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HEAVY VEHICLE ESCAPE RAMPS-- A REVIEW OF CURRENT KNOWLEDGE

April 1982
Final Report

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FOREWORD

This report presents a review of current literature regarding truck escape ramps. Good aspects as well as shortcomings are presented for the various types of truck escape ramps. These types are sandpiles, gravity ramps, ascending grade arrester beds, horizontal grade arrester beds, descending grade arrester beds, and roadside arrester beds.

Because little research has been performed in many of the areas within truck escape ramp technology, suggested topics for future research are provided as are interim design guidelines.

Thanks are extended to the many state transportation agencies which supplied much of the information cited in this report. Also, the authors are indebted to the Idaho Transportation Department, the New York State Department of Transportation, and the North Carolina Department of Transportation for their supplying this report with photographs of truck escape ramp facilities.

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16. Abstract

The objectives of this study are to: (1) review current truck escape ramp literature; (2) document all acceptable designs; (3) determine any and all shortcomings in the current method of arresting heavy vehicles and recommend specific research needs to eliminate these deficiencies; and (4) develop a framework of information, criteria, and specifications concerning truck escape ramps such that national design standards may later be developed.

Pertinent literature from all available sources, e.g., professional meeting proceedings, state transportation agencies' design plans and research studies, was gathered and critiqued for acceptable and poor design aspects. These design aspects are manifested in six types of truck escape ramps: sandpile, gravity ramp, ascending grade arrester bed, horizontal grade arrester bed, descending grade arrester bed, and roadside arrester bed.

Each of the truck escape ramp types has some design elements, e.g., length, width, depth, signing, etc., for which there are still many unanswered questions. Thus, there are several topics suggested for future research. In addition, interim guidelines are provided for the design of truck escape ramps.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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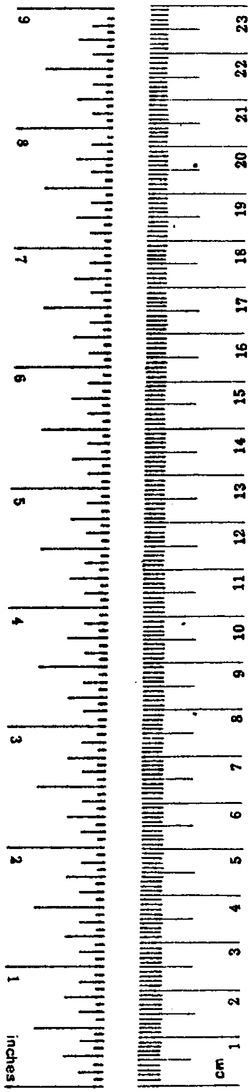
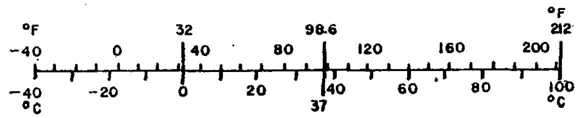
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This document constitutes the Phase II final report for the Federal Highway Administration under Contract DOT-FH-11-9342. The study was conducted by Southwest Research Institute.

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SECTION I

INTRODUCTION

Many states have provided escape ramp facilities for the purpose of reducing the runaway truck hazard on long, steep downgrades. These ramps are used by vehicles which have lost their braking capabilities and are out of control. They allow the runaway vehicle 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 in recent years that states have accelerated the advancement of truck escape ramp technology and construction.

State transportation agencies have largely designed their truck escape ramps based on the experiences of other successful truck escape ramps. This has sometimes been coupled with what the designers intuitively felt would improve the operation of the facility (1). Such an empirical method of design may not be conducive to developing the best design for a given escape ramp need.

A second problem with current truck escape ramp technology is the lack of national standards. Currently, interim guidelines for designing truck escape ramps do exist (2) or are being developed for inclusion in the new AASHTO policy statement (3). However, interim guidelines are not national standards; they are, in fact, temporary aids for use until acceptable national standards are approved. The many variables that go into truck escape ramps can create so many combinations with varying degrees of effectiveness that a truck driver may not know what to expect when entering a facility. Although total standardization is not feasible due to the variety of situational possibilities arising from factors such as differences in topography and availability of arresting material, a degree of standardization can be attained. Advantages to standardization include providing drivers of runaway vehicles with consistency and uniformity so that upon approaching a truck escape ramp, the driver can adequately anticipate the performance of the ramp via "word-of-mouth" communication with drivers who have used escape ramps previously (4). Another advantage to standardization is the elimination of truck escape ramps that are unacceptable or substandard.

Because of the problems of an empirical, rather than an analytical, method of design and the lack of a nationwide standard, this study has as its objectives the identification of current truck escape ramp technology, the identification of acceptable designs presented in the applicable literature, the presentation of interim guidelines for use in forming a framework for future national standards, and the recommendation of future research in the area of truck escape ramps.

SECTION II
CHARACTERISTICS OF CURRENT DESIGNS

The term, "truck escape ramp," encompasses up to 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, as illustrated in Figures 1 and 2. All of these function according to at least one of two basic methods of vehicle deceleration. In one method, vehicles are decelerated by directing the vehicle such that the major force acting against the direction of movement is gravity. The gravity ramp and the ascending grade arrester bed utilize this method. The other method uses some form of arresting material, 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, including some gravity 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 sandpile's surface may or may not be covered with transverse ridges. The profile of a typical sandpile is exhibited in Figure 1. When a vehicle enters such a truck escape ramp, the arresting material increases rolling resistance against the tires and, if the vehicle sinks far enough, against the undercarriage.

A gravity ramp consists of a hard surfaced lane which is on an ascending grade and 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 a possibility that an articulated vehicle may roll backward and jackknife. Vehicles which enter gravity ramps are decelerated primarily by the force resulting from gravity acting opposite to the direction of movement.

Truck escape ramps which 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 which has a bed of arresting material of some type of sand or gravel. The arresting material and gravity contribute to the deceleration of a vehicle which has entered the ramp. Horizontal grade arrester beds are truck escape ramps which are approximately level. For the purposes of classification in this study, grades up to ±2 percent are defined as horizontal. The deceleration of vehicles in these ramps is a result of the rolling resistance provided by the aggregate. Gravity offers no assistance to decelerate vehicles in horizontal grade arrester beds. 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 which is similar to the descending grade arrester bed is the roadside arrester bed as shown in Figure 2. The latter is parallel and adjacent to the main line with provisions such that a vehicle may

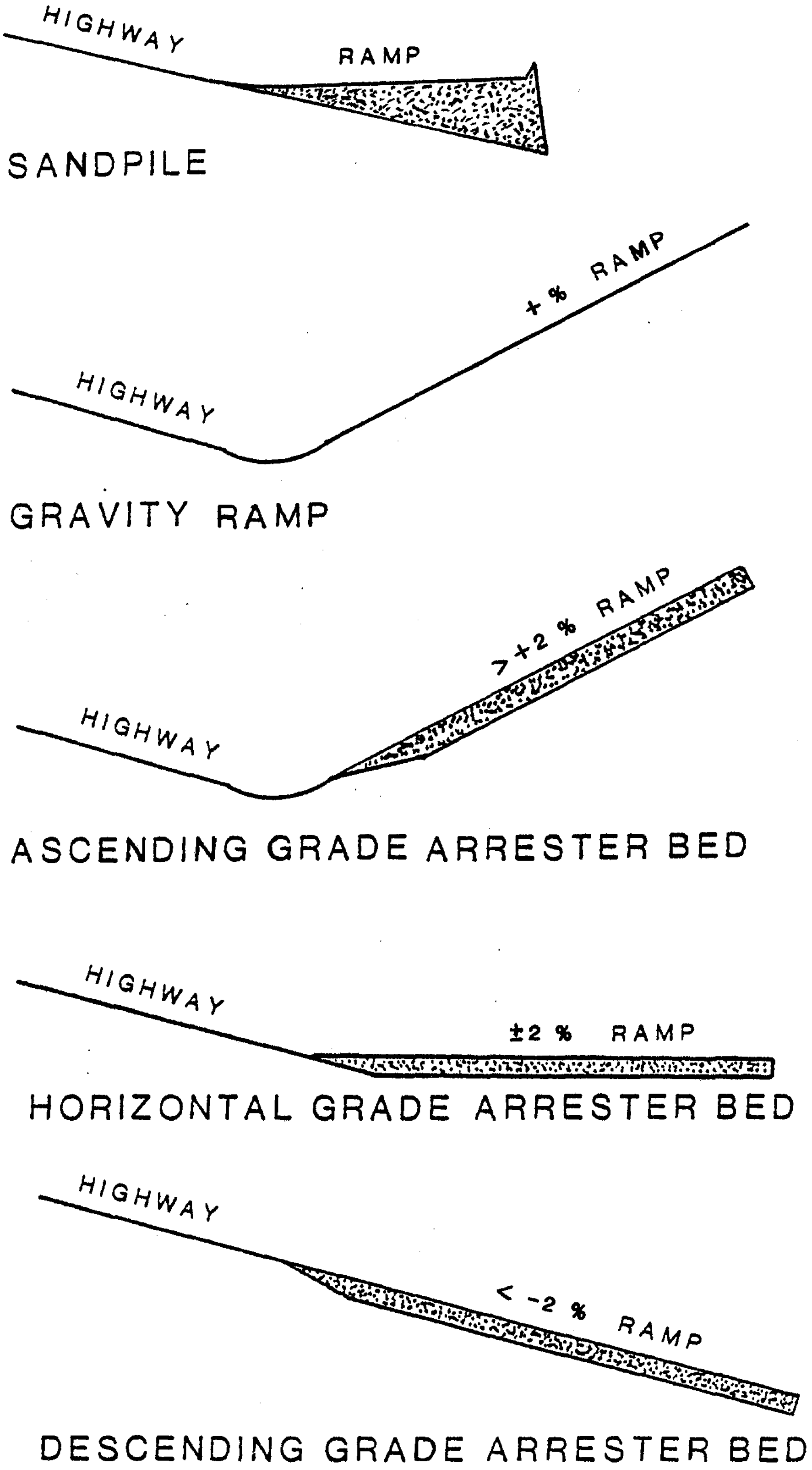


Figure 1. Five types of truck escape ramps.
Source: Modification of figure in Reference (2).

