

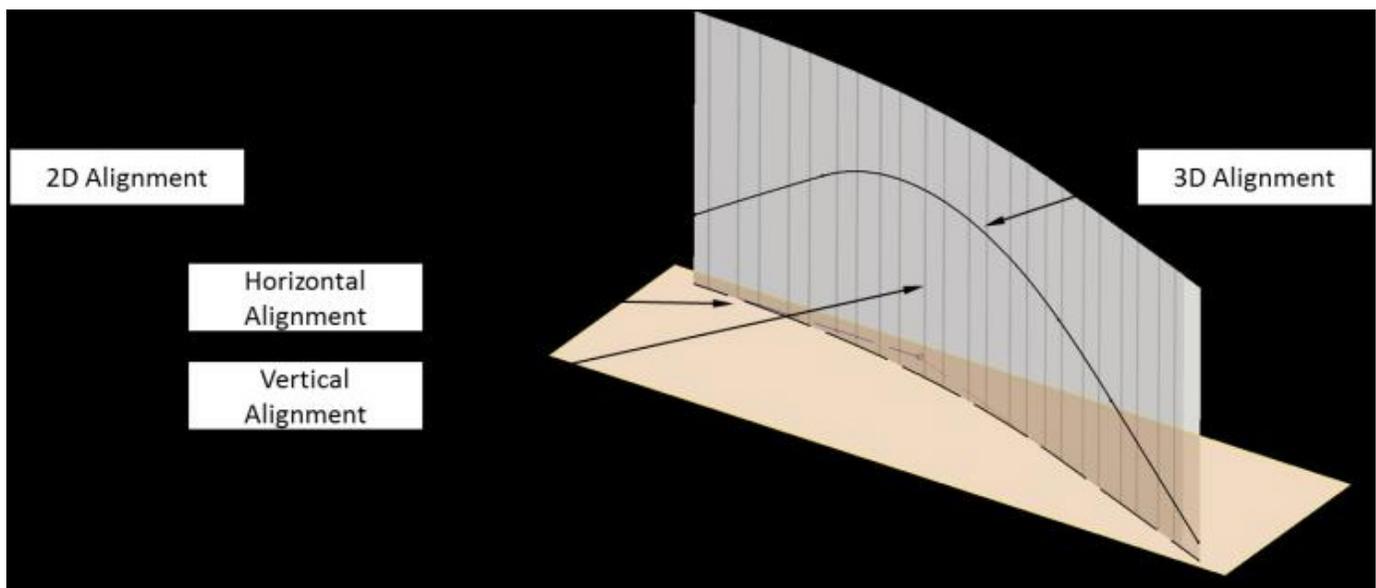
# 5. CROSS SECTION AND ALIGNMENT

Road design can be broken into three main parts: horizontal alignment, profile/vertical alignment, and cross section. Combined, they provide a three-dimensional layout for a roadway (figure 5.1).

- The horizontal alignment is the route of the road, defined as a series of horizontal tangents (straights) and curves (usually circular). This is usually represented in plan form as centerline geometry with lane and edge lines.
- The profile/vertical alignment is the vertical aspect of the road, including crest and sag curves, and the straight grade lines connecting them. This is usually represented in profile form and includes a section cut through the existing terrain along the line of the road centerline.
- The cross section shows the position and number of travel lanes, including cycle lanes and sidewalks, along with their cross slope or banking. Cross sections also show drainage features, pavement structure, and other items outside the category of geometric design. This could be a “typical section” showing the standard or recommended widths of design components, or sections at specific locations used to highlight particular features.

Each of these parts are comprised of geometric design elements, including horizontal curves and straights, vertical curves and gradients, lane widths, shoulder widths, median widths, superelevation, and crossfalls, among others. The design of these elements influences safety and very restrictive designs, such as sharp horizontal curves or very narrow lanes, relative to the

**Figure 5.1:** Three-dimensional layout combined with horizontal and vertical alignments.



travel speeds, and often results in considerably higher crash rates. Certain combinations of these elements may also result in severe crash consequences. It is important to keep in mind the principles to good geometric design as discussed in section 2.1. The design should result in a road environment that is consistent with the road users' expectations or "non-surprising," as well as "forgiving" in the sense that road users' mistakes can, as far as practicable, be corrected, if not avoided. The selected design speed on which road alignment and cross-section characteristics are determined needs to be realistic and compatible to the expected operational speed (see section 3.1). It should also be in accordance to the type and functional requirements of the road and compatible to the roadway environment (see chapters 2 and 1).

The key principles when designing a road are to provide consistency, readability, and predictability. As such, elements of the alignment that are inconsistent or out of context with the rest of the alignment should either be avoided or clearly signaled to the driver with additional signing, delineation, and other visual cues. Context is also important when considering the form, function, and primary purpose of the road. This will influence the width of the road, its look and feel, and also how drivers are likely to read it and select their driving speed.

In the following sections, the safety implications (i.e., the relationship between the design element and safety) as well as good design practice of various cross-section elements, and the horizontal and vertical alignment are discussed in detail. The combination of horizontal and vertical curves is discussed in section 5.3. Various case studies/ examples of both good and bad practice are also provided in each section. Design elements for vulnerable road users including footpaths, and cycle and motorcycle facilities, though part of the cross section, are discussed separately in chapter 4.

## 5.1. Road Width

### General description

Road width is the total width of the portion of the roadway that allows for the movement of through vehicular traffic, including shoulders but excluding facilities such as curbs, separated cycle facilities, sidewalks, or parking lanes.<sup>58</sup> It is the full width of the carriageway, including all the travel lanes and adjacent shoulders (if present).

A lane width is the cross-sectional dimension of a traffic lane, perpendicular to the direction of travel, measured between the center of lane markings and the faces of curbs or edge line at the shoulder, as applicable.

Road width affects safety through its influence on speeds and a vehicle's ability to remain within its assigned traffic lane. Generally, higher-speed facilities require wider roads/lanes compared to lower-speed facilities. The environment (whether urban or rural context) and the road function also play critical roles in the selection of road widths.

### Safety implications

It is important that the assignment of available space on the road is consistent and well considered to achieve a high level of readability and predictability. This means that all modes sharing the road corridor understand where they each should be and their position relative to each other, whether in adjacent lanes and shoulders or opposing lanes.

Wider roads/lanes generally encourage, and are associated with, higher operating speeds than narrower roads/lanes. As such, the use of wide roads/lanes can pose significant safety risks, especially within the urban traffic environment where pedestrians, cyclists,

<sup>58</sup> These facilities (curbs, bicycle facilities, sidewalks, parking lanes) are also essential elements of the road cross section within the right-of-way (total land area acquired for the construction of a roadway) and are covered in detail in separate sections. Shoulders are also discussed in detail in the following section.

**Figure 5.2:** Use of wide lanes in an urban area at the expense of vulnerable users (pedestrians and cyclists).



Source: Global Designing Cities Initiative, & National Association of City Transportation Officials (NACTO).

and crossing vehicles are embedded in the traffic mix (figure 5.2; see also figure 5.3 for appropriate use of wide lanes). Higher operating speeds and associated greater stopping sight distances can make it more difficult for motorists to bring their vehicles to a quick stop to avoid crashes. This is because the following distances at higher speeds may appear excessive, leading to vehicles cutting across on multilane roads and a tendency for drivers to drive closer to the car in front of them. The severity of crashes may also be increased.

- Wider road/lane widths in urban areas increase exposure and crossing distance for pedestrians at intersections and midblock crossings.
- Lanes that are too narrow (typically less than 2.8~3.0 m) have increased risks of poor lane discipline at high speeds, such as single vehicle run-off-the-road crashes and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe collisions. This may be due to encroachments onto adjacent lanes, insufficient space for overtaking wide vehicles, or reduced sightlines to other vehicles in congested conditions. Within urban areas, narrowing of lanes can be used to control speed.

**Figure 5.3:** Appropriate use of wide lanes on freeway.



Source: iRAP.

- Lanes that are excessively wide have increased crash frequencies. Studies report that the safety benefit of widening lanes stops once lanes reach a width of roughly 3.4 m, with crash frequencies increasing as lanes approach or exceed 3.7 m.<sup>59</sup>, <sup>60</sup> The use of lanes greater than 3.6 m may in fact be used as two lanes, which can lead to increases in sideswipe crashes. Higher speeds may also be expected, which increases the likelihood and severity of crashes.
- Narrow lanes at curves may not provide an adequate tracking width or swept path for wide vehicles or room for driver error and may result in head-on crashes, sideswipes (particularly with vulnerable users in shoulders), or run-off-the-road crashes. Superelevation around curves can be applied to help maintain good lane tracking.
- Narrow turning lanes at intersections may not accommodate the swept path of larger vehicles such as trucks and buses, which may lead to encroachments onto adjacent lanes increasing the risk of sideswipes (particularly with vulnerable users), and head-on and run-off-the-road crashes.

59 Dumbaugh, E., and Rae, R. 2009. Safe urban form: revisiting the relationship between community design and traffic safety. *Journal of the American Planning Association*, 75(3), 309–329.

60 Noland, R. B. 2003. Traffic fatalities and injuries: the effect of changes in infrastructure and other trends. *Accident Analysis & Prevention*, 35(4), 599–611.

## Good design practice/treatments/ solutions

- The selection of the lane width and the number of lanes will depend on various factors including:
  - Target vehicle speed (design speed, average speed, and posted limits) and lateral displacement.
  - Context (existing or future function of streets and land uses).
  - Level of pedestrian and cycle activities and facilities.
  - Vehicle volumes and capacity.
  - Vehicle type (large vehicles, transit vehicles, trucks) and the degree of truck proportion in total traffic.
  - Provisions for other users.
  - Nature, direction, and number of lane uses (turning lanes, through lanes, curbside lanes).
  - Situation adjacent to the lane (delivery, on-street parking, boulevards).
  - Emergency vehicle operations. Travel lanes should not be too narrow (less than 2.8~3.0 m) for vehicles pulling out from emergency vehicles' paths, and long uninterrupted medians should be avoided. Multiple lanes leave sufficient space for drivers to pull out of the way of emergency vehicles.
- Topography and geometry (continuous median, horizontal alignment, crossfall, or slope of the road).
- Other considerations (snow cleaning and storage, topography and road camber or curvature, maintenance, bridges and crossing points, planned changes of streets).
- Narrowing lanes is an effective tool for speed management since narrower lanes generally bring down operating speeds closer to safer speed limits, while maintaining consistent speed and minimum impact on corridor travel time.
- In urban areas, the use of narrower lanes has numerous benefits when considered within the assemblage of a given street, and urban streets can be redesigned to accommodate the needs of all road users through a road diet (figure 5.4). A road diet is generally described as reducing the number of travel lanes and/or narrowing travel lanes in a roadway and utilizing the space for other uses and travel modes. The benefits include:
  - Reclaimed space to serve other modes, including cycle lanes and sidewalks, which improves mobility and access for all road users.
  - Reclaimed space for geometric features that enhance safety, such as medians, pedestrian refuge islands, and turn lanes.
  - Allow greater and more attractive space for pedestrians to relax and linger.
  - Shorter pedestrian crossing times because of reduced crossing distances.

**Figure 5.4:** Example of a road diet in Brazil showing reduction in the number of lanes from three each way in 2009 to two each way in 2014, with the addition of a wide median footpath and cycle lanes.



Source: Urban ideas. Accessed at <https://www.urb-i.com/before-after-gallery>.

- Reduced interference with surrounding development.
- More economical to construct.
- Less stormwater runoff as more space can be left as vegetation.
- Wider lanes may be necessary at turning locations, including curves, turning lanes, and roundabouts,

especially when designed to accommodate larger vehicles. This allows more space for drivers to get around a curve/turn without encroaching onto the adjacent lane, shoulder, or even footpath. The amount of widening per lane will depend on the radius of the curve, the type/size of vehicle operating on the road, and some allowance for steering variations by different drivers.

## Case Study

### São Paulo, Brazil

**Figure 5.5:** Before and after of Joel Carlos Borges Street, São Paulo, Brazil, September 2017.



Source: © Daniel Hunter/WRI Brasil.

São Paulo's Berrini Train Station is connected to the city's central business district by Joel Carlos Borges Street that accommodates thousands of daily users. Before September 2017, the street had narrow sidewalks that were unable to safely accommodate the heavy pedestrian flow of approximately 4,700 pedestrians during the morning peak (between 7:00 am and 9:30 am). In contrast, only 170 vehicles travelled on the street at the same peak, translating to an average of 28 pedestrians for each car. Since the narrow obstacle-filled sidewalks could not meet this demand, people walked unsafely in the middle of the street and between parked and moving cars.

The city decided to increase the pedestrian area on the road by 70 percent by removing the parking lane and narrowing the vehicle travel lane (see figure 5.5). The narrow and rundown sidewalks gained an additional 3.5 m in width, providing ample space for pedestrian traffic. The city also improved signages, lowered speed limits, and added street furniture and green infrastructure.

This was the first temporary road intervention in the city that aimed to test low-cost transformation measures before performing expensive and more complex works. The project was well received by the public, and the city is now considering similar efforts in other high pedestrian areas such as schools and hospitals.

- Narrowing lanes on the approaches of signalized urban intersections can help manage the speeds and reduce pedestrian crossing times due to reduced crossing distances.
- Advance warning is needed whenever there is a change in the cross section, for example on approaching narrow bridges and culverts. This is in line with the principle of predictability and a “no surprises” approach in which road users are provided with appropriate and relevant information in a timely fashion to facilitate their decision-making.
- Since vehicle speeds increase when roads are widened and reduce when a lane is narrowed (to a reasonable degree), a safety assessment is needed to determine the appropriate lane width and the suitability of a lane widening/narrowing treatment at a given hazardous location or intersection.

## Further Reading

- Federal Highways Authority FHWA. 2016, July. Road Diets. Accessed at [https://safety.fhwa.dot.gov/road\\_diets/](https://safety.fhwa.dot.gov/road_diets/).
- Global Designing Cities Initiative, & National Association of City Transportation Officials. 2016. Global street design guide. Island Press. Accessed at <https://globaldesigningcities.org/publication/global-street-design-guide/>.
- National Association of City Transportation Officials. 2013. Urban street design guide. Island Press. Accessed at <https://nacto.org/publication/urban-street-design-guide/>.
- World Road Association (PIARC). 2009. *PIARC Catalogue of Design Safety Problems and Potential Countermeasures*, La Défense cedex. Accessed at <https://www.piarc.org/en/order-library/6458-en-PIARC%20Catalogue%20of%20design%20safety%20problems%20and%20potential%20countermeasures.htm>.
- European Commission. Getting initial safety design principles right. Accessed at [https://ec.europa.eu/transport/road\\_safety/specialist/knowledge/road/getting\\_initial\\_safety\\_design\\_principles\\_right\\_en](https://ec.europa.eu/transport/road_safety/specialist/knowledge/road/getting_initial_safety_design_principles_right_en).
- Karim, D. M. 2015, June. Narrower lanes, safer streets. In Proc. CITE Conf. Regina, pp. 1–21.
- Welle, B., Liu, Q., Li, W., Adiazola-Steil, C., King, R., Sarmiento, C., and Obelheiro, M. 2015. Cities safer by design: guidance and examples to promote traffic safety through urban and street design. Must read chapter, Kenya Urban Design Elements and chapter 5, Pedestrian Spaces and Access to Public Space.

## 5.2. Shoulder Width and Type

### General description

A shoulder is the portion of the roadway contiguous with the travelled way that, depending on the width, design, and maintenance, performs several functions. The benefits include:

- Accommodation of stopped vehicles for emergency use;
- The provision of a controlled recovery area for drivers who inadvertently stray from their lane, thus reducing the risk of run-off-the-road crashes (especially in high-speed locations);
- Provision of space for evasive maneuvers to avoid potential crashes or reduce their severity;
- Provision of a defined space for cyclists or pedestrians where designed safely, in the absence of separated facilities;
- The provision of structural support to the pavement;
- Reduction of pavement breakup by allowing storm water to be discharged farther from the travelled way, and therefore have both safety and asset management benefits;
- Provision of lateral clearance to roadside objects, e.g., curbs, signs, and guardrails; and

**Figure 5.6:** Paved shoulder.

Source: © John Barrell.

**Figure 5.7:** Unpaved gravel shoulder.

Source: Zeng, H., Schrock, S. D., and Mulinazzi, T. E. 2013. *Evaluation of safety effectiveness of composite shoulders, wide unpaved shoulders, and wide paved shoulders in Kansas* (No. K-TRAN: KU-11-1). Kansas Dept. of Transportation. Bureau of Materials & Research.

**Figure 5.8:** Partially-paved or composite shoulder

Source: Zeng, Schrock, and Mulinazzi, 2013.

- Improvement of sight distance in cut sections and enhancement of highway capacity and efficiency by encouraging uniform speeds.

Shoulders can be paved (figure 5.6), unpaved (i.e., granular or earthen shoulders; figure 5.7), or partially paved (i.e., shoulders comprising of a paved section and unpaved section; figure 5.8). These are also known as composite shoulders.

## Safety implications

- Shoulders that are too narrow do not provide an adequate recovery width for stray vehicles and enough through traffic clearance to vehicles stopped on the shoulder. These vehicles actually create roadside hazards and result in increased risks for run-off-the-road crashes, head-on and nose-to-tail collisions, and sideswipes.
- Shoulders with inadequate skid resistance may cause a vehicle that leaves the travelled way, especially one travelling at high speeds, to lose traction and control resulting in run-off-the-road crashes, with severe consequences upon impact with roadside objects or other vehicles.
- In the absence of other facilities with more separation, a shoulder that is too narrow or in poor condition inevitably displaces nonmotorized traffic onto the carriageway where they face increased

**Figure 5.9:** Narrow shoulders resulting in increased risks for cyclists on the travelled way

Source: iRAP.

**Figure 5.10:** Pavement edge drop.

Source: © Watetu Mbugua/World Bank.

**Figure 5.11:** Illegally parked trucks on shoulder.



Source: Indian Institute of Technology, Kharagpur. 2019. Report on Road Safety Audit of SH-11 During Operation Stage.

safety risks due to exposure to high-speed traffic (figure 5.9).

- Unpaved shoulders, especially on roads with high heavy-vehicle volumes in areas with heavy rainfall or abundant water runoff such as sag curves, may be eroded with time, resulting in pavement edge drop-offs (figure 5.10), i.e., where there is a difference between the height of the road surface and the height of the shoulder. Edge drops may cause a driver who drifts out of the travelled way to lose control of the vehicle and either veer off the road or overcorrect and veer into the oncoming traffic.
- Roadways with no clear distinction between the carriageway and the shoulder (due to lack of signs, pavement markings, or low curbs) may encourage the use of shoulders by motorized traffic, even when the shoulder is of a different surface material and intended to serve a separate purpose to the carriageway (figure 5.11).

**Figure 5.12:** 2.5 m shoulder people wrongly using as a traffic lane—Romania.



Source: © Alina F. Burlacu/GRSF/World Bank.

- Excessively wide shoulders, especially when paved, can pose some safety risks including:
  - Wide, paved shoulders result in higher operating speeds which, in turn, may impact the severity of crashes,
  - Paved shoulders greater than 2.5 m may be interpreted as a travel lane by drivers, or even as temporary places for commercial activity (such as selling items to passing motorists),
  - Wide shoulders may generate voluntary stopping on the shoulders, and
  - Wide roadway widths, resulting from wide shoulders and wide lanes, combined with limited right-of-way, may result in steeper side slopes or backslopes.
- Objects such as electricity posts, cable ducts, and raised drainage covers that are located along the shoulders are hazardous to all road users.

### Good design practice/ treatments/solutions

- It is recommended that the shoulder be constructed of the same materials as the carriageway in order to facilitate construction, improve pavement performance, and reduce maintenance costs.

**Figure 5.13:** Wide sealed shoulder.



Source: IRAP.



**Figure 5.14:** Wide, paved shoulder on curve.



Source: iRAP.

- The ideal width of shoulder depends on the usage of the road. A wide enough shoulder is recommended to provide an adequate refuge for vehicles to pull over and a recovery area in case of a roadway departure but not too wide to encourage the use of the shoulder as an additional lane (figures 5.12 and 5.13).
- The shoulder surface should provide sufficient skid resistance to prevent the loss of traction and control for stray vehicles. A sealed surface will provide the best grip for tires.
- Shoulders should be continuous regardless of the width to avoid intermittent stopping on the travelled way. This also provides a continuous path for cyclists and pedestrians when shoulders are used as cycle lanes or footpaths.
- The shoulder surface should connect to the pavement at approximately the same level to prevent loss of control for vehicles that erroneously leave the travelled way.
- Sealing shoulders (full width or partially) on otherwise gravel shoulders can reduce the amount of erosion on the gravel shoulder and provide a safe recovery zone for shoulder encroachments.
- The quality of shoulders, on low radius curves in particular, requires special attention given the higher probability of encroachment at these locations. This may be due to intentional driver behavior or inadvertent “off-tracking” of an articulated trailer. Wide, paved shoulders improve the safety of curves (figure 5.14), particularly on the inside

**Figure 5.15:** Paved shoulder with rumble strips used by cyclists.



Source: Bob Boyce/Ped Bike.

- edge (also see section 5.3).
- In the absence of other facilities with greater separation, wide, paved shoulders provide space for pedestrians and cyclists, thereby potentially improving the safety of vulnerable users. Noting that pedestrians and cyclists may be at risk when drivers inadvertently drift off the road, shoulder rumble strips or edge-line rumble strips could be installed to mitigate against this risk (figure 5.15).
- Rumble strips or textured edge markings, which can be produced either by cutting grooves or adding ribs to the road, may be placed on the shoulders (near the edge of the travel lane) to alert drivers when they are leaving the roadway. These are highly effective and significantly reduce run-off-the-road crashes due to inattention, distraction, and fatigue.
- Signs, pavement markings, and textured edge markings provide the necessary distinction between the shoulders and the carriageway and should be used to deter the use of shoulders by motorized traffic except in emergencies. In urban areas, curbs along the edge of the carriageway may be used.
- Objects that are located along the shoulders should be moved and/or buried beyond the shoulders, and where possible, beyond the clear zone (see section 5.7). It is essential that shoulders remain traversable to serve their function.
- The management and maintenance of the road and shoulder should be routine and simple.

## Further Reading

- American Association of State Highway and Transportation Officials. 2010. Highway Safety Manual (2010). Must read Highway Safety Manual Overview and chapter 3, Integrating the HSM in the Project Development Process.
- FHWA. Small Town and Rural Design Guide: Facilities for Walking and Cycling. Accessed at <https://ruraldesignguide.com>. Must read Visually separated part.
- PIARC. 2009. Catalogue of Design Safety Problems and Potential Countermeasures. Must read section 2, Cross-section and section 3, Alignment.
- PIARC. 2019. Road Safety Manual. Accessed at <https://www.piarc.org/en/PIARC-knowledge-base-Roads-and-Road-Transportation/Road-Safety-Sustainability/Road-Safety/safety-manual>.
- World Bank. 2005. Sustainable safe road design: A practical manual. Must read chapter 3, Sustainable safe road design: theory, and chapter 4, Sustainable safe road design: cross sections.

## 5.3. Horizontal Curvature

### General description

Horizontal curves are associated with higher safety risks compared to tangent sections. This difference becomes particularly apparent at radii less than 1,000 m and becomes increasingly significant as curve radii reduce further (< 200 m).<sup>61</sup> This is often the result of a mismatch between the radius, superelevation, and negotiation speed chosen by the driver. This creates an imbalance in the forces exerted on the vehicle and

does not match driver expectations, among other factors.<sup>62</sup> It should be noted, however, that while short horizontal curves of low radius may increase the crash risk in high-speed environments, the same curve length and radius may be appropriate in low-speed residential environments to help facilitate slower speeds,<sup>63</sup> or as part of a series of curves. In addition, high radius curves may be introduced into rural designs to manage vehicle speeds and reduce monotony.

Horizontal curves are associated with run-off-the-road crashes, head-on collisions, and side crashes. The severity of crashes has also been found to be high at horizontal curves. Studies in high-income countries (HICs) show that 25 percent to 30 percent of fatal crashes occur in curves and that 60 percent of the fatal crashes are single vehicle off-the-road crashes.<sup>64</sup>

The key objective while designing horizontal alignment is to ensure there is consistency and uniformity of alignment along the road corridor, thereby providing predictability that maximizes the overall safety of the road. This philosophy of “no surprises” provides a driver with visual cues in the form of a clear view of the curve ahead, with sufficient time to adjust their speed accordingly. Drivers are strongly influenced by their interpretation of the curve radius, and many assume that the combination of radius and applied superelevation is appropriate for the speed limit. If the road has been designed and well maintained, then this assumption is a reasonable one. However, if the road network has evolved over time, there may well be a mismatch between the shape of the road surface and posted speed limit. Without appropriate superelevation, the forces on the driver are not balanced and the driver might feel uncomfortable or potentially lose control.

61 Hauer, E. 2000. Safety of horizontal curves. Draft prepared in the course of project for UMA Engineering (for the new Canadian Geometric Design Guide) and for DELCAN.

62 Hummer, J. E., Rasdorf, W., Findley, D. J., Zegeer, C. V., and Sundstrom, C. A. 2010. Curve collisions: road and collision characteristics and countermeasures. *Journal of Transportation Safety & Security*, 2(3), 203–220.

63 American Association of State Highway and Transportation Officials (AASHTO). 2010. Highway Safety Manual.

64 Lamm, R., Psarianos, B., and Mailaender, T. 1999. Highway design and traffic safety engineering handbook.

## Safety implications

- Unexpectedly sharp curves often result in loss of control, skidding, or crashes onto roadside objects or oncoming vehicles when drivers mismatch their speed to the geometry and are forced to perform sudden corrective actions. This is made worse when the sharp curve is “out of context” or does not match with the alignment conditions adjacent to the sharp curve section that mislead or encourage high speeds, for example, a sharp curve after a series of gentler curves or after a long straight section.
- Obstructions located too close to the carriageway on the inside of the curve without the necessary horizontal sightline offset, limit the sight distance and the driver’s ability to see and anticipate road features ahead of the curve (figures 5.16 and 5.17).
- Sharp curves increase the width of a vehicle’s swept path, which may cause a vehicle to cross into the path of an approaching vehicle on narrow carriageways, or onto the shoulders and pedestrian areas, increasing the crash likelihood for other road users. This is worse for wide or long vehicles/trucks.
- Drivers may overtake on curves when it is unsafe despite the “no-overtaking” provision.
- The road surface on curves tends to polish more quickly than straight sections due to the higher forces exerted by the side thrust of the tire, resulting in reduced skid resistance with time.
- The loss of superelevation (positive camber), particularly on gravel roads, through the lack of maintenance increases the safety risk of curves.
- Other factors that influence the safety on curves include the roadside profile (whether level or drop-off if a vehicle leaves the road), the presence of unshielded roadside hazards, poor visibility, poor delineation (figure 5.18), poor drainage, inadequate or reverse superelevation, inadequate lane widths or lack of extra widening on curves.
- Poor coordination of horizontal and vertical curvature can result in visual effects that may mislead drivers thus contributing to crashes (figures 5.19 and 5.20). This usually occurs when horizontal and vertical curves of different lengths occur at the same location.
- The presence of crest curves immediately preceding sharp curves can hide the sharp curves from the drivers view, creating a lack of readability (figure 5.21).

