lane-drop taper length should be computed from Equation 3-39. The recommended length for the lane addition taper is one-half to two-thirds of the lane-drop length. Figures 3-29 and 3-30 are schematics for adjacent lane drop and lane addition tapers on a 2+1 roadway.

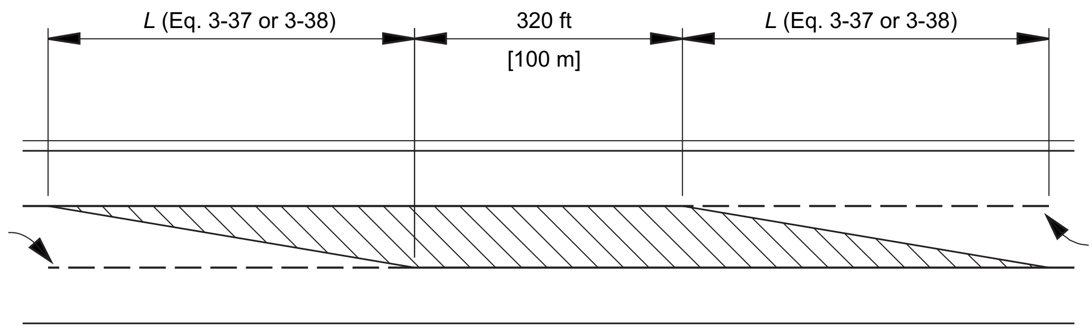


Figure 3-29. Schematic for Adjacent Lane Drop Tapers on a 2+1 Roadway

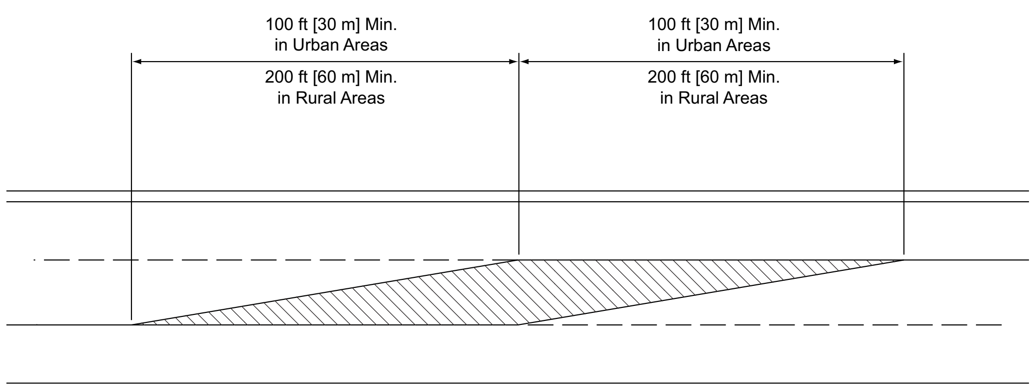


Figure 3-30. Schematic for Adjacent Lane Addition Tapers on a 2+1 Roadway

Lane and shoulder widths should be comparable to the widths determined for the volumes and speeds for two-lane highways for specific functional classes in Chapters 5 through 7.

Where existing two-lane highways with a normal crown are converted to 2+1 roadways, the location and transition of the crown is perhaps one of the more complicated design issues. A variety of practices relate to the location of the crown. Where an existing two-lane highway is restriped as a 2+1 road or widened to become a 2+1 road, the placement of the crown within the traveled way may be permitted. An existing highway may also be widened on one side only, with the result that the crown is located at a lane line. There is no indication of any difference in crashes between placing the roadway crown at a lane boundary and placing it within a lane. For newly designed 2+1 highways, the crown should be placed at a lane boundary.

Horizontal curves should be superelevated in accordance with the provisions of Section 3.3, "Horizontal Alignment." Superelevation should be handled no differently on a 2+1 road than on a comparable two-lane or four-lane undivided road.

While separation of the opposing traffic lanes may not be needed on every highway, some separation between lanes in opposing directions is desirable. A flush separation of 4 ft [1.2 m] between the opposing directions may be considered.

