations are the opposite, they are used when the ground level needs to be reduced. The level of risk of a slope depends on its height or depth, inclination and distance from the road. The analysis of the standards defining the thresholds for these parameters was performed by RISER. The photo below (Fig. 3.10) shows an example of a dangerous slope.

Fig. 3.10 Dangerous slope (source: CEDR, 2013).

3.2.3 Road traffic safety devices

Road safety devices (steel barriers, bridge barriers, rope barriers, etc.) are elements that aim to improve road safety. They protect dangerous objects, separate traffic on dual carriageways, and prevent vehicles from falling off the road. Nevertheless, if they are incorrectly made, located or damaged, they pose a danger to road traffic, statistics show that after trees and utility poles they are the third most dangerous obstacle in the road environment.
Barriers should be designed to deflect an impacting vehicle at a sufficiently low angle to minimize forces on occupants and to prevent the vehicle from running off the road. On the other hand, a deflected car poses a threat to other road users and may lead to serious accidents. In some countries, there are records that rope barriers are particularly dangerous when attacked by power cyclists, but research does not confirm these fears.

3.2.4 Curbs

In built-up areas, curbs are a more practical solution than roadsides. Generally, they are the boundary between the road and the sidewalk and are intended to prevent uncontrolled vehicles from entering the sidewalk, as well as to ensure adequate drainage of the road. Research has shown that curbs are not able to deflect vehicles like road barriers, and what is more, they are dangerous for motorcyclists.

3.2.5 Water

Water bodies located too close to the road, such as rivers, lakes, canals, etc., may be dangerous for vehicles leaving the road uncontrollably.

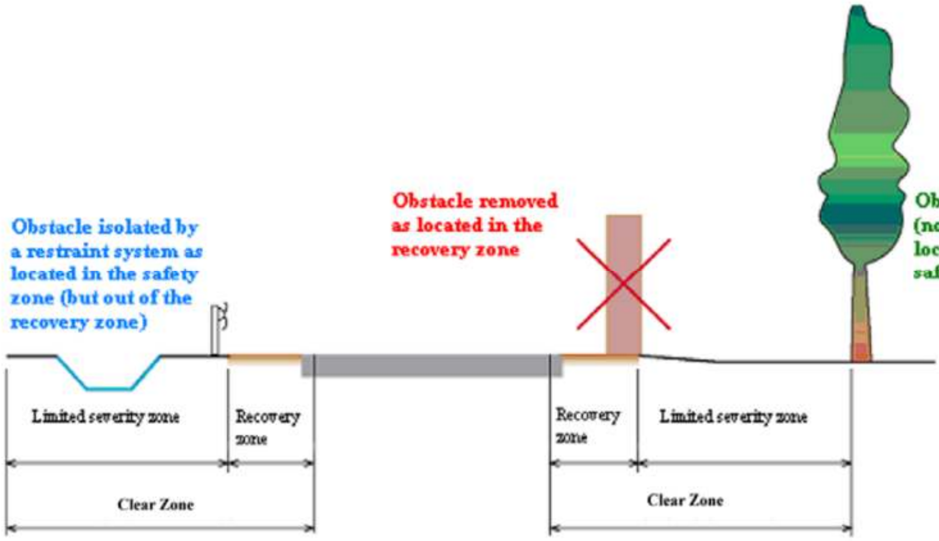
3.3 Dynamic hazards

Dynamic hazards, compared to those described above, move on and near the road, for example: cyclists, pedestrians. Dynamic obstacles are more common in urban areas. In an accident involving a vehicle and a pedestrian, the latter is exposed to greater danger, therefore the approach to the situation should be the opposite to that in the case of permanent obstacles, because in this case it is the obstacle that is protected, not the vehicle (Fig. 3.11).

Fig. 3.11 Road hazard for pedestrians and bicycles

4 CLEAR ZONE CONCEPT

Safety zones, or empty zones, are roadside zones in which all dangerous obstacles have been removed, modified so that they do not pose a hazard or covered with road safety devices. These zones provide adequate space for drivers to slow down and regain control of the vehicle in the event of an uncontrolled exit from the road. Some guidelines divide safety zones into 2 areas: the recovery zone and the limited safety zone, as shown in Figure 4.1.



Rys. 4.1 Clear Zone definition (source: CEDR, 2013)

However, not all national guidelines introduce a division of safety zones, but all of them specify the need to introduce zones of different dimensions. The width of the zones varies around the world, depending on the approach. As part of the RISER (Roadside Infrastructure for Safer European Roads) project, the dimensions of safety zones for 7 European countries were established. The main criteria taken into account are:

- Type of road;
- Traffic;
- Design speed;
- Road width;
- Slope of roadside slopes;
- Percentage of heavy vehicles;
- Curvyness of the road section;
- Hazard assessment.

Generally, the greater the risk of an accident, the wider the safety zone. The width of the zone also depends on the accident history on a given road section.
The clear zone width for any road (proposed or existing) is determined by a process that considers a range of four key factors:

- The operating speed of the traffic. The operating speeds of the traffic will dictate how far off a road an errant vehicle may travel. At 60 km/h, 85% of errant vehicles will recover within 3 m from the edge of the traffic lane but at 100 km/h, 85% of vehicles will require 9 m to recover. Faster equals further.

- The traffic volume. A higher volume of traffic results in greater exposure and an increased likelihood that one of those vehicles will run off the road. Thus, the traffic volume factor is a budgetary matter; it requires providing larger clear zones for busier roads. It allows smaller clear zones if traffic volumes are low. For low-traffic roads, with few motorists exposed to a roadside hazard, it is less cost-effective to provide the same clear zone as high-volume roads.
- The curve radius of the road. The clear zone is wider on the outside of a curve because errant vehicles travel further off the outside of a curve before recovering. A curve adjustment factor is available to increase the clear zone width as necessary.
- The steepness of the side slope. This factor influences how far an out-of-control vehicle will travel from the road. If the side slope is very steep (more than the critical slope), it is not counted as a part of the clear zone. The clear zone must extend beyond the slope, sometimes into neighboring fields. Steep slopes are not drivable, not recoverable, and they increase the risk an errant vehicle will overturn. Overturning crashes often result in serious injuries or fatalities. Adjustment factors are provided for adjusting the clear zone for roadside slope. Steep side slopes need wider clear zones.