**Figure 5.16:** Tree located too close to the carriageway on inside of curve. It obstructs line of sight and is a safety hazard. It also has the potential to push road users toward or even across the centerline at a curve, making it very unsafe.



Source: Indian Institute of Technology. 2019. Report on Road Safety Audit of SH-11 during operation stage.

**Figure 5.17:** Mountainous curve with tree obstructs where a road crash occurred.



Source: Nepali Times, 2021. Nepal's other pandemic: road fatalities. 2021. Accessed at <https://www.nepalitimes.com/here-now/nepals-other-pandemic-road-fatalities/>.

**Figure 5.18:** Insufficient delineation at curve.



Source: ChinaRAP.

**Figure 5.20:** Poor alignment combination showing optical breaks caused by steep sag curves along horizontal tangent.



Source: Barnaby Green.

## Good design practice/ treatments/solutions

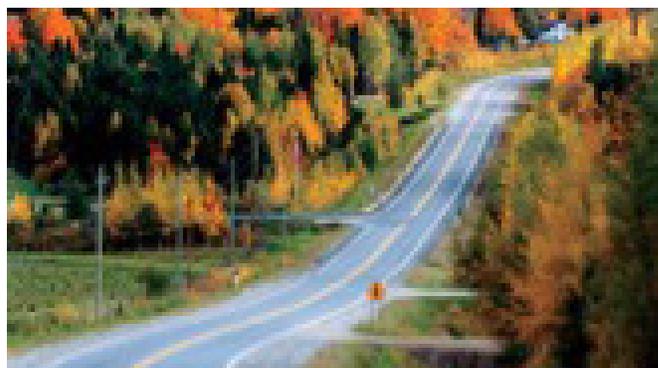
- It is important that a road is designed for a speed that exceeds, as a minimum, the speed often referred to as the operating speed or at which it is anticipated (or intended) drivers will travel.
- At the design stage, consistency and predictability of the driver experience are very important, and unexpectedly tight curves should be avoided. This can be done by either increasing the radius of the curve or ensuring the transition to sharper curves is carried out through gradual and progressive reduction of the radii along sequential curves.

**Figure 5.19:** Hazardous combination of horizontal curve at the base of a steep upgrade.



Source: Federal Highway Administration. 2007. Mitigation Strategies for Design Exceptions, US. <https://safety.fhwa.dot.gov/geometric/pubs/mitigationstrategies/>.

**Figure 5.21:** Hazardous combination: crest curve preceding sharp horizontal curve, with intersections and accesses.



Source: PIARC. 2003. *Road Safety Manual, First edition*.

- For tight horizontal curves, which are out of context compared to the rest of the design and cannot be re-aligned for financial or environmental reasons, special treatments at these curves should be specified and carried forward to the design and construction phases. These special treatments can be in the form of specific signs or markings that alert the driver to the change in conditions.
- Forward visibility and sight distances are important to help the driver assess the road ahead and adjust their speed in anticipation of the road condition. Sight obstructions on the inside of curves or the inside of the median lane in divided highways need to be removed to provide appropriate sight distance. In situations where it is impractical

to remove such obstructions (such as retaining walls, cut slopes, concrete barriers, buildings, and longitudinal barriers), the sight distance should still be optimized, but the design needs to evaluate the risk associated with the deficiency and assess the options for mitigating that risk. Because of the many variables in the design of curves, i.e., the alignment and cross section, and the number, type, and location of potential obstructions, it is necessary to conduct a specific study for each individual curve. Using sight distance for the design speed as a control, the designer can then check the actual conditions on each curve and make the necessary adjustments to provide adequate sight distance. These adjustments should take into account the extent or duration of the obstruction. For example, a retaining wall may represent a significant length of deficiency, thereby requiring some adjustment of design or speed, whereas a single building or clump of trees represents only a momentary reduction and therefore the risk is much lower.

- Curves should be superelevated in proportion to their radius and speed.
- Superelevation should be changed gradually and equally between curves of a different radius; between straights and curves it is normal to change two thirds of the superelevation on the straight and a third on the curve. The superelevation should always be changed at the same rate along an alignment. This is usually expressed as a percentage per second of travel time and is normally between 2.5 percent/s and 3.5 percent/s. This provides a consistent balance in the forces on the vehicle as its direction transitions from one curve to the next.<sup>65</sup>
- Transition curves may be provided between a tangent and a circular curve or between two circular curves, allowing the gradual introduction of superelevation. The length of the transition curves should be equal to the distance over which the superelevation changes. The full nature of approaching curves should be evident to the driver. Long transition curves that mask a sharp final radius should be avoided.
- While simple curves are preferred, compound curves can be used to satisfy topographical constraints that cannot be as effectively balanced with simple curves. For compound curves on open highways, it is generally accepted that the ratio of the flatter radius to the sharper radius should not exceed 1.5:1.
- Higher skid resistance materials can be used on critical bends, particularly in wet environments.
- Large radius horizontal curves may be introduced on straight alignments to break driver monotony and enable drivers to make better judgements of the speeds of approaching vehicles.
- It is worth noting that there is a difference between the European and US/Australian design philosophy regarding adopting long straight roads and more sinuous or curved alignments, which may be a result of the characteristics of the general terrain. In Germany, the condition for the alignment is to have over 70 percent curves with high radii. Straight roads should be avoided. In US/Australia the reverse is true. Either approach can result in unsafe conditions, but needs to be applied consistently, and mixing approaches can lead to greater risk.
- Lane (or curve) widening is normally applied to the inside edge of curves and is often necessary on lower radius curves to provide room for “off-tracking” of articulated vehicles. Especially relevant where radii are <500 m, this allows for the difference between the path of the rear axles of the trailer compared to the truck (tractor) unit.
- Adequate maintenance should be provided, especially on gravel roads, to maintain an acceptable cross-sectional profile with appropriate camber. When it is anticipated that such maintenance is

<sup>65</sup> For more details refer to design guidelines including Austroads. 2009. Guide to Road Design Part 3: Geometric Design and AASHTO (2018). Policy on geometric design of highways and streets (chapter 3). American Association of State Highway and Transportation Officials, Washington, DC.

unlikely, the design of the road and in particular the operating speed, should be based on the assumption of a level cross section.

- On surfaced roads, there is also a requirement for maintenance, including to ensure that debris is removed, as this will have a significant impact on surface friction and the potential loss of vehicle control. This is an issue for all vehicles, but particularly for motorcyclists.
- Where it is not possible to entirely separate horizontal and vertical curves, they should be combined with common changes for intersection points (where the ends and center of the vertical curve are coincident with the corresponding ends and center of the horizontal curve) to avoid the presentation of misleading information to drivers. Where possible, they should be of the same or similar length, and where this is not achievable, the preference is for the extent of vertical curves to lie wholly within a single horizontal curve. This arrangement should produce the most pleasing, flowing, three-dimensional result, which is more likely to be in harmony with the natural landform (figure 5.22). In addition, the following should be kept in mind:
  - Sharp horizontal curves in combination with a pronounced crest vertical curve should be avoided since drivers may not perceive the horizontal change in alignment, especially at night.
  - Sharp horizontal curves at or near the low point

**Figure 5.22:** Example of good combination of horizontal and vertical curvature providing good visibility.



Source: TRL & Department for International Development. 2001. Horizontal curves, highway design note 2/01, TRL Ltd, Crowthorne, UK.

of a pronounced sag vertical curve should be avoided since the view of the road ahead would be foreshortened, and curves in these locations tend to be sharper than they appear.

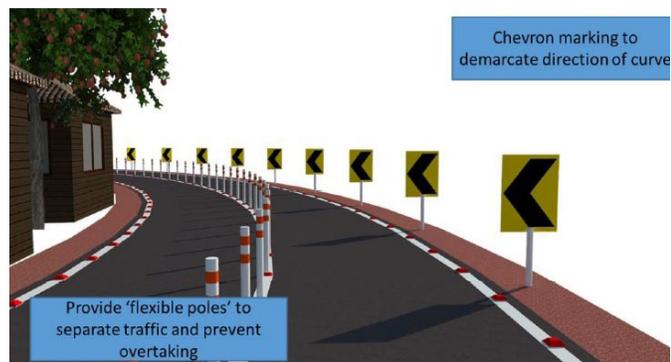
- The radius of horizontal curves or the camber applied to those curves may be increased in the order of 15 percent at the bottom of steep grades to improve perception and allow for vehicles running out of control. Alternatively, escape lanes may be provided to allow vehicles that are traveling too fast for the turn to safely stop.
- The horizontal and vertical alignment should be made as flat as possible at intersections and interchanges to allow the provision of sufficient sight distance.
- On two-lane roads where combinations of curves are likely, tangent sections may be provided with good passing sight distance to provide opportunities for safe overtaking.

Below is a summary of treatments for horizontal curves:

### Markings and signs

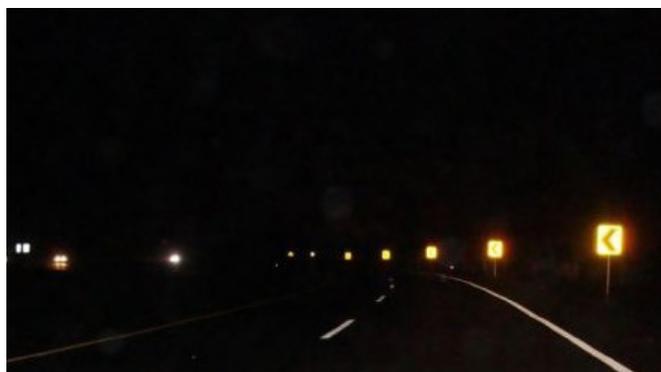
- Pavement markings are important in providing continuous information to help drivers navigate roadways successfully. These include:
  - Longitudinal pavement markings (centerlines and edge lines). Wider centerline markings can be used where space allows to increase separation between vehicles travelling in opposite directions.
  - Guideposts/delineators along the side of the road. They can be used for both unpaved and paved roads.
  - Flexible posts along the centerline of curves with limited sight distance to prevent overtaking. The flexible posts or poles should be at least 1 m high with retroreflective marking to ensure nighttime visibility (figure 5.23).
- Advance pavement markings for curves including

**Figure 5.23:** Illustration on provision of flexible poles and chevron signs at curves with limited sight distance.



Source: Indian Institute of Technology. 2018. Road Safety Audit of NH 60 and NH 117 and Capacity Building on Road Safety Issues in the State of West Bengal: Final Report on NH 117.

**Figure 5.25:** Chevron alignment signs providing good night-time visibility.



Source: iRAP

speed advisory markings and speed reduction markings/optical speed bSource: FHWA.ars (figure 5.24).

- Retroreflective raised pavement markers (RRPMs). Usually used in conjunction with painted line marking to warn drivers of changes in alignment in road ahead.

Signs may include chevron alignment signs (figure 5.25), advance warning signs (figures 5.26 and 5.27), and advisory speed plaques. Signage can be enhanced using larger devices, retroreflective strips on signposts, highly retroreflective and fluorescent sheeting, flashing beacons, and dynamic curve warning systems.

Figure 5.28 shows a set of treatments applied to a high-risk curve in Malaysia.

**Figure 5.24:** Transverse lines at the entrance of curve in China.



Source: iRAP.

**Figure 5.26:** Advance curve warning and speed sign.



Source: World Bank

- Route-based curve treatments

Route-based treatments are a method of ensuring consistency of signing of curves along a section of road. Each curve is classified based on risk factors, such as design speed, tangent speed, sight distances, and so forth. Once the risk of the curve has been identified, signs and markings for that curve are installed according to this risk category. The higher the risk category, the more treatments are installed. To avoid confusion and maintain driver confidence and compliance, treatments should be applied consistently where curves of similar risk categories receive similar treatments. Since it is applied along a route/network, this method is consistent with the self-explaining roads concept.

**Figure 5.27:** Horizontal curve at the base of a steep downgrade with advance warning sign.



Source: PIARC. 2003. *Road Safety Manual*, First edition.

**Figure 5.29:** Wide centerline with median rumble strips on curve in Australia.



Source: iRAP.

## Pavement countermeasures

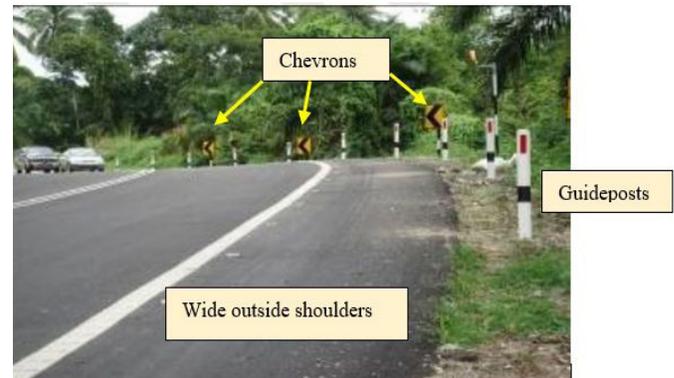
The following countermeasures may be applied to improve the pavement's skid resistance:

- High-friction surface treatments (HFSTs),
- Pavement grooving on concrete pavements to increase friction and improve watershedding,
- Provision/correction of superelevation, and
- Widening at curves to allow wide centerline treatment (figure 5.29).

The following treatments are applicable to shoulders:

- Shoulder widening to provide a recovery area for drivers to regain control in case of a roadway

**Figure 5.28:** Example of curve improvement in Malaysia.



Source: iRAP.

**Figure 5.30:** Safety edge. After installing the safety edge, the unpaved material adjacent to the edge should be graded flush with the top of the pavement.



Source: Fitzgerald, 2014.

departure, especially on the inside of the curve,

- Shoulder paving to replace unstable or narrow shoulders, and
- Safety edge—technique that involves shaping and consolidating the pavement edge into a 300 wedge (figure 5.30). The edge allows for controlled recovery of drivers after straying and also reduces the tendency of the pavement to separate or crumble, thereby improving the durability of the edge.

Rumble strips/stripes may also be installed to warn fatigued, distracted, and inattentive drivers when leaving their travel lane by either milling/cutting grooves or placing ribs/bumps on the road. These can be placed on the shoulders near the edge of the travel



## Examples of rumble strips/stripes

**Figure 5.31:** Shoulder rumble strips.



Source: FHWA, 2015. Rumble strip implementation fact sheet: pavement. Accessed at [https://safety.fhwa.dot.gov/roadway\\_dept/pavement/rumble\\_strips/media/RumbleStripFactSheet\\_Pavement/pavement\\_fs.cfm](https://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/media/RumbleStripFactSheet_Pavement/pavement_fs.cfm). September 14, 2021.

**Figure 5.32:** Edge line rumble stripes by adding ribs.



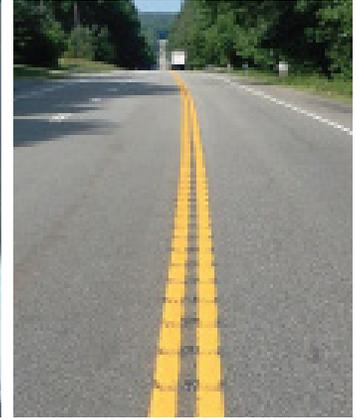
Source: iRAP.

**Figure 5.33:** Edge line rumble stripes by milling of road.



Source: FHWA, 2015.

**Figure 5.34:** Centerline rumble stripes by milling of road.



Source: FHWA, 2015. Rumble strip implementation guide: addressing pavement issues on two-lane roads. Accessed at [https://safety.fhwa.dot.gov/roadway\\_dept/pavement/rumble\\_strips/media/RumbleStripGuide\\_Pavement/pavement\\_bpg.cfm](https://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/media/RumbleStripGuide_Pavement/pavement_bpg.cfm). September 14, 2021.

**Figure 5.35:** Concrete barrier on curve section with chevron alignment signs.



Source: iRAP.

**Figure 5.36:** Semi-rigid barrier on horizontal curve in Nepal.



Source: GRSF.

**Figure 5.37:** Cable barrier on tangent section.



Source: iRAP.

lane (figure 5.31), at the edge of the travel lane in line with the edge line marking (figures 5.32 and 5.33), or at/near the centerline of an undivided highway (figure 5.34). They can be created by milling grooves in the road surface or the addition of intermittent raised edge line markings.

- Roadside improvements (see section 5.7, Road-sides).
- Provision of barriers. Barrier types may include concrete barriers (figure 5.35), guardrails (figure

5.36), and cable barriers (figure 5.37) (see section 5.8, Barriers).

- Provision of clear zones. Clear zones i.e., unobstructed and traversable areas beyond the edge of the through travelled way are useful for providing sight distance along curves and recovery areas for errant vehicles. Fixed objects such as poles or trees should not be located in the clear zone, especially within the vicinity of horizontal curves (also see section 5.7).

- Slope flattening. Flattening the slopes on the outside of curves may provide significant benefits by allowing recovery of a vehicle that leaves the travelled way and traverses over the shoulder. As a cost-saving measure, excavated material from other locations can be used to flatten slopes. For critical slopes and depending on the height of the slope, barriers should be installed.
- Delineation on barriers. Delineating barriers is particularly useful during nighttime, as it not only gives the indication that the barrier is present but also provides information about the alignment conditions of the roadway.
- PIARC. 2019. *Road Safety Manual*. Accessed at <https://roadsafety.piarc.org/en>. Must read chapter 8, Design for road users, characteristics, and compliance.
- World Bank. 2005. Sustainable safe road design: A practical manual. Must read Sustainable safe road design: cross section.
- Safety Edge. [https://safety.fhwa.dot.gov/roadway\\_dept/pavement/safedge/brochure/](https://safety.fhwa.dot.gov/roadway_dept/pavement/safedge/brochure/).
- TRL & Department for International Development. 2001. Horizontal curves, highway design note 2/01, TRL Ltd, Crowthorne, UK. <https://www.yumpu.com/en/document/read/32357056/horizontal-curves-transport-for-development>.
- Transport Research Laboratory. 2001. Combination of Horizontal and Vertical Curvature. <http://www.rhd.gov.bd/Documents/ExternalPublications/Trl/Combination%20of%20horizontal-vertical%20curves%20DFS.pdf>.

## Further Reading

- AASHTO. 2010. Highway Safety Manual. Must read part B, Roadway Safety Management Process.
- AASHTO. 2015. Roadside Design Guide. <https://downloads.transportation.org/RSDG-4-Errata.pdf>.
- Australian Road Safety Engineering Toolkit. <https://engtoolkit.com.au/default.asp?p=issue&i=15>.
- European Commission. Getting Initial Safety Design Principles Right. [https://ec.europa.eu/transport/road\\_safety/specialist/knowledge/road/getting\\_initial\\_safety\\_design\\_principles\\_right\\_en](https://ec.europa.eu/transport/road_safety/specialist/knowledge/road/getting_initial_safety_design_principles_right_en). Must read.
- FHWA. 2016. Low Cost Treatments for Horizontal Curves. Must read chapter 3, Marking, chapter 5, Pavement countermeasures, and chapter 6, Roadside improvement.
- FHWA. 2009. Manual on Uniform Traffic Control Devices (MUTCD). <http://mutcd.fhwa.dot.gov/pdfs/2009/part3.pdf>. Must read part 3, Marking.
- iRAP Toolkit. <http://toolkit.irap.org/default.asp?page=treatment&id=23>.
- PIARC. 2008. Human Factors Guidelines for Safer Road Infrastructure. <https://www.piarc.org/en/order-library/6159-en-Human%20factors%20guidelines%20for%20safer%20road%20infrastructure>.

## 5.4. Superelevation and Cross Slope (also referred to as “camber” or “crossfall”)

### General description

On straight sections of road, the surface is often crowned in the middle so that drivers are naturally moved away from opposing traffic. The amount of crowning is normally between 2 and 3 percent, and its value is primarily influenced by the ability of the surface to shed water.

On horizontal curves, superelevation is the transverse slope provided perpendicular to the direction of travel to counteract the centrifugal force generated by the speed in a circular motion. It is applied by raising the outer edge of the pavement with respect to the inner edge throughout the length of the horizontal curve (figure 5.38). It is usually applied over the length

**Figure 5.38:** Example of introduced superelevation on curve

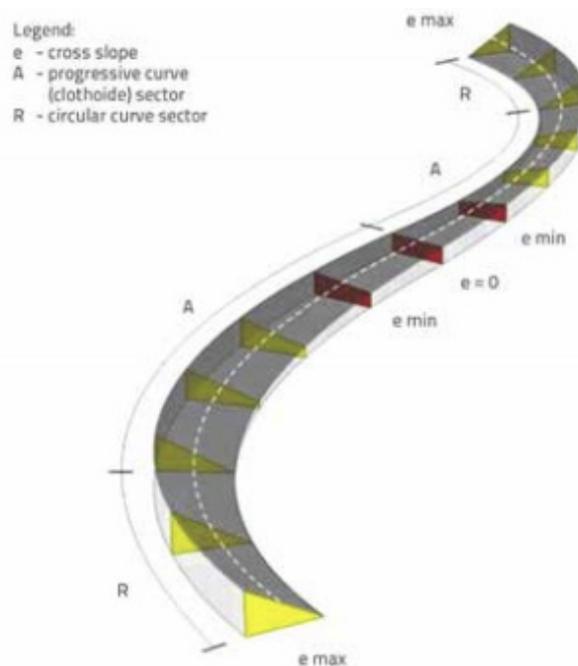


Source: TRL Limited. 2003. CaSE Highway Design Note 2, Horizontal Curves.

of a circular curve to reduce the sideways frictional demand between the tires and road surface and to increase comfort. The superelevation value is usually selected by road designers to be consistent with the combination of design speed, curve radius, and the road authority's policy for maximum superelevation. A transition curve, inserted between the tangent and circular curve, may be used to remove the adverse cross-slope (adverse camber) created by the road crown and introduce superelevation (figure 5.39).

On urban roads, values of maximum superelevation are usually 4 or 6 percent. This is because it is desirable that the cross section of urban streets be as close as possible to the natural ground level to support ready access to adjacent properties to the road. It also facilitates drainage of surrounding properties. In addition, high values of superelevation in urban areas would require distances of 100 m or more in the development of superelevation, which closely spaced intersections would make difficult to achieve.

**Figure 5.39:** Representation of two consecutive opposite transition curves



Source: Alina Burlacu, Carmen Răcănel, and Adrian Burlacu. 2018. Preventing aquaplaning phenomenon through technical solutions. *Grădevinar* 12/2018.

On rural roads, superelevation rates are normally in the range of 6 to 10 percent, with a maximum of 12 percent, owing partly to problems in construction and also the stability of heavy vehicles, in particular those with a high center of gravity. This is particularly relevant on steep uphill grades where trucks cannot generate sufficient centrifugal force to counteract the superelevation, thereby creating an imbalance. When icy conditions are present, the maximum superelevation is typically limited to 8 percent.

For gravel roads, a commonly accepted maximum superelevation is approximately 6 percent. When higher than that, it can be dangerous, especially where snow and ice can make roadways slippery. A higher superelevation also tends to cause aggregate to migrate to the bottom of the slope, or the inside of the curve. For more details, design references listed below or design codes of reference from countries should be referred.

## Safety implication

- If a road is not superelevated, the centrifugal force tends to push the vehicle toward the outside of the curve. At high speeds, the driving task will be uncomfortable and more demanding. As a result, vehicles may become less stable, lose traction, and skid due to insufficient frictional force between the tire and the road to counterbalance the centrifugal force, or topple sideways if the center of gravity is high. Vehicles on the outside of curves are more likely to experience run-off-the-road crashes resulting in collisions with road users or objects on the outside shoulders, or rolling over.
- The lack of superelevation also encourages drivers to use the center of the road or the inside lane irrespective of the direction of travel, which increases the probability of head-on collisions, especially on two-way, two-lane roadways.
- Since superelevation also assists with the drainage of water, too low superelevation is more susceptible to surface defects that may result in standing water on the carriageway, which increases the risk of loss of pavement friction. The film of water developed during and after rainfall increases the risk of hydroplaning/aquaplaning. Standing water may also result in pavement damage and loss of shape in the long term, which presents an additional safety hazard. A curve with a worn or polished pavement surface that provides little skidding resistance presents increased crash likelihood, particularly in wet conditions.
- Change in superelevation, also known as roll over, from one side of the road to the other or between straights and curves, inevitably creates areas of road surface without any camber or crossfall. It is important that these areas do not coincide with

very shallow longitudinal gradients, or the water will simply collect and ponds will form.

- Inadequate superelevation poses greater safety risks to motorcyclists given their lower vehicle stability, i.e., only two points of contact with the road. In the absence of superelevation, motorcyclists rely completely on the tire grip to remain on the road.
- Too high superelevation will result in the possibility of slow-moving vehicles sliding sideways or, in extreme cases, overturning. It has been observed that a 12 percent superelevation can cause trucks with high loads to lose their loads or tip over completely when trying to negotiate a curve at a low speed.<sup>66</sup>

## Good design practice/ treatments/solutions

- Where the radius of a curve is less than the specified minimum for each design speed, the introduction of superelevation and curve widening will minimize the intrusion of vehicles onto the adjacent lanes and encourage uniformity of speed, thus increasing vehicle safety at the curves. This consistency is achieved by using minimum acceptable side friction factors between the tires of a vehicle at the design speed and the road surface. Acceptable friction factors vary from 0.15 for 100 km/h to 0.33 for 50 km/h.
- The relationship between side friction demand and speed is not linear, and the relevant guidelines should be consulted for the appropriate values and locally adjusted equations.<sup>67, 68, 69</sup>
- By designing to a side friction demand of 50–60 percent of the maximum, a safety factor is built into the process that allows for a margin of error in a driver's choice of negotiation speed. This means

66 Wolhuter, K. M. 2015. Geometric design of roads handbook. CRC Press.

67 Austroads. 2009. Guide to Road Design Part 3: Geometric Design.

68 AASHTO. 2018. Policy on geometric design of highways and streets (chapter 3). American Association of State Highway and Transportation Officials, Washington, DC.

69 New Zealand Transport Agency. 2000. State Highway Geometric Design Manual (chapters 2 and 4).

that a driver travelling faster than intended around a curve will feel increasingly uncomfortable well before the side friction demand exceeds that available and they lose traction. This discomfort triggers the driver's natural response to ease off the accelerator.