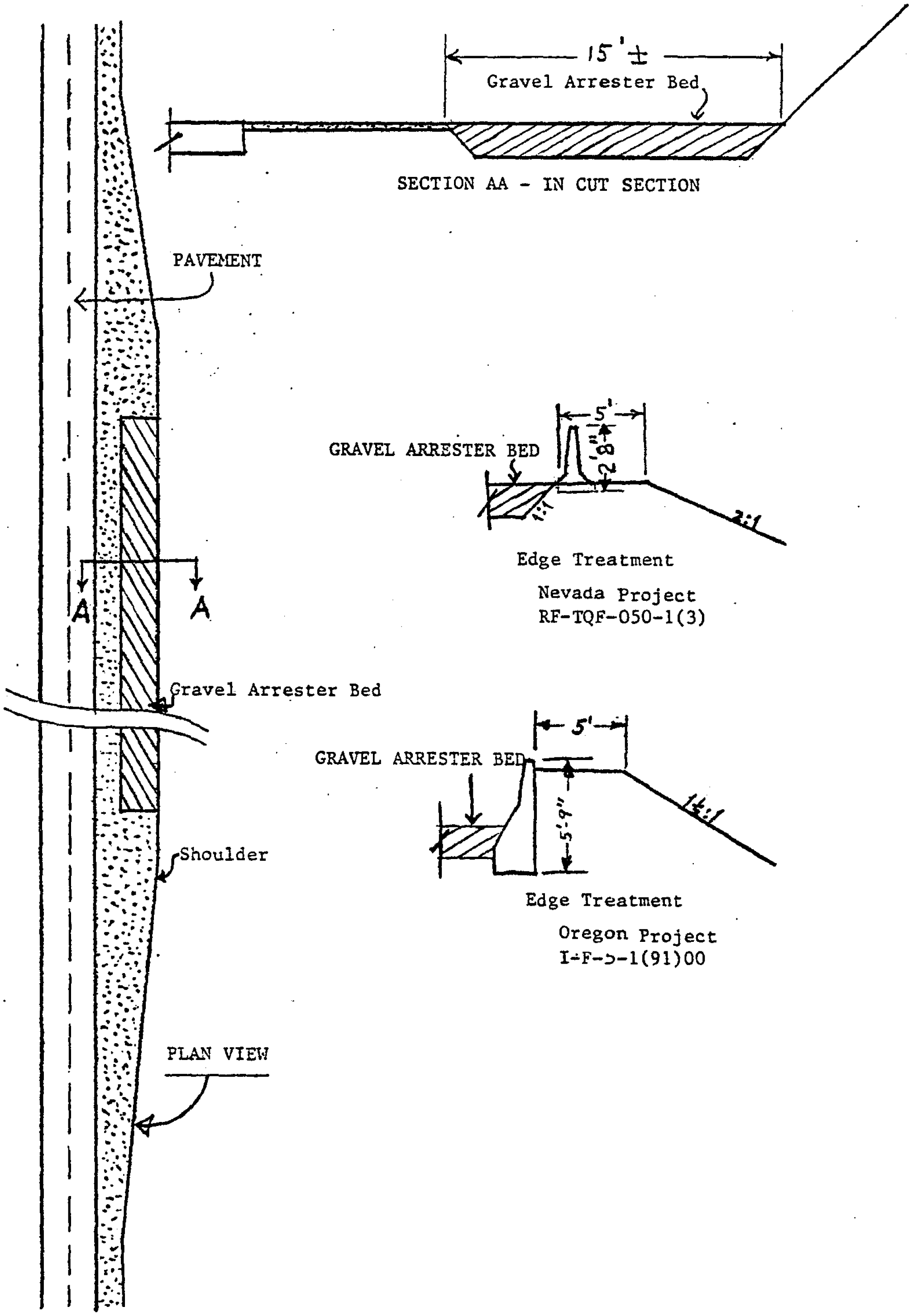


Figure 2. Roadside arrester bed.
Source: Reference (5).

enter from the side, as well as the upstream end, of the arrester bed.

Many truck escape ramps have multiple grades. For example, the facility at Rabbit Ears Pass, Colorado, has an arrester bed which begins on a -6.5 percent downgrade and then transitions to a +2.7 percent upgrade followed by a +42.8 percent upgrade (6). Because most of the arresting of a high-speed vehicle occurs on the ascending portions of this truck escape ramp, it is classified as an ascending grade arrester bed.

Every 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 design or an inadequate design.

For this reason, it is necessary to consider many design features. These include such areas as topographic, geometric, positional, and truck removal characteristics. In addition to the design features, other truck escape ramp considerations include cost items, maintenance, and driver comments. The purpose of this section is to identify the characteristics of the truck escape ramps in use today.

2.1 Truck Escape Ramp Characteristics Which are Associated with Ramp Type

All truck escape ramp characteristics can be categorized as being associated with a certain ramp type or independent of the ramp type. Table 1 illustrates typical characteristics which are associated with specific ramp types. This table was compiled from information presented in the current pool of truck escape ramp literature and, therefore, does not encompass every truck escape ramp currently in use.

2.1.1 Length

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

The shortest truck escape ramps are the sandpiles which are usually less than 400 ft in length. The shortest facility specifically cited in the literature is on US-421 in North Carolina and is only 210 ft long. However, Crowe (7) points out that such a length should be expanded to 400 ft to avoid a high-speed vehicle from passing completely through the sandpile.

Gravity ramps are typically long. Because these facilities have only limited means of decelerating runaway vehicles other than gravity, they are required to be lengthy. Pennsylvania has gravity ramps of 1200, 1525, and 1550 ft (8), and Hawaii has one that is 1300 ft long.

Table 1. Typical escape ramp characteristics associated with different ramp types.

	DESIGN FEATURES				COST ITEMS		OTHER CHARACTERISTICS			
RAMP TYPE	Ramp Length	Ramp Width	Arresting Material	Surface Ridges	Initial Cost	Maintenance Costs	Maintenance Required	Environ. Influence	Driver Comments	States
Sandpile	A_1	B_3,B_4	C_1,C_2	D_1	E_1	F_3	G_1,G_5,G_6	H_1	I_1,I_2	J_1
Gravity Ramp	A_3	B_1	C_4	D_2	E_4	F_1	G_5,G_8	H_2	I_1,I_3	J_2
Arrester Beds										
Ascending Grade	A_1,A_2,A_3	B_2,B_3,B_4	C_2,C_3	D_2	E_3	F_3	$G_2,G_4,G_5,$ G_6	H_1	I_1	J_3
Horizontal Grade	A_3	B_2,B_4	C_2	D_2	E_3	F_3	$G_2,G_3,G_4,$ G_5,G_6	H_1	I_1	J_4
Descending Grade	A_2,A_3	B_2,B_3	C_2	D_2	E_3	F_2	$G_2,G_3,G_4,$ G_5,G_6,G_7	H_1	I_1	J_5
Roadside	A_3	B_3	C_2	D_2	E_4	F_2	$G_2,G_3,G_4,$ G_5,G_6,G_7	H_1	I_4	J_6

See following pages for explanation of table code designators.

EXPLANATORY CODES FOR TABLE 1

DESIGN FEATURES

Ramp Length

A_1	$\leq$ 400 ft
A_2	401-1000 ft
A_3	> 1000 ft

Ramp Width

B_1	< 15 ft
B_2	15-19 ft
B_3	20-26 ft
B_4	$\geq$ 27 ft

Arrester Bed Material

C_1	Sand
C_2	Pea gravel (usually 1/4"-3/4" range)
C_3	Loose gravel
C_4	None

Surface Ridges

D_1	Surface ridges or mounds are present (these are usually transverse with respect to the direction of travel)
D_2	No surface ridges or mounds are present

COST ITEMS

Initial Cost

E_1	< $30,000
E_2	$30,000-$100,000
E_3	> $100,000
E_4	Unavailable information

Maintenance Costs

F_1	No costs
F_2	$\leq$ $100 per use
F_3	> $100 per use

OTHER CHARACTERISTICS

Maintenance Required

G_1	Reshape surface mounds after each use or monthly
G_2	Smooth out surface after each use or monthly
G_3	Replace arresting material that has been expelled from ramp
G_4	Replace contaminated arresting material periodically
G_5	Maintain ramp associated signs, luminaires, and other accompanying appurtenances
G_6	Apply deicing agent when needed
G_7	Recycle aggregate from low end of ramp back to upper end
G_8	Little maintenance required

Environmental Influence

H_1	Problem with freezing
H_2	No problem with freezing

Driver Comments

I_1	Ramp is often mistaken by motorists to be a rest area, roadside park, or the roadway's main line
I_2	Ridges should not be too high
I_3	Reluctant to use ramp for fear of rolling backwards and jackknifing
I_4	None associated with this ramp type due to lack of documentation and infrequent usage.

EXPLANATORY CODES FOR TABLE 1 (Continued)

States

J_1 States which have this type of ramp include North Carolina (7), Pennsylvania (9), and Virginia (10)

J_2 States which have this type of ramp include Alaska (11), Oregon (11), Pennsylvania (8), Vermont (11), Virginia (11), Washington (11), and Wyoming (11)

J_3 States which have this type of ramp include Colorado (12), Hawaii (13), Idaho (14), Kentucky (15), Oregon (11), Pennsylvania (11), South Dakota (16), Virginia (10), West Virginia (11), and Wyoming (17)

J_4 States which have this type of ramp include Idaho (11), Oregon (11), Tennessee (18), Utah (19), and Vermont (11)

J_5 States which have this type of ramp include California (20), Hawaii (13), Idaho (14), Kentucky (15), Montana (21), New York (22), South Dakota (16), Texas (23), and Wyoming (11)

J_6 States which have this type of ramp include Colorado (6), Idaho (14), Montanta (20), Nevada (5), and Oregon (24)

Ascending grade arrester beds exist with lengths from 330 ft to 1560 ft (8,13). The longest truck escape ramp is the 2480 ft horizontal grade arrester bed in Utah's Parley's Canyon on I-80. It is located in the median as shown in Figure 3. The length of this truck escape ramp is excessive due to the designers' assuming the rolling resistance provided by the aggregate was only 10 to 20 percent (19).

Descending grade arrester beds are generally longer than ascending grade arrester beds. Of course, the reason for this is the difference gravity makes in whether it works to the advantage or disadvantage of the deceleration process (20).

Most roadside arrester beds are quite long. The reason for this is this type of escape ramp, being adjacent to the mainline, always has a descending grade where gravity acts in opposition to the resistive forces. Colorado's Mt. Vernon Canyon's roadside arrester bed has a 2075 ft gravel bed, of which the last 325 ft has a sand barrel positive attenuator. This effectively reduces the standard aggregate bed length to 1750 ft (12).

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 in a subsequent section of this report.

2.1.2 Width

The width of a truck escape ramp is only loosely tied to the ramp type. However, ramp width is closely related to backup measures, i.e., alternatives for a runaway vehicle in the event that the truck escape ramp is already occupied. Because of this relationship, arrester beds and sandpiles typically need to be wider than gravity ramps, which are frequently 12 ft to 14 ft wide (25). Sandpiles and non-roadside arrester beds (i.e., 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. In a subsequent section of this report, the need for multiple occupancy width will be discussed. Newton (5) suggests roadside arrester beds, like gravity ramps, need not have widths adequate for multiple occupancy. Manifestations of such a suggestion are found in Colorado's Mt. Vernon Canyon roadside arrester bed, which has a width of only 20 ft, and Nevada's two roadside arrester beds on US-50, each of which are also 20 ft wide.

The other types of arrester beds generally have widths between 26 ft and 30 ft, although Tennessee's Monteagle Mountain horizontal grade arrester bed is 50 ft wide (18) and Hawaii's Pali Highway ascending grade arrester bed is 16 ft wide and tapers down to a 12 ft width at the end (13). There are other truck escape ramps which have tapered widths, e.g., New York's descending grade arrester bed on NY-28 which tapers from 18 ft to 12 ft in width (22). New York's idea in designing this escape ramp with this taper 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 constant.