4.1 Forgiving zone (Recovery zone)

The recovery zone is a side lane adjacent to the road. All obstacles located in this area must be removed so that drivers can return to the road safely if necessary, or stop the vehicle when necessary. This zone may be paved or unpaved. The recovery zone may include:

- hardened roadsides;
- unpaved roadsides;
- lanes dividing two roads;
- existing roadsides reinforced.

The hard shoulder is an asphalted extension of the road width. It is separated from the road by horizontal markings and is generally used to provide an emergency lane, parking space, bicycle paths or sidewalks. The introduction of hardened roadsides in undeveloped areas reduces the number of accidents by 5 to 10%, additionally results in widening the road and improving visibility on bends. The unpaved roadside is usually dirt. This makes it below road level. Large differences between these levels should be avoided due to the danger when the vehicle leaves the road uncontrolled. Unpaved roadsides are an unacceptable solution for roads with heavy traffic. When choosing such a solution, factors such as road geometry, available space, roadside dimensions, and traffic structure should also be taken into account (Fig. 4.2).


Fig. 4.2 Examples of paved and unpaved shoulder (source: CEDR, 2013)

Taking into account road traffic safety, it is necessary to consider not only the dimensions of the roadsides, but also the number of traffic lanes and their width. Wide shoulders may cause drivers to reach higher speeds.

4.2 Limited safety zone

Guidelines in some countries divide the safety zone into a "recovery zone" and a limited safety zone. The purpose of introducing such a division is to minimize the severity of accidents. The limited severity zone is defined as the part of the safety zone that lies outside the recovery zone but is still part of the zone. The purpose of this section is not to attempt to stop vehicles from going off the road, but to mitigate the effects of such an event.
In accordance with the guidelines, all dangerous obstacles should be removed in this zone, if possible. This includes removing any single hazard, such as poles or trees, as well as continuous hazards, such as walls. Since most guidelines do not describe restricted hazard zones, their dimensions are not always available. In some countries, the slope gradient is taken into account when determining the zone width. The wide restricted danger zone is shown in the photo in Figure 4.3.

Fig. 4.3 A narrow recovery zone, but a wide zone of limited safety zone. (source: CEDR, 2013)

4.3 Mediana

The dividing strip separates traffic directions on dual carriageways. Not all studies define it as part of the road surroundings, some guidelines define it as a separate element. However, it is described in this study because dividing strips can reduce the number of road trips and also reduce their adverse effects. These lanes provide the space needed to regain control of the vehicle in the event of an uncontrolled exit from the road, as well as space for a possible emergency stop. Another advantage of dividing strips is increasing visibility on the road. Research has shown that on roads with dividing lanes:

- the number of accidents involving cars traveling in opposite directions is reduced;
- the number of accidents in the median decreases when the lane width is greater than 9m;
- the number of accidents in the dividing lane increases with the increasing width of the lane, up to a width of 9 m;
- the effect of the width of the dividing lane on the total number of accidents is questionable.

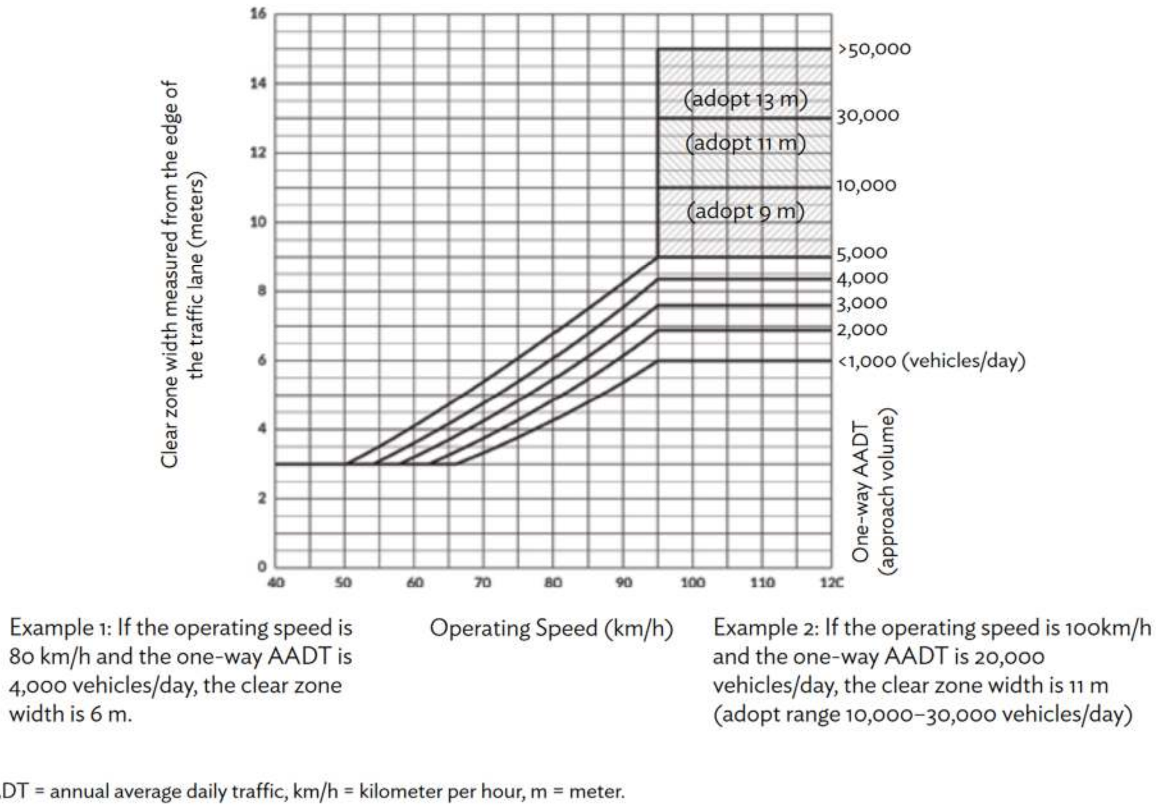
Recommended widths vary from country to country as they depend on the space available and the intention of using the lane. According to Swedish guidelines, the median can be divided into several types, as shown in Figure 4.4.