- On major roads with a superelevation deficiency, it is desirable to reconstruct the outer lane around the curves to provide superelevation that suits the operating speeds. It has been reported that improving superelevation may reduce the number of crashes by 5 to 10 percent.<sup>70</sup> It is also important to ensure that there is smooth transition between the crowned and superelevated cross sections on each end of the curve.
- Drainage conditions should be checked to ensure that combinations of slopes along and across the road are adequate to remove water from potential flat areas that can lead to standing water and potential risk of aquaplaning. Technical solutions, including transverse road gutters, diagonal slopes, and surface grooving may be applied to prevent aquaplaning for consecutive opposed curves where the vertical alignment is not helping with the drainage of pluvial waters from the carriageway.<sup>71</sup> The design of curves should be checked for consistency, with the selected value of maximum superelevation applied consistently on a regional basis. This will ensure that there are no variations in the rates of superelevation for curves of equal radius. It is widely accepted that drivers select their approach speeds to curves on the basis of the radius that they see and not on the degree of superelevation provided. For this reason, a lack of consistency with regard to superelevation would almost certainly lead to differences in side friction demand with possible critical consequences.
- By applying superelevation relative to the maximum value, the driver will experience a consistent level of comfort when travelling round a superelevated curve.
- If a superelevation deficiency cannot be reasonably or readily addressed, other safety measures may be considered, including:
  - Advance warning signs to warn drivers of a tight curve ahead and an indication of the reduced speed required to safely negotiate the curve,
  - Road markings, signs, and posts to draw the driver's attention to the curve,
  - Provision of shoulder and hazard free areas to provide a safe recovery area.
  - Improving the surface friction of the outside lane, and
  - Erecting safety barriers or designing clear zones around the outside of the curve (see section 5.8).
- Curves on residential streets and built-up areas are often constructed without superelevation due to the assumption of lower operation speeds. In such areas, speed management and traffic calming rather than road surface shape, is usually a more appropriate solution to reduce the additional risks created by vehicles travelling at high speeds.
- Rainfall after a long dry spell reduces side friction, especially in areas where the surface is polluted by oil spills, rubber, and other debris. Where any of these circumstances are likely to occur, a lower value of maximum superelevation is recommended in design.

## Further Reading

- AASHTO. 2018. Policy on geometric design of highways and streets (chapter 3). American Association of State Highway and Transportation Officials, Washington, DC.
- Austroads. 2009. Guide to Road Design Part 3: Geometric Design.

70 Zegeer, C. V., and Council, F. M. 1995. Safety relationships associated with cross-sectional roadway elements, Transportation Research Record Issue: 1512.

71 Alina Burlacu, Carmen Răcănel, and Adrian Burlacu. 2018. Preventing aquaplaning phenomenon through technical solutions. *Grădinar* 12/2018. Accessed at <http://casopis-gradjevinar.hr/assets/Uploads/JCE-70-2018-12-4-1578-EN.pdf>.

- Aram, A. 2010. Effective safety factors on horizontal curves of two-lane highways. *Journal of Applied Sciences (Faisalabad)*, 10(22), 2814–2822.
- Alina Burlacu, Carmen Răcănel, and Adrian Burlacu. 2018. Preventing aquaplaning phenomenon through technical solutions. *Građevinar* 12/2018. Accessed at <http://casopis-gradjevinar.hr/assets/Uploads/JCE-70-2018-12-4-1578-EN.pdf>.
- New Zealand Transport Agency. 2000. *State Highway Geometric Design Manual* (chapters 2 and 4).
- TRL Limited. 2003. *CaSE Highway Design Note 2, Horizontal Curves*. Accessed at <https://www.gov.uk/research-for-development-outputs/case-note-2-horizontal-curves>.

## 5.5. Vertical Curvature and Gradient

### General description

Vertical alignment involves the road grade (the rate of change of vertical elevation) and vertical curves (i.e., crests and sags). Its design is a derivative of the interaction between sight distance criteria, the topography of the roadway, and the designer's need to meet ancillary goals (e.g., balancing excavation and fill quantities) as important safety factors of roads.

**Figure 5.40:** Reduction in sight distance at a crest vertical curve.



Source: Federal Highway Administration. 2007. *Mitigation Strategies for Design Exceptions*, US. <https://safety.fhwa.dot.gov/geometric/pubs/mitigationstrategies/>.

Most passenger cars can readily negotiate grades as steep as 4 to 5 percent without an appreciable loss in speed below that normally maintained on level roads.

On steeper upgrades, speeds decrease progressively with increases in the grade. Specifically, speed differentials between passenger cars and heavy vehicles should be considered when conducting a safety analysis. On downgrades, passenger car speeds generally are slightly higher than on level sections, and there are increases in braking distances, but local conditions govern.<sup>72</sup>

The severity or sharpness of vertical curves is usually referred to in terms of a radius (circular arc) or “K-value” (parabola). The Austroads Guide to Road Design Part 3 (2016)<sup>73</sup> provides comprehensive information on the design and calculation of vertical profiles (alignments) using parabolic curves.

For the combination of horizontal and vertical alignment, see section 5.3 on Horizontal curvature.

### Safety implications

- Vertical alignment influences a driver's sight distance (figures 5.40 through 5.42). Crest vertical curves may limit sight distance by restricting a driver's line of sight. The crash frequency on crest

**Figure 5.41:** Reduction in sight distance at a sag vertical curve.

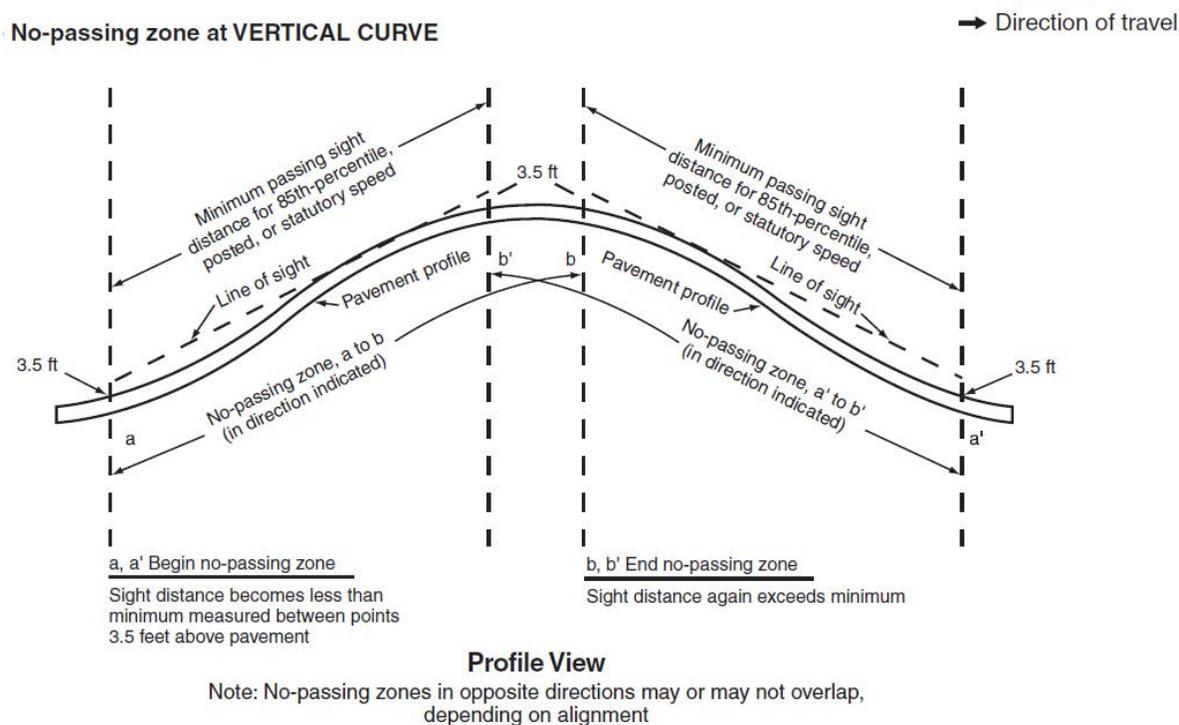


Source: FHWA, 2007.

72 AASHTO. 2018. *A Policy on Geometric Design of Highways and Streets*, 7th edition.

73 Austroads. 2016. *Guide to Road Design Part 3: Geometric Design*, section 8, and Appendix K.

Figure 5.42: Effect of crest vertical curves on sight distance.



Source: Federal Highway Administration. 2012. Manual on Uniform Traffic Control Device 2009 edition with Revision Numbers 1 and 2 incorporated, dated May 2012, US.

- curves with reduced sight distance is 52 percent higher than on curves with no reduction in sight distance<sup>74</sup> (see section 3.3 on Sight distance).
- Overtaking will be of higher risk at this location without auxiliary lanes (i.e., climbing or overtaking lane), especially on rural roads.
- Step gradients may increase the vehicle's speed by up to 5 percent; therefore large vehicle drivers may choose to descend grades at slower speeds to maintain better control of their vehicles.
- Long, steep downgrades may result in loss of control of vehicles, especially if present before horizontal curvature to perform sudden corrective actions. The higher the grade rate is, the higher the crash risk is. The crash risk rises more rapidly for grades over 6 percent as vehicle speeds become more difficult to manage.<sup>75</sup>
- Increases in braking distances and the possibility of heavy vehicle brake overheating should be concerning because this can lead to brake failure.
- Crash frequency and severity are higher on downhill grades than on uphill grades, with a high involvement of heavy vehicles.
- Other types of vehicles such as compact cars and recreational vehicles may have different speed loss and movements on vertical alignments.

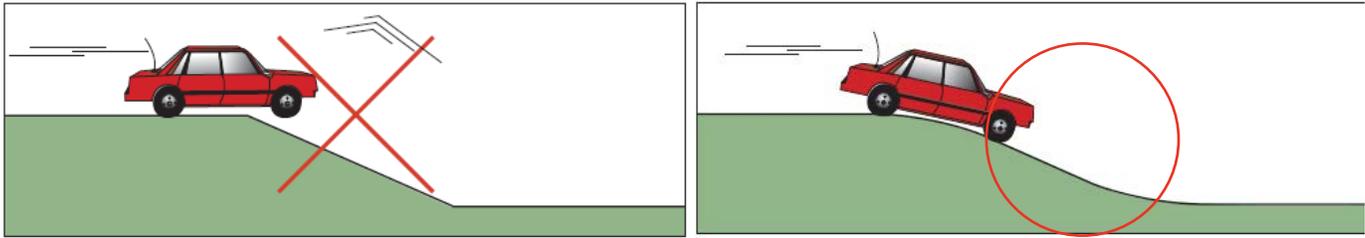
### Good design practice/ treatments/solutions

- On grades, the designer must avoid a combination of features that increase the probability of having to carry out difficult maneuvers, including intersections or other crossings (railway, crosswalk, bike

74 Olson, P. L., Cleveland, D. E., Fancher, P. S., Kostyniuk, L. P., and Schneider, L.W. 1984. Parameters affecting stopping sight distance, NCHRP Report 270, Transportation Research Board.

75 Federal Highway Administration. 2000. Prediction of the expected safety performance of rural two-lane highways, US. FHWA-RD-99-207.

**Figure 5.43:** Smoothing of slopes.



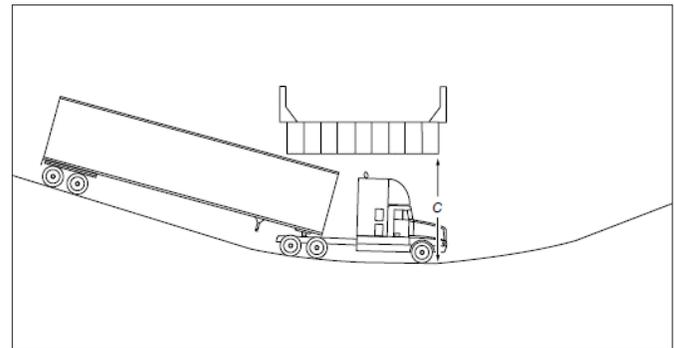
Source: PIARC, 2003.

**Figure 5.44:** Escape ramp (under construction) in China.



Source: © John Barrell.

**Figure 5.45:** Vertical clearance at undercrossings.



Source: AASHTO, 2018. A Policy on Geometric Design of Highways and Streets, 7th edition.

path, etc.), sharp horizontal curves, narrow structures, and no provision of protection.

- Overtaking must be prohibited to avoid head-on collisions, preferably by physical separation between the opposite direction of travel.
- Steep side slopes should be avoided. The maximum gradient that can be travelled by errant vehicles is in the order of 1:3 to 1:4. Ideally, in order to accommodate larger and high center of gravity vehicles, such slopes should be in the region of 1:6 to 1:106. The angle between shoulder/slope and slope/adjacent land should also be smoothed in surface level<sup>76</sup> (figure 5.43).
- At descending steep slopes, a short passing lane, auxiliary, or “slow vehicle turn-out” can be provided. If not provided, operations may be degraded for faster-moving vehicles from behind, creating an increased risk of rear-end crashes and risky

passing maneuvers.

- Increasing the superelevation on horizontal curves that coincide with steep down gradients improves heavy vehicle stability when braking.<sup>77</sup>
- Increasing radii at the bottom of steep downgrades is advisable, as these curves are often misread by drivers, and the visual distortion leads to “overdriving.”<sup>78</sup>
- At descending steep slopes, the provision of escape or runaway ramps for brake failure should be provided (figure 5.44).
- Sag vertical curves at underpasses should be designed to provide vertical clearance for the largest legal vehicle that could use the undercrossing without a permit. A tractor trailer will need a longer sag vertical curve than a single-unit truck to avoid the trailer striking the overhead structure (see figure 5.45).

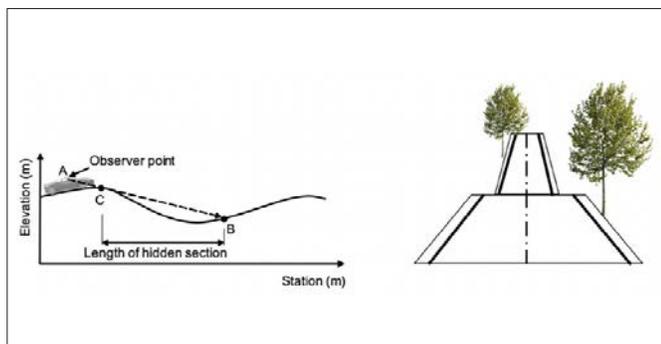
76 PIARC. 2003. Road Safety Manual, First edition.

77 Austroads Guide to Road Design. 2016. Part 3 section 7.6.1.

78 Austroads Guide to Road Design. 2016. Part 3 section 7.6.1.



**Figure 5.46:** Hidden sight dip: Left—road vertical profile; Right—road frontal 3D view.

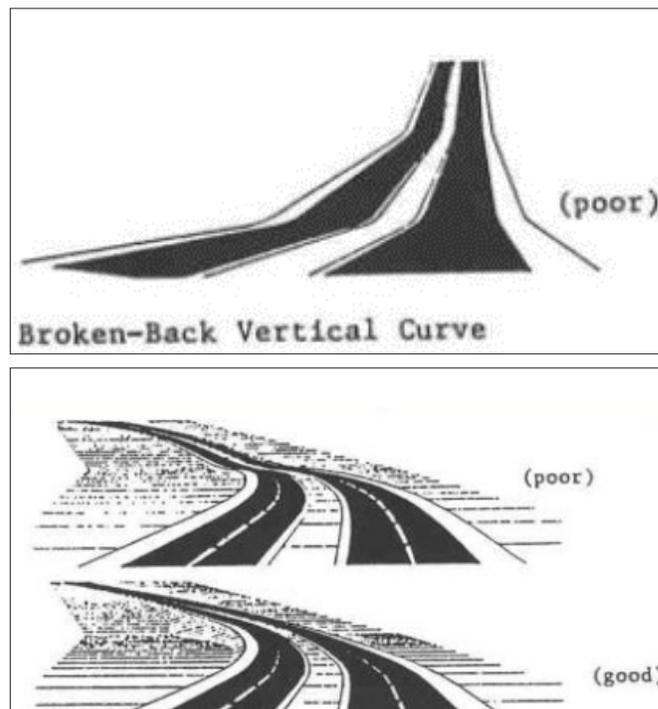


Source: González-G. and Castro, 2019.

- Grade rate of change is critical for sag curves where gravitational and vertical forces act in opposite directions. The hidden dip (roller coaster) type of profile should be avoided. Such profiles may occur on relatively straight, horizontal alignment where the roadway profile closely follows a rolling natural ground level. Hidden dips may create difficulties for drivers, because the passing driver may be deceived if the view of the road or street beyond the dip is free of opposing vehicles, even with shallow dips.<sup>79</sup> (see figure 5.46).
- A “broken-back” gradeline (two vertical curves in the same direction separated by a short section of tangent grade) generally should be avoided. This effect is particularly noticeable on divided roadways with open median sections (see figure 5.47).
- A minimum grade of 0.5 percent (0.3 percent for outer roadway edges) is needed for proper drainage on sag vertical curves to avoid mishandling related to ponding. However, it may be necessary to use flatter grades in some instances<sup>80</sup> (see section 5.11 on Drainage).

Markings and signs, roadside improvements, and terrain modifications could be treatments for vertical alignments.

**Figure 5.47:** Effect of broken-back vertical curves



Source: Bob L. Smith, and Ruediger Lamm. 1994. Coordination of Horizontal and Vertical Alignment with Regard to Highway Esthetics.

## Marking and signs

Safety is unlikely to be affected by limited stopping sight distance, but improving limited sight distance at locations where other vehicles may be slowing or stopping can be extremely important for safety.<sup>81</sup>

- Other improvements that can be made are to remove objects that are within the sight limited area as well as increase crash avoidance areas through lane widening or shoulder widening.
- An entering vehicle’s speed must be controlled. On vertical curves, the maximum designed speed differs from flat roads because of differences in sight distance affected by combinations of other features, including horizontal curvature, lane width, and so forth. Speed control for vehicles transitioning between a flat road and a vertical curve must be implemented.

79 González-G., Iglesias, and Rodríguez S. Castro. 2019. Framework for 3D Point Cloud Modelling Aimed at Road Sight Distance Estimations, *Remote Sensing*, 11, 2730. 10.3390/rs11232730.

80 Federal Highway Administration. 2007. Mitigation Strategies for Design Exceptions (archived), US.

81 PIARC. 2019. Road Safety Manual. Accessed at <https://roadsafety.piarc.org/en>.

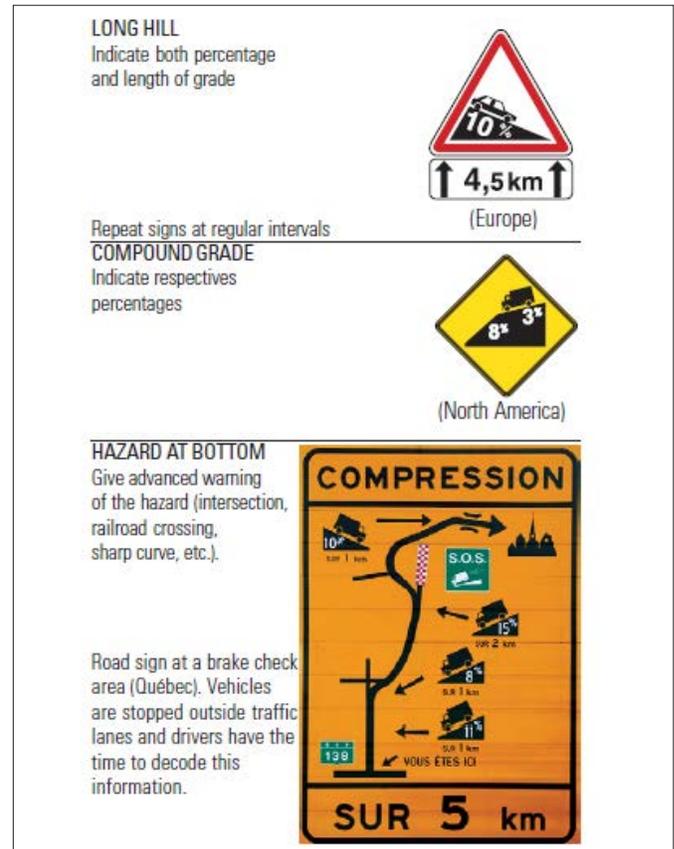
**Figure 5.48:** A steep grade warning sign along a road that appears to drop off in the distance.



Source: FHWA, 2007

- Signs can be used to provide drivers approaching a steep grade with advance warning (figures 5.48 and 5.49). Signs help drivers to adjust their behavior to deal with approaching hazards or decision points. Use of advance warning signs as a stand-alone measure is unlikely to sufficiently mitigate a design exception for grade, but it can be an effective component of a more comprehensive approach.
- Poorly designed/maintained/located signs must be re-installed. The retroreflectivity of signs is an important consideration for road use at night and when wet. Maintenance of signs can be problematic; signs may be stolen and broken in some areas (figure 5.50).
- Only placing warning signs may not attract drivers' attention. In that case, physical features (e.g., flexible, bollards) can be used to prevent crashes by prohibiting overtaking and downing the vehicle's speed.
- For increasing braking distance at downgrade, signs can indicate a lower speed and that a lower gear is required.

**Figure 5.49:** Examples of advance warning of a steep grade



Source: FHWA, 2007.

**Figure 5.50:** Broken signs without maintenance in India.



Source: Lokesh, T., Thejarathnam, T., Reddysaddam, P. et al. 2014. Road Safety Audit—Section Bhakarapet KM 77/4—Rangampet KM 93/6, India. <https://www.slideshare.net/lokeshthondamanati/batch-3>.

## Roadside improvements—barriers

- When locations have poor visibility, steep slopes, level difference, and a slower vehicle speed is likely, overtaking should be prohibited.
- Flexible posts can be applied at locations where lane discipline needs to be ensured, such as curves and intersections (figures 5.51 and 5.52).
- Flexible posts also contribute to improve visibility of the median of the road because of level differences. Treatment for visibility must be made, even though other vertical treatments will be costly.
- Furthermore, flexible posts can also be applied where there is a requirement for lane discipline along with traffic calming.
- Flexible posts are a quick and easy solution but can result in a high maintenance cost if repeatedly struck and require replacement. In these circumstances more robust and substantial treatment may be more appropriate (barrier or concrete median).
- On a downgrade where there is a significant drop in speed limit, speed control treatments can be used. Speed control treatments include a combination of prominent signs, road markings, and traffic calming measures, e.g., raised platforms or colored

pavements to make the change in road type clear (see section 3.2 on Speed compliance and traffic calming).

## Terrain modifications

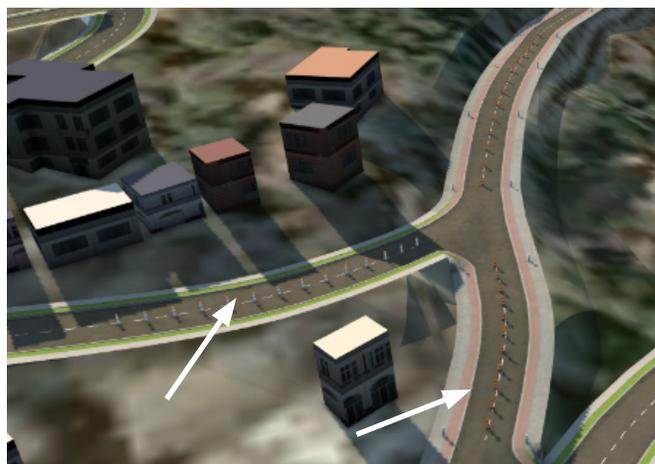
- Modifying a vertical alignment is often too costly and can have significant impacts to adjacent land uses. It is much better to design the road well before it is built than to rebuild it. The reconstruction of a crest vertical curve should be implemented when the hill crest hides major hazards from view, such as intersections, sharp horizontal curves, or narrow bridges (see figure 5.53).
- “Roller coaster” or “hidden dip” type of profiles should be avoided by use of horizontal curves or by more gradual grades.
- Road widening (either as wider shoulders or an overtaking lane) over a crest with less than adequate sight distance can be an effective countermeasure rather than flattening the crest. Long and steep downgrades can result in heavy vehicles travelling at crawl speeds to avoid loss of control on the grade. Slow-moving vehicles of this type may impede other vehicles. Auxiliary lanes can be provided to address this risk. They can be constructed on uphill and downhill grades to enable safe

**Figure 5.51:** Illustration on provision of flexible posts at curves with limited sight distance.



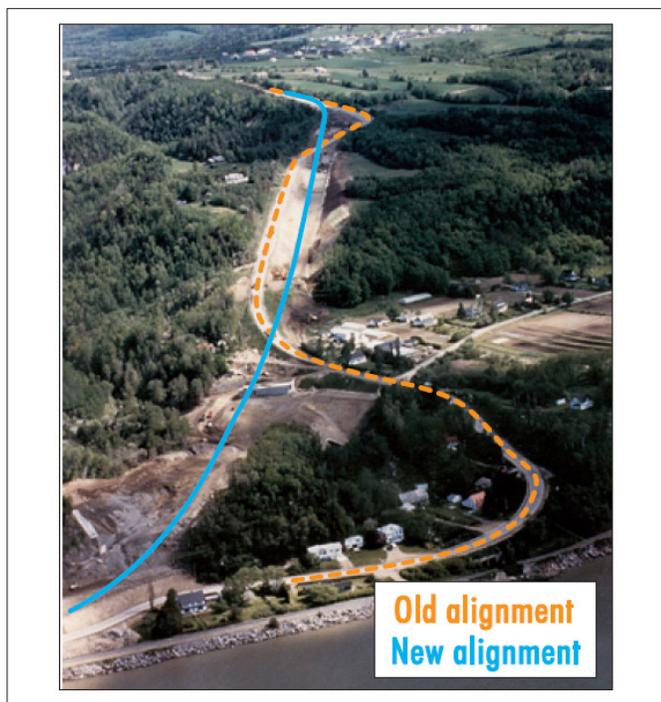
Source: © Kazuyuki Neki/GRSF/World Bank

**Figure 5.52:** Flexible posts improving visibility of median at intersection.



Source: © Kazuyuki Neki/GRSF/World Bank

**Figure 5.53:** Alignment modification to eliminate a sharp curve at the bottom of a steep grade.



Source: PIARC, 2003.

passing maneuvers by slower vehicles and reduce crashes by 5 percent to 15 percent. (see section 5.6 on Passing lanes). Since auxiliary lanes encourage passing maneuvers at relatively high speeds that are incompatible with the slower speeds of vehicles accessing and exiting the road, they should not be located in conjunction with intersections or other access points.

- Since safety problems in grades primarily involve heavy vehicles, solutions aimed at limiting their presence at high-risk locations may also be considered, when permitted by the configuration of the road network (dedicated heavy vehicle roads).

## Further Reading

- FHWA. 2009. *The Manual on Uniform Traffic Control Devices*. Must read chapter 2, Signs and chapter 3, Markings.
- FHWA. 2007. *Mitigation Strategies for Design Exceptions* (archived). Must read chapter 3, Controlling

criteria.

- PIARC. 2019. *Road Safety Manual*. Accessed at <https://roadsafety.piarc.org/en>.
- FHWA. 2003. *Geometric Design Consistency on High-Speed Rural Two-Lane Roadways* (NCHRP 502). Must read Interpretation, appraisal, and applications.
- AASHTO. 2018. *A Policy on Geometric Design of Highways and Streets*, 7th edition. Must read chapter 3, Elements of design.
- FHWA. 2016. *Highway Capacity Manual: A Guide for Multimodal Mobility Analysis*, Sixth edition. Must read chapter 16, Urban street facilities.
- PIARC. 2003. *Road Safety Manual*, First edition. Must read chapter 8, Design for road users, characteristics, and compliance.