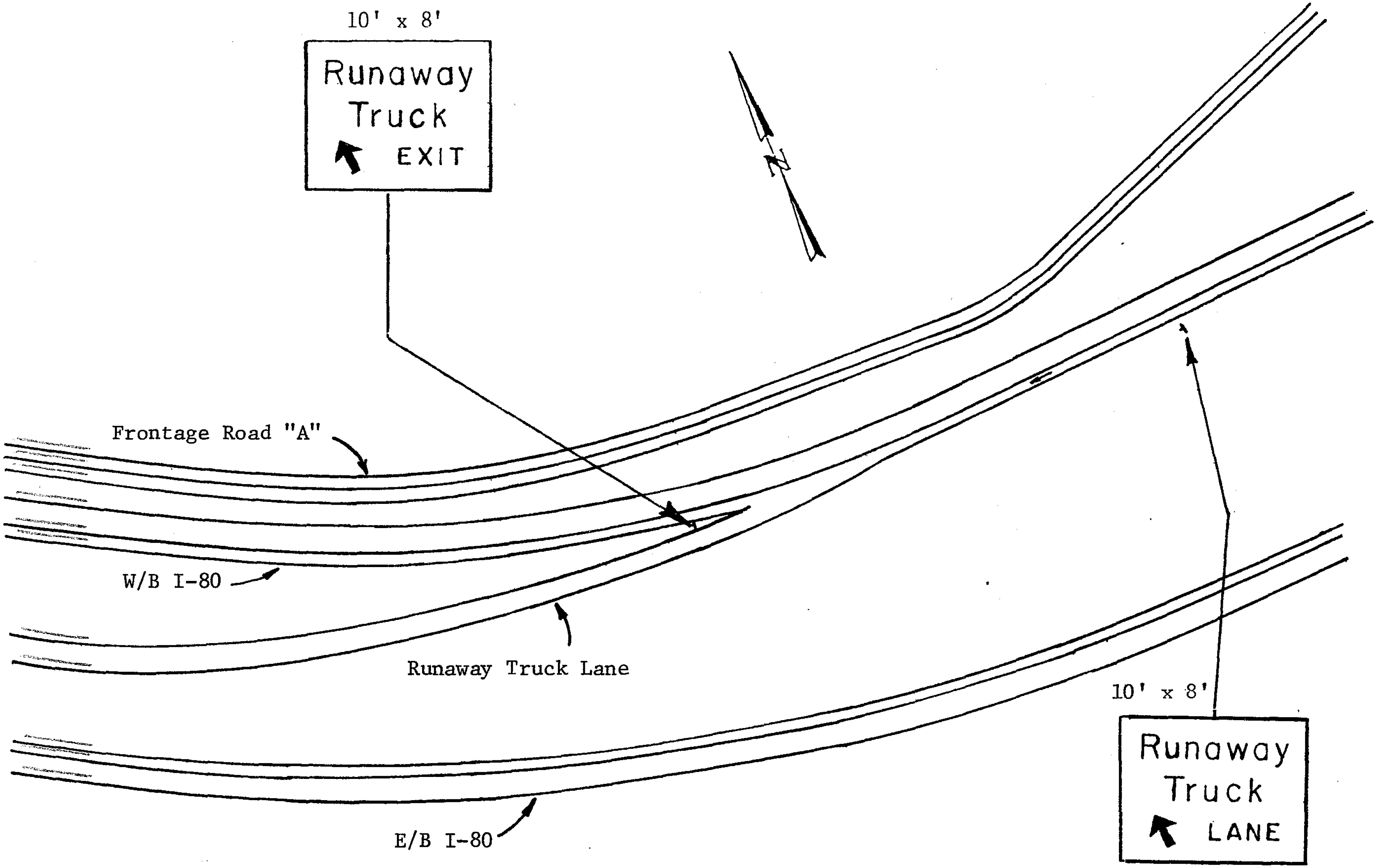


Figure 3. Horizontal grade arrester bed in Parley's Canyon, Utah.
Source: Modification of figure in Reference (19).

2.1.3 Arresting Material

One of the first applications of the term "sandpile" in describing a truck escape ramp was in Virginia (10). This was a good descriptor since the arresting material was, indeed, sand. Pennsylvania has truck escape ramps which are identified as sandpiles, yet none use sand; all Pennsylvania sandpiles utilize a form of gravel, most of which is pea gravel (9). These truck escape ramps are called sandpiles by virtue of their basic design, as illustrated in Figure 1, without regard to the arresting material.

Gravity ramps, of course, have no arresting material, by definition.

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, Hawaii's truck escape ramps use an angular aggregate because the more desirable pea gravel is unavailable at a reasonable cost (13). Applicable research on materials is discussed in greater detail in Section III.

2.1.4 Surface Ridges

North Carolina's and Virginia's early experiences with sandpiles prompted the addition of irregular mounds on the surface of the sandpiles (26). Arrester bed truck escape ramps have smooth surfaces although some states (27) have considered using transverse surface ridges. Experience has shown transverse surface ridges to be useful on sandpiles and research has shown them to be harmful on arrester beds. This is discussed further in Section III.

2.1.5 Initial Cost

The initial cost of a truck escape ramp is highly dependent upon several factors other than the basic ramp type. These factors include the amount of excavation required, the cost of right-of-way acquisition, and local labor costs. The type of truck escape ramp does affect the initial cost, as Table 1 indicates. Examples of costs of various ramp types are identified below.

Sandpiles are, by far, the cheapest truck escape ramp type. Virginia's two Route-52 sandpiles and its Route-33 sandpile were built in 1972 and 1975 for $10,000 each (10). North Carolina's sandpiles cost $25,000 each in 1974 and 1975 (28).

The initial costs of arrester beds vary greatly. Mt. Vernon Canyon's roadside arrester bed was constructed in 1979 in Colorado for $1,000,000, which makes it the most expensive truck escape ramp in the nation. This extraordinary cost is explained in that it also includes a television surveillance system at the ramp (29). Aside from this facility, the most expensive truck escape ramp is the lower of the two truck escape ramps on I-70 west of the Eisenhower Memorial Tunnel near Straight Creek Canyon in Colorado. That ascending grade arrester bed was constructed at a cost of $529,000 and opened in July, 1980 (6). Arrester beds' initial costs range from this half-million dollar amount down to $100,000, which was the cost of New York's only truck escape ramp (22,29).

Roadside arrester beds, because they 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, are reported to be generally less costly than other arrester bed designs (5). Depending on the type of truck escape ramp, the initial cost can be as low as $10,000 or as high as $500,000. It can cost even more as evidenced by Colorado's $1,000,000 escape ramp which included a television monitoring system.

2.1.6 Maintenance Costs

There is little documentation regarding maintenance costs of truck escape ramps. The information in Table 1 reflects the few values reported. The two sandpiles on US-70 and the one sandpile on US-421 in North Carolina reportedly average $200 per use in restoration expense (7,28). A descending grade arrester bed in the Siskiyou Mountains of southern Oregon averages $25 in repair costs for each usage of the facility (24). Versteeg and Krohn (20) report $73 per use as the average restoration cost on Oregon's two ascending grade arrester beds on the Willamette Highway. Oregon bills the driver of the runaway vehicle for this maintenance expense. These monies are used to restore the facility to its design state. Gravity ramps usually do not have any maintenance costs which are due to a particular ramp usage.

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

2.1.7 Maintenance Required

Of all the truck escape ramps, gravity ramps are closest to being trouble-free from a maintenance standpoint, although rollback-induced jackknifing requires some maintenance. The only attention they regularly need is the routine maintenance associated with the ramps' appurtenances, e.g., signs and luminaires. All truck escape ramps require this type of maintenance (20).

All other truck escape ramps, i.e., those which 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 before the next vehicle enters the bed or sandpile. Otherwise, the arresting mechanism created by the rolling resistance of the aggregate or sand may be hampered. In the case of truck escape ramps with transverse surface ridges, this means these ridges must be reformed after each use (28). On facilities without surface ridges, this means the surface must be smoothed out.

Because aggregate which is predominantly single sized is desirable, the arresting material must be replaced after it has accumulated too many fine particles (20). This type of gradation is preferred because of its good drainage characteristics due to its inability to be tightly packed. Replacement interval requirements due to excessive fines are not presently well defined and specified. As such, it can only be stated that this type of maintenance is performed only occasionally. Some facilities are built in a manner such that the arresting material is routinely expelled from the ramp during use; maintenance crews occasionally have to replace such material (5). Descending grade and roadside arrester beds have a special maintenance requirement because the vehicle enters these beds on the uphill end and the aggregate tends to pool at the low end. Therefore, maintenance crews must periodically "recycle" the aggregate from the low end back to the high end (30).

Sandpiles and arrester beds alike may require a deicing agent such as calcium chloride if the facility is in an area prone to freezing due to frequent cold and wet weather (25). Research on this subject is somewhat limited, and as such, detailed recommendations on the need for and use of deicing agents is not well documented.

These maintenance requirements illustrate the different types of maintenance associated with each ramp type, as shown in Table 1.

2.1.8 Environmental Influence

The relationship between the environment and the ramp type is strong but simple. The current literature pool does not comment on the effect of ice on gravity ramps, yet it may be expected that such an influence would adversely affect the performance of gravity ramps to some degree via the reduced coefficient of friction with truck tires. All other truck escape ramps can be adversely influenced by freezing temperatures in that the aggregate may freeze together and form a hard surface, although some facilities which incorporate arresting material have had no problems with freezing (7).

One ascending grade arrester bed (31) was reported to have performed satisfactorily even with a layer of snow covering it. The thickness of the snow blanket is unknown and the report reflects only one such incident.

Apparently, rain has had no significantly ill effects on truck escape ramps of any type.

Darkness is easily overcome with adequate illumination.

2.1.9 Driver Comments

Different truck escape ramp installations sometimes evoke different comments from truck drivers. Some of these are recorded in this subsection.

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 particularly vulnerable to jackknifing. Doughty (8) reports that truckers have expressed an unwillingness to use gravity ramps for fear of jackknifing and, consequently, losing their load. This leads them to the choice of "riding out" the grade, which frequently ends in harmful consequences.

Brittle (10) indicated that the truck escape ramps on I-77 in Virginia may not be used because the interstate highway's excellent alignment does not require truckers to use their brakes to the extent that they overheat. Because brake failure may be a rare event, the truck drivers may frequently ride out the grade.

Several states have grades which 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 (32) reports that under such conditions, experience shows that drivers prefer to use the lower ramp. This seems to point out the truckers' affinity for riding out a grade as long as possible.

In Alabama (11) and other states, truck drivers complain about the misuse of truck escape ramps. Often, passenger car motorists mistake the safety feature for a roadside park, rest area, or the roadway's main line. In addition, some four-wheel drive vehicles sometimes get entrapped in the arresting material while purposely "playing" in the facility (33). Such activity has two deleterious aspects: the surface of the arrester bed or sandpile has been disturbed and consequently requires maintenance; and secondly, such vehicles are in danger of being struck by a runaway truck which may enter the truck escape ramp for its legitimate and intended use.

Some truckers who have used sandpiles have expressed a desire for the height of the transverse surface ridges to be lessened (8). Such a comment would apply only to those facilities which had the highest transverse surface ridges. Similarly, another driver suggested that the depth of the aggregate in an ascending grade arrester bed should be lessened (15).

These comments made by truck drivers illustrate the influence human factors have on the use and operation of truck escape ramps.

2.1.10 States

Table 1 relates truck escape ramp type with states which have constructed these types. This list is not exhaustive, but it does indicate which states have various truck escape ramp types which are documented in the current pool of truck escape ramp literature.

2.2 Truck Escape Ramp Characteristics Which are Independent of Ramp Type

Aside from the truck escape ramp characteristics which are related to ramp type, as shown in Table 1, there are other characteristics which seem to bear no relationship with ramp type.

2.2.1 Design Equations

Analytical methods of determining ramp length are available in the form of design equations. Idaho (34) has developed a calculator program that uses an iterative approach toward a solution. The equation is as follows:

$$V = 5.469\ (.03343\ V_o^2 \pm H - KL - .000016\ V_m L - .0012\ FLV_n^2/W)1/2$$

where V = speed (mph) at the end of distance L

V_o = speed (mph) at the beginning of distance L

H = vertical distance (ft) corresponding to distance L

K = constant incorporating surface friction and speed-independent portion of mechanical loss: .01675 for pavement and .26175 for gravel bed

L = grade distance (ft)

V_m = average of V_o and V

F = frontal area of truck (ft^2)

V_n^2 = average of V_o^2 and V^2

W = truck weight (lb).

Another design equation is reported by the Federal Highway Administration (2) and is simply

$$L = \frac{V_i^2 - V_f^2}{30 \quad (R \pm G)}$$

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 equivalent percent gradient

G = percent grade divided by 100.

The values for rolling resistance, R, are found in Table 2.

The Institute of Transportation Engineers (25) suggests calculating the length of the arrester bed by either of the above two methods and then increasing that distance by 25 percent.

Bullinger (32) presents an equation which includes the effects of air resistance, rolling resistance, and gradient resistance:

$$L = \frac{0.0334 \; W \; V_o^2}{0.002 \; A \; (V_{avg})^2 + W \; (R \pm G)}$$

where L = distance (ft) of grade

W = weight of vehicle

V_o = initial velocity (mph)

A = frontal area (ft^2) of truck

V_{avg} = $(V_o + V_f)/2$

V_f = final velocity (mph)

R = rolling resistance (divided by 100) expressed as equivalent percent gradient

G = percent grade divided by 100.

Again, the values for rolling resistances of various materials can be found in Table 2.

Colorado (35) designs arrester beds according to the following equation:

$$L = \frac{V_i^2 - V_f^2}{5.98} - 5h$$

where V_i = initial velocity (mph)

V_f = final velocity (mph)

h = vertical distance - end elevation minus beginning elevation of ramp

L = horizontal distance - along total length of ramp.

Other procedures for determining length are reported by Williams (11). For example, data from California's Highway 99 gravity ramp, the first in the nation, was used to generate the following design guidelines:

Table 2. Suggested values for rolling resistance.

