Current State of Truck Escape-Ramp Technology

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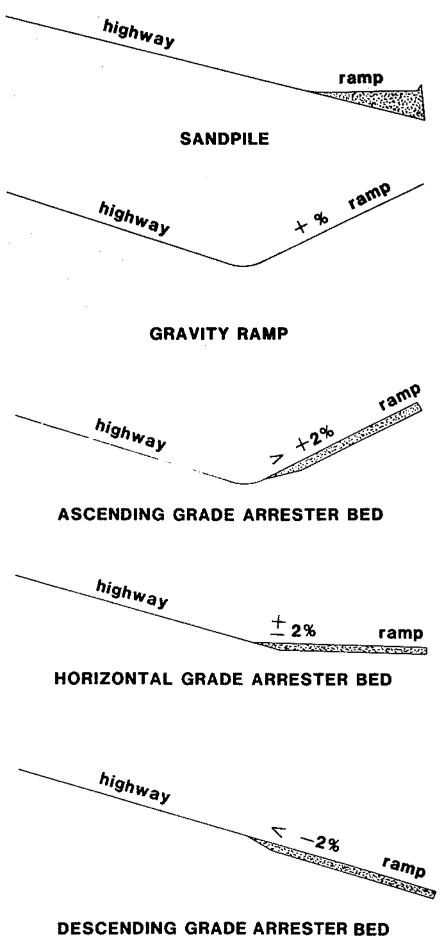
Drivers who lose control of their heavy vehicles on long, steep downgrades have an alternative to riding out the hill when a truck escape ramp is on the grade. There are six basic types of escape ramps in the United States. Only recently has there been an appreciable increase in the advancement of truck escape-ramp technology. Many of these advancements were developed by state transportation agencies and are documented individually in the various states' reports. The purpose of this paper is to provide a pool of information on the characteristics of the many truck escape ramps that are found in the numerous literature sources throughout the United States.

Many states provide escape-ramp facilities for the purpose of reducing the runaway truck hazard on long, steep downgrades. These ramps are used by vehicles that have lost their braking capabilities and are out of control. Escape ramps allow the driver to regain control by slowing or stopping the truck at an acceptable level of deceleration. Such facilities have been present in several states for many years; however, it has been only recently that states have accelerated the advancement of truck escape-ramp technology.

State transportation agencies have largely designed their truck escape ramps based on experience. This has sometimes been coupled with what the designers intuitively believed would improve the operation of the facility. Although they have merit, such empirical methods of design may not be conducive to developing the best design for a given escape-ramp need.

Most of the truck escape-ramp designs and operational successes have not been documented or have been documented individually or in small groups in a statewide status report. The purpose of this paper is to present a single document that describes pertinent aspects of truck escape-ramp technology found throughout the United States.

Figure 1. Five types of truck escape ramps.



CHARACTERISTICS OF CURRENT DESIGNS

The term truck escape ramp encompasses six different types of general designs: sandpile, gravity ramp, ascending-grade arrester bed, horizontal-grade arrester bed, descending-grade arrester bed, and roadside arrester bed. These designs are shown in Figures 1 (1) and 2 (2). All of these ramps function according to at least one of two basic methods of vehicle deceleration: (a) vehicles are decelerated by gravity (the gravity ramp and the ascending-grade arrester bed use this method), and (b) some form of arresting material is used, usually sand or gravel, such that the rolling resistance offered by the material is the predominant means of decelerating the vehicle (most truck escape ramps use this device to different degrees).

Sandpiles are masses of arresting material placed on the roadside such that the top surface is approximately level or at a slightly ascending grade. The surface of the sandpile may or may not be covered with transverse ridges. When a vehicle enters a sandpile truck escape ramp, the arresting material increases rolling resistance against the tires and, if the vehicle sinks in the sand far enough, against the undercarriage.

A gravity ramp consists of a hard-surfaced lane that is on an ascending grade that may or may not have a small aggregate bed near the top. The purpose of the bed is not to contribute significantly to the deceleration of the vehicle but to keep the vehicle in place once it has stopped. If no such aggregate bed is present, there is the possibility that an articulated vehicle may roll backward and jackknife. Vehicles that enter gravity ramps are decelerated primarily by the force that results from gravity acting opposite the direction of movement.

Truck escape ramps that incorporate arrester beds are all similar in design with the exception of the grade of the ramp. An ascending-grade arrester bed consists of a ramp on an ascending grade that has a

Figure 2. Roadside arrester bed.