## 5.6. Passing Lanes

### General description

A passing/overtaking lane is an additional lane provided on a conventional single-lane, two-way road to provide safe passing/overtaking opportunities and improve the overall traffic operations by breaking up traffic platoons and delays (figure 5.54).

**Figure 5.54:** Example of a passing lane.



Source: iRAP.

Passing lanes reduce the risk of head-on crashes, lane change/sideswipe crashes, and run-off-the-road crashes that result from unsafe passing due to insufficient passing opportunities. Inadequate passing opportunities on two-lane, two-way highways may be due to the combined effect of high traffic volumes with a high percentage of trucks or slow-moving vehicles, including agricultural machinery, animal-drawn carts, and animals in both directions, and sight distance restrictions. Queues and frustration may encourage drivers to undertake dangerous passing maneuvers such as in short gaps between opposing traffic or on a road section with inadequate sight distance that may result in a crash. On steep sections, drivers may not judge the time and distance required to overtake correctly due to the changed acceleration of vehicles. Constructing a passing lane thus serves to provide a safe overtaking space while also improving the general traffic flow along the roadway.

Various types of passing lanes exist, including passing/overtaking lanes in level or rolling terrain, climbing lanes, descending lanes, and slow-vehicle lanes (turn-outs). Overtaking lanes are generally installed only on high-speed rural arterial roads. Climbing lanes are provided on steep upgrades to reduce driver delay and frustration and improve safety. Descending lanes are provided for similar reasons as climbing lanes but on steep downgrades (since heavy vehicles are limited to slower speeds even on descent). Slow-vehicle turn-outs are short overtaking lanes (can be a short section of paved shoulder or an added lane) that allow slow vehicles to pull over and be overtaken. Slow-vehicle turn-outs are more appropriate in areas with low traffic volumes or where construction costs would be high, such as hilly or mountainous terrain.

Passing lanes are best arranged in pairs with a passing lane section for each direction of travel. As such, designers can choose from a variety of configurations, including separated passing lanes, adjoining passing lanes, overlapping passing lanes, and side-by-side/short four-lane sections. The choice of the configuration and the location of the added

lanes will depend on the particular local needs and constraints. The functional effectiveness of passing lanes will depend on the length of the passing section and the distance along a corridor between the passing sections.

## Safety implications

Constructing passing lanes results in safer operational conditions, perceived safety by motorists, and historical crash reductions.<sup>82</sup> Studies indicate that injury crashes after a passing lane has been constructed are likely to be in the range of 20–40 percent less than if it had not been constructed. The extent to which the reduction in crashes applies, however, varies from being specific to the passing lane itself, the passing lane and its immediately adjacent road, or for an entire route.

However, if not well designed, constructed, and maintained, passing lanes may pose some safety risks. Some of these safety deficiencies and risks are outlined below:

- Limited sight distance at the start and end points of passing lanes. This is particularly hazardous on merging sections implemented along or near horizontal or vertical curves with limited sight distance to drivers along the passing lane. This sight distance should be provided to the road markings so that drivers can see precisely where the lane and shoulder tapers, associated with the end of the passing lane, start and finish.
- Passing lanes located near towns, major intersections, or high-volume access roads may result in collisions from the high interaction of passing vehicles with turning movements and vulnerable road users. It should be noted that vehicle speeds are influenced for a significant distance after a passing lane, as overtaking drivers desire to distance themselves from the overtaken vehicle. As a result, the need for minor improvements to the downstream road corridor should be assessed.
- Passing lanes that have intersections within their length should be avoided if at all practicable.

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82 Espada, I., Stokes, C., Cairney, P., Truong, L., Bennett, P., Tziotis, M., and Tate, F. 2019. Passing Lanes: Safety and Performance (No. AP-R596-19).

- Narrow shoulder widths on passing sections. In many cases, the sealed shoulder width is reduced as part of the passing lane construction design, which can lower the safety benefit of three-lane passing sections. Narrower sealed shoulders are a safety risk as they may not provide an adequate space for vehicles to perform evasive maneuvers should it be necessary to avoid another vehicle.
- Inadequate signage and pavement markings. This adversely affects both the effectiveness and safety of the passing lane, as drivers are not sufficiently guided on the most appropriate action to take on the passing section, including the approaches and merges.

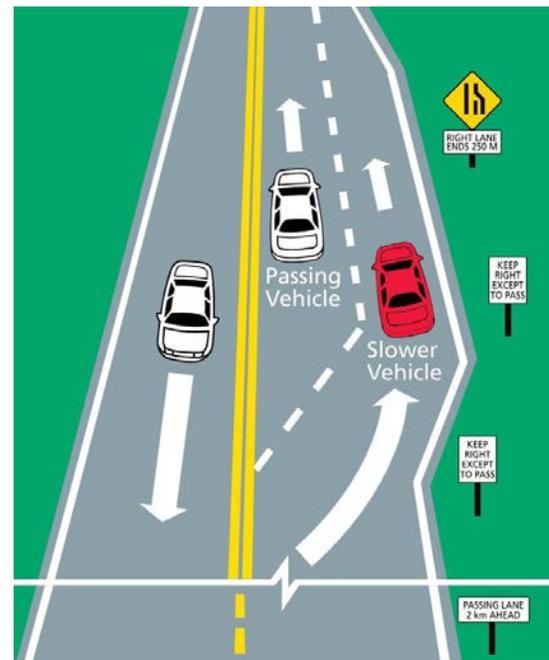
### Good design practice/ treatments/solutions

- The design of passing lanes should be considered carefully with regard to the road designs and conditions at both ends. The passing lane location should provide adequate sight distance to the road markings at the lane addition and lane drop tapers. The length of the tapers should also be adequate in relation to the operating speeds.
- The location of passing lanes will depend on the particular local needs and constraints. However, there are sites where passing lanes should not be constructed, including sites close to towns and/or high-volume access roads and sites with major intersections. This is because collisions may result from the interaction of passing vehicles with high turning movements and vulnerable users in these areas. Locations with other physical constraints, such as bridges and culverts, should also be avoided if they restrict the provision of a continuous shoulder. Highway sections with low-speed curves are not appropriate for passing lanes since passing, which requires drivers to speed up, may be unsafe.
- Proper signing and pavement marking (see figures 5.55 and 5.56) are required to enhance the driver's understanding of the intended use of the passing section and inform them of upcoming

opportunities to overtake, which results in increased efficiency and safety of the passing lane. For optimum signage, signs should be provided in the following six areas:

- In advance of the passing lane;
- The transition area of the lane addition of the passing lane;

**Figure 5.55:** Illustration of signing and markings in advance and along a passing section.



Source: Alberta. 2021. Passing on a multilane highway. <https://www.alberta.ca/passing.aspx>.

**Figure 5.56:** Example of markings on a climbing lane.



Source: Billy McCrorie/Geograph, PIARC, 2003.

**Figure 5.57:** Example of advance signing of a climbing lane.



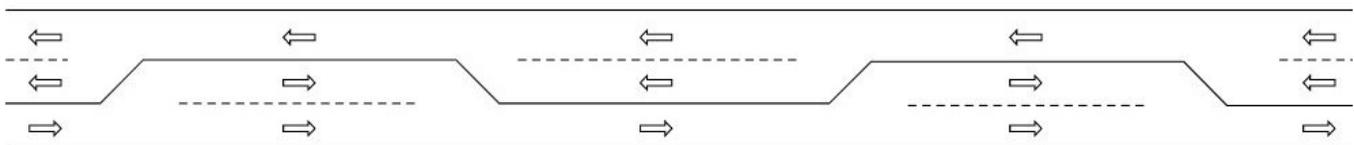
Source: Billy McCrorie/Geograph, PIARC, 2003.

- In advance of the termination of the passing lane;
  - The transition of the lane reduction of the passing lane;
  - The downstream area adjacent to the passing lane; and
  - In the opposing direction of the passing lane.
- A strategy for advance signing of passing lanes is desirable to alert road users of upcoming passing opportunities (figure 5.57). This reduces unsafe

overtaking prior to the passing lane, as motorists know that safer passing opportunities will be available shortly.

- On three-lane sections, vehicles travelling in the opposite direction to a passing lane should be discouraged from overtaking due to the high risk of a head-on collision. This information can be provided through longitudinal pavement markings or a combination of both signs and pavement markings. A site-by-site review is desirable to determine which passing lane sites are critical in the prohibition of passing by opposing traffic on the basis of limited sight distance, unusual geometrics, roadside development, and high-traffic volumes. The use of flexible posts along the centerline on these critical locations, in addition to the signs and pavement markings, may enhance the prohibition of passing by opposing traffic.
- 2 + 1 highways are a safety countermeasure for two-lane highways where a continuous three-lane cross section on which the central lane serves as a passing lane in alternate directions is provided throughout the length of the facility (see figure 5.58). Travel directions are separated by a median which could be physical (figure 5.59) or painted (figure 5.60). They are a cost-effective solution where a

**Figure 5.58:** Schematic view of 2+1 highway.



Source: Romana, M., Martin-Gasulla, M., and Moreno, A. T. 2018.

**Figure 5.59:** 2+1 highway with flexible barrier.



Source: Joel Torsson (Leojth). Own work, public domain. <https://commons.wikimedia.org/w/index.php?curid=2096153>.

**Figure 5.60:** 2+1 highway with painted median.



Source: © TrainSimFan.

two-lane road is not providing enough safety and/or traffic efficiency and the expansion to a four-lane roadway seems unjustified due to cost, demand, or environmental issues. Before implementing a 2+1 highway, unique design aspects linked to this configuration should be considered, including traffic volume; passing lane length; transition areas; cross section, intersection, and access design; and signing and markings.

## Case Study

Based on recommendations provided from Road Safety Inspection reports and from the 2017 World Bank capacity review report,<sup>83</sup> a national company of motorways and roads launched several road safety pilot infrastructure upgrade programs on high-risk sectors of their national roads.

For example, on national highways built in Eastern Europe under the communism era, where shoulders were 2.5 meters wide. Those highways are currently used as four-lane roads, although the road width is 12.00 meters: 3.50-meter lane width in each direction and 2.50-meter shoulders/emergency lane, which is a very dangerous design solution. On one of the national highways in Romania, a pilot section was upgraded into 2+1 alternative lanes, following the positive

fatality reduction experience from other neighboring countries who implemented such upgrades (see figure 5.61).

## Further Reading

- Austroads. 2016. Guide to road design part 3, geometric design (No. AGRD03-16).
- Lindsay Schumaker, Mohamed M. Ahmed, and Khaled Ksaibati. 2016. Policy considerations for evaluating the safety effectiveness of passing lanes on rural two-lane highways with lower traffic volumes: Wyoming 59 case study, *Journal of Transportation Safety & Security*, 10.1080/19439962.2015.1055415. <http://www.uwyo.edu/ahmed/papers/2016%20safety%20&%20security%20policy%20and%20safety%20considerations%20of%20adding%20passing%20lanes%20on%20rural%20two-way%20roadways.pdf>.
- Potts, I. B., and Harwood, D. W. 2004. *Benefits and design/location criteria for passing lanes* (No. RDT 04-008).
- Wooldridge, M. D., Messer, C. J., Heard, B. D., Raghupathy, S., Parham, A. H., Brewer, M. A., and Lee, S. 2001. Design guidelines for passing lanes on two-lane roadways (super 2). Austin, Texas. <https://journals.sagepub.com/doi/10.3141/2301-06>.

**Figure 5.61:** Romanian National Road 2 (DN2) pilot road upgrade program in 2019.



Source: © World Bank.

83 Global Road Safety Facility (GRSF) and World Bank Group Transport. 2017. Romania, Road Safety Management Capacity Review—Improving Safety of Road Infrastructure. Washington, DC: World Bank.



## 5.7. Roadsides—Forgiving Roadsides and Clear Zones

### General description

#### Forgiving roadsides<sup>84</sup>

The fundamental principle for designing safe roadsides is based on the knowledge that drivers (or riders) will make mistakes; occasionally they will lose control of their vehicles and leave the road. When this happens, a collision with unyielding objects such as trees or poles, or non-traversable features such as drains, steep side slopes, or rough surfaces, may result in the vehicle vaulting, rolling over, or coming to a sudden stop. This can lead to severe injuries or death for the occupants. Providing a forgiving roadside is intended to minimize the consequences of a vehicle leaving the roadway by providing a safe and forgiving area that is free of rigid objects, has flattened, smooth-sloped embankments and no other hazards, in which an errant vehicle can safely recover and stop. All aspects of the roadside should be designed to minimize the possibility of an occupant of an errant vehicle being seriously injured or killed.

A roadside hazard is any feature or object beside the road that may adversely affect the safety of the

#### Examples of roadside hazards

**Figure 5.62:** Unforgiving ditch with hazardous headwall (right) on high-speed road.



Source: Soames Job/GRSF/World Bank.

roadside area should a vehicle leave the road at that point. Roadside hazards are generally categorized into point hazards and continuous hazards. Point hazards are individual hazards or roadside hazards of limited length. Examples of point hazards include trees (especially those over 100 mm diameter), bridge end posts, large planter tubs, monuments, landscape features, non-breakaway signposts (over 100 mm diameter), interchange supporting piers, driveway headwalls, culvert headwalls, rigid utility poles (more than 100 mm diameter), solid walls, and pedestrian overpass piers and/or stairs. Continuous hazards, on the other hand, are hazards that extend over a considerable length of the road. These include rows and forests of large trees, uncovered longitudinal drains, retaining walls, steep embankments, rock cuttings, cliffs, areas of water (such as lakes, streams, channels over 0.6 m deep), unshielded hazards (such as cliffs) within reach of an errant vehicle, concrete guideposts, curbs with a vertical face of more than 100 mm high on roads with operating speeds above 80 km/h, and fences with horizontal rails that can spear vehicles. The length of a continuous hazard increases the likelihood of an errant vehicle striking it, and some hazards (such as cliffs) have a high crash severity regardless of the speed of the errant vehicle. See figures 5.62 through 5.71 for examples of roadside hazards.

**Figure 5.63:** Widened road but the poles not moved—Philippines.



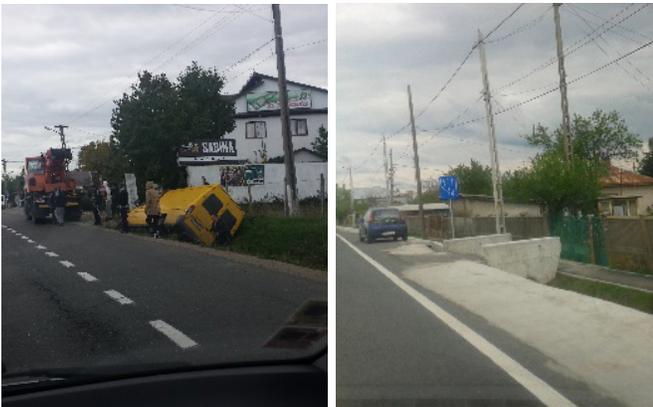
Source: © Alina F. Burlacu/GRSF/World Bank.

**Figure 5.64:** Concrete guideposts.



Source: Indian Institute of Technology. 2019. Report on Road Safety Audit of SH-11 during operation stage.

**Figure 5.66:** Uncovered drain and unsafe culvert—Romania.



Source: © Alina F. Burlacu/GRSF/World Bank

**Figure 5.68:** Unshielded overpass piers.



Source: CAREC, 2018.

**Figure 5.65:** Trees (over 100 mm diameter) located too close to the carriageway.



Source: IIT, 2019.

**Figure 5.67:** Unshielded water body with steep embankment.



Source: Indian Institute of Technology. 2019. Report on Road Safety Audit of SH-11 during operation stage.

**Figure 5.69:** Individual concrete blocks.



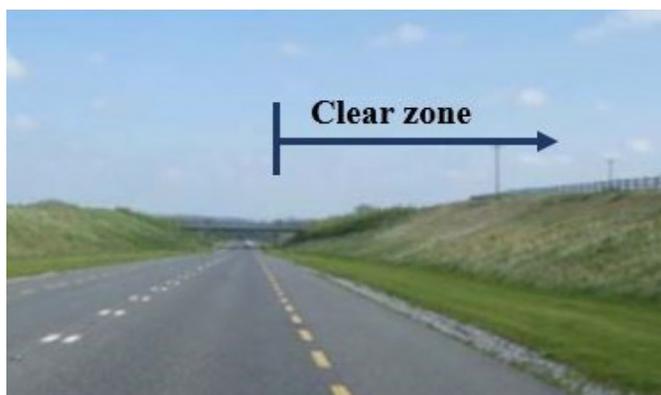
Source: CAREC, 2018.

**Figure 5.70:** Rigid mast on shoulder.

Source: IIT, 2019.

### Clear zone

A clear zone is defined as the area beside a road (measured at right angles from the edge line or the edge of the nearest traffic lane) that needs to be kept free of fixed roadside hazards to give an opportunity for drivers of errant vehicles to recover (figure 5.72). The concept of a clear zone was developed to define an area which reflects the probability of a severe crash occurring at a site to allow engineers to design and provide a drivable roadside area clear of hazards. Calculation of the required clear zone widths takes into account the traffic volume, 85th percentile speed, curve radius, and roadside slope. The clear zone concept does not prevent run-off-the-road crashes, but it reduces their consequences. It also enables a

**Figure 5.72:** Example of a clear zone.

Source: UNESCAP. 2017. Recommended Design Guidelines on Road Infrastructure Safety Facilities for the Asian Highway Network. <https://www.unescap.org/resources/recommended-design-guidelines-road-infrastructure-safety-facilities-asian-highway-network>.

**Figure 5.71:** Stacked materials by the roadside. These are a particular hazard to two or three wheelers especially at night.

Source: IIT, 2019.

risk management approach in the prioritization of treatments of roadside hazards at different locations. It is important to note that the clear zone figures are based on the recovery of 80–85 percent of errant vehicles, as the width required for the recovery of 100 percent of the vehicles is substantially wider and generally impracticable to achieve. Keeping this in mind, in certain situations it is more prudent to act in a way that includes the last 15–20 percent of the road vehicles that would theoretically travel beyond the normal clear zone. An example of such a situation would be in providing a barrier system when a major hazard (such as a high cliff) with certain severe consequences lies just outside the clear zone, to protect the last 15–20 percent of errant vehicles that would theoretically drive off beyond the clear zone. Given the cost of implementing and maintaining clear zones, guidance on the optimal width of clear zones differs between countries, and local guidance should be consulted. However, it is typical to find clear zones of around 9–10 m recommended on high-speed, high-volume roads, and 3–4 m for lower-speed, lower traffic environments.

### Safety implications

- Several studies have revealed that run-off-the-road crashes are not only frequent, but are especially serious, resulting in more severe injuries and deaths than most other crash types. The main factors that influence run-off-the-road crash outcomes are the

existence of vehicle recovery areas, roadside barriers, and the presence of infrangible objects. If a vehicle leaves the roadway but recovers on the shoulders or grassed verge, the outcome is likely to be no damage or minor damage. However, if an errant vehicle hits a rigid lighting column or a substantial tree at speed and comes to a sudden stop, the outcome is likely to be a severe injury or a fatality.

- The closer a roadside hazard is to the traffic lane and the higher the traffic speed, the higher the likelihood that the hazard will be struck by an errant vehicle. The presence of road curves adds to the overall likelihood of a run-off-the-road crash, as the driver needs to take more action to maintain the vehicle on the road. Ongoing traffic exposure to roadside hazards will increase the likelihood of crashes, i.e., higher traffic volumes increase the risk of a collision with the hazard over time. Rural roads have been shown to be more likely to produce severe consequences of run-off-the-road crashes due to generally high operating speeds and typically low levels of roadside modification, e.g., retaining original trees along the roadsides.
- Steep roadside slopes increase the risk of a rollover in case of a run-off-the-road crash, which generally has high severity. High speeds will add to the risk of high severity crashes. Slopes steeper than 1V:4H are deemed as nonrecoverable, i.e., a typical errant vehicle will travel to the base of the slope before being able to recover. The surface condition of the embankment also influences the recovery of an errant vehicle, with smooth firm slopes offering a better chance of recovery than soft, uneven slopes. High-volume roads with unshielded steep slopes tend to have a higher record of casualty crashes than roads with relatively flatter slopes or road safety barriers.
- Unprotected end posts of bridges are hazards due to their solid (rigid and infrangible) construction and proximity to the traffic. The narrower the bridge is, the higher the risk of a collision with an end post, as the hazard is closer to the traffic lane. Single lane bridges that can be approached

at high speeds and have no active traffic control have a high risk of head-on crashes, crashes into the bridge end posts, and pedestrian/cyclist crashes. Bridges with narrow lane widths, especially two-lane bridges and bridges that lack pedestrian/cyclist separation, can lead to increased risk of sideswipes, head-on crashes, or large vehicles becoming wedged.

- Overgrown or poorly planned vegetation can be a serious hazard depending on its location with respect to the road. When located close to the carriageway, they can obscure signs, hazard markers, and roadside hazards like ditches. Roadside vegetation may also interfere with sight distances at intersections and on road curves, which increases the risk of intersection, run-off-the-road, and head-on crashes.
- Overhanging tree branches can also interfere with the driving task, especially for buses and trucks, causing drivers to swerve into adjacent lanes to avoid damage to the vehicle or load. In urban areas, low decorative shrubs can block the visibility of pedestrians (especially children) at road crossing points, while overhanging tree branches can block sightlines to traffic signal displays. Trees, however, provide benefits, including shade for pedestrians and reduced soil erosion on site, and those less than 100 mm diameter are less likely to contribute to the severity of a crash.
- On high-speed facilities, curbs may be a safety hazard as they could cause an errant vehicle at high speed to jump or roll over (see section 5.12).

### Good Design practice/ treatments/solutions

- The safety of a roadside (or median) may be gauged by the width of the clear zone, which depends on operating speeds, traffic volumes, roadside slopes, and the road geometry. Wider clear zones are recommended near intersections or bends, where the complexity of the driving task and interaction with other vehicles adds to the likelihood of

run-off-the-road crashes. It should be noted that the clear zone widths are not a guarantee of safety but a compromise, a way of managing roadside risks. Nonetheless, generous forgiving roadside widths should be provided where feasible.

- In addition, the longer an errant vehicle traverses the roadside area, even if this is an extended clear zone, the greater the likelihood that the vehicle will roll over.<sup>85</sup>
- Clear zones need to be of good quality and well maintained to maximize their safety benefit. Uneven surfaces or exposed tree roots can snag vehicles causing them to roll, and this often results in severe crash outcomes.
- Some countries are moving to the use of continuous safety barriers (see section 5.8 on barriers) as their preferred roadside treatment over clear zones, as there are indications that the safety performance is better than for that of clear zones. In more densely populated areas where land is at a premium, land requirements to install a safety barrier system are greatly reduced compared to a clear zone, as are maintenance costs associated with vegetation control required in providing a clear zone that is of adequate width, of good quality, and that is well maintained. It is important that countries put in place appropriate controls for the design, installation, and maintenance of continuous safety barrier systems if they are to be used in preference to clear zones.
- In contrast, where land is relatively inexpensive, readily available, and only sparsely vegetated, applying the clear zone principles may provide an acceptably safe outcome for the limited funding and roadside risk.
- Avoid locating any new hazardous objects within the clear zone when designing a new road. This can be achieved through the development of policies that restrict the placement of new potentially hazardous objects on the roadside.
- All existing fixed roadside objects that are 100 mm

in diameter or larger should also be removed from the clear zone. In circumstances where it is not possible to completely remove a hazard from the clear zone, consideration should be made to relocate the hazard, preferably beyond the clear zone. Rigid poles, rigid lighting columns, and drains can be relocated to reduce the risk or replaced with frangible/passively safe columns (see below).

- The removal of trees, on the other hand, needs to be undertaken with consideration to the environment and community values. Large trees (more than 100 mm in diameter) that are close to the carriageway may be replaced with more appropriate plants to avoid soil erosion and regrowth affecting the site. Care should be taken not to leave large stumps and deep holes upon the removal of a tree, as these are also hazards. It is also important to trim and regularly maintain vegetation along the roadside.
- In locations where removing or relocating a hazard that is within the clear zone is not feasible or practicable due to economic or environmental constraints, altering or modifying the hazard can reduce the severity of a crash and the potential for serious injury. Common modifications of hazards include:

**Figure 5.73:** Traversable culvert end treatment for cross-drainage culverts. Allows vehicles that leave the roadway to drive over them without rolling or experiencing an abrupt change in speed.



Source: FHWA. 2009. Maintenance of drainage features for safety, a guide for local street and highway maintenance personnel.

**Figure 5.74:** Lightweight guidepost that is forgiving.



Source: CAREC, 2018.

**Figure 5.75:** Slip-base lighting column suitable for high-speed roads with little pedestrian activity and parking.



Source: CAREC, 2018.

**Figure 5.76:** Impact-absorbing lighting columns suitable for low-speed



Source: CAREC, 2018.

1. Modifying open longitudinal drains by piping them or covering them with a drivable cover;
  2. Modifying end walls of driveway culverts to make them drivable (figure 5.73);
  3. Redesigning rigid signposts and lighting columns to provide more forgiving frangible (breakaway) posts and lighting columns, i.e., impact absorbent or slip-base types (figures 5.74 through 5.76);
- Flattening a steep fill slope to make it drivable;
  - Replacing bridge rails with safety barriers with appropriate end treatments; and
  - Shielding bridge piers with rigid barriers (figure 5.77).
  - In situations where the road reserve may be limited, it may not be practical to create a clear zone. Reducing the operating speeds instead may be a more appropriate solution. A safety barrier system may also be considered that in itself presents a (reduced) collision risk but needs the terminals appropriately treated to minimize risk.
  - Good geometric design and the prudent use of road features can help to keep vehicles on the road and reduce the risk of a run-off-the-road crash. The geometric standard should be based on a realistic assessment of the likely operating speed of a road section considering the road function, the terrain through which the road exists, and the road environment. Some of the road design features that assist in keeping vehicles on the road include

**Figure 5.77:** Shielded piers with rigid barriers. An appropriate end treatment (cushions/impact attenuators) should also be applied on barrier systems.



Source: CAREC, 2018.