3.4.4.3 Turnouts

A turnout is a widened, unobstructed shoulder area that allows slow-moving vehicles to pull out of the through lane to give passing opportunities to following vehicles (*30, 31*). The driver of the slow-moving vehicle, if there are following vehicles, is expected to pull out of the through lane and remain in the turnout only long enough for the following vehicles to pass before returning to the through lane. When there are only one or two following vehicles, this maneuver can be accomplished without the driver of the vehicle needing to stop in the turnout. However, when this number is exceeded, the driver may need to stop in the turnout in order for all the following vehicles to pass. Turnouts are most frequently used on lower volume roads where long platoons are rare and in difficult terrain with steep grades where construction of an additional lane may not be cost-effective. Such conditions are often found in mountain, coastal, and scenic areas where more than 10 percent of the vehicle volumes are large trucks and recreational vehicles.

The recommended length of turnouts including taper is shown in Table 3-33. Turnouts shorter than 200 ft [60 m] are not recommended even for very low approach speeds. Turnouts longer than 600 ft [185 m] are not recommended for high-speed roads to avoid use of the turnout as a passing lane. The recommended lengths are based on the assumption that slow-moving vehicles enter the turnout at 5 mph [8 km/h] slower than the mean speed of the through traffic. This length allows the entering vehicle to coast to the midpoint of the turnout without braking, and then, if necessary, to brake to a stop using a deceleration rate not exceeding 10 ft/s^2 [3 m/s^2]. The recommended lengths for turnouts include entry and exit tapers. Typical entry and exit taper lengths range from 50 to 100 ft [15 to 30 m] (*30, 31*).

Table 3-33. Recommended Lengths of Turnouts Including Taper

U.S. Customary		Metric	
Approach Speed (mph)	Minimum Length (ft)[a]	Approach Speed (km/h)	Minimum Length (m)[a]
20	200	30	60
30	200	40	60
40	300	50	65
45	350	60	85
50	450	70	105
55	550	80	135
60	600	90	170
		100	185

[a] Maximum length should be 185 m (600 ft) to avoid use of the turnout as a passing lane.

The minimum width of the turnout is 12 ft [3.6 m] with widths of 16 ft [5 m] considered desirable. Turnouts wider than 16 ft [5 m] are not recommended.

A turnout should not be located on or adjacent to a horizontal or vertical curve that limits sight distance in either direction. The available sight distance should be at least 1,000 ft [300 m] on the approach to the turnout.

Proper signing and pavement marking are also needed both to maximize turnout usage and reduce crashes. An edge line marking on the right side of the turnout is desirable to guide drivers, especially in wider turnouts.

3.4.4.4 Shoulder Driving

In parts of the United States, a long-standing custom has been established for slow-moving vehicles to move to the shoulder when another vehicle approaches from the rear, and then return to the traveled way after that following vehicle has passed. The practice generally occurs where adequate paved shoulders exist and, in effect, these shoulders function as continuous turnouts. This custom is regarded as a courtesy to other drivers needing little or no sacrifice in speed by either driver. While highway agencies may want to permit such use as a means of improving passing opportunities without a major capital investment, they should recognize that in many states shoulder driving is currently prohibited by law. Thus, a highway agency considering shoulder driving as a passing aid may need to propose legislation to authorize such use as well as develop a public education campaign to familiarize drivers with the new law.

Highway agencies should evaluate the mileage of two-lane highways with paved shoulders as well as their structural quality before deciding whether to allow their use as a passing aid. It should be recognized that, where shoulder driving becomes common, it will not be limited to selected sites but rather will occur anywhere on the system where paved shoulders are provided.

Another consideration is that shoulder widths of at least 10 ft [3.0 m], and preferably 12 ft [3.6 m], are needed. The effect that shoulder driving may have on the use of the highway by bicyclists should also be considered. Because the practice of shoulder driving has evolved through local custom, no special signing to promote such use has been created.