Fig.4.4 Example of mediana

4.4 Calculating the clear zone (CAREC, 2018)

Figure 4.5 is used to determine the required basic clear zone required for a straight length of road. It is based on American Association of State Highway Transportation Officials (AASHTO) guidelines that originated in the 1960s and continue to be revised as required by various leading road authorities. Use this figure to calculate the required clear zone for a road (proposed or new) in a few simple steps:

- Estimate the operating speed of the traffic (the estimated operating speed, not the design speed, and not the speed limit).
- Estimate the daily traffic volume (note that the graph is for one direction flow only; double the figure for a two-lane, two-way highway).
- Take these two figures from Figure 4.5 to calculate the clear zone.

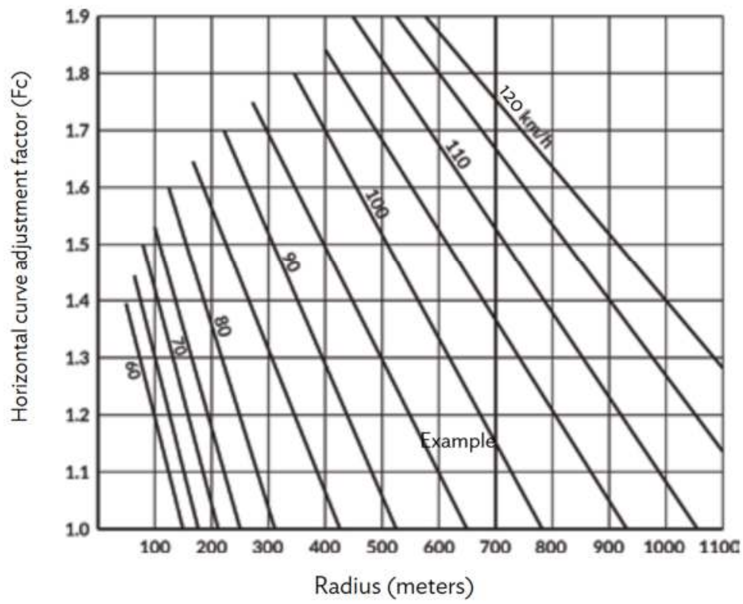


Fig, 4.5 Clear Zone for Straight Roads (source: VicRoads. 2011. Supplement to Austroads Guide to Road Design – Part 6 (Roadside Design, Safety and Barriers). Sydney, Australia)

Curve adjustments for the clear zone.

The horizontal alignment of a road (curve) can influence vehicle behavior and the potential for running off the road. The laws of physics will cause an errant vehicle to travel further off a road on the outside of a curve than on a straight. Therefore, the clear zone distance indicated in Figure 1 for straight roads should be adjusted where the part of the road is on a horizontal curve by multiplying the clear zone distance by the appropriate curve correction factor from Figure 4.6. Multiply the clear zone with this adjustment factor; it will give a wider clear zone, remembering that errant vehicles go further off a road on the outside of curves.

The correction only applies to clear zones on the outside of curves. Curves with a radius larger than 1,000 m do not require an adjustment. The curve correction factor is particularly important when crash histories for curves along a highway show that crash potential can be reduced by increasing the clear zone width. Even though the adjustment factor is only applied to the clear zone for the outside of curves, remember that many crashes do involve vehicles running off on the inside of a curve. This is a common form of run-off-road crash. Remember this when looking at blackspots on curves especially if accurate and reliable crash data is not available. Not all run-off- road collisions occur on the outside of curves.



Note: For radii > 1,000 meters use Fc = 1.0

Example:
On a 700 meter radius curve with an operating speed of 100 km/h, the graph suggests an Fc of 1.15.

Fc = curve correction factor, km/h = kilometer per hour.

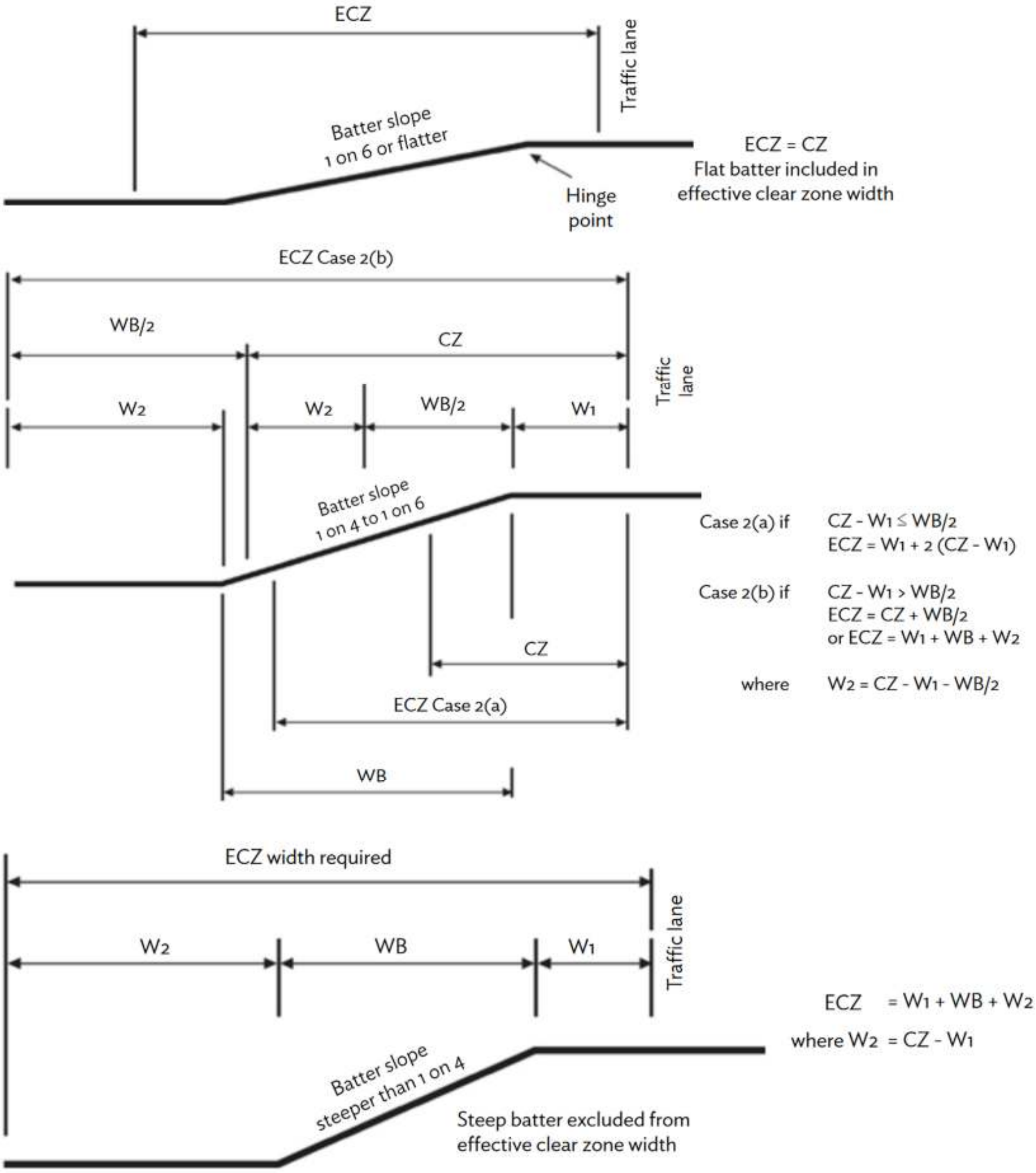
Fig. 4.6 Clear Zone Adjustment Factors for Curves (source: AUSTROADS. 2003. Rural Road Design. Sydney, Australia)