- appropriate lane widths and shoulder widths, predictable horizontal and vertical alignment, sufficient sight distance, and a sound road surface with proper drainage.
- There are various low-cost treatments that reduce the risk of run-off-the-road crashes, including proper delineation, chevron alignment markers (CAMs), warning signs, provision of hazard markers before any roadside obstruction such as bridge parapet wall, provision of sealed shoulders and tactile edge lines, and wide centerline treatments. All these can be applied to help vehicles stay on the road.
- Delineation and signage are essential safety aspects of preventing run-off-the-road crashes, as they serve as visual guidance to drivers along a highway. Such information and guidance become

**Figure 5.78:** Roadside tree delineated but inconspicuous—Italy.

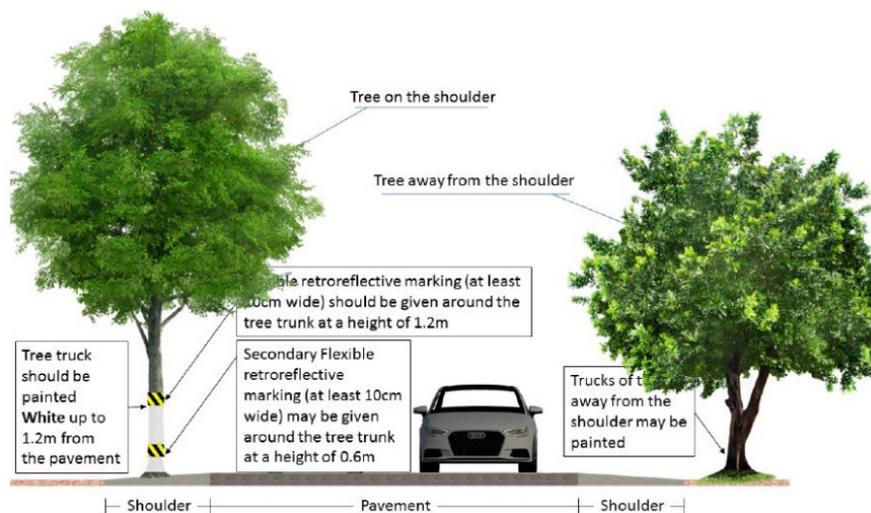


Source: © Alina F. Burlacu/GRSF/World Bank.

particularly important at night, requiring that the devices are fitted with retroreflective material. Good design and installation of signs and guideposts, as well as regular maintenance of the devices, are important to ensure that the devices perform as needed for the road conditions. Concrete guideposts should not be used as they are a hazard to errant vehicles. Narrow flexible guideposts made of timber, sheet metal, or plastic should be used as they present a lower risk to errant vehicles' occupants, particularly motorcyclists, if hit.

- As a last resort, it may be necessary to ensure that each hazard (particularly trees) is delineated so it can be more easily seen by drivers (see figures 5.78 and 5.79). This should be considered as a last option when treating hazards, as delineating a hazard will likely reduce incidental collisions or “innocent hits” but will not assist the occupants of an errant vehicle that is out of control. Delineating a hazard that is too close to the carriageway could be accompanied by other treatments, including a reduction in the speed of the highway (for instance to no more

**Figure 5.79:** Illustration on delineation of trees as a last resort treatment. Delineating hazards may be used in combination of other treatments, including reduction in speeds and protection by safety barriers.



Source: Indian Institute of Technology. 2019. Report on Road Safety Audit of SH-11 during operation stage.

than 50 km/h) or protection by safety barriers. The object hazard marking provided should be retroreflective to ensure visibility at night.

## Further Reading

- AASHTO. 2011. *Roadside design guide*. Must read chapter 5, Roadside barriers.
- Austroads. 2010. *Guide to Road Design*, Part 6: Roadside Design, Safety, and Barriers.
- Austroads. 2018. *Towards safe system infrastructure: a compendium of current knowledge* (No. AP-R560-18). <https://austroads.com.au/publications/road-safety/ap-r560-18>.
- Secretariat, CAREC. 2018. *CAREC Road Safety Engineering Manual 3: Roadside Hazard Management*. Asian Development Bank. Must read chapter 5, Using safety barriers correctly.
- C. A. Plaxico et al. 2005. *National Cooperative Highway Research Program Report 537: Recommended Guidelines for Curb and Curb-Barrier Installations*, Transportation Research Board. Washington, DC. Must read chapter 3, Summary of state surveys on curbs and curb barrier combinations.

## 5.8. Barriers

### General description

Barriers are used to shield hazards from errant vehicles. They can be used along the median (sometimes referred to as non-traversable medians) to prohibit movement of traffic across the median or on the roadsides to shield roadside hazards. They are designed to redirect an impacting vehicle and dissipate crash forces in a controlled manner, thus reducing the severity of crashes involving out-of-control vehicles.

Barriers broadly fall under three categories: flexible barriers (e.g., wire-rope safety barriers), semi-rigid barriers (e.g., steel beam), and rigid barriers (e.g., concrete). Each type of barrier has various benefits and constraints that make them suitable for some locations, but unsuitable for others. To avoid installing unsafe barriers or wasting resources, engineers need to understand the benefits and the limitations of each barrier type. A brief description of each barrier type is provided below.

#### Flexible barriers (wire-rope safety barriers)

Wire-rope safety barriers (WRSBs) (figure 5.80) consist of several tensioned wire ropes (generally three or four) that are held in place by anchorages at each end and supported at the necessary height by frangible

steel posts. Upon impact by an errant vehicle, the tensioned cables deflect and absorb the energy of the vehicle, causing the vehicle to slow down. The tensioned cables are designed to guide the impacting vehicle along the barrier while the posts progressively collapse when struck. Eventually, the errant vehicle is redirected back in the direction of travel or slowed down to a stop.

#### Semi-rigid barriers

These are usually made from steel beams or rails mounted on galvanized steel channel posts (figure 5.81). Other types of posts such as timber or concrete may be used where crash tests prove that they perform satisfactorily. These barriers deflect less than flexible barriers and, depending on the impact, they may be able to redirect secondary impacts (i.e., another impact at the same location).

#### Rigid barriers

These are usually reinforced concrete walls constructed to a profile and height that is suitable to contain and redirect errant vehicles (figure 5.82). They offer no or little deflection on impact; therefore, high impact forces may result in severe injuries to vehicle occupants as the vehicle entirely absorbs the impact energy. The most common types of rigid barriers include the F-profile barrier, the New Jersey barrier, the constant slope barrier and the vertical wall barrier.

**Figure 5.80:** Flexible (wire-rope) barrier.



Source: iRAP.

**Figure 5.81:** Semi-rigid barrier (W-beam).



Source: ACP. Australian Construction Products. ACP Sentry Barrier W-Beam System—Longitudinal barrier. <http://www.acprod.com.au/products/acp-sentry-barrier-w-beam-system-longitudinal-barrier>.

**Figure 5.82:** Rigid (F-profile) barrier.



Source: © Famartin.



## Safety implications

- Barriers that are not well-designed fail to perform satisfactorily and can be a safety hazard (see figures 5.83 through 5.86).
- A barrier that is too low can lead to an impacting vehicle to vault over it. A barrier that is too high (for flexible and semi-rigid barriers) can cause an errant vehicle to pass beneath the cables or railing leading to severe consequences.
- A barrier that is too close to the road leads to increased incidental impacts with the barrier, while a barrier that is too far from the road (and closer to

the hazard it is shielding) means less opportunity for the deflection of a flexible and semi-rigid barrier and may result in the impacting vehicle hitting the hazard. The farther away the barrier is from the road also means the greater the chance of a high angle impact which could result in severe injuries to the vehicle occupants especially when impacting a rigid barrier.

- A critical aspect of a barrier's design is the "length of need" required in order to adequately protect a hazard. A barrier that is too short in its length may cause the errant vehicle to pass behind the barrier and strike the hazardous object or collide with oncoming traffic.

**Figure 5.83:** Flexible barriers with too large posts.



The posts of flexible barriers should be designed to collapse when struck. However, the posts of this barrier are too large and rigid to perform in this manner.

Source: CAREC. 2018. CAREC Road Safety Engineering Manual 3: Roadside Hazard Management. Asian Development Bank.

**Figure 5.85:** Use of nonstandard median type on high-speed road.



Source: National Highway Authority. 2019. Guidelines for Road Safety Engineering, Part 1. Government of Pakistan. Retrieved November 15, 2019, from <http://www.roadsafetypakistan.pk/download/Guidelines-for-road-safety-engineering-part-1.pdf>.

**Figure 5.84:** The rail units overlap in the wrong way.



The rail units overlap in the wrong way such that the closest rail would push away from the road if struck, leaving the next rail exposed to spear through the impacting vehicle. The rigid concrete posts will not absorb the impact energy and may lead to severe injuries.

Source: CAREC, 2018.

**Figure 5.86:** Light-gauge rails with concrete curbs.



Source: CAREC, 2018.

**Figure 5.87:** The exposed end of the guardrail can spear through an impacting vehicle.



Source: World Bank.

**Figure 5.89:** Unsafe gap between guardrail and concrete



Source: CAREC. 2018. CAREC Road Safety Engineering Manual 3: Roadside Hazard Management. Asian Development Bank.

**Figure 5.88:** Unsafe ramped end of semi-rigid barrier that can launch an impacting vehicle.



Source: iRAP.

- The end points (terminals or end treatments) of barriers can be dangerous if not properly designed, constructed, and maintained. The end of a guardrail, for example, can spear through an errant vehicle that strikes it unless a correctly installed safe terminal is used (figure 5.87). Ramped or turned down terminals on the approach end of barriers can launch an impacting vehicle, especially when struck at high speeds (figure 5.88). The blunt ends of concrete barriers are a safety hazard.
- Poorly designed transitions between different barrier types and insufficient offsets to hazards may lead to pocketing, that is, where an errant vehicle strikes a barrier but is directed by that barrier into a fixed object. This can occur, for example, where a guardrail is poorly connected to a concrete bridge parapet causing a vehicle that strikes the guardrail to be directed to hit the blunt end of the concrete parapet upon the deflection of the guardrail (figure 5.89).
- Barriers may interfere with sight distance, especially on horizontal curves or when entering or leaving the road.
- Damage to barriers can reduce the safety benefits of barriers if they are not properly repaired. This is particularly essential for flexible barriers, as even a low force impact will require timely repairs to the barrier system.
- While all types of barriers are designed to protect people from hazards, they may still pose a risk to the vulnerable human body, particularly motorcyclists, due to the limited protection their bodies have compared to someone in a vehicle.
- A curb in front of and close to a barrier can cause an errant vehicle hitting the curb at high speed to jump and either vault over the barrier or hit the barrier at a greater height than provided for in the design and testing. Injuries can be more severe in such crashes.
- Since flexible barriers rely on the tension of the cables, the horizontal and vertical alignment can limit their use. On tight curves, the required tension and height may not be maintained during or after an impact. On sag curves, depending on the degree of curvature, the wire tension may cause the posts at the bottom of the curve to lift out of their sockets. Vehicles may also pass beneath the cables or become suspended at the bottom of the curve.
- Where there is a known risk of animals accessing the road corridor, in particular large animals like

deer, roadside barriers may be installed. Such barriers require special considerations, such as exclusion of animals by perimeter closed fencing, in addition to the safety points for barriers for vehicles.

## Good design practice/ treatments/solutions

- Traditionally it has been thought preferable to remove, relocate, or modify roadside hazards, but in some situations, shielding a hazard with barriers may be the only practical option where it is not feasible or economically viable to treat the hazard in other ways.<sup>86</sup> It is important to first assess the need for a barrier before installing one to determine if there are other ways to treat the hazard. This is because the barrier itself can represent a hazard to errant vehicles. A collision with the barrier should be less severe than collision with the hazard that the barrier is shielding.
- In selecting the barrier type that will best suit the needs, a range of factors need to be considered, including:
  - Performance capability and level of containment requirements, which might be based on vehicle mix and significance of roadside infrastructure;
  - Available clearance to the hazard, and the dynamic deflection characteristics of the proposed barrier;
  - Site conditions, such as vertical and horizontal alignments and cross-slopes;
  - End terminals;
  - Sight distance;
  - Compatibility with adjacent barriers;
  - Installation and maintenance costs;
  - Aesthetics and environmental impact; and
  - Maintenance capacity of organization.

(See also Austroads. 2020. Guide to Road Design Part 6, Roadside Design, Safety, and Barriers; 1.5, Principles considered in roadside design to achieve the safest system; and 5.2, Factors considered in barrier selection.)

(See also section 4.4 regarding motorcycle use and barrier types.)

- Safety barriers should only be installed if the manufacturer of the product has subjected it to an internationally accepted crash test to confirm it performs satisfactorily. The barrier should then be installed fully to the supplier's instructions, following the applicable standards on which the crash test was performed.
- Sufficient clearance from the hazard should be provided so that the expected deflection of the barrier will not allow the impacting vehicle to contact the hazard (figure 5.90). Barrier deflection depends on the type and installation arrangement of the barrier used, as well as the mass, speed, and impact angle of the vehicle. As a rule of thumb, the deflection of a semi-rigid barrier may be up to 1 m, and the deflection of a flexible barrier may be up to 3 m. Though the dynamic deflection of rigid concrete barriers is minimal (0.1 m or less), hazards that are

**Figure 5.90:** Example of a safe flexible barrier with good clearance. Since the deflections on these barriers can be high, it is important that an adequate offset between the barrier and the hazard is provided



Source: CAREC. 2018. CAREC Road Safety Engineering Manual 3: Roadside Hazard Management. Asian Development Bank.

<sup>86</sup> Some countries are moving to the use of continuous safety barriers as their preferred roadside treatment in light of new evidence that indicates well-installed and maintained barriers may provide superior safety performance compared to clear zones.

## End Terminals Examples

**Figure 5.91:** Fully re-directive crash cushion—Philippines.



Source: © Alina F. Burlacu/GRSF/World Bank.

**Figure 5.92:** Fully re-directive terminal, flared or tangential.



Source: Chan/Auckland motorways.

**Figure 5.93:** Flared energy absorbing terminal.



Source: Chan/Auckland motorways.

**Figure 5.94:** Safe crash cushion at the end of rigid barrier at a construction site.



Source: CAREC. 2018. CAREC Road Safety Engineering Manual 3: Roadside Hazard Management. Asian Development Bank.

taller than the barrier need to be offset far enough from the face of the barrier so that during impact, vehicles (especially high vehicles such as trucks) do not lean over the barrier and strike the hazard. This is referred to as the “roll allowance.” For flexible and semi-rigid systems, this roll allowance should be added to the deflection. For rigid systems, the deflection may be assumed to be zero, and a roll allowance of 1.1 m is adequate to protect a vehicle driver from impact.<sup>87</sup>

- Roadside barriers should be sufficiently offset from the travel way to allow space for vehicles to pull off the traffic lane.
- Since rigid barriers can cause serious injuries if struck at a high impact angle, they are located close to the traffic lane (usually within 4 m of the edge of the nearest traffic lane) to minimize the risk that vehicles will impact the concrete barrier at a high angle. On the other hand, it is desirable to install roadside flexible and semi-rigid barriers further from the traffic lane to maximize the chance of a driver regaining control of the vehicle before impacting the barrier.
- When located on horizontal curves, safety barriers

may need to be offset further from the edge of the traffic lane so that they do not impede horizontal sight distance. Sight distance is a factor that also needs to be considered near intersections, median breaks, pedestrian crossings, and driveways.

- It is preferable that the slope in front of a barrier is installed as designed. This essentially means vertical for semi-rigid and flexible systems or to the required, tested slope for rigid systems. This is irrespective of the barrier manufacturer used. This is because safety barriers perform best when they are impacted by vehicles with their center of gravity at or near the normal position.
- The terminals of barriers should be well designed to provide controlled deceleration of errant vehicles below recommended values that cause injury to vehicle occupants. They should also ensure that the vehicle is not speared, vaulted, snagged, or rolled on impact. Various types of terminals are commercially available, and the manufacturer’s specifications for installation should be followed to ensure that the terminals meet appropriate performance standards (see figures 5.91 through 5.94 for examples). It is also important that a terminal of known impact performance is installed on

the departure end of a barrier if that end is within the clear zone for oncoming traffic on a two-way carriageway.

- Semi-rigid barriers are often used to shield concrete bridge parapets that could result in a serious crash. The transition from the approach barrier to the bridge parapet should provide a continuous face along which an errant vehicle can be controlled. To prevent pocketing of the vehicle upon impact, it is important to enhance the strength and stiffness of the barrier gradually as it approaches the parapet, e.g., through reductions in the post spacings and to affix/embed the barrier firmly to the parapet (see figure 5.95).
- Minor damage to flexible and semi-rigid barriers needs to be repaired in a timely manner to maintain the integrity of the barrier. If incidents are not reported, manual inspections of the barrier systems may be required. It is also important to continuously monitor the wire tension of flexible barriers.
- It is preferable to avoid the use of curbing near safety barriers. But if a curb is necessary for drainage, the location of safety barriers relative to the curb needs to be considered carefully, as it may affect the barrier performance when impacted (see section 5.12 on curbs).

**Figure 5.95:** Safe connection between guardrail and rigid barrier on bridge with a transition section. Adding extra posts to the guardrail near the rigid barrier helps to create a transition section. The marker also helps in alerting drivers of sudden narrowing of the road ahead



Source: CAREC, 2018.

- It should be noted that while both the F-type and New Jersey have similar cross sections, studies show that the lower slope of the F-profile barrier reduces the likelihood that small cars will overturn and are thus preferred. The vertical face barrier and constant slope barrier help to further reduce the potential for small vehicles to overturn, but they also generate higher impact severities and are thus not so widely used.

## Further Reading

- AASHTO. 2011. *Roadside design guide*. Must read chapter 5, Roadside barriers.
- Austroads. 2010. *Guide to Road Design, Part 6: Roadside Design, Safety, and Barriers*.
- Austroads. 2018. *Towards safe system infrastructure: a compendium of current knowledge* (No. AP-R560-18). <https://austroads.com.au/publications/road-safety/ap-r560-18>.
- Secretariat, CAREC. 2018. *CAREC Road Safety Engineering Manual 3: Roadside Hazard Management*. Asian Development Bank. Must read chapter 5, Using safety barriers correctly.
- C. A. Plaxico et al. 2005. *National Cooperative Highway Research Program Report 537: Recommended Guidelines for Curb and Curb-Barrier Installations*, Transportation Research Board. Washington, DC. Must read chapter 3, Summary of state surveys on curbs and curb barrier combinations.

## 5.9. Medians

### General description

A road median is an area of separation between opposing flows of traffic. In effect, the median converts a “two-way” movement into two “one-way” movements. It can be constructed (often referred to as “raised”) using curbing or median barriers (for example—see section 5.8); provided via paint (sometimes called a

“flush” median or wide centerline); or provided using an unpaved or grassed area (see figures 5.96 through 5.103). Vehicles are physically prevented from crossing the median with constructed medians, while they are only discouraged when using other types of medians. Medians provide a degree of separation between opposing directions of traffic, meaning that when vehicles stray from their lane, they have time to recover and return safely to their lane, or are physically directed back into their lane (in the case of median barriers, and to some extent with curbed

medians). They can be used in urban areas as well as on high-speed roads. They may be supplemented with rumble strips, particularly on higher-speed roads, to alert inattentive or distracted road users that they are leaving their lane. In some settings, a median can provide a holding point for pedestrians trying to cross multiple lanes of traffic, especially when the median is accompanied by a pedestrian refuge island.

Median openings are typically provided for cross traffic movement at intersections and sometimes at access points allowing left, right (or both), and U-turns

### Types of road medians

**Figure 5.96:** Flush median.



Source: FHWA.

**Figure 5.97:** Flush median with rumble strips.



Source: FHWA.

**Figure 5.98:** Median with pavement bars.



Source: Speed uHUmP Australia.

**Figure 5.99:** Grassed median with curb.



Source: Florida Department of Transportation.

**Figure 5.100:** Curbed median.



Source: Austroads road safety engineering toolkit.

**Figure 5.101:** Painted median on high-speed road.



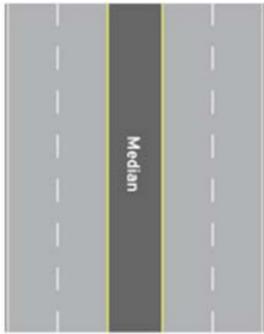
Source: © Blair Matthew Turner/GRSF.

**Figure 5.102:** Semi-rigid median barrier on expressway.

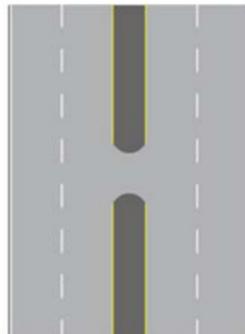
Source: Tony Mathew. (n.d.). Road Safety Infrastructure Facility Standards—Indian Context.

**Figure 5.103:** Raised median on dual carriageway.

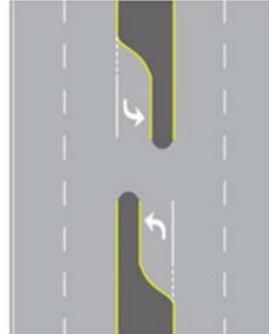
Source: Tony Mathew (n.d.).

**Figure 5.104:** Full median with no opening.

Source: FHWA.

**Figure 5.105:** Median crossover opening, with no left/right turn bay.

Source: FHWA.

**Figure 5.106:** Median crossover, opening, with left/right turn bay.

Source: FHWA.

**Figure 5.107:** Median crossover, with directional left/right turn bays (prevents crossing).

Source: FHWA.

on the roadways where a physical median is present. Different types of median openings are shown in figures 5.104 to 5.107.

Although median openings facilitate traffic movements, they can also introduce risks, especially when no turning bay is provided, or if the median is not of adequate width. It is essential that adequate turning provision be provided, especially in higher-speed locations.

## Safety implications

- Medians are used to improve overall safety and efficiency for vehicles, and if designed correctly may also provide benefits for vulnerable road users. By providing a central refuge, pedestrians are required to cross traffic from only one direction at a time.
- Road crashes can result from the presence of unnecessary or less predictable (readable) median openings (both for pedestrian crossings and vehicular U-turn movement) and smaller medians. Narrow medians and lack of adequate turning provisions, especially in higher-speed environments, can significantly increase crash risk.
- Proper planning and designing of median openings are critical for safety, access control, and maintaining traffic flow. This includes allowance for large vehicles, particularly buses or articulated ones to turn without their envelope encroaching into a through lane. Median openings should also not encroach on the functional area of another median opening or intersection.
- Specific benefits of adequately sized medians, especially non-traversable medians, include:

- Reduced chance of vehicles travelling in opposing directions colliding (reduced head-on crashes by approximately 40 percent).<sup>88</sup>
- Reduce all crash types by approximately 15 percent for painted medians, and between 45–55 percent for built-up median in urban areas and rural areas, respectively.<sup>89, 90, 91</sup>
- Reduced lane width can lead to reduced vehicle speeds on the roadway.<sup>92</sup>
- Better access control.
- Providing refuge area for pedestrians crossing the street.
- Managing the location of intersection traffic conflict points.
- Provide space to install improved lighting at pedestrian crossing locations (shown to reduce nighttime pedestrian fatalities at crossings by 78 percent).<sup>93</sup>
- There are significant benefits from providing medians at certain high-risk intersections to eliminate cross traffic turning movements (see section 6.6), but care needs to be taken to ensure alternative, compensatory safe U-turning arrangements are provided in close proximity.
- Drainage issues may occur when using a raised median resulting in an increase in crash risks (for instance due to reduced road surface friction).
- For painted medians or where rumble strips are used, the risk for two-wheeled vehicles can be increased due to reduced or variable skid resistance.
- Where curbing or raised pavement devices are used, there may be an increase in risk for two-wheeled vehicles and pedestrians (trip hazard).
- There are also some efficiency benefits in addition to those for road safety, including decreased delays for motorists and increased capacity of roadways.

## Good design practice/ treatments/solutions

- Reduction in head-on crashes can be achieved through selection of a suitable width of the median or the use of median barriers. Few out-of-control vehicles travel further than 9 meters from the edge of lane, so that this width of median would be sufficient to avoid many head-on crashes.<sup>94</sup> The use of a wide open-space median may also be useful in withholding the land reserve for future expansion of the road to avoid encroachments.
- Adequate widening to provide an optimum turning radius should be provided to ensure vehicles do not block the roadway while turning, as shown in Figure and figure 5.109. Dedicated turning lanes should also be provided to ease congestion or conflicts between turning and non-turning vehicles. This includes allowance for large vehicles, particularly buses or articulated ones, to turn without their envelope encroaching into a through lane. Consideration should also be given to the distance of the U-turn to access points in order to reduce congestion, depending on the amount of traffic flow on the road.

88 Beck, D. 2016. Guidance on median and centreline treatments to reduce head-on casualties (No. AP-R519-16).

89 Bahar, G. B., Masliah, M., Wolff, R., and Park, P. 2007. Desktop reference for crash reduction factors (No. FHWA-SA-07-015; 7067). United States. Federal Highway Administration. Office of Safety.

90 Turner, B., Steinmetz, L., Lim, A., and Walsh, K. 2012. Effectiveness of road safety engineering treatments (No. AP-R422/12).

91 Austroads road safety toolkit.

92 King, M. R., Carnegie, J. A., and Ewing, R. 2003. Pedestrian safety through a raised median and redesigned intersections. Transportation research record, 1828(1), 56–66.

93 The Federal Highway Administration, FHWA. 2019. State Best Practice Policy for Medians—FHWA-SA-11-019. FHWA Safety Program. Accessed at [https://safety.fhwa.dot.gov/ped\\_bike/tools\\_solve/fhwasa11019/fhwasa11019.pdf](https://safety.fhwa.dot.gov/ped_bike/tools_solve/fhwasa11019/fhwasa11019.pdf).

94 SANRAL. Geometric Design Guidelines.



**Figure 5.108:** U-Turn on narrow median (with waiting lane).



Source: Al-Jameel, H. A. 2015. Contribution to the U-turn Design at Median Openings in Iraq: Al-Najaf City as a Case Study. *Kufa Journal of Engineering*, 6(1).

**Figure 5.110:** Vehicles using raised median as lane during congestion.

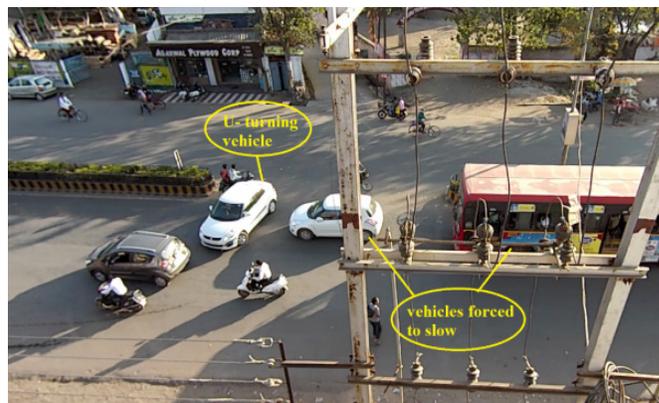


Source: Great about Perth. Accessed at <https://whatssogreataboutperth.wordpress.com/2010/03/16/traffic-in-perth-ha/>.

**Solution:** Median should be adequately raised to stop vehicles from using it as an additional lane.

- Both flush and raised road medians may be used illegally by drivers during traffic congestions (see figures 5.110 and 5.111). Pavement bars or flexible posts should be used on flush medians in sections where congestion may cause drivers to illegally use the flush median as a lane. Frangible signs can be used at intervals on raised medians to deter drivers from using it as an additional lane during congestion.