3.4.4.5 Shoulder Use Sections

Another approach to providing additional passing opportunities is to permit slow-moving vehicles to use paved shoulders at selected sites designated by specific signing. This is a more limited application of shoulder use by slow-moving vehicles than shoulder driving described in the previous section. Typically, drivers move to the shoulder only long enough for following vehicles to pass and then return to the through lane. Thus, the shoulder-use section functions as an extended turnout. This approach enables a highway agency to promote shoulder use only where the shoulder is adequate to handle anticipated traffic loads and the need for more frequent passing opportunities has been established by the large amount of vehicle platooning.

Shoulder-use sections generally range in length from 0.2 to 3 mi [0.3 to 5 km]. Shoulder use should be allowed only where shoulders are at least 10 ft [3.0 m] and preferably 12 ft [3.6 m] wide. Adequate structural strength to support the anticipated loads along with good surface conditions are needed. Particular attention needs to be placed on the condition of the shoulder because drivers are unlikely to use a shoulder if it is rough, broken, or covered with debris. Signs should be erected at both the beginning and end of the section where shoulder use is allowed. However, since signing of shoulder-use sections is not addressed in the MUTCD (*24*), special signing should be used.

3.4.5 Emergency Escape Ramps

3.4.5.1 General

Where long, descending grades exist or where topographic and location controls indicate a need for such grades on new alignment, the design and construction of an emergency escape ramp at an appropriate location is desirable to provide a location for out-of-control vehicles, particularly trucks, to slow and stop away from the main traffic stream. Out-of-control vehicles are generally the result of a driver losing braking ability either through overheating of the brakes due to mechanical failure or failure to downshift at the appropriate time. Considerable experience with ramps constructed on existing highways has led to the design and installation of effective ramps that save lives and reduce property damage. Reports and evaluations of existing ramps indicate that they provide acceptable deceleration rates and afford good driver control of the vehicle on the ramp (*78*).

Forces that act on every vehicle to affect the vehicle's speed include engine-, braking-, and tractive-resistance forces. Engine- and braking-resistance forces can be ignored in the design of escape ramps because the ramp should be designed for the worst case, in which the vehicle is out of gear and the brake system has failed. The tractive-resistance force contains four subclasses: inertial, aerodynamic, rolling, and gradient. Inertial and negative gradient forces act to maintain motion of the vehicle, while rolling-, positive gradient-, and air-resistance forces act to retard its motion. Figure 3-31 illustrates the action of the various resistance forces on a vehicle.