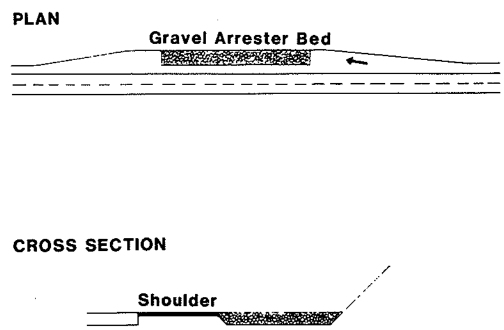
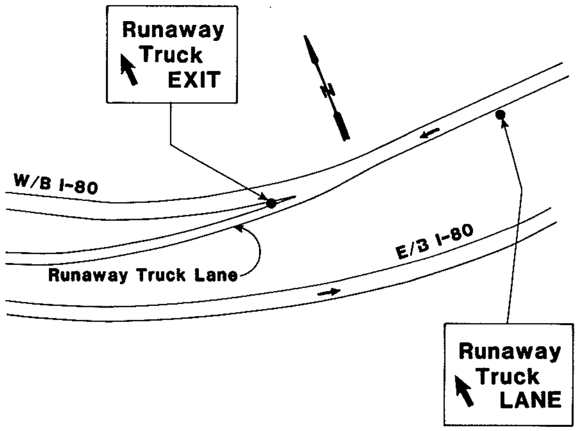


Figure 3. Horizontal-grade arrester bed in Parley's Canyon, Utah.



bed of arresting material (usually sand or gravel). The arresting material and gravity contribute to the deceleration of a vehicle that enters the ramp. Horizontal-grade arrester beds are truck escape ramps that are approximately level. For purposes of classification in this paper, grades of ±2 percent are defined as horizontal. The deceleration of vehicles in these ramps is the result of rolling resistance provided by the aggregate. Descending-grade arrester beds are facilities in which the vehicle is decelerated by the arresting material. The force provided by this material must also counteract the effect of the descending grade.

Another type of escape ramp that is similar to the descending-grade arrester bed is the roadside arrester bed. The roadside arrester bed is parallel and adjacent to the main line and has provisions whereby a vehicle may enter from the side, as well as the upstream end, of the arrester bed.

Every truck escape ramp in the United States today is one of these six types. Because each truck escape-ramp location is unique, the designer must carefully consider several ramp characteristics. The different combinations of the many truck escape-ramp characteristics can lead to either an acceptable or an inadequate design.

TRUCK ESCAPE-RAMP CHARACTERISTICS ASSOCIATED WITH RAMP TYPE

Truck escape-ramp characteristics can be categorized as being associated with a certain ramp type or independent of the ramp type. This section describes the characteristics associated with the ramp type.

Length

The length of a truck escape ramp is a key design feature. The required length of a ramp depends on design entry speed, type of arresting material, and grade. Because these last two factors differ for the different ramp types, the typical lengths for these ramps also differ. Preferably the lengths of truck escape ramps should be determined by analytical techniques. Many facilities in the United States were designed on such a basis. The design parameters for the different truck escape ramps resulted in facilities of various lengths.

The shortest truck escape ramps are the sandpiles, which are usually less than 400 ft long. The shortest cited facility is on US-421 in North Carolina, which is only 210 ft long. However, Crowe (3) reports that such a short length should be expanded to 400 ft in order to avoid having a high-speed vehicle pass completely through the sandpile.

Gravity ramps are typically long because they have only limited means of decelerating runaway vehicles other than gravity. Pennsylvania has gravity ramps of 1,200, 1,525, and 1,550 ft, and Hawaii has one that is 1,300 ft long.

Ascending-grade arrester beds exist with lengths from 330 to 1,560 ft. The longest truck escape ramp is the 2,480-ft horizontal-grade arrester bed in Parley's Canyon on I-80 in Utah (4). It is located in the median, as shown in Figure 3 (4). The length of this truck escape ramp is excessive due to the design assumption of only 10 to 20 percent rolling resistance provided by the aggregate.

Descending-grade arrester beds are generally longer than ascending-grade arrester beds because of the difference that gravity makes in whether it works to the advantage or disadvantage of the deceleration process (5).

Most roadside arrester beds are quite long due to being adjacent to the descending main line, where gravity acts in opposition to the resistive forces. The roadside arrester bed at Mt. Vernon Canyon in Colorado has a 2,075-ft gravel bed, of which the last 325 ft has a sand-barrel positive attenuator, which effectively reduces the standard aggregate bed length to 1,750 ft.

In designing truck escape ramps, regardless of the type, the length should be determined by analytical techniques. Such techniques, in the form of design equations, are discussed later in this paper.