Surfacing Material	Rolling Resistance #/1000#GWV	Equivalent Grade % 1/
Portland Cement Concrete	10	1.0
Asphalt Concrete	12	1.2
Gravel Compacted	15	1.5
Earth, sandy, loose	37	3.7
Crushed aggregate, loose	50	5.0
Gravel, loose	100	10.0
Sand	150	15.0
Pea Gravel	250	25.0

1/ Rolling Resistance expressed as equivalent gradient

Source: Reference (2)

Runaway Speed - MPH		Stopping Dist. - Ft
Radar Recorder	Driver Estimate	Measured from Entrance
20-30	25-40	100-300
30-40	35-50	300-500
40-50	45-65	500-650
50-65	60-80	650-700
65-70	75-90	700-750

Virginia designs its sandpiles according to a formula which was developed by the Virginia Department of Highways and Transportation (11). The formula, which incorporates speed, friction, air resistance, grade, 50 lbs per ton rolling resistance, a 90 mph entry speed, and a truck weight of 72,000 lb, produced the following guidelines:

Ascending Grade %	Resistance	Length Required Linear Ft
10	.10	2,080
15	.15	1,500
20	.20	1,175
25	.24	1,000
30	.29	820
35	.33	750

All of these equations and guidelines require or are based on entry speed as an input parameter. Consequently, it is incumbent to report what some escape ramp designers choose for design entry speed. Colorado's Design Manual (35) employs 100 mph for truck escape ramps on the interstate highway system. For all other highways, Colorado uses a speed which is 40 percent greater than the design speed of the highway itself. FHWA (2) and Bullinger (32) recommend a design speed of 80-90 mph. These choices are reasonable in light of the estimated speeds reported in ramp usage records. Such records are discussed in a subsequent section of this report.

These equations and empirical guidelines represent all the analytical design methods that are found in the current literature pool. It is difficult to identify which is the best method due to the literature's general lack of detailed development of the equations and guidelines; however, the FHWA's equation is reportedly used by several designers (2,19,20,32).

2.2.2 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, of course, need no special drainage provisions. However, truck escape ramps which have arresting material may need some special attention in this area.

In North Carolina, the sandpiles which utilize fine, yet predominantly single sized, sand drain well and have presented no problems with freezing (7,28,36). The sand also has a deicing agent, calcium chloride, mixed with it (36).

Montana's descending grade arrester bed design includes a flat bottom drainage channel and no pipe network (21). Other facilities around the nation include pipes, e.g., the descending grade arrester bed on Idaho's Mullan Hill; this installation includes an 8 inch perforated pipe and a filter cloth (37). The ascending grade arrester bed in Lee County, Kentucky, is drained by a longitudinal and three lateral 6 inch perforated pipes (15). Several facilities (19,15,37) include in their drainage provisions a sloped cross section at the bottom of the bed. Nevada's upper roadside arrester bed on US-50 was constructed with an 8 inch downdrain and woven fabric. This was supplemented, in a retrofit application, with two French drains and a 12 inch slotted drain.

Thus, it is apparent that adequate drainage at different escape ramps is achieved by a wide variety of provisions ranging from free draining aggregate of a predominantly single size to relatively elaborate pipe networks.

2.2.3 Aggregate Gradation

The best gradation of truck escape ramp aggregate is one which is predominantly single sized. As an example of such a gradation, one sample from Colorado's Mt. Vernon Canyon arrester bed has the following sieve analysis results (12):

Sieve Size	Percent Passing
3/4 inch	100
3/8 inch	91
#4	18
#10	5
#40	1
#200	1

Because predominantly single size gradations for truck escape ramps are all similar to this, the more descriptive characteristic of the aggregate is its maximum size. Examples of various states' maximum size aggregate are described herein.

West Virginia uses a relatively large maximum size aggregate; Bullinger (32) reports this size as 1.50 inches. There are truck escape ramps in Pennsylvania, Oregon, Montana, Utah, and Colorado that use 1.00 inch aggregate. Colorado, Idaho, and Oregon have truck escape ramps with 0.75 inch maximum size aggregate. California, New York, South Dakota, and Oregon use 0.50 inch aggregate in some or all of their arrester beds (32).

At the small end of the spectrum, neglecting the very small percent passing values, 0.25 inch minimum aggregate is used in arrester beds in New York, Utah, and Idaho (19,22,37).

Although Crowe (36) reports the sand in North Carolina's sandpiles generally is predominantly single size, there is no documented information regarding gradation for sandpiles.

2.2.4 Depth of Arresting Material

Colorado (12) reported that uses of its arrester beds (having 18 to 24 inch depths) produced 12 inch ruts. These measurements indicate what may be a necessary minimum depth. However, the different arrester beds throughout the country indicate 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 inches (13,22,23,37). The New York ramp has a tapered entry, i.e., the depth of the arrester bed increases as the vehicle travels into the gravel. The bed depth at this particular facility tapers from 0 to 24 inches and then back to 0 inches. The taper back to 0 inches is considered necessary in New York's design because a positive attenuation device is present at the end and the designers desired to bring the vehicle back onto a hard surface in the crash cushion area. Figure 4 illustrates an arrested truck in this New York truck escape ramp. Texas' two descending grade arrester beds are also tapered at both ends; in the first 300 ft the depth increases from 0 to 18 inches and in the last 300 ft the depth decreases from 18 to 0 inches. One of the most unusual descending grade ramp designs is that in Leslie County, Kentucky, as shown in Figure 5. The aggregate depth increases from 0 to 120 inches over a distance of 520 ft. Kentucky's motivation in this design was to build a truck escape ramp that was deeper and thus better than some other designs (15). However, at least one trucker complained that his truck was decelerated unnecessarily abruptly (38).

Among roadside arrester beds, which are akin to descending grade arrester beds, the aggregate bed depth is the same as for descending grade arrester beds, namely, 18 to 24 inches. (24,33,39). Colorado's Mt. Vernon Canyon roadside arrester bed tapers from 0 to 24 inches, but does not return to 0 inches at the low end. Newton (5) suggests that roadside arrester beds have tapers at both ends. Nevada's (39) two roadside arrester beds have depth tapers from 0 to 18 inches in the first 15 ft at the entry and 18 to 0 inches 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 which has traveled the entire length of the bed to be elevated back to the main line level for reentry onto the main line.

Oregon's Siskiyou Mountains truck escape ramp on I-5, as illustrated in Figure 6, is much like a roadside arrester bed; although there is no barrier between the main line and the aggregate bed and the bed is approximately parallel to the main line, the aggregate bed has no tapering and has a uniform depth of 18 inches (40).

The aggregate beds in ascending grade arrester beds are quite varied. One such facility in Fulton County, Pennsylvania has only a 6 inch depth. This truck escape ramp decelerates the vehicles solely by gravity for a distance of 924 ft, then utilizes the 636 ft long shallow arrester bed (8). Colorado's Rabbit Ears Pass ascending grade arrester bed is relatively shallow; it tapers from 4 inches to 12 inches. Other ascending grade arrester beds have depths as follows: Lee County, Kentucky, and Carbon County, Pennsylvania, 18 inch uniform depth; Kalihi Valley, Hawaii, 24 inch uniform depth; and Idaho's Lewiston Hill's third ramp, 30 inch uniform depth.

Utah's Parley's Canyon horizontal grade arrester bed tapers from a 3 inch depth to a maximum depth of 12 inches (19) and Tennessee's Monteagle Mountain horizontal grade arrester bed uses a 36 inch bed depth (18).

The depth of sandpiles always increases from the entry to the far end. The reason for this is that the base of the sandpile descends as the main line descends and the top surface of the sandpile is typically approximately

Figure 4. Arrested truck in descending grade arrester bed.
Source: Reference (22).

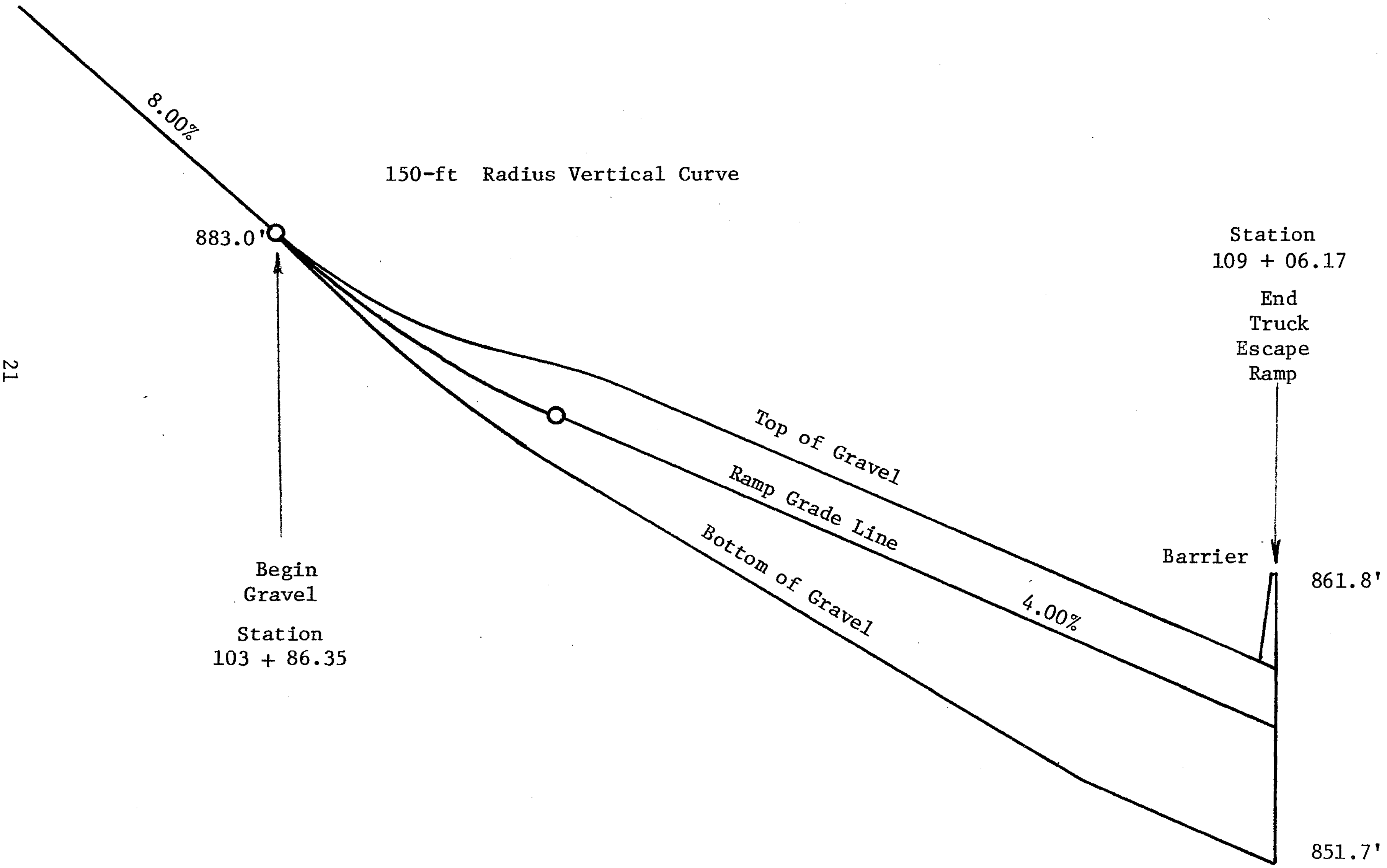


Figure 5. Truck escape ramp in Leslie County, Kentucky.
Source: Modification of figure in Reference (15).