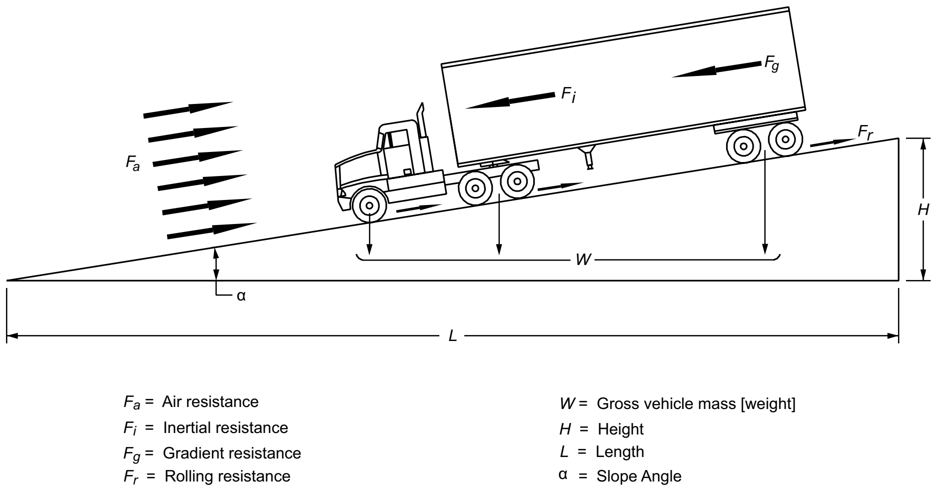


Figure 3-31. Forces Acting on a Vehicle in Motion

Inertial resistance can be described as a force that resists movement of a vehicle at rest or maintains a vehicle in motion, unless the vehicle is acted on by some external force. Inertial resistance must be overcome to either increase or decrease the speed of a vehicle. Rolling- and positive gradient-resistance forces are available to overcome the inertial resistance. Rolling resistance is a general term used to describe the resistance to motion at the area of contact between a vehicle's tires and the roadway surface and is only applicable when a vehicle is in motion. It is influenced by the type and displacement characteristics of the surfacing material of the roadway. Each surfacing material has a coefficient, expressed in lb/1,000 lb [kg/1 000 kg] of gross vehicle weight (GVM [GVW]), which determines the amount of rolling resistance of a vehicle. The values shown in Table 3-34 for rolling resistance have been obtained from various sources throughout the country and are a best available estimate.

Gradient resistance results from gravity and is expressed as the force needed to move the vehicle through a given vertical distance. For gradient resistance to provide a beneficial force on an escape ramp, the vehicle must be moving upgrade, against gravity. In the case where the vehicle is descending a grade, gradient resistance is negative, thereby reducing the forces available to slow and stop the vehicle. The amount of gradient resistance is influenced by the total weight of the vehicle and the magnitude of the grade. For each percent of grade, the gradient resistance is 10 lb/1,000 lb [10 kg/1 000 kg] whether the grade is positive or negative.

The remaining component of tractive resistance is aerodynamic resistance, the force resulting from the retarding effect of air on the various surfaces of the vehicle. Air causes a significant resistance at speeds above 50 mph [80 km/h], but is negligible under 20 mph [30 km/h]. The effect of aerodynamic resistance has been neglected in determining the length of the arrester bed, thus providing a small additional margin of safety.

Table 3-34. Rolling Resistance of Roadway Surfacing Materials

	U.S. Customary		Metric	
Surfacing Material	Rolling Resistance (lb/1,000 lb GVW)	Equivalent Grade (%)[a]	Rolling Resistance (kg/1,000 kg GVM)	Equivalent Grade (%)[a]
Portland cement concrete	10	1.0	10	1.0
Asphalt concrete	12	1.2	12	1.2
Gravel, compacted	15	1.5	15	1.5
Earth, sandy, loose	37	3.7	37	3.7
Crushed aggregate, loose	50	5.0	50	5.0
Gravel, loose	100	10.0	100	10.0
Sand	150	15.0	150	15.0
Pea gravel	250	25.0	250	25.0

[a] Rolling resistance expressed as equivalent gradient.

3.4.5.2 Need and Location for Emergency Escape Ramps

Each grade has its own unique characteristics. Highway alignment, gradient, length, and descent speed contribute to the potential for out-of-control vehicles. For existing highways, operational concerns on a downgrade will often be reported by law enforcement officials, truck drivers, or the general public. A field review of a specific grade may reveal damaged guardrail, gouged pavement surfaces, or spilled oil indicating locations where drivers of heavy vehicles had difficulty negotiating a downgrade. For existing facilities, an escape ramp should be provided as soon as a need is established. Crash experience (or, for new facilities, crash experience on similar facilities) and truck operations on the grade combined with engineering judgment are frequently used to determine the need for a truck escape ramp. Often the impact of a potential runaway truck on adjacent activities or population centers will provide sufficient reason to construct an escape ramp.

Unnecessary escape ramps should be avoided. For example, a second escape ramp should not be needed just beyond the curve that created the need for the initial ramp.

While there are no universal guidelines available for new and existing facilities, a variety of factors should be considered in selecting the specific site for an escape ramp. Each location presents a different array of design needs; factors that should be considered include topography, length and percent of grade, potential speed, economics, environmental impact, and crash experience.

Ramps should be located to intercept the greatest number of runaway vehicles, such as at the bottom of the grade and at intermediate points along the grade where an out-of-control vehicle could cause a catastrophic crash.