**Figure 5.109:** U-turning vehicle encroaching on road space for approaching traffic.



Source: Sharma, V. K., Mondal, S., & Gupta, A, 2017.

**Figure 5.111:** Illegal U-turn over the median.



Source: Ghana web. Accessed at <https://www.ghanaweb.com/GhanaHomePage/features/Tema-Motorway-A-necessary-death-trap-872413?gallery=1>.

**Solution:** Medians should be designed to prohibit illegal U-turns, and adequate median openings should be provided.

- Unnecessary median openings (both for pedestrian crossings and vehicular U-turn movement) should be removed, and smaller narrow medians should be avoided where possible. Figures 5.112 through 5.115 illustrate some unsafe and safe median strips.
- Restriction of turning movements may be an issue for raised medians, and community input and acceptance should be sought. Regular provision of

## Examples of unsafe median strips

**Figure 5.112:** Unsafe median opening leading to contraflow.



Source: World Highways. India's road to safety. Accessed at <https://www.worldhighways.com/sections/world-reports/features/indias-road-to-safety/>, November 15, 2019.

## Examples of safe medians strips

**Figure 5.114:** Raised median with turn lane dedicated for the U-Turn



Source: National Highway Authority. 2019. Guidelines for Road Safety Engineering, Part 1. Government of Pakistan. Accessed at <http://www.roadssafety-pakistan.pk/download/Guidelines-for-road-safety-engineering-part-1.pdf>, November 15, 2019.

gaps may be needed to address this issue (ensuring that such gaps are well designed with appropriate turning facilities).

- Appropriate median widths should be determined according to the road classification and function of the median. This will include whether turning movements are required (into and out of side

**Figure 5.113:** Use of nonstandard median type and unsafe median opening on a high-speed road.



Source: Tony Mathew (n.d.). Mathew T. 2019. Road Safety Infrastructure Facility Standards—Indian. International Road Federation. Accessed at [https://www.unescap.org/sites/default/files/3.3%20India\\_Mr.%20Tony%20Mathew.pdf](https://www.unescap.org/sites/default/files/3.3%20India_Mr.%20Tony%20Mathew.pdf), November 15, 2019.

**Figure 5.115:** Raised median on carriageway.



Source: © D. Allen Covey/VDOT

streets), U-turn requirements, and pedestrian use.

- Check there is adequate sight visibility for drivers turning in/out of accesses and at intersections.
- Median should be highly visible both night and day and should contrast with the travelled way.
- Clear advance warning and visibility should be provided for raised medians.

- Appropriate drainage facilities should be included when installing raised medians.
- Placement of rumble strips, curbs, and raised pavements should be carefully considered so as to avoid being a hazard for two-wheeled vehicles. Similarly, painted medians with poor skid resistance should not be used where they might become a hazard for these road users.
- Raised medians can also be used to provide additional plastic shields to prevent glare from opposing traffic lanes (figure 5.116).
- Traffic volume should be carefully considered when deploying a flush median. Four-ft flush medians have positive safety benefits (CMF < 1) under lower

average daily traffic volumes (e.g.,  $\leq 6,000$ ) while negative benefits (CMF > 1) under greater average daily traffic volumes (e.g.,  $\geq 15,000$ ).<sup>95</sup>

- Flush medians with rumble strips or chatter bars were found to be the safest medians in reducing crashes, followed by raised medians and undivided segments.<sup>96</sup>

## Further Reading

- The American Association of State Highway and Transportation Officials, AASHTO. 2018. A Policy on Geometric Design of Highways and Streets—Green Book. 7th edition. Must read chapter 4, Cross-sectional elements.
- Austroads. Guide to Road Design. Must read Part 3, Geometric Design.
- Florida Department of Transportation. 2017. 2014 Median Handbook FDOT. <https://www.fdot.gov/docs/default-source/PLANNING/systems/programs/sm/accman/pdfs/FDOT-Median-Handbook-Sept-2014.pdf>.
- Kennaugh D. Median Design. Accessed at <https://www.cedengineering.com/userfiles/Median%20Design.pdf>.

**Figure 5.116:** Anti-glare barrier on top of median.



Source: © Alina F. Burlacu/GRSF/World Bank.

95 Li, X., Liu, J., Yang, C., and Barnett, T. 2021. Bayesian Approach to Developing Context-Based Crash Modification Factors for Medians on Rural Four-Lane Roadways. *Transportation Research Record*, 03611981211007141.

96 Jiang, X., Yan, X., Huang, B., and Richards, S. H. 2011. Influence of Curbs on Traffic Crash Frequency on High-Speed Roadways. *Traffic Injury Prevention*, Vol. 12, No. 4, pp. 412–421.

## Case Studies/ Examples

### Central medians and median openings in Addis Ababa <sup>a,b</sup>

**Figure 5.117:** Narrow unsafe median



Source: James Jeffrey/The World. The World, US-Ethiopia relationship changing amid Horn of Africa power struggle. November 8, 2018. <https://www.pri.org/stories/2018-11-08/us-ethiopia-relationship-changing-amid-horn-africa-power-struggle>.

Unsafe narrow median, with insufficient width to provide refuge for crossing pedestrians (figure 5.117). Pedestrians are forced to stand within the traffic lanes. The median's contrast and height may not be visible for road users, especially in dark conditions.

Note: Sufficient width needs to be provided for pedestrians while crossing multilane highways to protect them from vehicles on the roadway. In some situations where there is inadequate width, a full height median barrier may be considered instead.

A central median with trees and shrubs in Addis Ababa helps green the street, prevents conflict between vehicles, and provides a refuge (at grade) for pedestrians crossing. The median openings for pedestrians are also adequately sized, and wider openings have concrete stumps to prevent vehicles from using them as areas for U-turn movements (figures 5.118 and 5.119). However, the vegetation may obscure pedestrians and needs to be maintained to ensure adequate visibility to other road users.

a Welle, B., Liu, Q., Li, W., Adiazola-Steil, C., King, R., Sarmiento, C., and Obelheiro, M. 2015. Cities safer by design: guidance and examples to promote traffic safety through urban and street design.

b Eskindir, Z. 2019. Investigation of the Effect of Roadway Elements on Traffic Safety in Addis Ababa: A Case of Nifas Silk Lafto Sub City (Doctoral dissertation, Addis Ababa University).

**Figure 5.118:** Wide median opening with concrete stumps



Source: © John Barrell.

**Figure 5.119:** Median opening for pedestrian use



Source: Eskindir, Z. 2019. Investigation of the Effect of Roadway Elements on Traffic safety in Addis Ababa: A Case of Nifas Silk Lafto Sub City (Doctoral dissertation, Addis Ababa University).

## 5.10. Road Surfacing

### General description

Road surface characteristics affect road safety in several ways. One way is the surface friction which affects the resistance to sliding or skidding of tires across the road surface. This friction force, known as skid resistance, provides the grip that a tire needs to maintain vehicle control and for emergency stopping. Skid resistance is particularly important during wet weather conditions, as water on the pavement acts as a lubricant, reducing the direct contact between the tire and the pavement. In addition to climate and water on the pavement, the potential for a skidding crash depends mainly on the speed of the vehicle, the cornering path, the magnitude of acceleration or braking, the condition of the vehicle tires, and the characteristics of the road surface.<sup>97</sup> The road surface characteristics that influence surface friction include microtexture, macrotexture, megatexture/ unevenness, chemistry of materials, temperature, thermal conductivity, and specific heat.

Microtexture refers to irregularities in the surfaces of the stone particles, that is, the fine-scale texture. The magnitude of microtexture depends on the initial roughness on the aggregate surface and the ability of the aggregate to retain this roughness against the polishing action of traffic. As such, microtexture is an aggregate-related property that can be controlled by the careful selection of aggregates with desirable polish-resistant characteristics.

Macrotexture refers to the larger irregularities of the road surface, that is, the coarse-scale texture. The initial macrotexture on a pavement surface will be determined by the size, shape, and gradation of the coarse aggregates used in the pavement construction, as well as the particular construction techniques used

for the pavement surface layer. Macrotexture is also essential in providing escape channels to water from beneath the tires, which reduces the potential for aquaplaning/hydroplaning. It also reduces the splash and spray potential of the road in wet conditions, which can adversely affect the visibility of the road in wet weather.

Megatexture is the unevenness in the scale of the contact surface between the vehicle tire and the pavement surface. It describes irregularities that can result from rutting, potholes, patching, surface stone loss, and major joint cracks, and it mainly affects noise levels and rolling resistance.

Roughness, on the other hand, refers to surface irregularities larger than megatexture that also affect rolling resistance, in addition to ride quality and vehicle operating costs. It provides an overall measure of the pavement condition and is computed through the International Roughness Index (IRI).

Road surface conditions can also have a significant influence on vehicle speeds, which affect both the crash risk and severity. Extensive rutting or the presence of potholes can reduce vehicle speeds, but also provide increased risk for two-wheeled users. Regrading or resurfacing provides a smoother, more comfortable ride with associated increases in speed. As such, increases in speeds from road improvement and rehabilitation schemes can result in higher safety risks unless mitigating safety strategies are used.

Figures 5.120 through 5.122 illustrate various types of road surfacing.

### Safety implications

- The relationship between skid resistance and crash risk is well understood, with low skid resistance being directly related to increased crash risks,<sup>98</sup> especially on wet roads. Low skid resistance is likely to result in longer stopping

97 Harwood, D. W., Blackburn, R. R., and Heenan, P. J. 1980. Pavement macrotexture review (No. FHWA-RD-80-505 Final Rpt.).

98 Wang, C., Quddus, M. A., and Ison, S. G. 2013. The effect of traffic and road characteristics on road safety: A review and future research direction. *Safety Science*, 57, 264–275.

**Figure 5.120:** An asphalt road surface in good condition.



Source: Highways Today. 2017. AfDB funded Thika Highway continues to impact Kenyan lives five years on. <https://highways.today/2017/11/09/afdb-thika-highway-kenya/>.

**Figure 5.121:** Concrete blocks (adoquines) surfacing in good condition and appropriate drainage facilities.



Source: World Bank.

**Figure 5.122:** Otta seal surfacing on low volume road in good condition with satisfactory results. (left image: close-up of the otta seal surfacing).



Source: World Bank.

distances and may cause longitudinal or side-ways skidding and loss of vehicle control. Loss of control of the vehicle may lead to run-off-the-road crashes, head-on crashes, sideswipes, and rear-end crashes. Research performed in some EU countries demonstrated that the use of road pavements with sufficiently high skid resistance could improve road safety by not only reducing the vehicle's sliding risk but also the crash risk and severity<sup>99</sup>. This is because drivers who lose their ability to brake effectively are more likely to encounter higher impact speeds compared to

vehicles that decelerate prior to impact. The risk of crashes is also much higher at high traffic volume intersections than at low traffic volume locations owing to increased exposure to the pavement deficiency. Pavement defects that indicate poor skid resistance include:

- A polished surface (rounded or worn out aggregates) in the wheel path,
- "Bleeding" of the pavement (upward movement of bitumen/asphalt as evidenced by a shiny black surface film),

99 Gothie, M. 1996. Relationship between Surface Characteristics and Accidents, in Proceedings of 3rd International Symposium on Pavement Surface Characteristics, 271–281.

- Accumulation of oil or localized spill of slippery substance (especially on curves and intersection approaches),
  - Loss of top layer of aggregate (bitumen pavement), and
  - A significant difference in friction between wheel paths.
- Several studies have investigated the relationship between road surface characteristics such as macrotexture, rutting, potholes, and roughness to road safety outcomes. Such studies are almost exclusively from high-income countries (HICs), and may not be easily transferable to low- and middle-income countries (LMICs), where there may be more extreme levels of surface defects as well as a different traffic mix. However, the evidence indicates that the crash risk increases considerably when the macrotexture is less than 1 mm in sand-patch texture depth (SPTD) units,<sup>100</sup> and crash rates may increase by 25 percent when the rut depth exceeds 20 mm.<sup>101</sup> Studies relating roughness to crash rates are mixed, with one study summarizing the research by indicating that increased unevenness is related to increased, decreased, and unchanged safety outcomes.<sup>102</sup> Some studies have found that the conflicting results may be due to good pavements inducing higher speeds and therefore higher severity crashes.<sup>103</sup> One recent study<sup>104</sup> summarized much of the previous research and conducted further analysis on this issue. The study found a relationship between rutting and roughness and safety, and concluded that these can be contributing factors to crashes. However, the study also identified that the relationships can be unclear, with the need to combine information on these surface factors with other contributory elements such as human factors and road geometry.
  - There is evidence that relates road surface condition, particularly roughness, to vehicle speeds, which are known to affect the crash risk and severity. Recent US research<sup>105</sup> indicates that when the IRI exceeds 80 inches per mile (127 cm/km), speeds reduce substantially; by around 10 mph (16 km/h) when the IRI increases from 80 inches per mile to 130 inches per mile (206 cm/km). One review of research<sup>106</sup> based on experience in HICs identified increases of up to 10 km/h from resurfacing where unevenness is improved, although speed increases of 2–5 km/h were more typical. One limited study from India<sup>107</sup> found a similar relationship, with a substantial decrease in speeds for different types of vehicles, with speeds dropping by 30–40 km/h when roughness increased from around 470 IRI (cm per km) to 800 IRI. Speeds were around 60 km/h at the lower levels of roughness (already a low free speed given the existing level of roughness) but dropped to between 20 and 30 km/h at the higher roughness level.
  - Evidence indicates a strong relationship between changes in vehicle speeds and safety outcomes. One comprehensive analysis<sup>108</sup> of over 100 prior

100 Cairney, P., and Bennett, P. 2008, May. Managing road surfaces for safety at the network level: is macrotexture enough. In *2008 Saferroads International Conference—Managing Roads and Runway Surfaces to Improve Safety*. Cheltenham England (pp. 11–14).

101 Cairney, P. 2010. Road safety engineering risk assessment part 11: road safety and maintenance.

102 Cairney, P. 2010. Road safety engineering risk assessment part 11: road safety and maintenance.

103 Li, Y., L. Chunxiao, and D. Liang. 2013. Impact of Pavement Conditions on Crash Severity. *Accident Analysis & Prevention*, 59, pp. 399–406.

104 Mamlouk, M., Vinayakamurthy, M., Underwood, S., and Kaloush, K. 2018, Effects of the International Roughness Index and Rut Depth on Crash Rates *Transportation Research Record*, Vol. 2672(40) 418–429.

105 Liccardo, N. 2017. Methodology for Roughness-Speed Relationship with SHRP2 Naturalistic Driving Study Data. Unpublished Masters thesis, University of Nevada, Reno.

106 Liccardo, N. 2017. Methodology for Roughness-Speed Relationship with SHRP2 Naturalistic Driving Study Data. Unpublished Masters thesis, University of Nevada, Reno.

107 Ch. Ravi Sekhar, J. Nataraju, S. Velmurugan, Pradeep Kumar, and K. Sitaramanjaneyulu. 2016. Free Flow Speed Analysis of Two Lane Inter Urban Highways. *Transportation Research Procedia* 17, 664–673.

108 Elvik, R. 2009. The power model of the relationship between speed and road safety: update and new analyses, TOI Report 1034: 2009, Institute of Transport Economics, Oslo, Norway.

studies identified this relationship for different types of roads. For rural roads, the results indicate that for every 1 km/h increase in speed, there is around a 4.5 percent increase in risk of a fatal crash outcome. Increasing speeds through road reconstruction and improvements could thus result in substantial increases in crash risk, even taking into account the benefits from better quality road surfacing. The Global Road Safety Partnership<sup>109</sup> highlighted that it is frequently the case that road improvement and rehabilitation schemes in LMICs result in increased traffic, higher speeds, and increased crashes. Gichaga (2017)<sup>110</sup> reports that the improvements to a 50-km high class, high traffic volume road in Kenya has brought with it the unfortunate consequence of speeding vehicles colliding with pedestrians crossing at undesignated locations on the high-speed road (design speed of 100 km/h). The issue of speeding has also been documented in HICs in the US, noting that paved roads tempt drivers to travel faster.<sup>111</sup> They suggest that to facilitate such an increase in speed safely, roads must be straighter, wider, and as free as possible from obstructions for them to be safe.

## Good design practice/ treatments/solutions

- Skid resistance is most important at locations where enhanced braking performance may be required including curves, approaches to intersections, areas near pedestrian crossings, etc.
- Crash rates can significantly be reduced by implementing proper measures to increase skid resistance at potentially dangerous locations such as curves, intersections, and bridges. There are two main options for the treatment of pavements with low skid resistance:
  - Retexturing: This treatment type involves mechanical reworking of the existing road surface to improve its frictional characteristics. The methods include diamond grooving, shot blasting, bush-hammering, and high velocity water blasting.
  - Resurfacing: These include relatively low-cost thin surfacing treatments that not only improve the surface texture and resistance to wet road skidding but can also seal the surface against water penetration and arrest disintegration of the existing road surface. They include surface dressing applications and high friction surfacing (HFS) (figures 5.123 through 5.125)

**Figure 5.123:** High friction surface treatment on high-risk curve.



Source: FDOT.

**Figure 5.124:** A high friction surface applied at both approaches of the intersection.



Source: iRAP.

**Figure 5.125:** High friction surface (colored) applied on the approach to a mini roundabout.



Source: iRAP.

109 Global Road Safety Partnership. 2008. *Speed Management: a road safety manual for decision-makers and practitioners*. Geneva.

110 Gichaga, F. J. 2017. The impact of road improvements on road safety and related characteristics. *IATSS research*, 40(2), 72–75.

111 FHWA. 2015. *Gravel Roads Construction & Maintenance Guide*. Federal Highways, Washington, DC.



- Since skid resistance lessens over time, especially on roads with high heavy vehicle volumes and in tropical climates, regular monitoring of the pavement's skid resistance is essential. Several road authorities carry out proactive periodic programs of pavement surface testing which are prioritized on the basis of traffic volume, operating speeds, the requirement for stopping, wearing course age and type, concerns over crashes in wet conditions, and known drainage deficiencies. The pavement testing and inspection reports are then assessed against the recommended investigatory levels for different situations, e.g., curves, approaches to signalized intersections, or pedestrian crossings. For sites that fall below the recommended level, further investigation is undertaken to determine the remedial action that may be required.
- While much of the research relates to improvement and rehabilitation of sealed roads, there is evidence that applying the same principles of ensuring regular road surface maintenance to provide low roughness (an IRI of 1.9m/km) and providing incentives for a smooth pavement over the design life will ensure better pavement and construction quality, and can reduce safety risk for all users.<sup>112</sup>
- Special attention on the pavement's skid resistance should be given on road sections where the effect of aggregate polishing caused by traffic is known to be most frequent. These include curves, roundabouts with small radii, sections where vehicles accelerate or decelerate, and in areas close to crossings.
- The choice of aggregates and bituminous mixes that retain skid resistance (rather than polish with wear) may be considered. Studies show that the polishing behavior of aggregates is influenced by their mineralogy composition, with rocks containing metamorphic parts being less susceptible to wearing than sedimentary materials with better frictional properties of pavement surface,<sup>113</sup> and that just by choosing the right type of aggregates for a road surface, the stopping sight distance can be reduced by about 10 m at speeds of 100 km/h and more than 20 m at higher speeds.<sup>114</sup> As such, a petrography examination is a valuable tool for understanding the behavior of aggregates at polishing and their use in an asphalt mixture. In some situations, the use of synthetic aggregates may also be appropriate. Laboratory testing and screening of aggregates provide the necessary control on the quality of aggregates used in the asphalt mix.
- The selection of the appropriate pavement marking material is important when considering pavement friction, especially in wet conditions. This is because large pavement markings such as stop bars, large arrows, school zone marking, and box junctions can decrease skid resistance, particularly in the approach to a roundabout or intersection.
- There are a number of safety strategies that can be implemented to mitigate increases in crash risks resulting from increased speeds due to resurfacing. When included at initial design, many of these interventions can be included at low cost or even no additional cost. These include:
  - Traffic calming at key locations
  - Gateway treatments on entering a village or other built-up area
  - Speed limits
  - Provision of wide sealed shoulders
  - Visual narrowing of roads
  - Segregated footpaths
  - Widening of curves
  - Centerline and edge-line marking
  - Advanced warning signs
  - Advanced warning signs with advisory speeds

112 B King University of South Queensland. 2014. The Effect of Road Roughness on Traffic Speed and Road Safety.

113 West, T. R., Choi, J. C., Bruner, D. W., Park, H. J., and Cho, K. H. 2001. Evaluation of dolomite and related aggregates used in bituminous overlays for Indiana pavements. *Transportation Research Record*, 1757(1), 137-147.

114 Burlacu, F. A., Racanel, C., and Burlacu, A. 2016. The influence of road materials characteristics on road safety. *Revista Romana de Materiale—Romanian Journal of Materials*, 46(4), 552-559.

- Chevrons
- Barriers (median and roadside) (see section 5.8)
- Route-based curve assessment and intervention
- Improved sight distance
- Increasing visibility of intersections

## Further Reading

- High Friction Surface Treatments. <https://austroads.com.au/publications/pavement/agpt04k/types-of-sprayed-seal-treatments/other-treatments/high-friction-surface-treatment>.
- Institute for Transportation and Development Policy. 2019. Street Design Manual for Kenyan Cities. Must read chapter 4, Street elements.

## 5.11. Drainage

### General description

The primary purpose of highway drainage facilities is to prevent surface runoff from reaching the roadway and to remove rainfall or surface water efficiently from the roadway. Drainage facilities, including

channels, shoulders, and surfaces, capture sheet flow from the highway pavement and backslope and convey that runoff to larger channels or culverts within the drainage system. The gradient of drainage typically parallels the grade of the roadway. A stable conveyance design is a critical component in roadside channels.

Highway drainage facilities can be broadly classified into two major categories based on construction: (1) open-channel (figure 5.126) or (2) closed-conduit facilities (figure 5.127). Open-channel facilities include roadway channels, median swales, curb and gutter flow, and others. Closed-conduit facilities include culverts and storm drain systems.

Drainage structure includes:

- A gutter, the triangular-shaped area defined by the curb on roadsides, is an open-channel flow section for conveying runoff. A gutter section can be an effective countermeasure for reducing spread on the pavement.
- Shoulder curbs are placed at the outer edge of the shoulder, as combined with a gutter section, to control drainage, improve delineation, control access, and reduce erosion. Swale sections, typically circular or V-shaped (figure 5.128), are used where curbs are used to prevent water from eroding fill slopes.

**Figure 5.126:** Open channels.



Source: Department of Transport and Main Roads, Brisbane, Qld. 2010. Road drainage manual.

**Figure 5.127:** Closed drainage filled in with porous materials for anti-erosion and falling.,



Source: Department for International Development, UK. 2003. CaSE Highway Design Note 1, Surface Water Drainage Channels.

**Figure 5.128:** Conventional v-shaped drainage.



Source: DFID, 2003.

## Safety implications

- The lack of good drainage can lead to the ingress of water into the road structure leading to structural damage and costly repairs, while surface water can form a road safety hazard. Water on the pavement will contribute to crashes from hydroplaning and loss of visibility from splash and spray. The aim of drainage facilities is to prevent surface runoff from reaching the roadway and to remove rainfall or surface water efficiently from the roadway.
- Water may accumulate in shoulder areas like ponds, also creating a risk.
- Poor drainage causes early pavement distresses and damage of shoulders, leading to driving problems and structural failures of the road (figure 5.129).
- One study showed that 22 percent of all run-off-the-road (ROR) rollover crashes involved hitting a ditch or embankment and another study determined that 55 percent of ROR rollover crashes result in injury. A very high proportion of these are on rural roads.
- Culvert end treatments may become hazardous obstructions to errant vehicles (figure 5.130). Culverts that have unprotected headwalls close to the carriageway are a hazard to vehicles using the sealed shoulder.
- Drainage is usually more difficult and costly for urban than for rural highways. This is because of more rapid rates and larger volumes of runoff, costlier potential flood damage to adjacent property, higher overall costs from more inlets and underground systems, greater restrictions from urban development, lack of natural water body areas to receive flood water, and higher volumes of vehicular and pedestrian traffic.
- Swale sections present less hazards to traffic than a near vertical curb and hydraulic capacity that is not dependent on spread on the pavement.
- Pavements (surface drainage) typically require a minimum gutter slope of 0.3 percent to promote drainage, and this differs depending on a design discharge and an allowable spread of water across the pavement. In high-speed and high-volume roads, minimizing the spread of water on the traffic lanes should be achieved. Roadway geometric features greatly influence pavement drainage design.<sup>115</sup>
- Partial overlays and pavement repairs can result in water being trapped and retained on the travel way surface (figure 5.131). Partial overlays, either to correct shoulder deterioration or widen the roadway surface, result in a pavement edge where

**Figure 5.129:** Wide paved shoulder and drainage facility on a downhill slope.



Source: PIARC. 2003. Road Safety Manual, First edition.

**Figure 5.130:** Typical culvert headwall to be extended/replaced.



Source: © John Barrel.

**Figure 5.131:** Edge of partial pavement overlay causing water to be retained on surface



Source: Federal Highway Administration. 2009. Maintenance of Drainage Features for Safety, US.

the overlay stops. Depending on the size of aggregate in the overlay mix and the effort taken to feather the lip into the existing pavement, water can be retained on the travel way. When the lip is along the wheel path, the thin layer of retained water can initiate hydroplaning, reduce braking ability, or freeze and contribute to skidding.<sup>116</sup>

## Good design practice/ treatments/solutions

- An important part of highway design is consistency, which prevents discontinuities in the highway environment and considers the interrelationship of all highway elements. The interrelationship between the drainage channel and sideslopes is important because good roadside design can reduce the potential severity of crashes that may occur when a vehicle leaves the roadway.
- Discontinuous sections of curbing, as at the gore of ramps, and variable curb offsets should not be used as expedients to handle pavement drainage where these features could contribute to loss of control by vehicles that run off the road.
- Deep and open drainage structures near the roadway must be avoided, as they constitute rigid obstacles that may aggravate crash severity.
- Adequate sight distance for drivers must be provided to ensure vehicles can stop before entering any floodwaters. The floodway longitudinal profile should be horizontal so that the same depth of water exists over the entire floodway length. The floodway length should be limited and on a straight stretch of road where possible. Adequate permanent and temporary signage and delineation must be installed.
- When combined with the design of an elevated roadway on earth embankment to ensure drainage of the subgrade, the streamlined cross

section results in a roadway that needs minimal maintenance and operating costs and operates with fewer severe crashes. Inadequate height and slope of the embankment and any infrastructure to prevent run-off-the-road can be a risk.

- Hydraulic capacities and locations should be designed to take into consideration damage to upstream and downstream property and to reduce the likelihood of traffic interruption by flooding.
- Inadequate drainage can lead to high maintenance costs and adverse operational conditions.
- In areas of significant snowfall, roadways should be designed so that there is sufficient storage space outside the travelled way for plowed snow and proper drainage for melting conditions.
- Median areas should preferably not drain across travelled lanes, and often the inside lanes and shoulder of multilane highways will drain to the median area where a center swale collects the runoff. Medians may be drained by drop (grate)-type inlets.
- Drainage channel design in rural areas should incorporate traversable roadsides, good visibility, control of pollutants, and economical maintenance. This may be accomplished with flat sideslopes, broad drainage channels, rain gardens, and liberal warping and rounding. In urban areas, runoff is often captured in enclosed storm drains, and rain gardens may be used to reduce the amount of runoff.