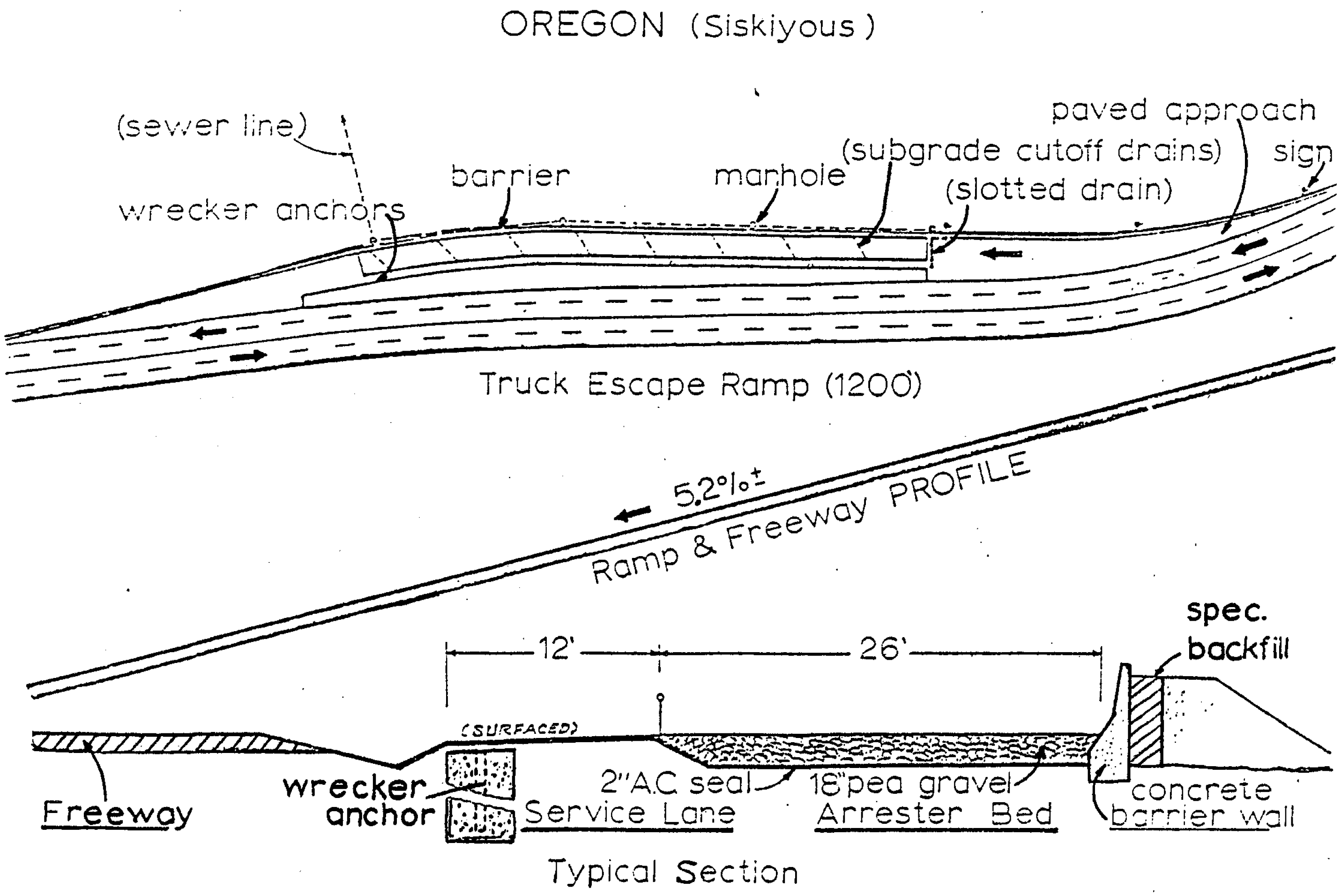


Figure 6. Roadside arrester bed on I-5 in the Siskiyou Mountains of Oregon. Source: Reference (39).

level. Crowe (36) reported that many North Carolina sandpiles have horizontal top surfaces, but some newer sandpiles have an ascending grade top surface. The sandpile near Kittanning, Pennsylvania, which is composed of pea gravel, has a maximum height of 11 ft (8). Williams (11) asserts sandpiles typically have heights of 10 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 defining the optimum depth of aggregate for various types of ramps and aggregates is lacking.

2.2.5 Lateral Constraints

Where the consequences of a lack of a lateral constraint on one or both sides is severe, such a constraint should be installed. As with conventional longitudinal barriers in the highway system, these lateral constraints should be included in the overall escape ramp design based on the elements of safety and economics. Examples of what some states have done in terms of lateral constraints are described herein.

There are several types of lateral constraints in use today at truck escape ramps. These range from New York's heavy triple W-beams on both sides of the descending grade ramp, as shown in Figure 7 (22), to no lateral constraints at all, as in Texas' two descending grade arrester beds.

Crowe (36) reported that North Carolina's sandpiles have no lateral constraints; however, they would be installed if the consequences of their absence were serious.

The Rabbit Ears Pass ascending grade arrester bed in Colorado has no lateral constraints (31). In contrast, ascending grade arrester beds in Alaska have 4 ft high gravel berms on each side of the arrester beds (20). The ascending grade arrester bed in Lee County, Kentucky has a guardrail on the fill side (15).

Among horizontal grade arrester beds, Utah's Parley's Canyon ramp has no barrier, but does have a 6 ft shoulder on one side and a 10 ft service lane on the other (19).

Descending grade arrester beds other than the New York and Texas ramps previously mentioned which have lateral constraints include Montana's ramp which uses heavy guardrail and Idaho's Mullan Hill which has concrete barriers located on both sides of the gravel bed (21,37). Truck escape ramps with lateral constraints on both sides may tend to trap snow within the ramp. However, there is no mention of this problem in current truck escape ramp literature.

Newton (5) suggests one concrete barrier for roadside arrester beds. Indeed, one roadside arrester bed in Nevada and one in Colorado employ a concrete safety shape barrier on the outside edge of the aggregate bed (33,39). The other roadside arrester bed on Nevada's US-50 grade has no barrier at all; it does, however, have a service lane situated on the outside edge of the gravel bed. The first ramp on that grade has, in addition to the concrete barrier, a 6 inch asphalt dike separating the bed from the main line (39).

2.2.6 Truck Removal

For ease in truck removal, many

Figure 7. New York's descending grade arrester bed on NY-28.
Source: Reference (22).

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

Some service lanes are paved and 12 ft in width, e.g., Siskiyou Mountains roadside arrester bed in Oregon and Nevada's two roadside arrester beds on US-50 (24,39). The roadside arrester bed at Mt. Vernon Canyon in Colorado has an 8 ft paved shoulder and the Lee County ascending grade arrester bed in Kentucky has a 10 ft paved service lane (15,31).

The service lane in Parley's Canyon in Utah is fully compacted gravel as opposed to paved (19). All 12 truck escape ramps in Pennsylvania are without service lanes.

Only four of the Pennsylvania facilities have tow anchors (8). The majority of truck escape ramps with tow anchors have them spaced approximately 300 ft apart. This distance allows most tow truck operators to make good use of the tow anchors.

2.2.7 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 (8,11,15,22,31). The variety of secondary retarders is wide; many states use different types of retarders, e.g., gravel berms, standard impact attenuators, and specially designed sand barrels. Examples of these follow herein.

Two ascending grade arrester beds on Oregon's Willamette Highway have pea gravel mounds at the ends to provide additional attenuation (40). The ascending grade Rabbit Ears Pass arrester bed in Colorado has a 5 ft mound of gravel at the end of the ramp (33). The ascending grade arrester bed in Lee County, Kentucky has no secondary attenuator. Yet the truck escape ramp in Leslie County, Kentucky employs a 5 ft high mound of gravel at the end (15).

The horizontal grade arrester bed in Utah has no secondary attenuator and does not need one since its 2480 ft length is more than sufficient for any of today's trucks at any attainable speed. The horizontal grade ramp on Tennessee's I-24 used to have bales of hay at the end of the bed for secondary attenuation (20). These were removed after trucks plowed through them without appreciably decelerating.

New York's descending grade ramp includes 88 sand-filled barrels in 11 bays placed on pedestals, as illustrated in Figure 8, so that heavy trucks with high centers of gravity will properly impact the impact attenuating barrels. There is a smaller, more conventional crash cushion placed directly in front of these 88 barrels. This presents a staged attenuator such that slow or small vehicles will not be unduly harmed by striking the higher, less yielding barrel configuration (22). The Mullan

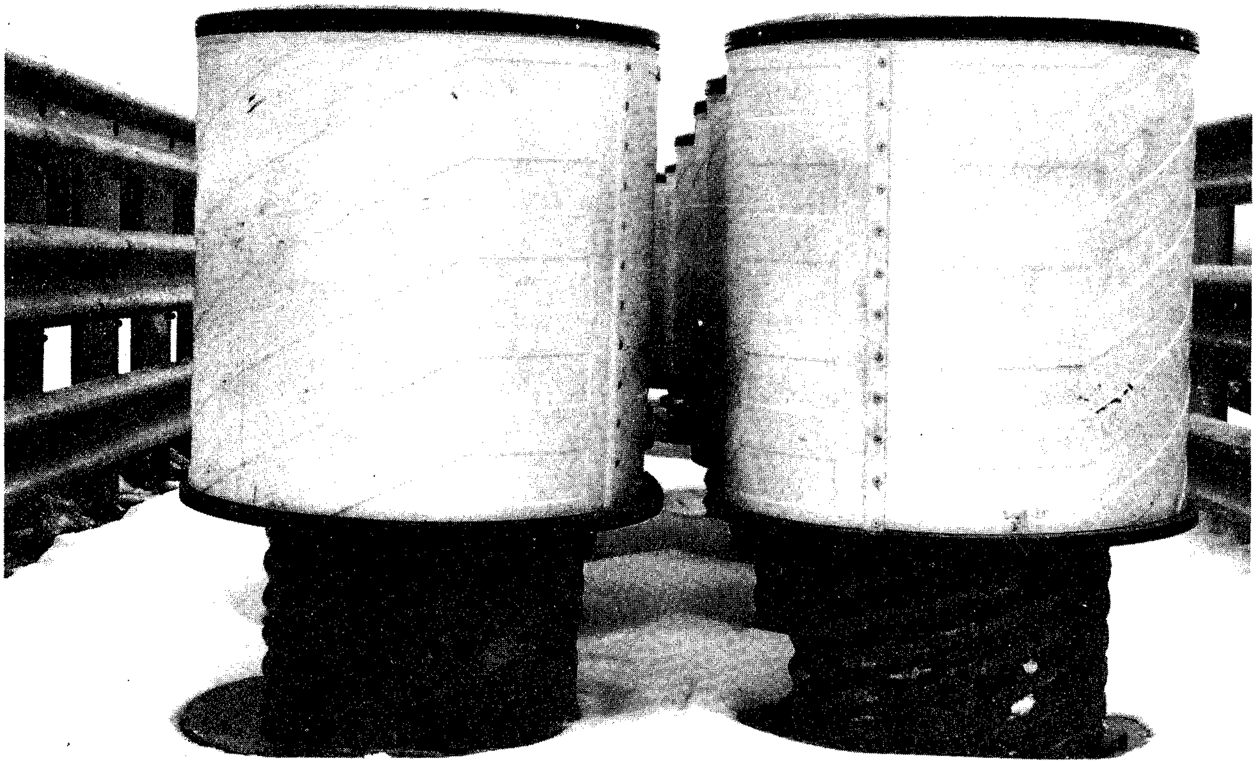


Figure 8. Sand barrel impact attenuator on pedestals at end of the truck escape ramp on NY-28, New York.

Hill descending ramps in Idaho have no secondary attenuators (37). The descending grade arrester bed on South Dakota's US-16 is unique in that there is a 4 ft high longitudinal windrow in the center of the bed along the last 300 ft of the 750 ft ramp as shown in Figure 9 (41). The purpose of the windrow is to decelerate a truck by friction between the windrow and the truck's undercarriage.

Newton (5) recommends that roadside arrester beds have no secondary attenuators so that a vehicle may exit from the ramp back to the main line. Such facilities in the Siskiyou Mountains, Oregon and in Nevada comply with that idea (39,40). However, Colorado's Mt. Vernon Canyon roadside arrester bed has a Fitch Inertial Impact Attenuator Barrier System at the end (31).