A technique for new and existing facilities available for use in analyzing operations on a grade, in addition to crash analysis, is the *Grade Severity Rating System* (*21*). The system uses a predetermined brake temperature limit (500°F [260°C]) to establish a safe descent speed for the grade. It also can be used to determine expected brake temperatures at 0.5-mi [0.8-km] intervals along the downgrade. The location where brake temperatures exceed the limit indicates the point that brake failures can occur, leading to potential runaways.

Escape ramps generally may be built at any practical location where the main road alignment is tangent. They should be built in advance of horizontal curves that cannot be negotiated safely by an out-of-control vehicle without rolling over and in advance of populated areas. Escape ramps should exit to the right of the roadway. On divided multilane highways, where a left exit may appear to be the only practical location, difficulties may be expected by the refusal of vehicles in the left lane to yield to out-of-control vehicles attempting to change lanes.

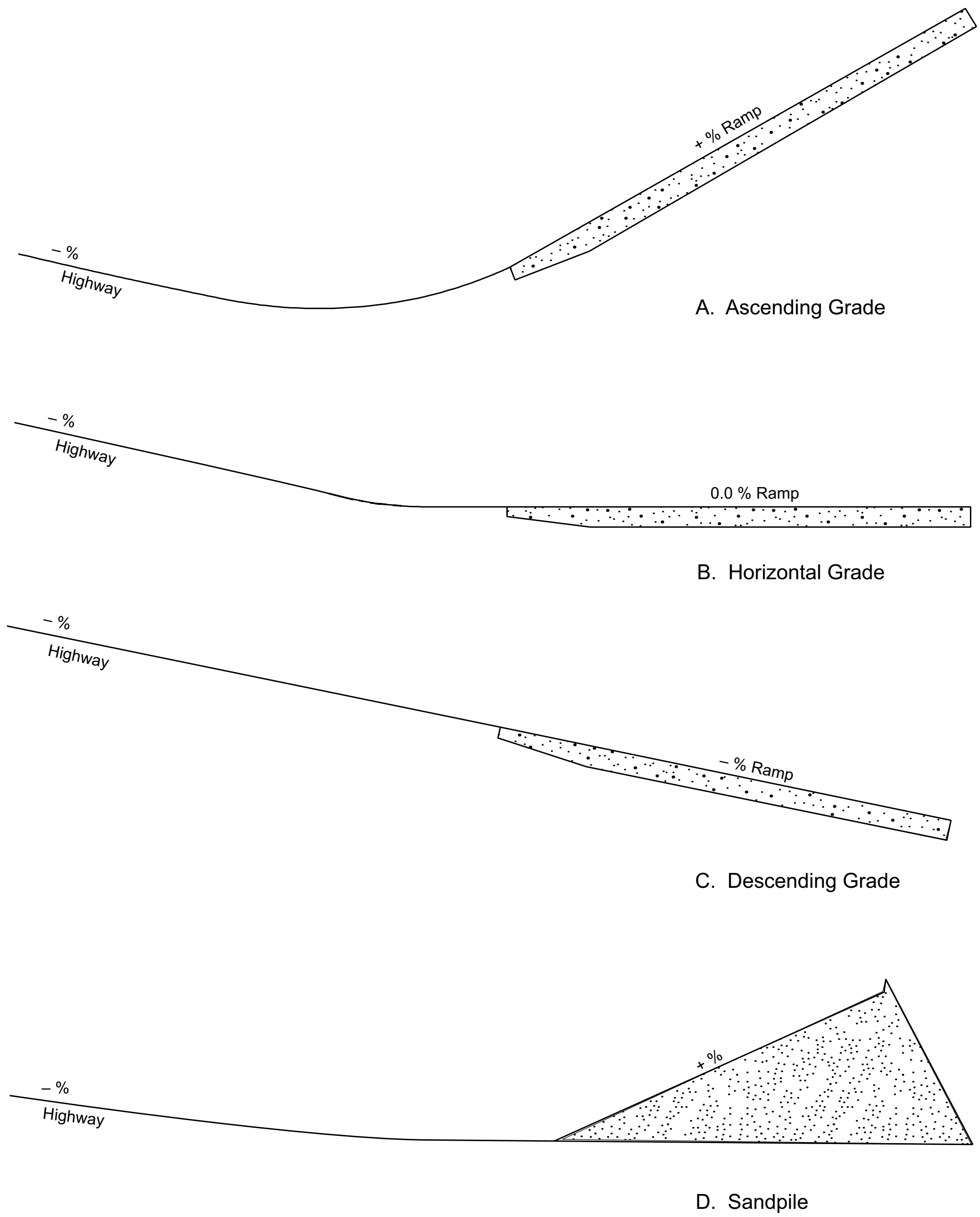
Although crashes involving runaway trucks can occur at various sites along a grade, locations having multiple crashes should be analyzed in detail. Analysis of crash data pertinent to a prospective escape ramp site should include evaluation of the section of highway immediately uphill, including the amount of curvature traversed and distance to and radius of the adjacent curve.