Width

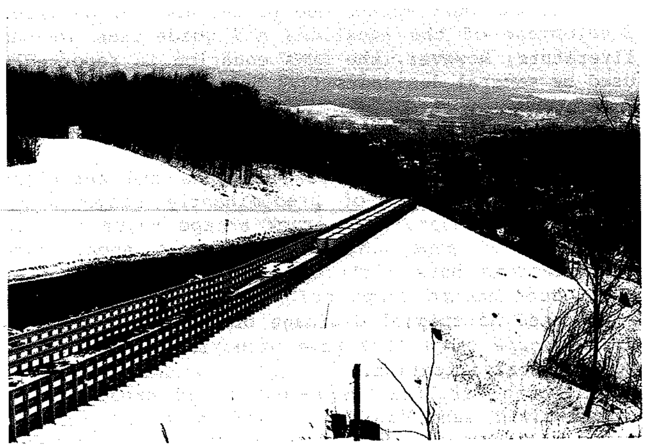
The width of a truck escape ramp is not generally a function of ramp type; it is closely related to the backup measures used, i.e., alternatives for a runaway vehicle in the event that the truck escape ramp is already occupied. Because of this relation, arrester beds and sandpiles typically need to be wider than gravity ramps, which are frequently 12 to 14 ft wide (6). Sandpiles and ascending-, horizontal-, and descending-grade arrester beds need to be wide enough for more than one vehicle to occupy the facility at the same time. Newton (2) suggests that roadside arrester beds, like gravity ramps, do not need to have widths adequate for multiple occupancy. Manifestations of this suggestion are found in the Mt. Vernon Canyon roadside arrester bed in Colorado, which has a width of only 20 ft, and in two roadside arrester beds on US-50 in Nevada, both of which are also 20 ft wide.

The other types of arrester beds generally have widths between 26 and 30 ft, although the Monteagle Mountain horizontal-grade arrester bed in Tennessee is 50 ft wide (7) and the Pali Highway ascending-grade arrester bed in Hawaii is 16 ft wide and tapers down to a 12-ft width at the end. There are other truck escape ramps that have tapered widths, e.g., the descending-grade arrester bed on NY-28 in New York, which tapers from 18 to 12 ft in width (8), as illustrated in Figure 4 (8). The idea behind designing this tapered escape ramp was to channelize the vehicle and minimize excessive yawing and jackknifing. However, the problem with such a design is that fewer vehicles can simultaneously occupy the far end of the ramp than if the width was held constant.

Arresting Materials

One of the first applications of the term sandpile in describing a truck escape ramp was in Virginia (9). This was a good descriptor because the arresting material was, indeed, sand. Pennsylvania has

Figure 4. Descending-grade arrester bed on NY-28 in New York.



truck escape ramps that are identified as sandpiles, yet none use sand; all Pennsylvania sandpiles use a form of gravel. These truck escape ramps are called sandpiles by virtue of their basic design, as shown in Figure 1, without regard to the arresting material.

The material employed in arrester beds is independent of the grade; i.e., ascending-grade, horizontal-grade, descending-grade, and roadside arrester beds all use approximately the same aggregate types. The most common aggregates are pea gravel and loose gravel, where the latter refers to rather angular aggregate as opposed to the rounded pea gravel. The type of aggregate used is a function of availability. For example, truck escape ramps in Hawaii use an angular aggregate because the more desirable pea gravel is unavailable at a reasonable cost. Pea gravel is more desirable because of the high percentage of voids, which provides better drainage than angular aggregate.

Surface Ridges

Early experiences in North Carolina and Virginia indicated that smooth-surfaced sandpiles did not always stop the runaway vehicles. Therefore, the addition of irregular mounds on the surface of the sandpiles was introduced in the expectation that these would increase their deceleration abilities (10). Arrester bed truck escape ramps have smooth surfaces, although some states (11) have considered using transverse surface ridges. Experience has indicated that transverse surface ridges are useful on sandpiles, and research has revealed that they are harmful on arrester beds (8,10,11).

Initial Cost

The initial cost of a truck escape ramp must consider excavation, right-of-way acquisition, and local labor costs. Examples of costs of various ramp types are identified in this section.

Sandpiles are the least expensive type of truck escape ramp. In Virginia two VA-52 sandpiles and the VA-33 sandpile were built in 1972 and 1975 for $10,000 each (9). Sandpiles in North Carolina cost $25,000 each in 1974 and 1975 (12).

The initial costs of arrester beds vary greatly. The most expensive truck escape ramp is the $529,000 ascending-grade arrester bed on I-70 west of the Eisenhower Memorial Tunnel in Colorado (13). The initial costs of arrester beds can be as low as $100,000, which was the cost of the only truck escape ramp built in New York (8).

Because roadside arrester beds are built adjacent to the roadway and do not need to be wide enough for multiple occupancy if they are built in pairs on the downgrade, they are less costly than other arrester beds (2).

Maintenance

There is little documentation on maintenance costs of truck escape ramps. Three sandpiles in North Carolina reportedly averaged $200/use in restoration expense from 1975 to 1978 (3,12). A descending-grade arrester bed in the Siskiyou Mountains in Oregon averaged $25 in 1980 in repair costs for each use of the facility. In 1977 Versteeg and Krohn (5) reported $73/use as the average restoration cost on the two ascending-grade arrester beds on the Willamette Highway in Oregon. In Oregon the driver of the runaway vehicle is billed for this maintenance expense. These monies are used to restore the facility to its design state. Gravity ramps usually have no reported maintenance costs due to ramp use.

Other expenses are usually incurred in the act of removing the vehicle from the arrester bed or sandpile and in routine maintenance that is not a result of ramp use.