4.5 Fill slope adjustments for the clear zone (CAREC, 2018)

Ideally, a safe roadside should be flat, particularly if it is to be traversable for errant vehicles. If a roadside is not flat, an errant vehicle that leaves the roadway may encounter a side slope on a fill embankment, a side slope in a cutting, or a drainage ditch. These geometric features will affect the path of the errant vehicle and the distance it needs to recover.

Fill side slopes cause an errant vehicle to travel further from the road before it can be brought under control than do flat side slopes. Fill slopes can be classified as recoverable, nonrecoverable, or critical for errant vehicles. The classification of the slope will affect the clear zone distance required as follows (Figure 4.7):

a. Recoverable slopes are traversable and need no adjustment to the clear zone width. Recoverable slopes generally have a slope of 1V:4H or flatter.
b. Nonrecoverable fill slopes are slopes steeper than 1V:4H, and flatter than 1V:3H. Most errant vehicles on these slopes will continue to the bottom of the slope, so an errant vehicle recovery area beyond the toe of the nonrecoverable fill slope is required. In these cases, the clear zone distance excludes the width of the nonrecoverable embankment slope. Therefore, the clear zone needs to continue beyond the bottom of the slope.
c. Critical fill slopes (which are nonrecoverable slopes) are considered as critical if the slope exceeds 1V:3H. Critical slopes usually cause an errant vehicle to roll over. These slopes need to be flattened or shielded with safety barrier, if the slope is within the clear zone.
d. The surface of the fill is also a factor that affects whether a fill slope is traversable or a hazard to errant drivers. The embankment surface must also be relatively smooth, sufficiently compacted, and free of fixed objects. The surface may be relatively even or it may be uneven with low obstacles that can snag a vehicle and cause it to roll over. On sandy roadsides, such as those found along many highways, the probability of a vehicle overturning is high, even at slopes of less than 1V:3H.
e. Slopes can be made more traversable if the top and bottom of the slope are rounded to help an errant vehicle remain in contact with the ground. Many cross-section drawings show a “rounding” of the fill at the road level, but most show nothing at the base of the fill. This location is often close to the edge of the road reserve and is often close to fields. It is easy to forget but rounding the bottom of the slope is a valuable safety treatment.
f. The recommended maximum side slope on fill embankments for new road projects is 1V:6H. Where it is not economically practical to achieve or better this side slope, safety barriers shall be installed on all fill slopes with heights of 2 m or higher.
g. In some instances, it may be possible to avoid the need to introduce a safety barrier by constructing a 1V:5H side slope from the edge of the shoulder to the limit of the clear zone, with a steeper embankment (not exceeding 1V:3H) beyond that point. This option may be preferable and more economical than providing safety barriers.



1. CZ is the clear zone width determined from Figure 4.7 adjusted for horizontal curve where necessary.
2. ECZ is the effective clear zone width.
3. W1 is the width from edge of through lane to hinge point.
4. WB is batter width.
5. W2 is width from toe of batter.
6. S is batter slope (m/m).
7. Provide batter rounding to all batter top and toe hinge points.

Fig. 4.7 Effects of Side Slopes on Clear Zone Widths (source: CAREC, 2018)

4.6 Frangible lighting columns (CAREC, 2018)

Lighting columns are frequently-struck roadside objects. They tend to be close to roads and highways to provide sufficient illumination of the road, and until now, tend to be made from rigid concrete and/or steel. If struck by an errant vehicle, such columns can cause serious injuries, even fatalities to occupants of the errant vehicle. To reduce this risk, many road authorities place these rigid light columns behind semirigid barriers. This leads to a higher cost, added maintenance issues, and sometimes a less-attractive roadside environment. Safer lighting column options are now available.

Street light poles with passive safety characteristics are elements of road safety infrastructure, reducing the negative effects of road incidents (accidents, collisions). The severity of road accidents for drivers and passengers of motor vehicles in the event of a collision with lighting poles depends, among others, on the safety characteristics of the poles.

The functional category of street light poles is a combination of the speed class, energy absorption category, passenger safety class, type of aggregate used in the foundation, loss of stability mechanism, direction class and the risk of roof crushing.