## For roadside users

- Drainage facilities should be designed to minimize their impacts on motor vehicles. Culvert end treatments should not be an obstruction, either through relocation of the feature outside of the 5 m clear zone from the edge of the running lane, or where this is not possible, an assessment

116 FHWA Federal Highway Administration. 2009. A Guide for Local Street and Highway Maintenance Personnel, US. [https://safety.fhwa.dot.gov/local\\_rural/training/fhwasa09024/](https://safety.fhwa.dot.gov/local_rural/training/fhwasa09024/).

should be undertaken to establish whether the end treatments can be made traversable (figure 5.132). If neither remedial treatment is possible then safety barriers should be considered. All shoulder slopes into ditches should be at a maximum of 1:3 and desirably 1:6.

- In areas where roadway surfaces are warped, such as at cross streets or ramps, surface water should be intercepted just before the change in cross slope. Flumes are used to carry the water collected by intercepting channels down cut slopes and to discharge the water collected by shoulder curbs. Flumes can either be open channels or pipes (figure 5.133), but closed flumes or pipes are preferred to avoid failure due to settlement and erosion.
- Visual, audible, and other physical deterrents, such as safety barriers, should be used to warn drivers of hazardous locations (e.g., steep slopes or drains close to a carriageway) and to prevent vehicles straying from the carriageway (figure 5.134).
- When the capacity of the curb/gutter/pavement section has been exceeded (e.g., near low points of sag vertical curves, pedestrian crossings, etc.), drainage inlets that are connected to a storm drain pipe can be installed to divert runoff from the roadway surface. However, grate inlets alone are not recommended in sag locations because of potential clogging.
- Pit lids of inlets and channels should be designed to ensure the safety of motor traffic, maintenance vehicles and plants, and pedestrians and cyclists. Pit lids should be designed to carry the appropriate motorist's, cyclist's and pedestrian's passing and loading if necessary.
- For high-speed roads, pit lids should not be located within the traffic lanes. If necessary, they should be located outside the clear zone. On low-speed roads, pit lids should also be located outside of traffic lanes, as the lids can cause impacts, cause noise, come loose, and cause safety problems.

### For maintenance

- To prevent reduction in the hydraulic capacity or clogging, drainage facilities should be designed and located to prevent silt and debris carried in suspension from being deposited on the travelled way where the longitudinal gradient is decreased.
- Lining materials (e.g., glass, concrete, chutes, etc.) should be considered depending on flexibility, durability, cost, and so forth.
- Drainage channels should be kept clean and free of material that would lower the channel's capacity by timely and periodic maintenance (e.g., removing garbage, backfilling for erosion, weeding, etc.). As floodwaters recede, silt and debris can be left on the road surface of a floodway, and this can be

**Figure 5.132:** Typical extended culvert and revised headwall design.



Source: © John Barrel.

**Figure 5.133:** Piped flume.



Source: FOA, 2020. NZ Forest Owners Association. 2020. NZ Forest road engineering manual, operators guide 2020, New Zealand.

**Figure 5.134:** Physical barrier in front of the drain.



Source: DFID, 2003.

**Figure 5.135:** Poorly drained road with rough driving surface (sediment source).



Source: -> USAID. 2003. Low- Volume Roads Engineering: Best Management Practices Field Guide, US.

**Figure 5.136:** Poor road location with creek and hydrological connection to streams.



Source: USAID.

**Figure 5.137:** Slide material blocking drainage ditches.



Source: USAID.

a hazard to road users. The road agency should inspect each affected floodway as soon as possible after a flood event and clear the surface if required.

- Figures 5.135 through 5.137 show some examples of poorly drained roads.
- Below is a summary of minimum grades; however, no general recommendation can be made for adopting any particular axis of rotation or conditions.

### Cross slopes

- Drainage of curbed roadways on sag vertical curves needs careful profile design. At a level point on a crest vertical curve, there is no difficulty with drainage if the curve is sharp enough or the road surface has sufficient crossfall or superelevation.
- Flat grades can typically provide proper surface drainage on uncurbed highways where the cross slope is adequate to drain the pavement surface laterally. With curbed highways or streets, longitudinal grades should be provided to facilitate surface drainage.
- Warping of the gutter for curb-opening inlets should be limited to minimize adverse driving

effects. The width of a vertical or sloping curb is considered a cross-section element entirely outside the travelled way. Also, a gutter of contrasting color and texture should not be considered part of the travelled way. When a gutter has the same surface color and texture as the travelled way and is not much steeper in cross slope than the adjoining travelled way, it may be considered as part of the travelled way. This arrangement is used frequently in urban areas where restricted right of way width does not allow for the provision of a gutter.

- In the superelevation transition section, the combination of an inadequate crossfall and a longitudinal design gradient may result in the edge of the pavement having negligible longitudinal fall. This can lead to poor pavement surface drainage, especially on curbed cross sections. This length of the transition section should be closely contoured to understand the wider pavement shape, including the tangent runout section and an equal length of the runoff section on the curve (see section 5.4 Superelevation).
- For these problems, providing a minimum profile grade or a minimum edge-of-pavement grade in the transition section can be considered to maintain a certain profile grade and edge-of-pavement grade.

- The depth of a roadside open drain or channel should be minimized, but less than 150 mm in depth to prevent the vehicle from overturning. Deeper drains should be accompanied with flatter slopes.<sup>117</sup>

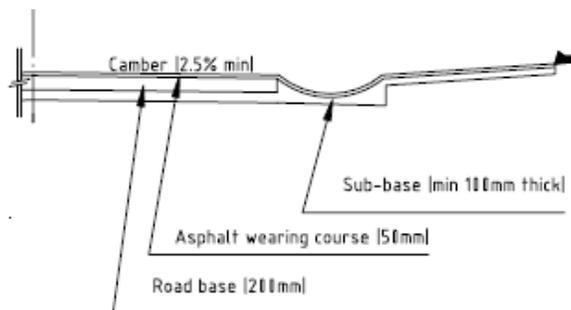
### Good practices/examples

**Figure 5.138:** Hazardous drainage facility on a narrow and hilly road.



Source: PIARC, 2003.

**Figure 5.140:** Parabolic dish drainage (good hydrodynamics but low capacity).

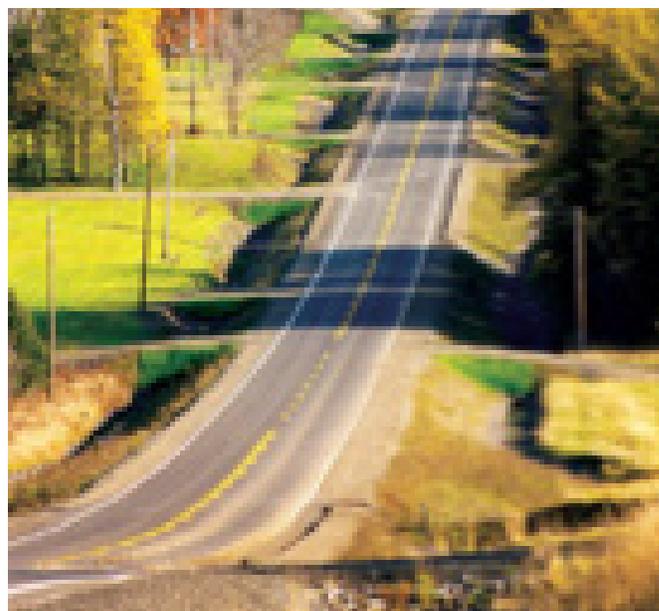


Source: DFID, 2003.

### Channel side slopes

- A broad, flat, rounded drainage channel provides a sense of openness with a sideslope of 1V:4H or flatter. Weather conditions should be considered.

**Figure 5.139:** The combination of roadside accesses and deep opened drainage ditches increase the risk and potential severity of crashes.



Source: PIARC, 2003

**Figure 5.141:** Earth excavated drainage in Malawi.



Source: DFID.

117 DFID, 2003. CaSE Highway Design Note 1 Surface Water Drainage Channels. DFID (2003). CaSE Highway Design Note 1, Surface Water Drainage Channels.

**Figure 5.142:** Unprotected drainage.



Source: DFID, 2003.

**Figure 5.144:** Safely widened shoulder and drainage.



Source: DFID, 2003.

**Figure 5.143:** Armor ditches with vegetation, rock, masonry, or concrete to resist ditch erosion.



Source: USAID, 2003.

**Figure 5.145:** Armored roadside ditch with graded rock (riprap) for erosion control.



Source: USAID, 2003.

## Case Study

### Transverse Gutters on Highway, Germany<sup>118</sup>

In the German region of Brandenburg, in a sector of the A10 Highway south of Berlin, there is a highly dangerous road segment made of concrete, which was built in the years immediately following the unification of Germany. Even though its design took into consideration weather conditions with heavy rainfall, due to climate change the proposed transverse slope was not sufficient, which subsequently resulted in a high number of road crashes due to the phenomenon of aquaplaning. The only adequate method for this section involved construction of transverse gutters made of concrete and covered with metal bars (figure

5.146). These gutters were built across the entire width of the carriageway, including the emergency lane in the case of highways. The gutters are no less than 30

**Figure 5.146:** Transverse gutter.



Source: Burlacu, F. A., Răcănel, C., and Adrian Burlacu, A., 2018.

118 Alina Burlacu, Carmen Răcănel, and Adrian Burlacu. 2018. Preventing aquaplaning phenomenon through technical solutions. *Građevinar* 12/2018. Accessed at <http://casopis-gradjevinar.hr/assets/Uploads/JCE-70-2018-12-4-1578-EN.pdf>.



cm in width, and several can be assembled along a sector, at a minimum distance of 5 meters between individual gutters. An analysis of this solution using a dedicated computer software called “Pavement Surface Runoff Model” showed that the transverse gutters result in the decrease of water film depth from 6 mm to 4 mm, and even to 2 mm, which considerably diminishes the risk of aquaplaning.

## Further Reading

- AASHTO. 2018. Green Book (GDHS-7). Must read chapter 3, Elements of design.
- Austroads 2018. Guide to Road Design Part 5, Drainage—General and Hydrology Considerations.
- USAID. 2003. Low-Volume Roads Engineering: Best Management Practices Field Guide. Must read chapter 5, Hydrology for drainage crossing design.
- DFID. 2003. CaSE Highway Design Note 1, Surface Water Drainage Channels. <https://www.gov.uk/research-for-development-outputs/case-note-1-drainage>.
- FHWA. 2009. A Guide for Local Street and Highway Maintenance Personnel. [https://safety.fhwa.dot.gov/local\\_rural/training/fhwasa09024/](https://safety.fhwa.dot.gov/local_rural/training/fhwasa09024/).

## 5.12. Curbs

### General description

Curbs (also kerbs) are raised or vertical elements located very near the edge of the travelled way that usually extend 75 to 200 mm above the road surface. They serve the following purposes: drainage control, delineation of the pavement edge, delineation of pedestrian walkways, right-of-way reduction, reduction of maintenance operations, aesthetic purposes, and assistance in orderly roadside development.<sup>119</sup>

Curbs are commonly used in urban areas, with a major benefit in containing drainage within the pavement area, separating pedestrians from traffic flow, and in channelizing or controlling traffic into and out of adjacent properties. They can be placed on medians or edges of the travelled way. Curbs may be constructed using various materials, including cement concrete, granite, and asphalt/bituminous concrete and are often combined with gutter sections.

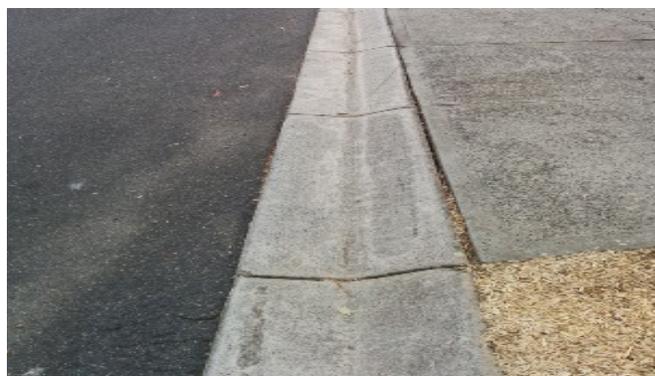
There are two basic curb design types: vertical (figure 5.147) and sloping curbs (figure 5.148). Vertical curbs, also referred to as barrier curbs, have a vertical or

**Figure 5.147:** Concrete vertical curb.



Source: Government of UK, Department of Transport. 2020. Transport Secretary acts to make pavements safer for pedestrians. Accessed at <https://www.gov.uk/government/news/transport-secretary-acts-to-make-pavements-safer-for-pedestrians>.

**Figure 5.148:** Sloping curb providing access to driveway.



Source: Wayne Eddy. <http://lgam.wikidot.com/fully-mountable-kerb-and-channel-photo-no-1>.

119 AASHTO. 2001. Policy on geometric design of highways and streets. American Association of State Highway and Transportation Officials, Washington, DC, 1(990), 158.

nearly vertical face and deter vehicles from leaving the roadway. Sloping curbs, also referred to as mountable curbs, have a sloped face to permit vehicles to encroach on them readily when needed. They are usually used in situations where it is desirable to provide access to the roadside in emergency situations and to adjacent properties. From these basic curb design types, there are further types, including semi-barrier and semi-mountable curbs with a variety of designs.

## Safety implications

- Curbs are primarily used on low-speed facilities, and caution should be applied when installing curbs on high-speed facilities. According to AASHTO (2010),<sup>120</sup> installing curbs instead of narrow flush shoulders on urban four-lane undivided roads appears to increase off-the-road and on-the-road crashes of all severities. Installing curbs on suburban multilane highways instead of narrow flush shoulders appears to increase crashes of all types and severities.
- Vertical curbs have an ability to redirect an errant vehicle in a direction parallel to the travelled way provided the impact velocity and angle are modest; a situation applicable to low-speed facilities. The redirection capabilities occur at speeds of approximately 40 km/h or lower.
- Vertical curbs or steeply sloped curbs can be a hazard to cyclists and motorcyclists.
- On high-speed facilities, vertical curbs are a safety hazard (figure 5.149). A high-speed impact with the curb will introduce a roll moment since the vehicle's center of gravity is much higher than that of the top of the curb. This in turn introduces instability into the vehicle's trajectory that may limit a driver's ability to control the vehicle. Since curbs are primarily used for drainage purposes, they are

**Figure 5.149:** Hazardous vertical curbs on high-speed road.



Source: National Highway Authority. 2019. Guidelines for Road Safety Engineering, Part 1. Government of Pakistan. Retrieved November 15, 2019, from <http://www.roadsafetypakistan.pk/download/Guidelines-for-road-safety-engineering-part-1.pdf>.

- often found in conjunction with steep side-slopes where a rollover would be even more likely.<sup>121</sup>
- Figure 5.149: Hazardous vertical curbs on high-speed road.
- There are often circumstances that warrant the use of curbs in combination with safety barriers, for example on the approach to bridge structures where a curb is needed for drainage purposes and an approach guardrail is needed to shield motorists from the steep side slopes of the approaching structure. Concrete barriers can be used as drainage devices so there is no significant reason why a curb would be necessary. It is also unusual to have curb-flexible barrier combinations since these barrier types accommodate very large deflections, up to 3 m, and the vehicle would likely mount the curb while interacting with the barrier. Semi-rigid barriers, on the other hand, are widely used in conjunction with curbs, and an inadequate design of this curb-barrier combination can result in unpredict-

120 AASHTO. 2010. Highway Safety Manual. American Association of State Highway and Transportation Officials, Washington, DC.

121 National Academies of Sciences, Engineering, and Medicine. 2005. Recommended Guidelines for Curb and Curb-Barrier Installations. Washington, DC: The National Academies Press. <https://doi.org/10.17226/13849>.

**Figure 5.150:** Example of dangerous curb-barrier combination with the steel barrier just behind the curb.



Source: UNESCAP. 2017. Recommended Design Guidelines on Road Infrastructure Safety Facilities for the Asian Highway Network. Accessed at <https://www.unescap.org/resources/recommended-design-guidelines-road-infrastructure-safety-facilities-asian-highway-network>.

**Figure 5.152:** Triple curb in Bucharest, limiting access by pedestrians.



Source: Cozmei, V. 2019, April 23. The sidewalk in Bucharest with three rows of different curbs. HotNews.ro. <https://www.hotnews.ro/stiri-administratie-locala-23104851-foto-trotuarul-din-bucuresti-trei-randuri-borduri.htm>.

able impact trajectories causing vehicles to vault or underide the barrier (see figure 5.150).

- Very high curbs (greater than 150 mm) on the edges of sidewalks limit access by pedestrians (see figures 5.151 and 5.152).

**Figure 5.151:** Very high curb (approx. 250 mm) limiting access by pedestrians to the walkway.



Source: UTTIPEC, Delhi Development Authority. 2011. Kerb Heights for Footpaths and Medians PPT. New Delhi.

## Good design practice/ treatments/solutions

- Vertical curbs are recommended for built-up areas adjacent to footpaths with considerable pedestrian traffic, shared use paths, and at bus bays (figures 5.153 and 5.154). This is because they reduce the risk to pedestrians, not only as a physical barrier, but also as a psychological barrier as drivers generally tend to shy away from the curb line.
- While curbs are to be designed to discourage motorists from encroaching onto the pedestrian realm, it is desirable that pedestrians can still step up and down from the pedestrian realm to the travelled way. The typical preferred curb height is 150 mm.
- At pedestrian crossing locations, dropped curbs are ideal, as they allow pedestrians, particularly the physically disabled, elderly, and those with prams/strollers, to cross the road with ease<sup>122</sup>.
- As an alternative, particularly for unsignalized pedestrian priority crossings, the carriageway can

122 World Bank. 2013. Improving Accessibility to Transport for People with Limited Mobility: A Practical Guidance Note. Washington, DC. <https://openknowledge.worldbank.org/handle/10986/17592> License: CC BY 3.0 IGO.

**Figure 5.153:** Vertical curb adjacent to footpath.



Source: Designing Buildings. 2021. Kerbs. <https://www.designingbuildings.co.uk/wiki/Kerbs>. World Bank. 2013. Improving Accessibility to Transport for People with Limited Mobility : A Practical Guidance Note.

**Figure 5.155:** Dropped curb at both ends of pedestrian crossing with tactile paving surface.



Source: Zigmars Rozentals. 2017. The “Curb cut effect”—why making things accessible helps everyone, Medium. <https://medium.com/@rozentals/the-curb-cut-effect-why-making-things-accessible-helps-everyone-2f712b2c86e>.

**Figure 5.154:** Bus-stop curb to ease passenger access.



Source: Designing Buildings, 2021.

**Figure 5.156:** Dropped curb providing access to property.



Source: © Merton Council/Government of the UK.

be raised to footway level and act as a speed control measure (see also section 3.2).

- Where drop curbs are used, they need to be matched at both ends of the crossing location, with a tactile paving surface to facilitate the movement of visually impaired persons (figure 5.155). Drop curbs are also used to allow access by vehicles to properties (figure 5.156).
- Where encroachment by motorists onto the pedestrian realm is an issue, protective techniques such as bollards and planters may be employed, rather than higher curbs.

- Sloping curbs are generally used in the following situations:
  - At the outer mountable island area of intersections, small corner islands, and roundabouts to outline standard vehicle travelled paths.
  - To define the edge of a through carriageway where the crossfall of the adjacent shoulder or parking strip is opposite to that of the through carriageway.
  - Where crossing or encroachment by vehicles larger than the design vehicles is permitted

(e.g., at roundabouts) or expected under emergency conditions (fire truck turnings, etc.).

- On pedestrian and cycle paths along the grassed edge of asphalt paths to reduce damage to the path from the grass growing into the asphalt path. Curbing along paths also provides visual contrast to the path edge and prevents the verge material erosion onto the path. Figure 5.157 shows an example of the use of sloping and vertical curbs.
- The use of curbs is generally discouraged in high-speed roadways (greater than 60 km/h) because of their effect on a vehicle's trajectory upon impact. However, they may be required because of restricted right-of-way, drainage considerations, access control, delineation, and other curb functions. It is recommended that sloping curbs be used where such a need exists and should be located at the outer edge of shoulders rather than the edge of the travelled way. Sloping curbs would also enable access to the roadside in case of emergency situations, and motorists can park clear from the travelled way in case the width of the sealed shoulders is not wide enough.
- Since the appearance of cement concrete and bituminous concrete curbs offers little visibility in contrast to normal pavements, particularly during foggy conditions or at night when surfaces are wet, marking of curbs with reflectorized materials such as paints (figure 5.158) and thermoplastics or attaching reflectorized markers to the top of the curb enhances their visibility. Periodic cleaning or repainting is required to maintain this visibility.
- For curb-barrier combinations, it is important to note that a curb can have an effect on a vehicle's trajectory, which often involves the transformation of longitudinal kinetic energy to vertical and rotational kinetic energy that is hard to control. For this reason, one approach to the design is to place the curb behind the face of the barrier or flush with the barrier and limiting the deflection of the barrier by stiffening. It is recommended that the curb

**Figure 5.157:** Sloping curb provided on the median to allow occasional mounting by vehicles on the traffic island as needed, while the vertical curb is provided on the edge of the carriageway to delineate the footpath and discourage mounting by vehicles.



Source: UNESCAP. 2017. Recommended Design Guidelines on Road Infrastructure Safety Facilities for the Asian Highway Network. <https://www.unescap.org/resources/recommended-design-guidelines-road-infrastructure-safety-facilities-asian-highway-network>.

**Figure 5.158:** Painted curb on median. The curb, however, does not provide access for persons with disabilities at the crossing.



Source: UTTIPEC, Delhi Development Authority. 2011. Kerb Heights for Footpaths and Medians PPT. New Delhi.

to be used should be of the sloping type and not more than 100 mm in height. Common methods of stiffening the guardrail include nesting two sections of W-beam, adding a W-beam on the back of the barrier, adding a rub rail, and reducing the post spacing. A second approach is to laterally offset the barrier behind the curb by a distance sufficient to allow a traversing vehicle to return to

its predeparture vehicle suspension rate.<sup>123</sup> This distance will depend on the impact speed but it is recommended that a minimum distance of 2.5 m is adopted for operating speeds greater than 60 km/h. It should be borne in mind that the alternative situation in which the barrier is omitted may not be an acceptable safety outcome. Careful consideration and safety risk assessment are needed for locations where the above solution cannot be achieved to determine whether a modified outcome is safer than providing no barrier at all.

## Further Reading

- AASHTO. 2001. Policy on geometric design of highways and streets. American Association of State Highway and Transportation Officials, Washington, DC, 1(990), 158. Must read chapter 4, Cross-sectional elements.
- AASHTO. 2010. Highway Safety Manual. American Association of State Highway and Transportation Officials, Washington, DC. Must read A3, Roadside elements.
- National Academies of Sciences, Engineering, and Medicine. 2005. Recommended Guidelines for Curb and Curb-Barrier Installations. Washington, DC: The National Academies Press. <https://doi.org/10.17226/13849>.
- Transportation Officials. Task Force for Roadside Safety. 2011. Roadside design guide. AASHTO. Must read chapter 3, Roadside topography and drainage features.
- UNESCAP. 2017. Recommended Design Guidelines on Road Infrastructure Safety Facilities for the Asian Highway Network. <https://www.unescap.org/resources/recommended-design-guidelines-road-infrastructure-safety-facilities-asian-highway-network>.
- UTTIPEC, Delhi Development Authority. 2011. Kerb Heights for Footpaths and Medians PPT. New

Delhi. <https://www.slideshare.net/UTTIPECworks/uttipec-street-design-guidelines>.

## 5.13. Road Signs

### General description

Traffic signs are placed by the traffic authority, through the powers provided by specific national legislation, to provide warnings, information, and details of restrictions or regulations to road users at an appropriate time for them to modify their behavior accordingly. Apart from signs warning of approaching features, there are others for use at the site itself, such as direction chevrons at bends or intersections and regulatory signs at the point of enforcement. The three main functions of traffic signs are to regulate, warn, and inform. In addition, there are increasing amounts of commercial or advertising signage on the highway. These are not strictly traffic signs but do impact on road user safety.

As vehicle technology advances good quality and consistent signing will become increasingly important.

Commercial signs (both regulated and unregulated) are increasingly common in urban areas, and whilst not strictly road signs, can have a significant impact on road safety. The police and certain other public bodies and statutory authorities also have the right to place traffic signs, but only in the limited circumstances provided for by the relevant legislation.

While the national/federal government sets the legislation governing traffic signs' appearance and meaning, decisions about which signs to place and in which scenario is a matter for traffic authorities.

The legal aspects of signage are sometimes misunderstood by practitioners, particularly the prohibition on an authority unilaterally inventing its own nonstandard signs.

123 Transportation Officials. Task Force for Roadside Safety. 2011. Roadside design guide. AASHTO.

- The use of nonprescribed signs on public highways without authorization by the national/federal authority might be deemed unlawful.
- The erection of an unauthorized sign in the highway is an obstruction, and the possible consequences can be severe.

The UN Convention on Road Signs and Signals, commonly known as the Vienna Convention, is a multilateral treaty designed to increase road safety and aid international road traffic by standardizing the signing system for road traffic in use internationally. It was first introduced in 1931 and the latest European Agreement was in 1971. Adoption of the Vienna Convention is however not universal.

Road signs used by countries in the Americas are significantly influenced by the Manual on Uniform Traffic Control Devices (MUTCD), first released in 1935. This reflects the influence of the United States. There are also several American signatories to the Vienna Convention. Both systems are widely used internationally.

With increasing traffic flow and speed, the signing convention is to use more pictograms or symbols than words to convey the message. UN compliant signs must make use of more pictograms in contrast to more text-based US variants. Indeed, most Pan American nations make use of more symbols than allowed in the US MUTCD.

There is a different group of signs for each function, and the signs in each group have a uniform shape

to help drivers recognize them quickly. The three groups are:

**Regulatory signs.** These signs give orders. They tell drivers what they must not do (prohibitory), or what they must do (mandatory). Most of them take the form of a circular disc, although two signs, the Stop sign and the Give Way (Yield) sign, have distinctive individual shapes.