Among truck escape ramps, gravity ramps are closet to being maintenance-free, although rollback-induced jackknifing requires some maintenance. The only routine maintenance needed is that associated with the appurtenances for the ramp, e.g., signs and luminaires. All truck escape ramps require this type of maintenance (5).

All other truck escape ramps (i.e., those that have arresting material) require maintenance after each use. When a vehicle enters a facility, its wheels create ruts in the arresting material. These ruts must be eliminated and the shape of the bed must be restored before the next vehicle enters the bed or sandpile.

Predominantly single-sized aggregate is the best aggregate to use because it has good drainage characteristics. The arresting material must be replaced after it has accumulated too many fine particles (14). Replacement-interval requirements due to excessive fines are not currently well defined; thus related maintenance is performed only occasionally. Some facilities are built such that the arresting material is routinely expelled from the ramp during use; maintenance crews occasionally have to replace such material (2).

Sandpiles and arrester beds alike may require a deicing agent if the facility is in an area prone to freezing (6).

Environmental Influence

Truck escape ramps, other than gravity ramps, can be adversely affected by freezing temperatures because the aggregate may freeze to form a hard surface, although some facilities that incorporate arresting material have not had problems with freezing (3).

One ascending-grade arrester bed (15) was reported to have performed satisfactorily even when covered with a layer of snow. The thickness of the snow blanket is unknown, and the report reflects only one such incident.

Driver Comments

Different truck escape-ramp installations sometimes evoke different comments from truck drivers. A primary problem with gravity ramps is their inability to prevent a truck from rolling backwards after it has been brought to a stop. Articulated vehicles are vulnerable to jackknifing. Reportedly, truckers have expressed an unwillingness to use gravity ramps for fear of jackknifing, which leads them to the choice of riding out the grade, which frequently ends in serious consequences.

Several states have grades that have more than one truck escape ramp. Usually, where there are two or more facilities on a grade, they are a few miles apart. Bullinger (16) reports that, on grades that have two escape ramps, experience indicates that drivers prefer to use the lower ramp. This appears to point out the truckers' affinity for riding out a grade as long as possible.

Some truck drivers complain about the misuse of truck escape ramps (17). Passenger car motorists often mistake the safety feature for a roadside park, rest area, or the main line of the roadway. In addition, some four-wheel drive vehicles sometimes get entrapped in the arresting material while purposely playing in the facility (18). Such activity has two deleterious aspects: (a) the surface of the arrester bed or sandpile has been disturbed and consequently requires maintenance, and (b) such vehicles are in danger of being struck by a runaway truck that may enter the truck escape ramp for its intended use.

TRUCK ESCAPE-RAMP CHARACTERISTICS INDEPENDENT OF RAMP TYPE

Aside from the truck escape-ramp characteristics that are related to ramp type, there are other characteristics that appear to bear no relation to ramp type. The characteristics described in this section are of this type.

Design Equations

Analytical methods of determining ramp length are available in the form of design equations. A calculator program has been developed in Idaho (19) that uses an iterative approach toward a solution based on entering and final velocity, grade, friction, frontal area, and truck weight.

A design equation reported by FHWA (1) is simply

$$L = (V_i^2 - V_f^2)/30(R \pm G) \quad (1)$$

where

- L = distance (ft) of grade,
- V_i = velocity (mph) at beginning of distance L,
- V_f = velocity (mph) at end of distance L,
- R = rolling resistance (divided by 100) expressed as an equivalent percent gradient, and
- G = percent grade divided by 100.

The suggested values for rolling resistance are 0.15 and 0.25 for sand and pea gravel, respectively.

Sandpiles in Virginia are designed according to a formula that incorporates speed, friction, air resistance, grade, rolling resistance, a 90-mph entry speed, and a truck weight of 72,000 lb (17).

Because all of these equations and guidelines are based on entry speed, it is necessary to report what some escape-ramp designers use for design entry speed. The Roadway Design Manual in Colorado (20) uses 100 mph for truck escape ramps on the Interstate highway system. For all other highways in Colorado, a speed that is 40 percent greater than the highway design speed is used. Other research (1,16) recommends a design speed of 80 to 90 mph. These choices are in line with estimated speeds reported in the records of ramp use.

These equations and empirical guidelines represent all of the analytical design methods found in the current literature. It is difficult to identify which is the best method due to the lack of detailed development of the equations and guidelines in the literature; however, the FHWA equation is reportedly used by several designers (1,4,5,16).

Drainage Provisions

Sufficient drainage of arrester beds and sandpiles is usually a result of predominantly single-sized aggregate; however, some truck escape ramps require some type of pipe network. Different escape-ramp installations have different drainage requirements. Most truck escape ramps are free-draining. Gravity ramps need no special drainage provisions. However, truck escape ramps that have arresting material need some special attention.

In North Carolina the sandpiles of predominantly single-sized sand drain well and have not experienced problems with freezing (3,12). The sand also has been mixed with calcium chloride (a deicing agent).