In 2019, PN-EN 12767:2007 standard “Passive safety of support structures for road equipment” was revised. The revision, PN-EN 12767:2019, is significantly different than the 2007 version in terms of the classification of street light poles due to the potential hazard to road users. The three the slip base lighting column and the impact-absorbing lighting column (Fig. 4.7):

1) Non energy (NE) absorbing poles allow the vehicle to continue after an impact with a limited reduction in speed. They therefore represent a lower primary injury risk than Energy absorbing support structures.
2) High energy (HE) absorbing poles slow down the vehicle considerably on impact. The risk of secondary collisions with trees, pedestrians and other road users is reduced. In urban areas where risk of a secondary accident is high, poles require a high energy absorbing classification.
3) Low energy (LE) absorbing poles are generally designed to bend in front of and under the impacting vehicle before shearing or detaching toward the end of the impact.

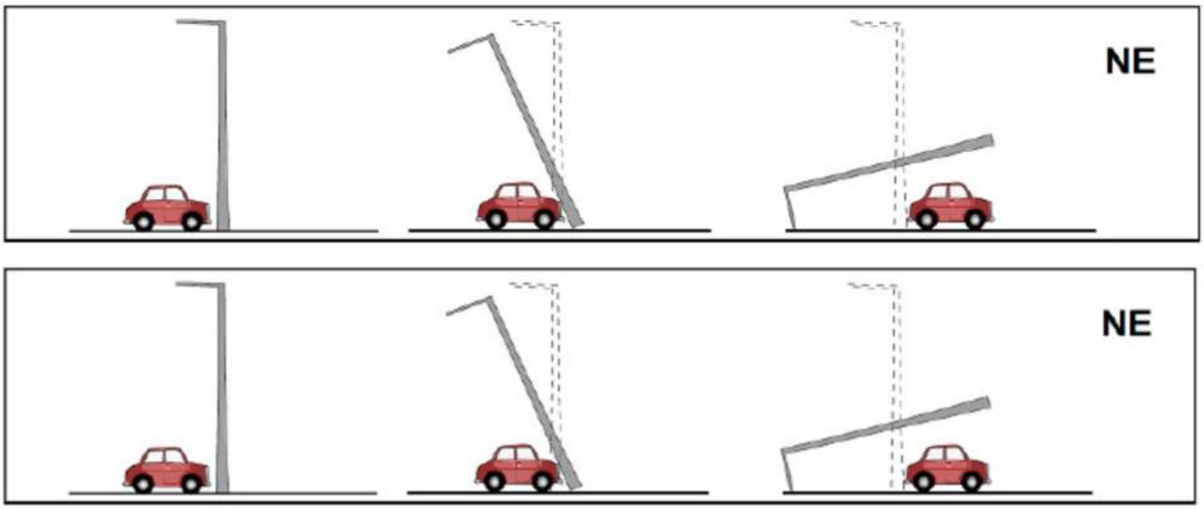


Fig. 4.7 Crash-friendly poles (source: https://www.hydro.com/en-PL/aluminium/products/poles/safety-poles/)

5 INVESTIGATING ROADSIDE HAZARDS:A ROADSIDE SAFETY MANAGEMENT STRATEGY (CAREC, 2018)

The technical knowledge about how best to treat a roadside hazard can also be applied during road safety audits of the designs of new highway projects. Road safety audit teams, when trained and experienced, can inject safety into new road designs. They can draw attention to potentially unsafe roadside objects during their audits and can assist design teams to produce safer designs. Applying the clear zone concept to new road designs is taking a positive road safety initiative. Road safety audits can do a lot to prevent unsafe design features from progressing. No one wants to build any more unsafe roadsides.

The five-step roadside hazard management strategy offers five options to treat each identified hazard:

- keep vehicles on the road,
- remove the hazard,
- relocate the hazard,
- modify the hazard, and
- shield the hazard.

Figure 5.1 shows how this strategy offers a logical step-by-step approach to the treatment of a roadside hazard.

5.1 Keeping vehicles on the road

The first objective in roadside hazard management is to keep road users safely on the roadway with a reasonable width, a sound road surface, a predictable alignment, and good delineation and signs. The best way to think of this option is to remember that if no vehicle ever leaves the road, there will not be a roadside hazard management problem.

This is, essentially, the first and last option in the five-step roadside hazard management strategy. Do all with low-cost options (delineation, chevron alignment markers, warning signs, sealed shoulders, tactile edge lines) to keep all vehicles on the road.

In some locations, it may be necessary also to ensure that each hazard (particularly trees and poles) is delineated so it can be more easily seen by drivers. Reserve this as the last option; delineating a hazard will likely reduce incidental collisions (sometimes called “innocent hits”), but will be useless to assist the occupants of an errant vehicle that is out of control.

Then, after applying the other four steps in the strategy and finding they do not offer a full or appropriate treatment for the hazards, return to this first step as the only viable option that may be open. Recheck to be doubly sure all has been done to keep all the vehicles on the road. Remember that, if all vehicles remain “on the road,” then there will not be a roadside hazard problem

5.2 Remove the hazard

This step in the strategy seeks to remove all existing roadside objects that are fixed and are 100 mm in diameter or larger within the clear zone. Removing the hazards will not prevent a crash, but it will substantially reduce the consequences of a crash. Fixed roadside hazards injure and kill the occupants of errant vehicles. During impact, they impose enormous forces on the occupants; sometimes, these are so strong that the occupants suffer unforgiving internal injuries.

If there are several fixed roadside hazards in one location, try to remove all of them. If this is not possible, perhaps half can be removed, determine what else can be done to make the roadside safer. Remove those hazards? It is always good to eliminate hazards. But what if a safety barrier is installed to shield the remaining hazards? Perhaps all the hazards could have been left and shielded with the same barrier?

This is one of the many options that require experience and logic. Whatever happens, keep going back to the roadside hazard management strategy and use it as guidance in every location.

To prevent the problem of hazardous objects being created within the clear zone, develop policies that will avoid the placement of new potentially hazardous objects on the roadside. When designing a new road, avoid locating any new hazardous objects within the clear zone.