Secondary retarders in truck escape ramps exist in different styles around the country, as is evidenced from these accounts. The styles range from no attenuator to gravel windrows to conventional systems as they exist in the highway system. The use of secondary retarders should be approached with caution, as little or no safety research exists on the use of such devices. Since guidelines regarding the design of secondary retarders are lacking, care should be exercised to insure that the safety of heavy vehicle occupants is increased, not jeopardized.

2.2.8 Location on Grade

The selection of the location on the grade for a truck escape ramp can be a critical one. 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. Different states have different ideas on what criteria are critical in the determination of the site of the facility.

Eck (4) reports several states' guidelines in choosing the distance between the summit of the grade and the location of the truck escape ramp. New York advocates locating a truck escape ramp as near the base of the grade as possible. Hawaii chooses to construct them near a downhill tangent section just prior to a horizontal curve. Colorado maintains that the location is site-determined, i.e., such a decision must be made for each problem grade. Oregon recommends a location approximately four miles from the summit. Eck also points out that truck escape ramps which are near the summit are seldom used.

Erickson (31) of Colorado states that experience shows 70-80 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. In addition, there is a probable point on the grade after which runaway trucks attain hazardous speeds and that the safety facility should be located downhill from this point. Idaho's equation, as shown in Section 2.2.1, may be useful in locating this probable point if the equation uses K = 0.01675, signifiying the surface is paved rather than loose aggregate.

Sandpiles are located 3.3 and 3.4 miles from the summit on US-70 in

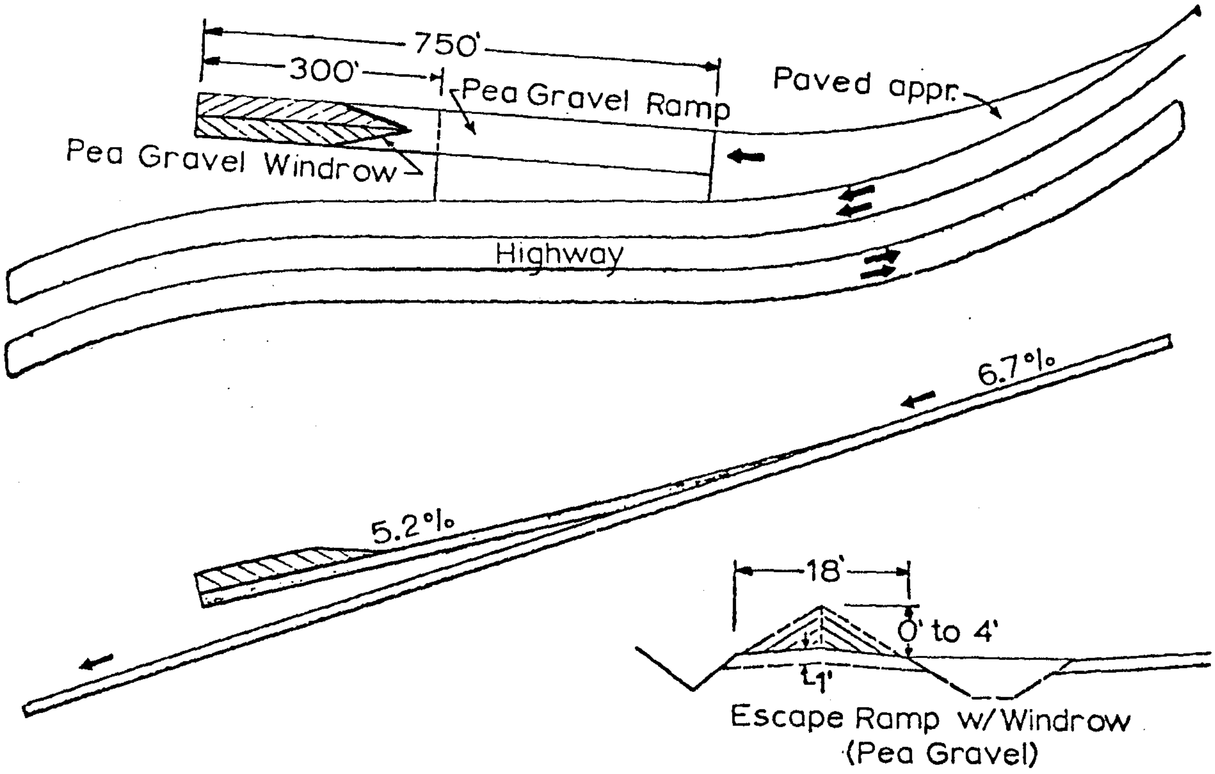


Figure 9. South Dakota's descending grade arrester bed with 300 ft longitudinal windrow. Source: Reference (20).

North Carolina. These two sandpiles are 350 ft apart and the upper one is 1.3 miles downhill from a truck brake check area (28). The sandpile on US-421 in North Carolina is 3.4 miles from the summit and 0.3 miles uphill from a narrow bridge which is immediately followed by a sharp horizontal curve (7). A sandpile just north of Roanoke, Virginia, on an exit ramp at the interchange of Route 220 and I-81 is located just prior to an 18 degree curve (10).

An ascending grade arrester bed on Rabbit Ears Pass, Colorado is 4.5 miles from the summit (31). Another such facility in Lee County, Kentucky is at the base of a six percent grade just prior to a community (15). The two ascending grade arrester beds on Oregon's Willamette Highway are 1.5 and 3.0 miles from the summit of a 3.5 mile grade (41). Similarly, two such ramps on Oregon's I-80N are two and four miles from the summit of a 6.8 mile grade. A similar facility in South Dakota on US-385 is situated one-third to one-half the length of the grade from the top (16).

Descending grade arrester beds include the one in Leslie County, Kentucky, which is at an approach to a T-intersection (15), and one on New York's NY-28, which is located just uphill from a village (15,22).

Oregon's roadside arrester bed in the Siskiyou Mountains is 4.7 miles from the summit and 1.7 miles uphill from an interchange (40). Nevada's two roadside arrester beds on US-50 are four miles apart (39).

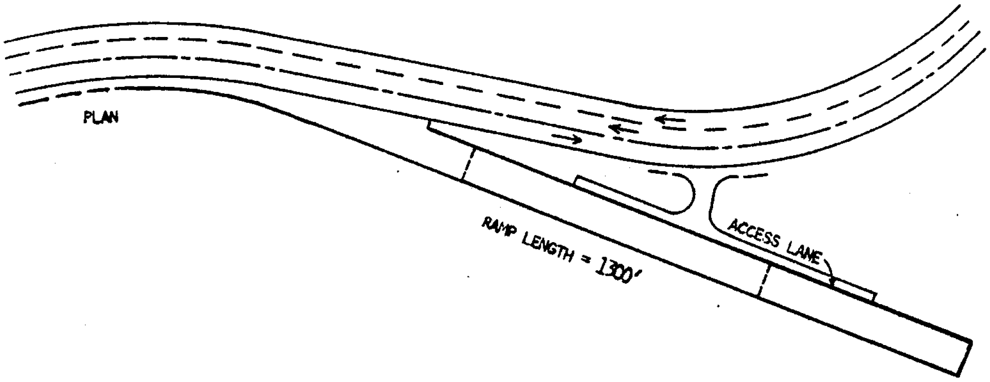
Lewiston Hill in Idaho has six truck escape ramps; one of these is located one mile below a grade change from six to seven percent where some runaway truck accidents had been concentrated (30).

Some references identify the location on the grade by the escape ramp's distance from the summit, and others do so by its distance from another escape ramp on the grade. A review of these literature sources also points out the states' differences in locating a facility on a grade. Although some guidance can be obtained from a review and study of the references, as has been indicated, precise specifications regarding the optimum location of truck escape ramps on grades is not, at present, available.

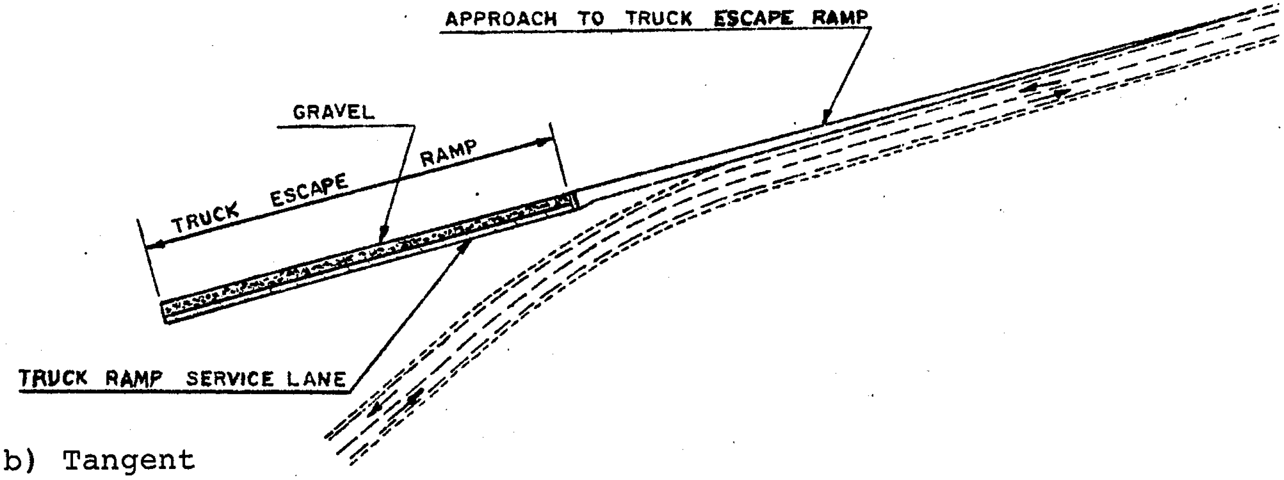
2.2.9 Position with Respect to Main Line

In conjunction with a truck escape ramp's location on the grade is its position with respect to the main line. There are three primary positions of truck escape ramps with respect to the main line: angled, tangent to a curve, and parallel. These are illustrated in Figure 10. Existing right-of-way geometry at the chosen site strongly influences the ramp's position. Some examples of escape ramps of all three varieties are discussed in this subsection.

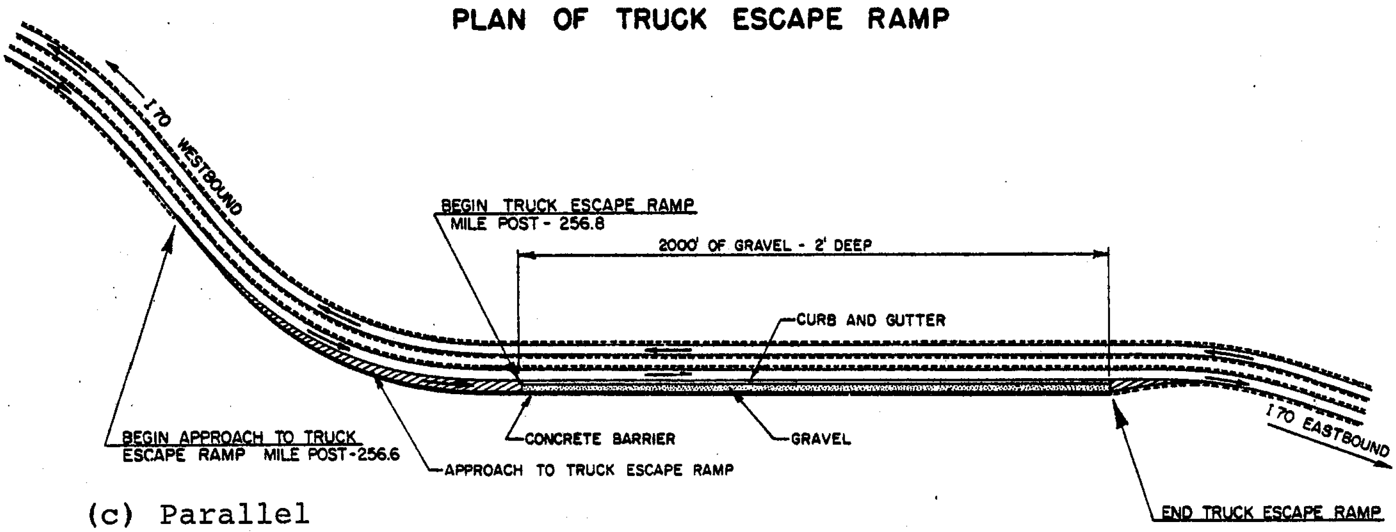
Among escape ramps which are angled to the main line are sandpiles in Pennsylvania and North Carolina (20), and ascending grade arrester beds on Alaska's Skagway-Carcross Road, Colorado's Rabbit Ears Pass, and Hawaii's Kalihi Valley and Pali Highway. Descending grade arrester beds which are



(a) Angled



(b) Tangent



(c) Parallel

Figure 10. Examples of truck escape ramps angled, tangent to a curve, and parallel to the main line. Source: Reference (6,20).

angled to the main line include one on South Dakota's US-16, one in California's San Diego County, one in Hawaii, and one in Leslie County, Kentucky (20).