Some arrester beds do not incorporate special drainage provisions other than the design of a sloped cross section (4), whereas others use perforated pipes or filter fabrics.

Aggregate Gradation

The best aggregate gradation for a truck escape ramp is one that is predominantly single sized. As an example of such gradation, one sample from the arrester bed at Mt. Vernon Canyon in Colorado has the following sieve analysis results:

Sieve Size	Percent Passing
0.75 in.	100
0.375 in.	91
No. 4	18
No. 10	5
No. 40	1
No. 200	1

The more descriptive characteristic of the aggregate is its maximum size. West Virginia uses a relatively large maximum size aggregate of 1.50 in. There are truck escape ramps throughout the United States that use 1.00-, 0.75-, or 0.50-in. maximum size aggregate (16).

At the other end of the spectrum, neglecting the very small percent passing values, 0.25-in. minimum aggregate is used in arrester beds in New York, Utah, and Idaho (4,8).

Although the the sand in the sandpiles in North Carolina is reportedly predominantly single sized, there is no documented information regarding gradation for sandpiles.

Depth of Arresting Material

It has been reported that arrester beds in Colorado that have 18- to 24-in. depths produced 12-in. ruts. These measurements indicate what may be a necessary minimum depth. Nevertheless, the different arrester beds throughout the country indicate that a variety of bed depths, as well as depth tapers, are currently in use.

Descending-grade arrester beds in Hawaii, Idaho, New York, and Texas have aggregate bed depths of 18 to 24 in. (8). The New York ramp has a tapered entry; i.e., the depth of the arrester bed increases as the vehicle travels into the gravel. This bed depth tapers from 0 to 24 in. and then back to 0 in. Two descending-grade arrester beds in Texas are also tapered at both ends; in the first 300 ft the depth increases from 0 to 18 in., and in the last 300 ft the depth decreases from 18 to 0 in. Care should be exercised in choosing the bed depth so that vehicles are not decelerated too abruptly.

Among roadside arrester beds, which are similar to descending-grade arrester beds, the depth of the aggregate bed is the same as for descending-grade arrester beds, namely 18 to 24 in. (14,18). Newton (2) suggests that roadside arrester beds have tapers at both ends, although all of them do not. The two roadside arrester beds in Nevada have depth tapers from 0 to 18 in. in the first 15 ft at the entry and 18 to 0 in. in the last 15 ft at the low end. The purpose for depth tapers at the low end of roadside arrester beds is to allow a vehicle that has traveled the entire length of the bed to be elevated back to the main line level for reentry onto the main line.

The aggregate beds in ascending-grade arrester beds vary. One such facility in Fulton County, Pennsylvania, has only a 6-in. depth. This truck escape ramp decelerates the vehicles solely by gravity for a distance of 924 ft and then uses the 636-ft-long shallow arrester bed. The ascending-grade arrester bed at Rabbit Ears Pass in Colorado is relatively shallow; it tapers from 4 to 12 in. The third ramp of an ascending-grade arrester bed at Lewiston Hill in Idaho has a 30-in. uniform depth.

The depth of sandpiles always increases from the entry to the far end because the base of the sandpile descends as the main line descends, and the top surface of the sandpile is usually level. The sandpile near Kittanning, Pennsylvania, which is composed of pea gravel, has a maximum height of 11 ft.

As with other truck escape-ramp design elements, there is a wide variety of depths and tapers among the existing truck escape ramps. Research that defines the optimum depth of aggregate for various types of ramps and aggregates is lacking.

Truck Removal

In order to easily remove trucks from escape ramps, many truck escape ramps are equipped with a service lane or shoulder and tow anchors, which allow tow trucks to be anchored while pulling the arrested vehicle from the bed. The types and widths of service lanes and shoulders vary among the types of truck escape ramps. In addition, not all facilities have these truck removal appurtenances.

Secondary Retarders

Because of the possibility of a high-speed vehicle traveling through the entire length of the truck escape ramp, some states have placed a secondary attenuator at the end of the ramp so that, if all else fails, the vehicle will stop and not travel beyond the length of the ramp (8,15,17). States use different types of retarders, including gravel berms, standard crash cushions, and specially designed sand barrels, such as those shown in Figure 5.

The use of secondary retarders should be approached with caution because little or no safety research exists on the use of such devices in truck escape-ramp applications. Therefore, care should be exercised when using such retarders to ensure that the safety of the occupants of heavy vehicles is increased, not jeopardized.

Location on Grade

The selection of the location on the grade for a truck escape ramp is critical. Considerations include how far the escape ramp is from the summit, whether it is above or below the halfway point on the grade, and where it is with respect to a critical grade change. States have different ideas on what site criteria are significant.

In New York a truck escape ramp is located as near the base of the grade as possible. In Hawaii the escape ramp is constructed near a downhill tangent section just before a horizontal curve. In Colorado the location is site determined, i.e., such a decision must be made for each problem grade. It is recommended in Oregon that the location be approximately 4 miles from the summit. Eck (21) reports that truck escape ramps near the summit are seldom used.