5.3 Relocate the hazard

Relocation of hazards to a less vulnerable location will reduce the risk of an errant vehicle hitting them. This may mean relocation to further from the edge of the road or it could mean relocation from the outside of a curve to a location on a straight section of the road.

If not possible to totally remove a roadside hazard from the clear zone, the next option is to relocate it beyond the clear zone to minimize the potential for it to be hit by an errant vehicle. Poles, structures, lighting columns, even drains can be relocated. A relocation of even a few meters will reduce risk, even if it is not possible to place the hazard outside the clear zone.

An example of an avoidable new roadside hazard is placing large sign supporting posts in high speed gore areas at expressway exits. Rather than automatically assuming these will be shielded with barrier, look for other locations outside the clear zone so that a hazard is not built in the first place. Relocating the sign gantry at the design stage will be cheaper and safer than having to do this some years later. It will likely save on barrier too.

Trees are a hazard that generally cannot be relocated. They are also one of the most common hazards along roads. As a rule, if a large tree is within the clear zone, there are three choices: remove it (albeit with environmental issues), shield it (with suitable barrier), or do all possible to keep the vehicles on the road at that point. Trees are a hazard that cannot be relocated in any practical way.

5.4 Alter the hazard

After doing all that can be practically done to keep the vehicles on the road, examining the possible removal of the hazards, and considering options to relocate the hazards, the next step in the strategy is to alter (or redesign) the roadside hazard to reduce its potential for severe injury or death during a crash.

This option includes covering drains with drivable covers, replacing rigid posts with frangible (breakaway) posts, flattening side slopes, or installing drivable end walls at driveway crossings. There are many safer roadside devices and furniture now available.

Altering or modifying a hazard is an option to consider when attempting to improve roadside safety in locations where removal or relocation of a roadside hazard within the clear zone area is not feasible or practicable. Modifying a roadside hazard can reduce the severity of a crash and the potential for serious injury. Common modifications include:

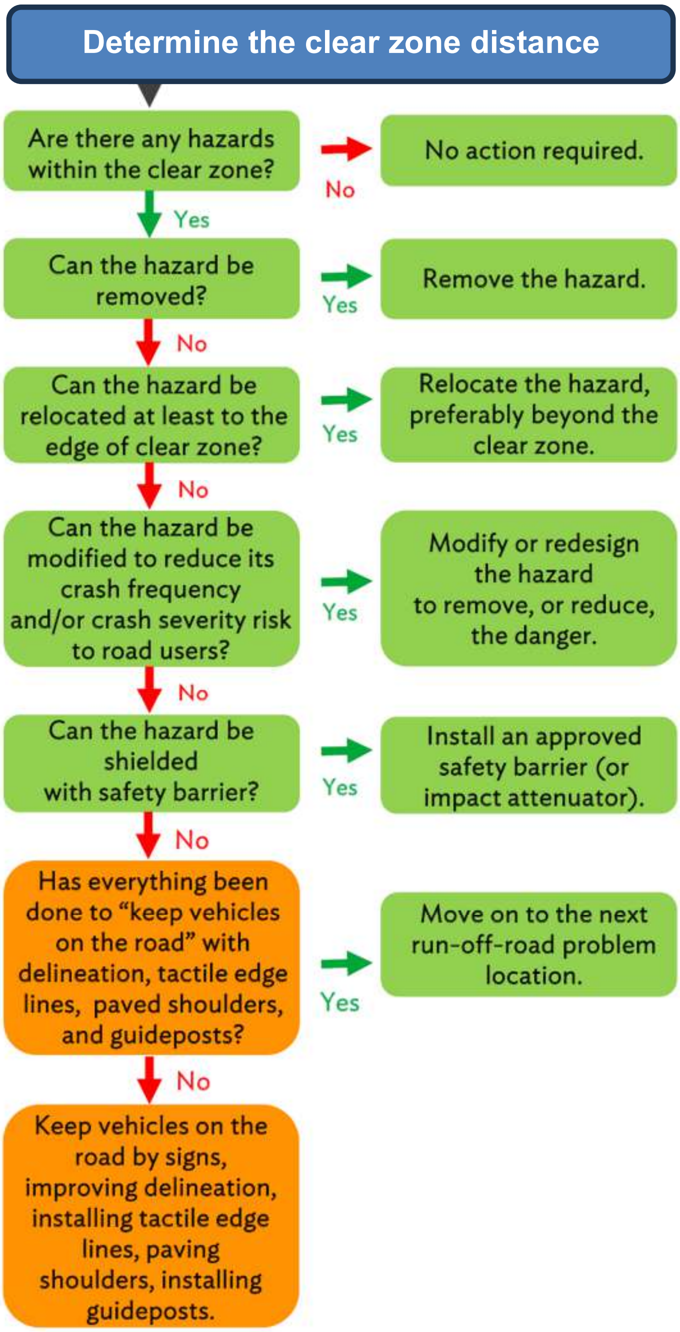


Fig. 5.1 Flowchart Outlining the Five-Step Roadside Hazard Management Strategy (source: Roads and Transport Authority of Dubai. 2008. Roadside Design Guide for Dubai)

- modifying open longitudinal drains by piping them or covering them with a drivable cover;
- modifying end walls of driveway culverts to make them drivable;
- redesigning rigid sign posts to provide frangible (breakaway) posts;
- designing frangible posts that break away, if struck;
- redesigning rigid street lighting columns to provide frangible columns;
- flattening a steep fill slope to make it drivable.

Longitudinal cut slopes will generally not represent a significant roadside hazard, if kept smooth and free of obstacles. However, they can lead to overturning or “snagging” of a vehicle if the cutting has jagged rocks. In such cases, a cutting may need to be shielded with a suitable barrier.

5.5 Shield the hazard

The clear zone should be kept free of fixed roadside hazards. But we know this cannot always be achieved. So, where the earlier steps in the roadside hazard management strategy have been examined without being adopted, we are left with one option: to protect the occupants of errant vehicles from striking the hazards by the installation of safety barriers.