An integral part of the evaluation should be the determination of the maximum speed that an out-of-control vehicle could attain at the proposed site. This highest obtainable speed can then be used as the minimum design speed for the ramp. The 80- to 90-mph [130- to 140-km/h] entering speed, recommended for design, is intended to represent an extreme condition and therefore should not be used as the basis for selecting locations of escape ramps. Although the variables involved make it impractical to establish a maximum truck speed warrant for location of escape ramps, it is evident that anticipated speeds should be below the range used for design. The principal factor in determining the need for an emergency escape ramp should be the safety of the other traffic on the roadway, the driver of the out-of-control vehicle, and the residents along and at the bottom of the grade. An escape ramp, or ramps if the conditions indicate the need for more than one, should be located wherever grades are of a steepness and length that present a substantial risk of runaway trucks and topographic conditions will permit construction.

3.4.5.3 Types of Emergency Escape Ramps

Emergency escape ramps have been classified in a variety of ways. Three broad categories used to classify ramps are gravity, sandpile, and arrester bed. Within these broad categories, four basic emergency escape ramp designs predominate. These designs are the sandpile and three types of arrester beds, classified by grade of the arrester bed: descending grade, horizontal grade, and ascending grade. These four types are illustrated in Figure 3-32.

The gravity ramp has a paved or densely compacted aggregate surface, relying primarily on gravitational forces to slow and stop the runaway. Rolling-resistance forces contribute little to assist in stopping the vehicle. Gravity ramps are usually long, steep, and are constrained by topographic controls and costs. While a gravity ramp stops forward motion, the paved surface cannot prevent the vehicle from rolling back down the ramp grade and jackknifing without a positive capture mechanism. Therefore, the gravity ramp is the least desirable of the escape ramp types.



Note: Profile is along the baseline of the ramp.

Figure 3-32. Basic Types of Emergency Escape Ramps

Sandpiles, composed of loose, dry sand dumped at the ramp site, are usually no more than 400 ft [120 m] in length. The influence of gravity is dependent on the slope of the surface. The increase in rolling resistance is supplied by loose sand. Deceleration characteristics of sandpiles are usually severe and the sand can be affected by weather. Because of the deceleration characteristics, the sandpile is less desirable than the arrester bed. However, at locations where inadequate space exists for another type of ramp, the sandpile may be appropriate because of its compact dimensions.

Descending-grade arrester-bed escape ramps are constructed parallel and adjacent to the through lanes of the highway. These ramps use loose aggregate in an arrester bed to increase rolling resistance to slow the vehicle. The gradient resistance acts in the direction of vehicle movement. As a result, the descending-grade ramps can be rather lengthy because the gravitational effect is not acting to help reduce the speed of the vehicle. The ramp should have a clear, obvious return path to the highway so drivers who doubt the effectiveness of the ramp will feel they will be able to return to the highway at a reduced speed.

Where the topography can accommodate, a horizontal-grade arrester-bed escape ramp is another option. Constructed on an essentially flat gradient, the horizontal-grade ramp relies on the increased rolling resistance from the loose aggregate in an arrester bed to slow and stop the out-of-control vehicle, since the effect of gravity is minimal. This type of ramp is longer than the ascending-grade arrester bed.