Erickson (15) reports that experience in Colorado indicates that 70 to 80 percent of runaway trucks will be intercepted by a truck escape ramp 3 to 4.5 miles from the summit. However, no documented data are provided regarding how this conclusion was developed.

Sandpiles are located 3.3 and 3.4 miles from the summit on US-70 in North Carolina. The upper sandpile is located 1.3 miles downhill from a truck brake check area (12). The sandpile on US-421 in North Carolina is 3.4 miles from the summit and 0.3 mile uphill from a narrow bridge that is immediately followed by a sharp horizontal curve (3). A sandpile north of Roanoke, Virginia, is located just before an 18° curve (9).

A descending-grade arrester bed in Leslie County, Kentucky, is located at an approach to a T-intersection, and one on NY-28 in New York is located just uphill from a village (8).

Lewiston Hill in Idaho has six truck escape ramps; one is located 1 mile below a grade change from 6 to 7 percent, where some runaway truck accidents have occurred.

Some reports identify the location on the grade by the distance of the escape ramp from the summit, and others do so by its distance from another escape ramp on the grade.

Left- or Right-Hand Exit

There is some debate regarding left-hand versus right-hand exits on a divided highway. Arguments supporting the former are based on the idea that speeding runaway trucks operate in the fast lane (i.e., the left lane) and therefore would not have to maneuver around other vehicles to enter a ramp to the left of the main line. Conversely, proponents of right-hand exits maintain that left-hand exits violate driver expectancy (6).

Figure 5. Sand-barrel impact attenuators on pedestals at end of the truck escape ramp on NY-28 in New York.

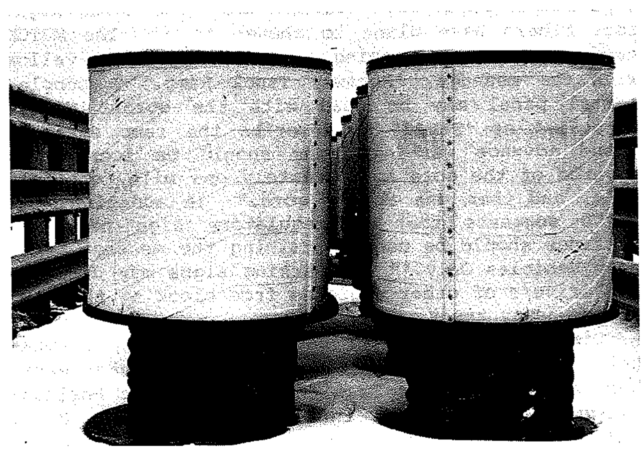
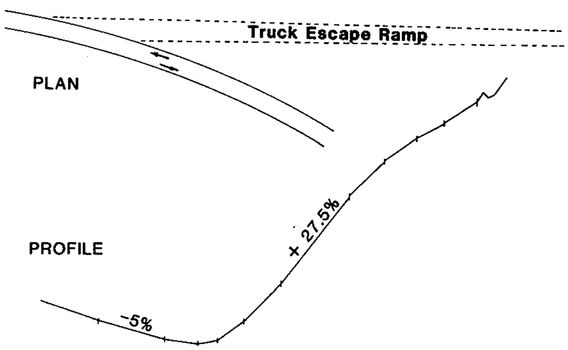


Figure 6. Schematic views of left-hand escape ramp on US-16 in Wyoming.



All truck escape ramps in the United States exit to the right of the main line, with the notable exceptions of those in the median of a divided roadway and some unusual designs in Wyoming. Parley's Canyon in Utah has a horizontal-grade arrester bed in the median. This design was incorporated into the construction plans when the I-80 facility was in the planning stages (4).

Wyoming has three ascending-grade arrester beds that exit to the left side of two-lane undivided highways on US-16 and in Teton Pass. One of these is shown in Figure 6 (21). Such a design obviously means that the runaway truck must enter opposing lanes of traffic. The Wyoming State Highway Department believed that the probability of a truck colliding with a vehicle traveling in the opposing direction as the truck heads for the left-hand ramp is no greater than the probability of the truck striking a vehicle as the driver tries to maneuver the runaway vehicle down the grade by using both lanes. In other words, without a truck escape ramp at all, the runaway truck uses both lanes of the two-lane highway in negotiating the grade, and this could bring the truck into opposing traffic just as using a truck escape ramp with a left-hand exit would. It is important to realize that these highways have low traffic volumes.

Signing

A dual signing continuum is necessary on a steep downgrade. One system of signs informs truckers of the danger of the upcoming downgrade and, where it exists, the location of the brake check area. The second sign system guides the driver of a runaway truck into the truck escape ramp (17).