Safety barriers are designed to redirect an impacting vehicle and dissipate crash forces in a controlled manner. While it is preferable to remove, relocate, or modify roadside hazards, in some situations, shielding a hazard (with barrier) may be the only practicable option where it is not feasible or economically viable to treat the hazard in other ways. The use of safety barriers requires a good understanding of how barriers work, and what amount of space they need in which to operate correctly, if struck. Barriers cannot be safely fitted to shield all roadside hazards.

Safety barriers need to meet appropriate standards to ensure they perform satisfactorily. They must be capable of redirecting errant vehicles and absorbing energy to reduce the severity of a crash to levels that will minimize injury to vehicle occupants. In short, barriers cannot fail when they are needed. The design of safety barriers is based on their ability to perform in a satisfactory manner when impacted by a vehicle. Therefore, care and attention need to be given to selecting the correct barrier and to installing it fully according to the supplier’s instructions. A range of factors need to be taken into consideration when selecting and designing safety barriers. These include:

- the need for a barrier (remember that an impact with a safety barrier should be less severe than the impact with the hazard being shielded.);
- the crash performance requirements of the barrier based on the operating speed and the types of vehicles using the road;
- design requirements, including offset from traffic lanes, clearance from the hazard, the slope and condition of the surface in front of the barrier, and any restrictions imposed by vertical or horizontal geometry;
- the length of the barrier required to effectively shield a hazard;
- the type of barrier required;
- terminals for the ends of the barrier so they are not hazardous;
- maintenance requirements and issues.

The three categories of safety barriers are:

- flexible barriers,
- semirigid barriers,
- rigid barriers.

Each has various benefits and constraints that make them suitable for some locations, but unsuitable for others. Engineers need to understand the benefits as well as the limitations of each group of barrier to avoid wasting resources or, worse, installing unsafe barrier.

6 ROAD RESTRAINT SYSTEM

6.1 Rigid barriers

Concrete road barriers are made of reinforced concrete and do not change their position or shape in the event of a collision, which often leads to serious accidents (Fig. 6.1). These types of barriers do not take up much space and do not allow vehicles to get to the other side, which is why they are mainly used as two-way traffic separators.

Fig. 6.1 Example of rigid barrier (source: CEDR, 2018)

6.2 Semi-rigid barriers

Compared to concrete barriers, they are usually made of steel and have less stiffness, which makes them more flexible upon impact, and accidents involving them are less dangerous for road users (Fig. 6.2). These barriers have 2 main purposes: stopping the vehicle from entering the area they protect and partially absorbing the impact energy. A vehicle hitting this type of barrier is reflected at a certain angle, which creates a risk of collision with other vehicles. A popular type of semi-rigid barrier "W-beam" is shown in the photo below

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Fig. 6.2 Example of semi-rigid barrier „W-beam". (source: CEDR, 2018)

6.3 Flexible barrier

Compared to other types of barriers, flexible ones reduce the forces acting on the vehicle during an impact, which makes collisions involving them relatively safer for road users (Fig. 6.3). In order for this type of barriers to fulfill their purpose, the surrounding area should be flat to avoid additional collisions with slopes, and it should also have appropriate dimensions, because the flexible barrier reflects the vehicle in the event of a collision, which increases the risk of an accident with other road users. Examples of flexible barriers are shown in the photo below.

Fig. 6.3 Example of flexible barriers. (source: CEDR, 2018)

6.4 Temporary barrier

Temporary barriers are generally used to protect roadworks (Fig. 6.4). They are made of various materials, e.g. metal, concrete or plastic. Compared to permanent road barriers, temporary ones are not attached to the ground. They are also less safe, but roadworks safety depends largely on other factors. Traffic speed is the most important factor and is reduced on work sections. The second factor is the geometry of the road, the dimensions are usually reduced, which means that drivers have to be more attentive.

Fig. 6.4 Example of temporary barrier (source: https://grawil.saferoad.com)

6.5 Crash cushion

Energy-absorbing covers or crash cushions prevent vehicles from hitting an obstacle directly. They should be used when other methods are unavailable in a given situation. Covers can be divided into allowing and non-letting. Recessive cushions are those that allow the vehicle to enter their area and continue driving, examples are: barrels with water or barrels with sand placed in an appropriate formation, often triangular. Non-allowing ones stop the vehicle and prevent it from hitting the object they are protecting. An example of such solutions are segmented crash cushions, composed of several segments that collapse successively during a collision. Examples of recessive and non-retractable crash cushions are shown in the photos below (Fig. 6.5).

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Fig. 6.5 Example of crash cushion

7 DEVELOPMENT OF A SYSTEMATIC APPROACH TO ROADSIDE SAFETY MANAGEMENT (SOURCE: PROGRESS, 2019)

Even though most European countries have unique roadside safety standards, most share similar approaches in the way they define roadside risk and the procedures they recommend for mitigating it. This was clearly shown in SAVeRS (Erginbas at al., 2014), under which the national roadside design guides and standards of 35 different countries were analysed and compared in detail. This study defined roadside risk as the product of likelihood (including the likelihood of a vehicle leaving the carriageway and the likelihood of an errant vehicle reaching a hazard) and consequences (for occupants of the errant vehicle and for third parties) of a roadside accident (Fig. 5.1).