A gravity ramp in Vermont and one in Washington exit tangent to the main line immediately preceding a curve (20). Boot Jack Hill in Pennsylvania has two gravity ramps, each of which exit tangent to the main line immediately preceding a curve to the left (8,11,20). Two horizontal grade arrester beds, Tennessee's Monteagle Mountain ramp on I-24 and Utah's Parley's Canyon ramp, are tangent to the main line.

Roadside arrester beds must be approximately parallel to the main line so that vehicles entering the bed may do so with ease. The two roadside arrester beds on US-50 in Nevada are parallel to the main line as are Oregon's Siskiyou Mountain ramp, the Mt. Vernon Canyon ramp in Colorado, and a roadside arrester bed in Montana (20). One ramp in New York is parallel to the main line, but is classified as a descending grade bed instead of a roadside arrester bed due to the heavy guardrail between the bed and the main line (22).

2.2.10 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 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 (25). Because of driver expectancy and because a runaway truck may use all lanes on the roadway when negotiating downgrade curves, a right hand exit should be designed if the terrain permits it. However, because the terrain does not always allow a right hand exit, there are some left hand exit escape ramps in the United States. Some of these are discussed in this subsection.

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 as the I-80 facility was in the planning stages (19).

Wyoming has three ascending grade arrester beds which exit to the left side of two-lane undivided highways on US-16 and in Teton Pass. One of these is shown in Figure 11. Such a design obviously means that the runaway truck must enter opposing lanes of traffic. The Wyoming State Highway Department reasoned 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 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

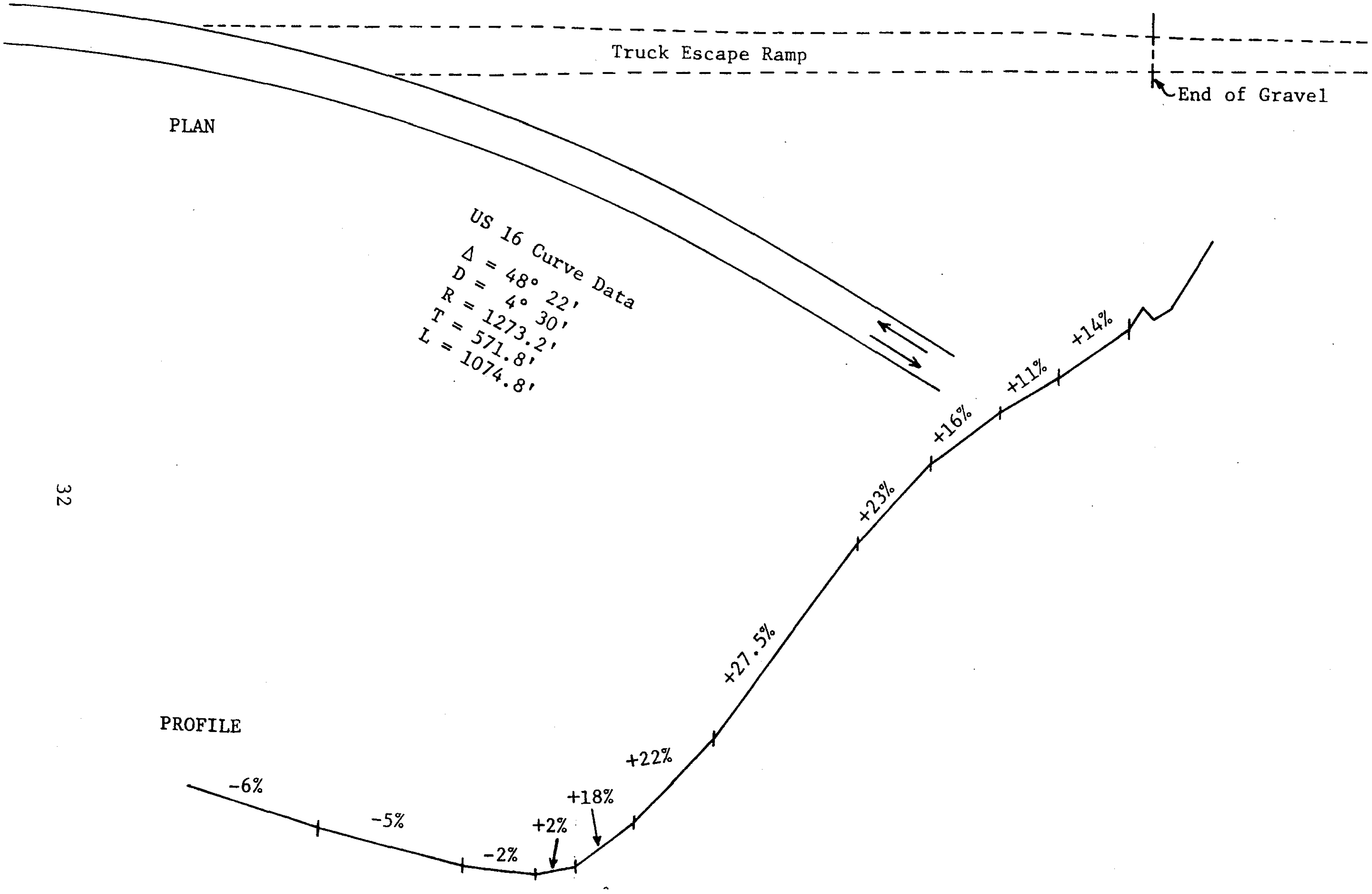


Figure 11. Schematic views of left-hand escape ramp on US-16 in Wyoming.
Source: Reference (4).

bring the truck into opposing traffic just as utilizing a truck escape ramp with a left-hand exit would. It is important to realize that these highways have very low traffic volume (17).

A negative feature of left-hand exit escape ramps is the extraordinary signing that is required. When this type of truck escape ramp is in the median of a divided highway, as shown in Figure 3, the necessary signing includes arrows pointed different from standard MUTCD signs. Left-hand exit escape ramps requiring the driver to cross lanes of opposing traffic need special signs to warn drivers traveling in the opposite direction of the upcoming possible hazard (17).

2.2.11 Brake Check Areas

Brake check areas are safety-related facilities distinct from truck escape ramps, but are related in that they help reduce the runaway truck problem. Two basic aspects of a brake check area are its type and its location. A low type area is characterized by a general lack of amenities, e.g., manned booth, diagrammatic signs, advisory signs, etc. Conversely, a high type area generally has some of these amenities such that the area is more than just "a wide place in the road." A low type area is found at the summit on US-16 in Wyoming and on US-421 three miles from the summit in North Carolina, both of which precede a truck escape ramp. In contrast is a high type brake check area at the summit prior to a 5 mile grade on which North Carolina's US-70 sandpiles are located. This information station is a mandatory stop. An actuated traffic signal is timed such that each trucker is given an adequate amount of time to read the advisory signs which inform him of the speed limit and the steep downgrade ahead (20).

Most brake check areas are at the summit before the grade and many include information regarding the percent grade ahead. Some provide diagrammatic signs, as shown in Figure 12, which illustrate the locations of the truck escape ramps; these include Mullan, Lewiston, and White Bird Hills of Idaho and about half of the truck escape ramps in Pennsylvania (8,14).

The literature of several states report the presence of some form of turnout area without much detail regarding the degree of sophistication of the facility. States that have such brake check areas are Oregon (Siskiyou Mountains), North Carolina (US-421), Arizona (US-60), New York (NY-28), Wyoming (US-16), and West Virginia (US-50 (4,7,17,22,24,42).

Eck (4) conducted a simple study where an observation of a mandatory brake check area was made at one location in West Virginia in May, 1978. This study showed that only 25 percent of all vehicles which were required to stop actually did so, and only 50 percent of the five-axle trucks actually stopped.

Other interesting statistics by Azarpajooh (43) show that 76 percent of the questioned truck drivers favor the presence of brake check areas on mountainous roadways, but only 42 percent advocate their being required by law to stop.

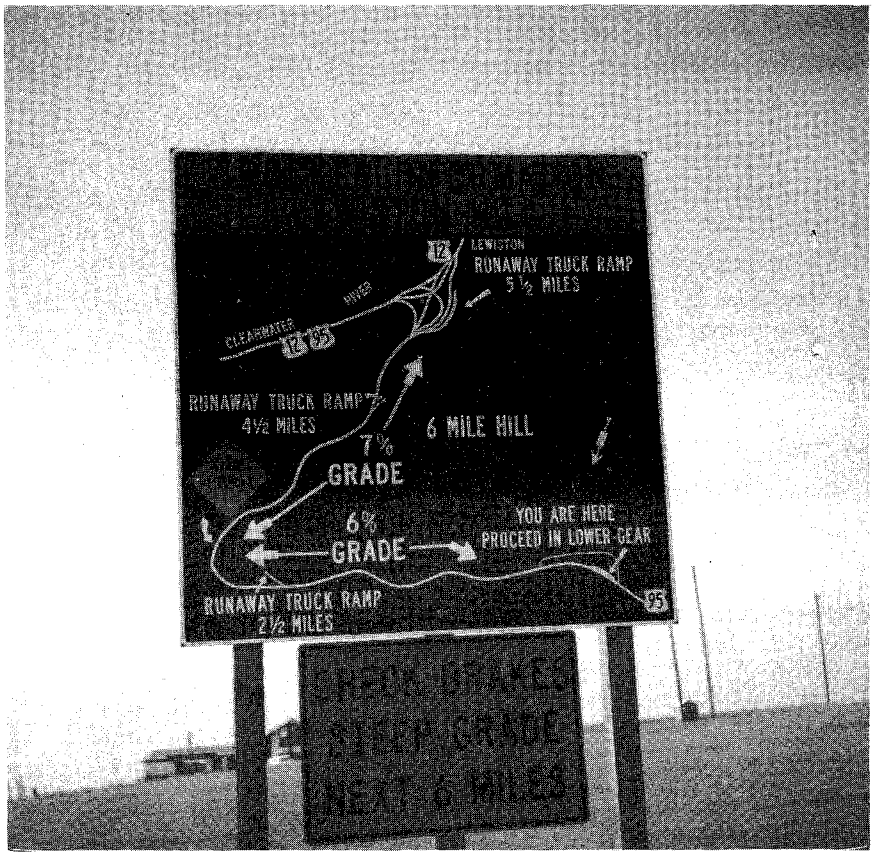


Figure 12. Diagrammatic sign illustrating the downgrade on Idaho's Lewiston Hill.
Source: Reference (<u>14</u>).

Although brake check areas are safety improvements distinct from truck escape ramps, they are closely related and they can serve to inform drivers of the presence of an escape ramp. The literature cited above illustrates what is documented concerning brake check areas' role in truck escape ramp technology.

2.2.12 Signing

Engineers acquainted with the operation of truck escape ramps agree that adequate signing is an essential part of the truck escape ramp design. 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 existing, location of the brake check area, usually at the summit. The second sign system guides the driver of a runaway truck into the truck escape ramp (11,44).

Prior to the issuance of the 1978 Manual on Uniform Traffic Control Devices (MUTCD) (45), 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." Additionally, the MUTCD suggests a "regulatory sign near the entrance should be used containing the message 'Runaway Vehicles Only.'" No Parking signs are helpful also in discouraging drivers of other vehicles from blocking the runaway truck's path.