Before the issuance of the 1978 Manual on Uniform Traffic Control Devices (MUTCD) (22), there was little uniformity in advance signing for truck escape ramps. Today most states follow the MUTCD signing; others have plans to change to it. The MUTCD mandates that the signing "shall be black on yellow with the message, 'Runaway Truck Ramp.' A supplemental panel may be used with the words 'Sand,' 'Gravel,' or 'Paved' to describe the ramp surface. These advance warning signs should be located in advance of the gore approximately one mile, one-half mile, and then one at the gore." In addition, the MUTCD suggests that a "regulatory sign near the entrance should be used containing the message 'Runaway Vehicles Only.'" No Parking signs may discourage drivers of other vehicles from blocking the path of a runaway truck.

The roadside arrester bed in the Siskiyou Mountains in Oregon on I-5, the ascending-grade arrester bed near Rabbit Ears Pass in Colorado, the horizontal-grade arrester bed in Parley's Canyon in Utah, and a descending-grade arrester bed on Mullan Hill in Idaho are among those escape ramps that use MUTCD signing (4,14,15). Some truck escape ramps have signs that are not found in the 1978 MUTCD. Some of these facilities are described in the following paragraphs.

The Parley's Canyon truck escape ramp is located in the median; hence the exit is to the left. Because this violates driver expectancy, all signs, including an advance sign 2 miles uphill from the ramp entrance, have arrows pointing at a diagonal toward the lower left (4).

The ascending-grade arrester bed with the left-hand exit on US-16 between Buffalo and Tensleep in Wyoming has a special signing requirement--there are warning signs that inform drivers climbing the grade that they may encounter a runaway truck in their lane.

Delineation

Delineation at the approach of a truck escape ramp is important in that the driver of the runaway truck must be properly led into the ramp and yet other motorists must not be mistakenly led off the main line into the escape ramp. The MUTCD (22) provides pavement marking, object marker, and post-mounted delineator designs for use throughout the highway system. But because of the dual criteria required for truck escape-ramp delineation, special attention is necessary.

Williams (17) suggests that some new type of delineation mechanism be developed that is different from the standard yellow and white delineators. It is believed that motorists observing standard color delineators can mistakenly be led into the truck escape ramp. To remedy this problem, Williams suggests red delineators. Pennsylvania will soon be experimenting with just such a delineation method.

Backup Measures

In the event a truck escape ramp is occupied, a backup measure is needed. In the current inventory of facilities there are two backup measures: (a) the truck escape ramp is designed to be wide enough for more than one vehicle to occupy it simultaneously, and (b) a second truck escape ramp is constructed downstream from the first.

Some sources (1,23) use trucks with wheel bases of 40 to 50 ft as the design vehicle. Because these trucks are 8.5 ft wide (23), the width of the arrester bed is suggested to be 26 ft or more. This constitutes a backup measure.

The second backup method is the construction of a second facility nearby. A sandpile in North Carolina was constructed solely as a backup measure (12). In the Rocky Mountains some steep, long grades have more than one truck escape ramp, e.g., Lewiston and White Bird Hills in Idaho, Willamette Highway in Oregon, and the hill on US-50 near Carson City, Nevada. Such multiple facilities function as backups.

Gravity ramps usually do not need backup measures because the time of occupancy in the ramp is generally short compared to arrester beds and sandpiles, which usually hold vehicles for a few hours before the vehicle is finally back onto the hard surface (6). However, if a truck jackknifes in a gravity ramp, the time of occupancy can be high.

Regardless of the type of backup measure, the truck escape ramp should be designed such that the driver of a runaway truck can see the entire ramp to know whether it is occupied or not.

Grades

The grades of the various truck escape ramps differ because of the terrain at the sites. Sandpiles, gravity ramps, and arrester beds use a variety of grades.

Most sandpiles in North Carolina have horizontal top surfaces; however, some newer sandpiles in that state have ascending-grade tops. This may be a less-acceptable design because the front ends of the trucks tend to dig into the sand, which results in damage to the truck.

The gravity ramp with the steepest slope is the 1,200-ft ramp in Franklin County, Pennsylvania, which has a +21.5 percent grade (17). The flattest gravity ramp is also in Pennsylvania; it is the lower ramp on Boot Jack Hill. This ramp is composed of two grades: a +6 percent grade followed by a +13 percent grade.

The steepest truck escape ramp in the United States is the ascending-grade arrester bed at Rabbit Ears Pass in Colorado. It has a +42.8 percent grade, which follows a +2.64 percent grade (15).

The steepest descending-grade arrester bed is on NY-28 east of Utica, New York. This facility is on a -10 percent grade. Williams (17) describes a -2.5 percent grade on the 800-ft descending-grade arrester bed west of Buffalo, Wyoming, on US-16. Other descending-grade arrester beds are on grades between these two extremes (14,16,22).

The roadside arrester bed in the Siskiyou Mountains in Oregon is constructed on a -5.5 percent grade (14). The Mt. Vernon Canyon roadside arrester bed in Colorado is on a -5.6 percent downgrade (13).