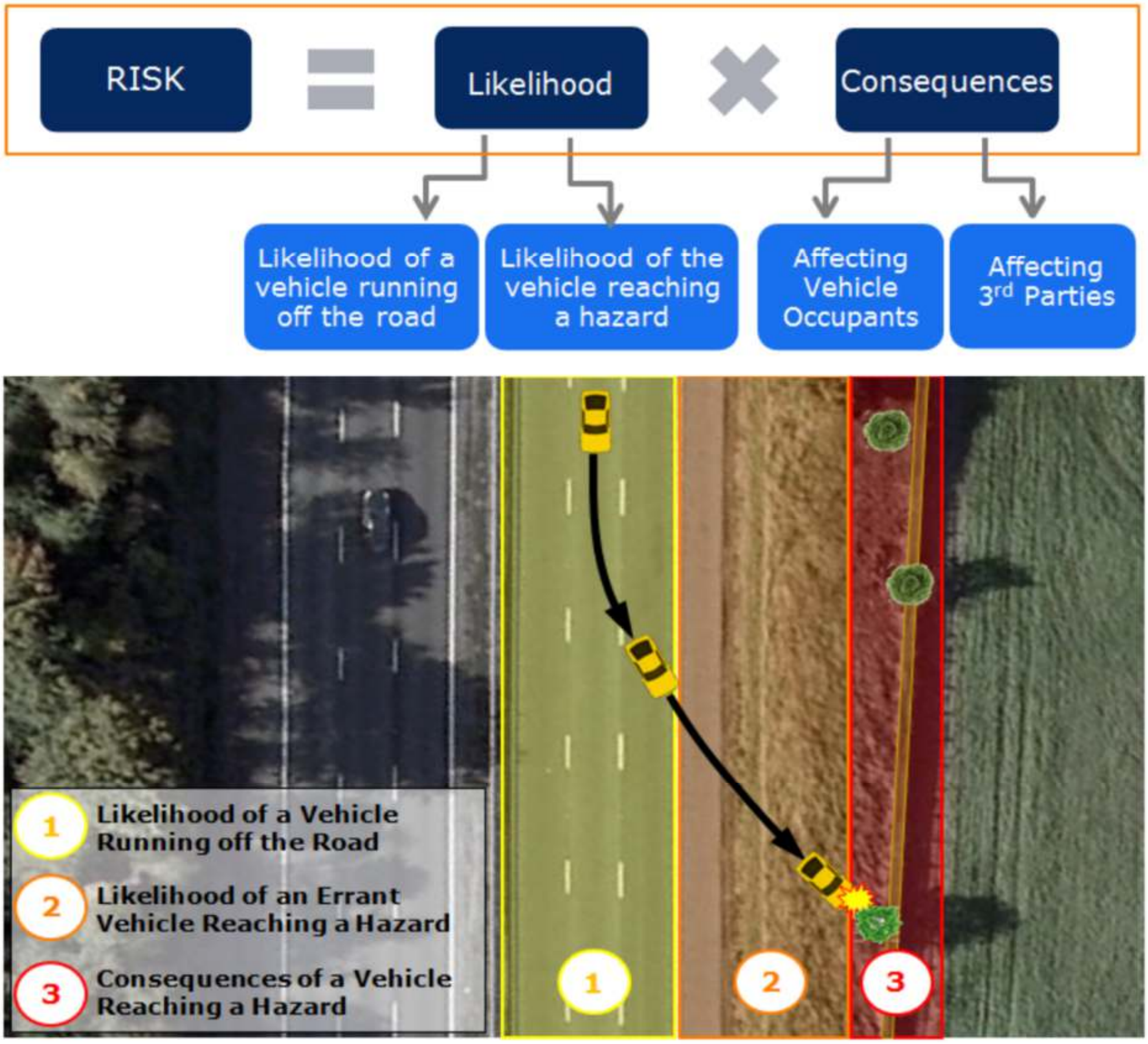

Fig. 5.1 Risk from a roadside safety perspective (source: Erginbas et al., 2016)

In the standards, the likelihood part of the risk formula is assessed through clear zone models. A minimum recommended clear zone width is calculated for a roadside under evaluation and if there are any objects or terrain features located within that area it is assumed that they are likely to be reached by an errant vehicle. Similarly, in the majority of standards, the consequences part of the risk formula is assessed through the identification of roadside objects and terrain features which are considered a hazard for each country; in other words, they are considered to have high consequences if reached by an errant vehicle and therefore warrant risk mitigation measures. While some countries such as the UK calculate the risk in terms of scale measures (such as equivalent fatalities per 100 million vehicle km) and check if it is under the acceptable limit, others adopt a binary approach of simply checking if objects which are considered hazards are located within the minimum recommended clear zone or not. In either case, if the risk is perceived to be unacceptable, mitigation measures are justified.

A fundamental issue that is directly related to roadside safety is the choice of mitigation method, once the risk is identified as high. The risk can be mitigated through a number of measures, which would reduce either the likelihood or consequences of a vehicle leaving the travelled way. These often include the removal of the hazard (decreases both likelihood and consequences), relocation of the hazard further away from the road (again decreases both likelihood and consequences), replacing the hazard with a passively safe alternative or modifying it to be safely traversable (decreases consequences), shielding the hazard with vehicle restraint systems (decreases consequences but increases likelihood) or even just delineation (decreases likelihood). These measures can be grouped into two primary strategies, according to their fundamental effect. The first is to provide adequate clear zones and the second is to shield the hazards with vehicle restraint systems. Generally, countries seem to have adopted a mixture of these two strategies with the rule being providing (obstacle free) clear zones and the exception providing vehicle restraint systems to screen off objects/obstacles that may constitute a safety hazard for road users. Vehicle restraint systems are considered hazards themselves (even if they pose lower consequences than the objects they are shielding) and therefore when cost is not taken into consideration, eliminating the likelihood of an impact through clear zones is seen as a lower risk option. The problem however, is that the majority of the roadside design standards do not provide the necessary guidance to assess the decision between clear zone and shielding from an economic perspective.

Furthermore, in both cases an important factor remains unexplored, namely the definition of obstacles and the levels of maintenance over time. For example, trees become obstacles/hazards once their trunks reach a certain diameter, greenery grows and restricts visibility and these aspects require monitoring. The same applies to vehicle restraint systems, frangible posts and masts, time (ageing/deterioration) could affect their (safety) performance and they may require replacement (2019). It is equally important that such systems and “crash friendly” posts are not inadvertently replaced with rigid and potentially unsafe elements. A corroded or improperly installed vehicle restraint system can pose a higher risk to errant vehicles than the hazards it is installed to shield. On another level, a roadside barrier which was impact tested with an old vehicle (for example a pre-NCAP era vehicle with considerably lower structural stiffness), may not be able to safely contain a modern one, such as an SUV. Effective management of roadside elements is essential to ensure that not only roadsides alongside new roads are safely designed and laid out, but that these are also maintained and kept safe during the operational life of the road. Associated with the maintenance of roadsides is the safety of road workers. Inherent to safe roadsides is effective management and quality control.

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