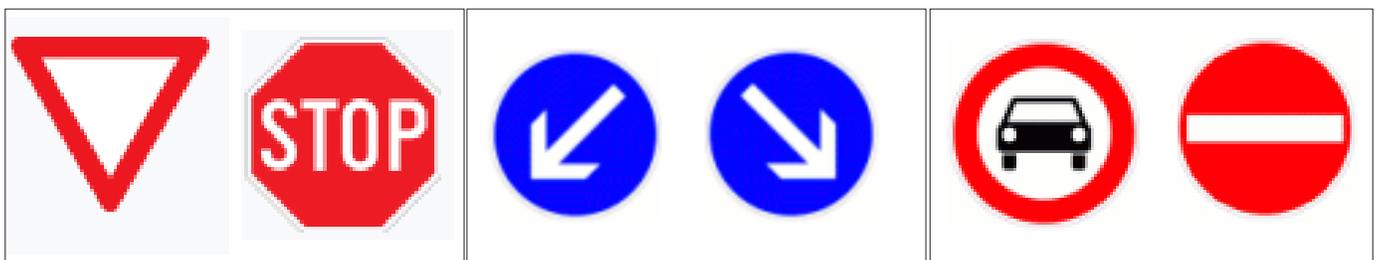
**Warning signs.** These warn drivers of some danger or difficulty on the road ahead. Most of them take the form of a diamond or an equilateral triangle that points upward.

Nearly all countries in the Americas use yellow diamond warning signs, while Vienna Convention-based countries use triangular signs. Recognizing the differences in standards across Europe and the Americas, the Vienna Convention considers these types of signs an acceptable alternative to the triangular warning sign.

**Information signs.** Most of these signs give drivers information to enable them to find their way to their destination or information about facilities. It is a varied group of signs, but they are all either square or rectangular in shape in advance of a junction. At junctions they will include a triangular end. The background coloring depends on the status of the route (i.e., motorway, or principal or local road).

**Commercial signs** are large outdoor advertising structure (a billboard), typically found in high-traffic areas such as alongside busy roads. They present

## Regulatory signs



Yield (Give Way) and STOP signs

Traffic MUST pass to the right or left

Prohibition of vehicles/entry

Warning signs.



Approaching turn may be hazardous without first reducing speed



Bend ahead



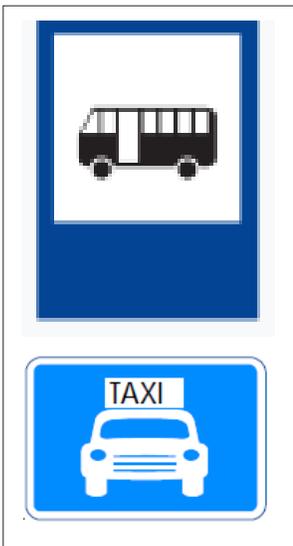
Roadworks ahead



Animal warning sign

Source: Bangladesh Road Transport Authority, 2000.

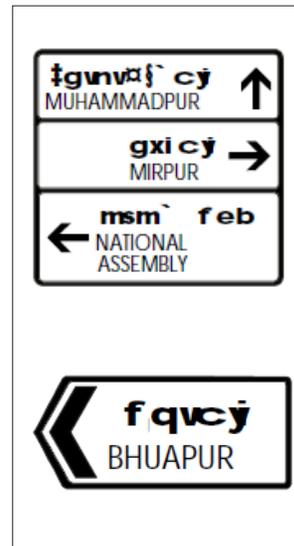
Information signs



Bus stop/taxi parking



Major route direction signs



Local direction signs

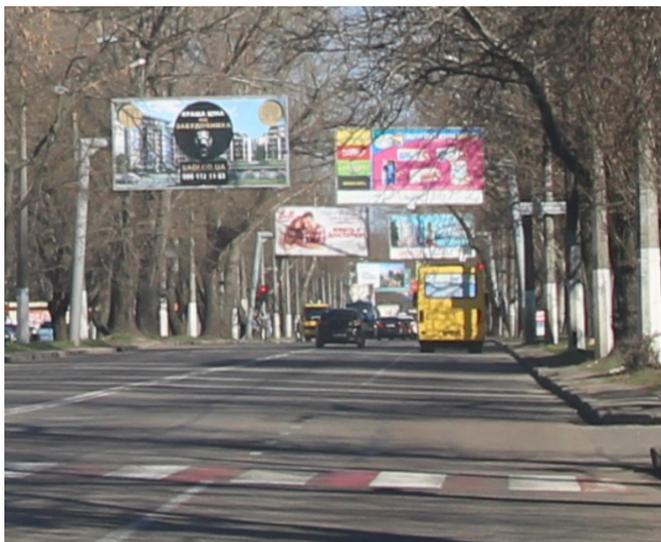
Source: Bangladesh Road Transport Authority, 2000.

large advertisements to passing pedestrians and drivers. While they are present on the highway, they are not classed as traffic signs.

The largest ordinary-sized billboards are located primarily on major highways, expressways, or principal arterials and command high-density consumer exposure (mostly to vehicular traffic) (figure 5.159). These afford the greatest visibility due not only to their size, but because they allow creative “customizing” through extensions and embellishments.

Other commercial signs include extensive shopfront signs and footway mounted “A” boards (figure 5.160). They are all designed to be noticeable and can consequently distract from other relevant signage. Regulations of commercial signs usually exist through the planning process. Their location can present a distraction to drivers and obstruct nonmotorized users’ movement, hence, they are a safety concern.



**Figure 5.159:** Highway advertising—Ukraine.

Source: © John Barrell.

**Figure 5.160:** Footway signage—Ghana.

Source: © John Barrell.

## Safety implications

- There is often a lack of signs in LMICs, or those that are provided are nonstandard and poorly located/maintained.
- In some developing countries there is a multiplicity of languages and written signs require numerous words, which can then become small and difficult to read.
- Literacy may also be limited.
- Consistency of sign appearance and use are essential for road safety, as is the selection of sizes appropriate for the prevailing traffic speed.
- Signs need to be visible in enough time to understand the message and take appropriate action.
- Signs may not be visible at night because of poor illumination, lack of regular maintenance, or continuous power supply.
- Reflective signs not regularly cleaned may not maintain their design properties.
- Maintenance is vital as poor quality, bent, or missing signs are not able to convey messages clearly.
- A recurring problem with signs is their obscuration, either by permanent features such as street furniture, road alignment, and vegetation or by parked vehicles and, on dual carriageways, by moving vehicles in the nearside lane.
- Signs can themselves obscure other features and may be visually intrusive from an environmental point of view
- A major issue in LMICs is the theft and vandalism of signs.
- Overuse of signs is distracting to the road user.
- Too many signs can detract from their objective by overloading the driver with information leading to confusion, or to a situation where the driver ignores some signs.
- Warning signs sited at different distances from the associated hazards in different localities, for instance, could mislead road users who venture outside their local area.
- Inconsistency in route guidance can result in drivers making unsafe and inappropriate lane and turn decisions.
- Advertising signs are designed to attract the user's attention and pose a major distraction. Their prominent use at junction and complex locations is dangerous.

- A common problem occurs at roadworks as signs are often poorly placed by contractors.
- There is an emerging trend in the literature suggesting that roadside advertising signs can increase crash risk, particularly for those signs that have the capacity to frequently change (often referred to as digital billboards).<sup>124</sup>
- A comprehensive review found that crash risk increases by approximately 25–29 percent in the presence of digital roadside advertising signs compared to control areas.
- However, studies based on correlations between crashes and billboards face the problem of under-reporting: drivers are unwilling to admit responsibility for a crash, so will not admit to being distracted at a crucial moment. Even given this limitation, some studies have found higher crash rates in the vicinity of advertising using variable message signs or electronic billboards.<sup>125</sup>

## Good design practice/ treatments/solutions

- In order to achieve safe and efficient operation of a highway network, it is essential that all signing provided is:
  - Necessary,
  - Clear and unambiguous,
  - Gives its message to road users at the appropriate time and is easily understood at the point it is needed—neither too soon that the information might be forgotten, nor too late for the safe performance of any necessary maneuver, and
  - Does not provide an unnecessary distraction.
- To obtain the fullest benefits of uniformity,

therefore, there should not only be uniformity of signs but also uniformity in their use, siting, and illumination (figure 5.161).

- The siting of signs is critical—they need to be far enough in advance of a feature to give sufficient time for the message to be understood and obeyed, but not so far in advance for the message to be forgotten by the time the feature is reached.
- The amount of information given at a single location or sign should be limited to no more than four lines/messages, as anything more cannot be absorbed in time (figure 5.162).

**Figure 5.161:** Inconsistency of guidance information.



Source: © Alina F. Burlacu/GRSF/World Bank.

**Figure 5.162:** Overuse of signs is distracting.



Source: © Alina F. Burlacu/GRSF/World Bank

124 Oviedo-Trespalacios, Oscar; Truelove, Verity; Watson, Barry; and Hinton, Jane A. April 2019. "The impact of road advertising signs on driver behaviour and implications for road safety: A critical systematic review." *Transportation Research Part A: Policy and Practice*, 122: 85–98.

125 Farby, J., Wochinger, K., Shafer, T., Owens, N., and Nedzesky, A. 2001. *Research review of potential safety effects of electronic billboards on driver attention and distraction*. Washington, DC: Federal Highway Administration.

**Figure 5.163:** Expressway with interchange signs and lighting in Hyderabad, India.



Source: © Krishnan Srinivasan/World Bank.

- To avoid problems of signs not been seen in time, attention should be paid to vegetation (bearing in mind the rapid growth that occurs seasonally) and parking restrictions. If sign blockage is thought likely due to other moving vehicles then overhead signs or repeated side-mounted signs should be considered.
- Signs must be visible in darkness. In rural areas this can be achieved with reflective signs; in urban areas it may require externally or internally illuminated signs, depending upon prevailing lighting conditions, as reflectivity can be affected by other light, and drivers may not be using full headlights in urban areas (figure 5.163).
- Regular maintenance is important to maintain visibility, function, and presence of signs.
- Making signs of material that have little value or other uses, together with mounting at a height that is difficult to reach (while still being readily seen by users) can make them less susceptible to theft. Secure fixing to supports that are equally redundant if removed also helps.
- It is particularly important that they should not constitute a hazard in themselves to vehicles leaving the road or obstruct visibility or movement.
- Signs should be sited far enough away from the running lanes as to not present a hazard should a vehicle leave the highway. Where signs may

present a hazard to errant vehicles, they need to be adequately protected. To this end, recent developments include a variety of signs which absorb impact energy or knock down and can be driven over but spring back into position in the event of a collision.

## Further Reading

- FHWA. 2009. Manual on Uniform Traffic Control Devices (MUTCD). Must read part 2, Signs.
- UNECE. 2006. Vienna Convention on Road Signs. Accessed at [https://unece.org/DAM/trans/convention/Conv\\_road\\_signs\\_2006v\\_EN.pdf](https://unece.org/DAM/trans/convention/Conv_road_signs_2006v_EN.pdf).
- Department for Transport, UK government. 2018. Traffic signs manual. <https://www.gov.uk/government/publications/traffic-signs-manual>.

## 5.14. Line Marking

### General description

A line marking (or road marking) is any kind of device or material that is used on a road surface to provide guidance and information to all road users.

The essential purpose of road markings is to guide and control traffic on a highway. They supplement the function of traffic signs, serve as a psychological barrier, and signify the delineation of a traffic path and its lateral clearance from traffic hazards for the safe movement of traffic. Hence, they are very important to ensure the safe, smooth and harmonious flow of traffic. This is likely to become more important with autonomous vehicles that rely on good quality road markings for lane guidance.

They can be used to delineate traffic lanes, inform motorists and pedestrians, serve as noise generators (when installed with an audio tactile raised profile) when run across a road, or attempt to wake a sleeping driver when installed in the shoulders of a road. Road surface markings can also indicate regulations for

parking and stopping. They can be either longitudinal (along the roadway); transverse (across the roadway) or provide written words or symbols.

Uniformity of the markings is an important factor in minimizing confusion and uncertainty about their meaning, and efforts exist to standardize such markings across borders. However, countries and areas categorize and specify road surface markings in different ways.

- In general European countries follow the Vienna Convention on road signs and signals, which describes what road signs and road markings shall look like. Most European countries use white for routine lane markings of any kind. Yellow is used to mark forbidden parking, such as at bus stops. However, Norway has yellow markings separating traffic directions.
- Many countries use yellow, orange, or red to indicate when lanes are being shifted temporarily to make room for construction projects.
- Almost all countries in North and South America have solid and intermittent yellow lines separating traffic directions.
- Chile and Argentina have intermittent white lines separating traffic when overtaking is permitted from both directions, and solid yellow lines when overtaking is prohibited from both directions; when overtaking is permitted from only one direction, such countries separate traffic with a combination of white and yellow lines.

Line markings serve a very important function in conveying to road users information and requirements which might not be possible using upright signs. They have the advantage that they can often be seen when an upright sign is obscured and can also provide a continuing message.

They are comparatively cheap to install but need regular maintenance, as heavy traffic can wear them out quickly. Different types of line markings have different durability and reflectivity properties (described below). Selection of type of line marking should consider these

important aspects of performance.

There is continuous effort to improve the road marking system, and technological breakthroughs include adding retro reflectivity, increasing longevity, and lowering installation cost.

## Safety implications

- Line markings have their limitations.
  - They can be completely obscured by snow,
  - They provide less skid resistance than the surrounding road surface,
  - Removal and repositioning of road markings can leave a ghost marking that can confuse users,
  - Their conspicuity is impaired when wet or dirty, and
  - Their effective life is reduced if they are subjected to heavy trafficking.
- Marking on traffic calming devices is very important and sometimes due to rain, or over time due to the quality of the paint, the marking is not visible (figure 5.164).

**Figure 5.164:** Faded pedestrian crossing markings in Cambodia.



Source: © Blair Turner/GRSF.

- They make a vital contribution to safety, e.g., by clearly defining the path to be followed through hazards, by separating conflicting movements, and by delineating the road edge on unlit roads at night.
- They can also help to improve junction capacity and make best use of available road space. In particular, widespread use of lane markings is desirable as they encourage lane discipline and improve the safety and efficiency of traffic flow.
- The guidance function is less critical (although still important) in daylight or on lit roads because there are many visual cues available to enable the driver to judge course and position. On unlit roads at night, conditions are very different; the visual stimuli in the distance and to the sides of the road are largely absent. Road markings then become the most important aid in enabling the driver to follow the road.
- Collaborative European research has shown that drivers need to be able to detect guidance markings at a distance equivalent to a minimum of two seconds of travel time. If the visibility is less than this, drivers tend to adjust too late when the road changes direction. They run too close to the centerline on nearside bends, or too close to the road edge on offside bends. The higher the prevailing traffic speed, the greater the visibility distance required to maintain this two second “preview time.” If it is not provided, drivers tend to miss the curve, or proceed in a series of staggers.
- Almost all the recent crash research has been geared toward adding edge lines to highways. Recent crash studies as well as those more than a half century old have conclusively shown that adding edge lines to rural two-lane highways can reduce crashes and fatalities. In a recent study, driver workload was reduced after edge lines were added to narrow two-lane highways.<sup>126</sup>
- Visibility distance is adversely affected by glare from oncoming vehicles, dirty headlamps, or windscreen, and especially by rain; the glass beads which produce the nighttime luminance are drowned by excess water, greatly reducing the brightness of the line.
- Older drivers also see a marking less well than younger drivers; someone seventy years old might suffer a reduction in visibility distance of more than 20 percent compared with drivers in their twenties.

### Good design practice/ treatments/solutions

- Line marking layout should always be considered in detail at the design stage of any scheme.
- Markings have two principal functions:
  - The first is symbolic; the driver needs to have learned, for example, that a hollow triangular marking with its apex downward means “yield”.
  - The second is guidance; centerlines, edge lines, and lane lines help drivers to maintain their lateral position on the road. Some markings, e.g., hazard lines and double white line systems have both symbolic and guidance functions.
- A variety of factors influence the visibility distance of a road marking. It is increased when a line is wider, has a higher mark-to-gap ratio, or has a higher coefficient of retroreflected luminance (in the day time, higher contrast with the road surface).
- Longitudinal lines should be designed to ensure a flowing alignment, avoiding sudden changes of direction or sharp tapers of inadequate length (figure 5.165). They can be machine or hand laid in paint, thermoplastic, or preformed tape.
- For line markings to be effective, they need to be clearly visible both by day and by night.
- Most line markings that have a guidance function

126 Paul J. Carlson, Eun Sug Park, and Carl K. Andersen. 2008. The Benefits of Pavement Markings: A Renewed Perspective Based on Recent and Ongoing Research. US Federal Highway Administration.

**Figure 5.165:** Unexpected deviation of line marking—India



Source: Blair Turner/GRSF.

are required to be illuminated by retroreflecting material (figure 5.166). Retroreflectivity is achieved through the addition of glass beads applied directly to the surface of the line marking during the application process and, in the case of thermoplastic, through the presence of glass beads incorporated within the material itself. This makes the marking much brighter at night than non-reflectORIZED materials.

## Further Reading

- FHWA. 2009. Manual on Uniform Traffic Control Devices (MUTCD). Must read part 3, Markings.
- Department for Transport, UK government. 2019. Traffic signs manual. Must read chapter 5, Road markings, MUTCD.

## 5.15. Street Lighting

### General description

A streetlight is a raised source of light, usually situated on top of a light pole (column), lamppost, or lamp standard on the edge of a road or path, or in the median of a divided carriageway. It may also be suspended on wires over the carriageway.

**Figure 5.166:** Line markings illuminated by retroreflecting material.



Source: Training presentation by John Barrell, © Fabian Marsh.

It is rarely provided in isolation, but as part of a wider network to create a consistent level of illumination across a wider, usually urban, area or road corridor.

Increasingly urban lighting is also being installed in low-level bollards and flush with the footway to provide less light pollution.

Many lamps have light-sensitive photocells that activate the lamp automatically when needed, at times when there is little to no ambient light, such as at dusk, dawn, or at the onset of dark weather conditions. This function in older lighting systems could be performed with the aid of a solar dial.

Many streetlight systems are being connected underground instead of wiring from one utility post to another.

Street lighting provides a number of important benefits. It can be used to promote security in urban areas and to increase the quality of life by artificially extending the hours in which it is light so that activity can take place.

Street lighting also improves safety for drivers, riders, and pedestrians.

Incandescent lamps were primarily used for street lighting until the advent of high-intensity gas-discharge lamps. They were often operated at high-voltage series circuits. Series circuits were popular since their higher voltage produced more light per watt consumed. Furthermore, before the invention of photoelectric controls, a single switch or clock could control all the lights in an entire district.

Today, existing street lighting commonly uses high-intensity discharge lamps. Low-pressure sodium (LPS) lamps became commonplace after World War II for their low power consumption and long life. Late in the twentieth century high-pressure sodium (HPS) lamps were preferred. Such lamps provide the greatest amount of photopic (color) illumination for the least consumption of electricity.

New street lighting technologies, such as LED or induction lights, emit a white light that provides high levels of scotopic (low-level) lumens, allowing street lights with lower wattages and lower photopic lumens to replace existing street lights. However, there have been no formal specifications written around photopic/scotopic adjustments for different types of light sources, causing many municipalities and street departments to hold back on implementation of these new technologies until the standards are updated.

## Safety implications

- Major advantages of street lighting include prevention of crashes and increase in safety.<sup>127</sup>
- White light sources have been shown to double driver peripheral vision and improve driver brake reaction time by at least 25 percent to enable pedestrians to better detect pavement trip hazards and to facilitate visual appraisals of other people associated with interpersonal judgements.<sup>128</sup> Studies comparing metal halide and high-pressure sodium lamps have shown that at equal photopic light levels, a street scene illuminated at night by a metal halide lighting system was reliably seen as brighter and safer than the same scene illuminated by a high-pressure sodium system.<sup>129</sup>
- Street lighting represents a major infrastructure cost for LMICs, and the reliability of maintenance and power supplies can render their provision less effective. Advances in solar power are increasing the viability and acceptance of street lighting as a positive social and safety improvement in communities.
- There are also physical dangers to the posts of streetlamps. Streetlight stanchions (lampposts) pose a collision risk to motorists and pedestrians.
- Most of the information drivers utilize in traffic is visual. Visual conditions can therefore be very significant for safe travel.
- In the dark, the eye picks up contrast, detail, and movement to a far lesser extent than in daylight. This is one of the reasons why the risk of a crash is higher during darkness than during daylight for all road users.
- Studies have shown that darkness results in a large number of crashes and fatalities, especially those

127 Rea, M. S., J. D. Bullough, C. R. Fay, J. A. Brons, J. Van Derlofske, and E. T. Donnell. 2009. Review of the Safety Benefits and Other Effects of Roadway Lighting (report to the National Cooperative Highway Research Program). Washington, DC: Transportation Research Board.

128 Fotios S., and Cheal C. 2013. Using obstacle detection to identify appropriate illuminances for lighting in residential roads. *Lighting Research & Technology*, 45(3); 362–376.

129 Fotios, S. A., and Cheal, C. 2007. Lighting for subsidiary streets: investigation of lamps of different SPD. Part 2—Brightness, *Lighting Research & Technology*, 39(3); 233–252.

involving pedestrians; pedestrian fatalities are 3.00 to 6.75 times more likely in the dark than in daylight.<sup>130</sup>

- Many local authorities (for instance in England and Wales) have reduced street lighting at night to save money and reduce carbon emissions. However, research has not found any statistical evidence that any street lighting adaptation strategy was associated with a change in collisions at night.<sup>131</sup>
- The loss of night vision because of the accommodation reflex of drivers' eyes is the greatest danger for drivers in terms of optical safety risk.
- As drivers emerge from an unlit area into a pool of light from a streetlight their pupils quickly constrict to adjust to the brighter light, but as they leave the pool of light, the dilation of their pupils to adjust to the dimmer light is much slower, so they are driving with impaired vision.
- As a person gets older the eye's recovery speed gets slower, so driving time and distance under impaired vision increases.
- Oncoming headlights are more visible against a black background than a gray one. The contrast creates greater awareness of the oncoming vehicle. Lighting therefore needs to highlight the silhouette of an approaching vehicle or pedestrian effectively.

- High winds or accumulated metal fatigue also occasionally topple streetlights if not maintained.
- Similarly, streetlights are only effective when working. Poor maintenance or lack of consistent power supply can render them ineffective and a collision hazard.

## Good design practice/ treatments/solutions

- Lighting is most appropriate in urban streets, and key locations include intersections and places where pedestrians cross.
- The level of illumination needs to be consistent, and maintenance is most important.
- Lighting should provide a uniformly lit road surface against which vehicles, pedestrians, or other objects are seen in silhouette (figure 5.167).
- The design of the lighting system should relate to the road surface reflection characteristics in order to provide the optimum quality and quantity of illumination.
- Light colored surfaces give better silhouette vision than do dark ones.
- Lighting systems can be expensive to install and

**Figure 5.167:** Village lighting—India.



Source: World Bank.

**Figure 5.168:** Solar powered streetlights.,

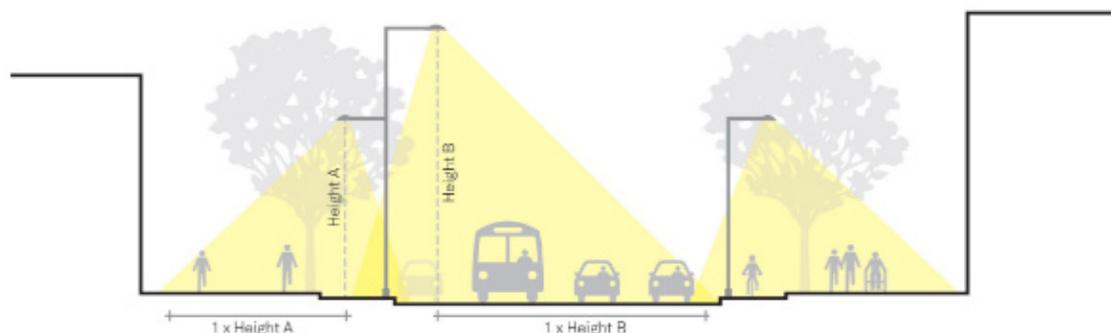


Source: World Bank.

130 John M. Sullivan, and Michael J. Flannagan. 2002. The role of ambient light level in fatal crashes: inferences from daylight saving time transitions. *Accident Analysis & Prevention* Volume 34, Issue 4, July 2002, pages 487–498.

131 Steinbach, R., Perkins, C., and Tompson, L. et al. 2015. The effect of reduced street lighting on road casualties and crime in England and Wales: controlled interrupted time series analysis. *J Epidemiol Community Health* 69:1118–1124.





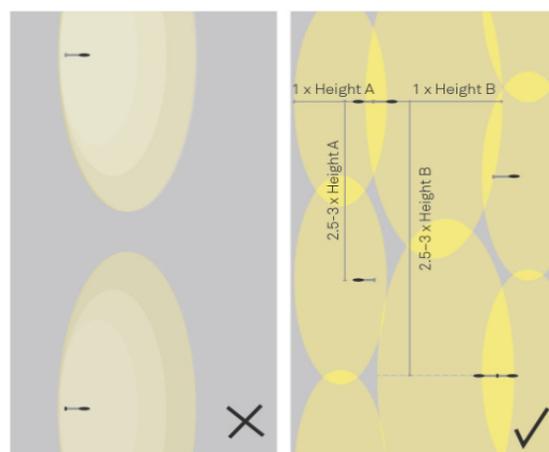
maintain. Frequent interruptions to power supplies can also reduce effectiveness. Recent technological advances in solar power generation are making lighting more appropriate for remote communities and LMICs (figure 5.168).

- Spacing between light poles is typically 2.5 times the height of the light source. A single row of lights might be sufficient for a narrow street, but multiple sources are needed for wider streets.
- Light poles that are too far apart result in areas of darkness and can leave users feeling unsafe, as well as affecting the driver's perception of shadow and silhouette
- Rigid lighting columns may be redesigned to provide more forgiving frangible (breakaway) posts and lighting columns, i.e., impact absorbent or slip-base types (figures 5.169 and 5.170).

**Figure 5.169:** Slip-base lighting column suitable for high-speed roads with little pedestrian activity and parking.



Source: CAREC, 2018.



- Collision risk can be reduced by locating columns away from runoff areas or designing them to break away when hit (frangible or collapsible supports), protecting them by guardrails, or marking the lower portions to increase their visibility, particularly for pedestrians.

**Figure 5.170:** Impact-absorbing lighting columns suitable for low-speed environments with higher pedestrian activity and parking.



Source: CAREC, 2018.

## Further Reading

- FHWA. 2012. Lighting Handbook. [https://safety.fhwa.dot.gov/roadway\\_dept/night\\_visib/lighting\\_handbook/](https://safety.fhwa.dot.gov/roadway_dept/night_visib/lighting_handbook/).
- Queensland Department of Transport and Roads. 2016. Road Planning and Design Manual, 2nd edition, Volume 6—Lighting. <https://www.tmr.qld.gov.au/-/media/busind/techstdpubs/Road-planning-and-design/Road-Planning-and-Design-2nd-edition/RPDM2ndEdVolume6.pdf?la=en>.
- Transport Infrastructure Ireland (TII). 2018. Design of Road Lighting for the National Road Network.
- DN-LHT-03038. <https://www.tiipublications.ie/library/DN-LHT-03038-03.pdf>.
- Texas Department of Transport. 2018. Highway Illumination Manual. <http://onlinemanuals.txdot.gov/txdotmanuals/hwi/hwi.pdf>.