It is evident that some types of truck escape ramps may be found with a variety of grades. Conversely, other types (i.e., roadside arrester beds) are generally built with similar grades.

CONCLUSIONS

Although truck escape ramps have been present in the United States since 1956 (17), it has been only recently that the state of the art has witnessed accelerated advances. Literature on the details of design and operation of the various escape ramps is generally scattered among transportation agencies.

The characteristics of many of these escape ramps have been discussed in this paper. These characteristics include physical dimensions, arresting material, maintenance, cost, design equations, drainage, truck removal, signing, delineation, and gradient.

The individual truck escape ramps in the United States present alternative responses to each of the characteristics just mentioned. This indicates that optimum designs may not yet be identified, and there is still opportunity for further advancement in truck escape-ramp technology.

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Designing Highways for Buses: The New Jersey Experience

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In this paper a procedure and set of criteria for accommodating bus operations through transit-sensitive highway design are described. A set of bus operational needs (including bus stopping, passenger waiting, and bus priority requirements) are compared with the current arterial highway design standards and features used by the New Jersey Department of Transportation. Bus needs that are not accommodated by standard highway design are described, including bus turnouts, pedestrian-actuated crossing signals, and bus priority lanes. The transit impact review process includes an evaluation of current and future bus needs, a determination of whether the proposed highway design will serve those needs, and identification of those highway projects that require highway design changes to better accommodate bus needs. The approach taken stresses the joint effort of highway engineers and transit planners in order to (a) evaluate the transit impact of proposed highway improvement projects and (b) suggest workable design modifications.

The provision of bus priority measures through highway design has received considerable attention in transportation research literature during the past decade. Demonstration projects that involve bus priority lanes, bus preferential ramp metering, and traffic signal preemption are among the specialized design elements through which highway design engineers have shaped the transit system environment (1).

Despite the increased interest in strategies for bus operating performance through highway design, most highway designs that are sensitive to bus operating needs involve specialized additions or modifications to the original highway elements. In New Jersey the design of state highways has not specifically considered the needs of existing or future (potential) bus operations. Although the highway project approval process traditionally called for an evaluation of impacts on transit, this review admittedly did not relate the needs of a bus operation to the highway design standards as required by the state.

Criteria for establishing an approach to better accommodate bus operations are outlined in this paper, and a modified highway project approval process for determining situations where existing highway design standards can accommodate bus operations is described. The process further requires that both the lead unit of the New Jersey Department of Transportation (NJDOT) for the highway project and transit planners from the New Jersey Transit Corporation (NJ TRANSIT) share the task of identifying those projects that may require specialized highway design elements in order to properly accommodate bus operating needs. Other states should find this planning approach to transit-sensitive highway design applicable to their respective transportation departments' procedures.

BACKGROUND

The motivation to develop a transit sensitivity process came from an arterial highway project that affected a major commuter bus corridor. Route 9 is a north-south arterial highway that runs the length of eastern New Jersey. The central portion, which traverses Middlesex, Monmouth, and Ocean counties, varies in paved width from a two-lane undivided roadway to a six-lane arterial highway with a median barrier.

The most heavily traveled commuter bus corridor in New Jersey operates on nearly 40 miles of Route 9 in central New Jersey. The various routes operating on Route 9 serve daily passenger trips to and from destinations in Newark, Jersey City, and New York City. Commuter bus passengers represent more than 50 percent of the total passenger volume carried on Route 9 during the peak period.

For these reasons, the impact of highway widening projects on Route 9 became a concern of transit planners at NJ TRANSIT. Because NJ TRANSIT is a new agency, this concern developed after the highway design process for widening Route 9 in Middlesex County had been completed. The particular project replaced an existing grass median with a concrete median barrier and created an additional travel lane by removing the existing shoulder lanes. The completed project had several adverse impacts on bus operations. The removal of the shoulder lanes resulted in the elimination of two major commuter bus stops and the discontinuance of a bus priority lane on the shoulder during the morning peak period. The concrete barrier, which was unbroken for a distance of 1.5 miles, prevented bus passengers from safely crossing the highway, which contributed to the elimination of a southbound bus stop.

Because the project did not require additional right-of-way acquisition, it was classified as a categorical exclusion project. As such, the project was excluded from the more detailed environmental reviews required for major projects because of the relatively minor impacts on the community. However, the waiving of standard highway design features such as shoulder lanes and vehicle turnarounds (which afford breaks in the median barrier) resulted in adverse impacts on existing bus operations.

To cope with the dislocation created by the highway improvements, NJDOT staff worked with NJ TRANSIT staff to negotiate needed accommodations, which included temporary bus loading areas, a permanent bus turnout, and a commuter priority lane for high-occupancy vehicles during the commuter peak period. This cooperative effort led to the development of evaluation criteria and a process for accommodating bus operating needs in the highway design process.

TRANSIT NEEDS CRITERIA AND REVIEW PROCESS

The criteria for evaluating the impact of highway