The most commonly used escape ramp is the ascending-grade arrester bed. Ramp installations of this type use gradient resistance to advantage, supplementing the effects of the aggregate in the arrester bed, and generally, reducing the length of ramp needed to stop the vehicle. The loose material in the arresting bed increases the rolling resistance, as in the other types of ramps, while the gradient resistance acts in a downgrade direction, opposite to the direction of vehicle movement. The loose bedding material also serves to hold the vehicle in place on the ramp grade after it has come to a safe stop.

Each of the ramp types is applicable to a particular situation where an emergency escape ramp is desirable and should be compatible with established location and topographic controls at possible sites. The procedures used for analysis of truck escape ramps are essentially the same for each of the categories or types identified. The rolling-resistance factor for the surfacing material used in determining the length needed to slow and stop the runaway truck safely is the difference in the procedures.

3.4.5.4 Design Considerations

The combination of the above external resistance and numerous internal resistance forces not discussed acts to limit the maximum speed of an out-of-control vehicle. Speeds in excess of 80 to 90 mph [130 to 140 km/h] will rarely, if ever, be attained. Therefore, an escape ramp should be designed for a minimum entering speed of 80 mph [130 km/h], with a 90-mph [140-km/h] design speed being preferred. Several formulas and software programs have been developed to determine the runaway speed at any point on the grade. These methods can be used to establish a design speed for specific grades and horizontal alignments (*21, 40, 78*).

The design and construction of effective escape ramps involve a number of considerations as follows:

- To safely stop an out-of-control vehicle, the length of the ramp should be sufficient to dissipate the kinetic energy of the moving vehicle.
- The alignment of the escape ramp should be tangent or on very flat curvature to minimize the driver's difficulty in controlling the vehicle.
- The width of the ramp should be adequate to accommodate more than one vehicle because it is not uncommon for two or more vehicles to have need of the escape ramp within a short time. A minimum width of 26 ft [8 m] may be all that is practical in some areas, though greater widths are preferred. Desirably, a width of 30 to 40 ft [9 to 12 m] would more adequately accommodate two or more out-of-control vehicles. Ramp widths less than indicated above have been used successfully in some locations where it was determined that a wider width was unreasonably costly or not needed. Widths of ramps in use range from 12 to 40 ft [3.6 to 12 m].
- The surfacing material used in the arrester bed should be clean, not easily compacted, and have a high coefficient of rolling resistance. When aggregate is used, it should be rounded, uncrushed, predominantly a single size, and as free from fine-size material as practical. Such material will maximize the percentage of voids, thereby providing optimum drainage and minimizing interlocking and compaction. A material with a low shear strength is desirable to permit penetration of the tires. The durability of the aggregate should be evaluated using an appropriate crush test. Pea gravel is representative of the material used most frequently, although loose gravel and sand are also used. A gradation with a top size of 1.5 in. [40 mm] has been used with success in several states. Material conforming to the AASHTO gradation No. 57 is effective if the fine-sized material is removed.
- Arrester beds should be constructed with a minimum aggregate depth of 3 ft [1 m]. Contamination of the bed material can reduce the effectiveness of the arrester bed by creating a hard surface layer up to 12 in. [300 mm] thick at the bottom of the bed. Therefore, an aggregate depth up to 42 in. [100 mm] is recommended. As the vehicle enters the arrester bed, the wheels of the vehicle displace the surface, sinking into the bed material, thus increasing the rolling resistance. To assist in decelerating the vehicle smoothly, the depth of the bed should be tapered from a minimum of 3 in. [75 mm] at the entry point to the full depth of aggregate in the initial 100 to 200 ft [30 to 60 m] of the bed.
- A positive means of draining the arrester bed should be provided to help protect the bed from freezing and avoid contamination of the arrester bed material. This can be accomplished by grading the base to drain, intercepting water prior to entering the bed, underdrain systems with transverse outlets, or edge drains. Geotextiles or paving can be used between the sub-