The roadside arrester bed in Oregon's Siskiyou Mountains on I-5, the ascending grade arrester bed near Rabbit Ears Pass in Colorado, the horizontal grade arrester bed in Utah's Parley's Canyon, and a descending grade arrester bed on Idaho's Mullan Hill are among those which use MUTCD signing with certain of the signs mounted overhead (19,24,31,37). Some truck escape ramps have required signs which are not found in the 1978 MUTCD. Some of these facilities are described below.

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 two miles uphill from the ramp entrance, have arrows pointing at a diagonal toward the lower left. This facility also employs a "Dead End" sign (19).

The ascending grade arrester bed with the left-hand exit on Wyoming's US-16 between Buffalo and Tensleep has a special signing requirement. Wyoming employs warning signs informing drivers climbing the grade that they may encounter a runaway truck in their lane (17).

The Mullan Hill truck escape ramp in Idaho uses an overhead sign 70 ft in advance of the entry. This sign is similar to the MUTCD sign except that the arrow points directly downward instead of to the upper right (37).

Prior to the 1978 edition of the MUTCD, North Carolina used signing that did not include the word, "runaway."

This was purposely done so the state would avert any possible liability (28). However, now North Carolina uses the MUTCD guidelines since they have been accepted by the MUTCD Advisory Committee (36).

The MUTCD has successfully provided uniformity to advance signing for truck escape ramps. However, it is the opinion of some that signing at the ramp itself has not yet been sufficiently addressed (14). For ramps angled to the main line, Wyoming places the sign illustrated in Figure 13a, which is similar to MUTCD's sign W7-4A, on the right just prior to the ramp entry. For ramps that are tangent to the main line, Wyoming places the sign, illustrated in Figure 13b, on the right just prior to the ramp entry (46).

2.2.13 Delineation

Delineation at the approach of a truck escape ramp is very 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 (45) provides pavement marking, as shown in Figure 14, 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 incumbent. Examples of what some states use for delineation are described in this subsection.

For delineation, Idaho uses 16 Type 3 object markers (MUTCD 3C-1) on the right side of the approach at 50 ft intervals (37).

North Carolina uses MUTCD pavement markings for delineation and reports there have been no delineation related problems with the truck escape ramp (36).

Williams (11) 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 (9).

2.2.14 Illumination

There is very little documentation regarding illumination of the truck escape ramp and its approach although the American Association of State Highway and Transportation Officials (3) and the Federal Highway Administration (2) advise in favor of their inclusion in the design plans.

The only known illuminated escape ramps are the two sandpiles on US-70 and the one sandpile on US-421 in North Carolina (28), as shown in Figure 15.

2.2.15 Backup Measures

In the event a truck escape ramp is occupied and a second truck is in need of such a safety facility, a backup measure is needed. In the current inventory of facilities, there are two backup measures. The first is achieved by designing the truck escape ramp wide enough for more than one vehicle to occupy it simultaneously. The second

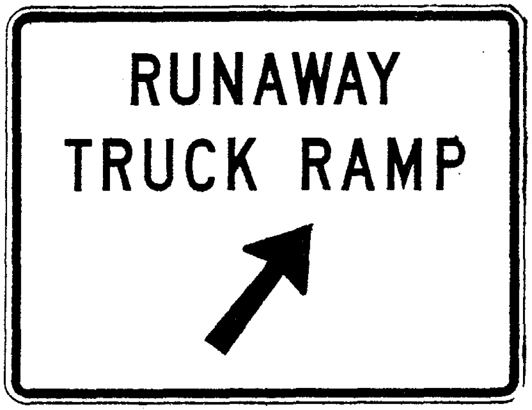


Figure 13a. At-ramp signing for escape ramp angled to the main line. Source: Reference (46).

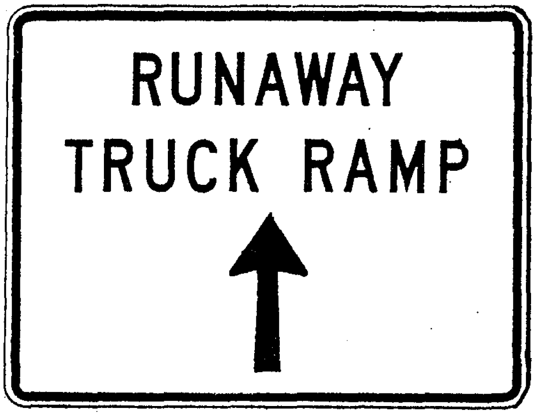


Figure 13b. At-ramp signing for escape ramp tangent to a main line curve. Source: Reference (46).

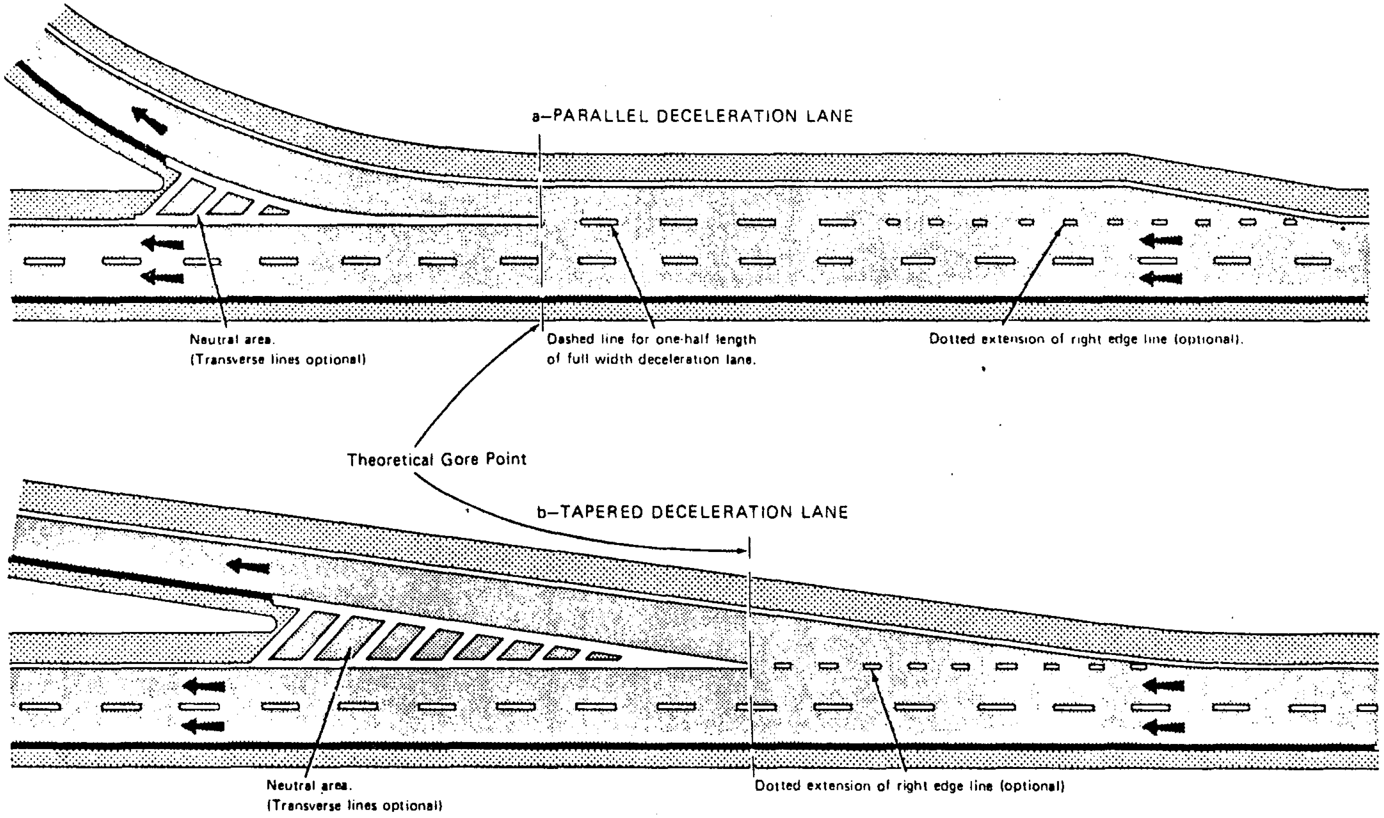


Figure 14. Standard MUTCD pavement markings for gore areas.
Source: Reference (45).

Figure 15. Illuminated sandpile on North Carolina's US-70.

type of backup measure is in duplication, i.e., a second truck escape ramp is constructed nearby.

Because some sources (2,3,42) use a WB-40 or WB-50 (AASHTO nomenclature for trucks with wheel bases of 40 or 50 ft, respectively) tractor-trailer combination as the design vehicle and these are 8.5 ft in width (3), the width of the arrester bed is suggested to be 26 ft or more. This constitutes a backup measure. The following facilities meet that suggested width: Oregon's Siskiyou Mountains ramp (26 ft), Kentucky's Leslie County ramp (26 ft), Idaho's Mullan Hill ramp (26 ft), the lower ramp on Oregon's Emigrant Hill (this ramp once held three trucks simultaneously), and Idaho's Lewiston Hill ramps (30 ft). Some truck escape ramps which may be too narrow to provide multiple occupancy backup include: North Carolina's US-421 sandpile (20 ft), Colorado's Mt. Vernon Canyon roadside arrester bed (20 ft), Kentucky's Lee County ramp (24 ft), New York's descending grade arrester bed (18 ft), Utah's Parley's Canyon horizontal grade arrester bed (18 ft) and Nevada's two roadside arrester beds on US-50 (20 ft each).

The second backup method is the construction of a second facility nearby. North Carolina constructed a sandpile only 350 ft downhill from an existing sandpile solely as a backup measure (28). In the Rocky Mountains, some steep long grades have more than one truck escape ramp, e.g., Idaho's Lewiston and White Bird Hills, Oregon's Willamette Highway, and Nevada's US-50 hill near Carson City. Such multiple facilities function as backups.

Gravity ramps usually do not need backup measures because the ramp's time of occupancy 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 (25). The occupancy time of a gravity ramp with a jackknifed truck can, however, be high.

Roadside arrester beds can be narrow because they may not require multiple capacity for a backup measure; they lend themselves to being duplicated which is the other backup technique.

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.

2.2.16 Grades

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

Sandpiles usually have top surfaces that are sloped at a constant gradient such that the end of the surface is about 10 ft above the ground (32). Most of North Carolina's sandpiles have horizontal top surfaces; however, some newer sandpiles in that state have ascending grade tops. This may be a less acceptable design because trucks' front ends tend to dig into the sand and this results in damage (36).

All gravity ramps obviously have ascending grades. Literature regarding truck escape ramps shows the gravity ramp with the steepest slope is in

Franklin County, Pennsylvania on TR-30 at the Cape Horn Curve. This gravity ramp is 1200 ft in length on a +21.5 percent grade (8,11). The flattest gravity ramp is also in Pennsylvania; it is the lower ramp on Boot Jack Hill near Ridgeway on TR-219 in Elk County. This ramp is composed of two grades--a +6 percent grade followed by a +13 percent grade (8). Another gravity ramp is Washington's Alpowa Summit ramp which has a maximum grade of +19.6 percent (11).

Pennsylvania's truck escape ramp on TR-40 near Hopwood in Fayette County was constructed on a +20 percent grade in 1966. In 1980, uncompacted aggregate was retrofitted into the former gravity ramp transforming it into an ascending grade arrester bed (8). However, this ascending grade ramp is not the steepest in the nation; Colorado's Rabbit Ears Pass ramp has a +42.8 percent grade which follows a +2.64 percent grade (31). Virginia's I-77 has four ascending grade arrester beds which are on grades of +20, +20.7, +21, and +23.4 percent (10). Williams (11) reported that two ascending grade arrester beds in West Virginia on US-48 have only +10 percent grades. Versteeg (20) identified an Alaskan ascending grade arrester bed as having a +17 percent grade followed by a +8 percent grade.

Truck escape ramps that decelerate runaway trucks primarily by the rolling resistance provided by the arrester bed where the grade of the arrester bed is between -2 percent and +2 percent are considered as horizontal grade arrester beds. The arrester bed in Parley's Canyon, Utah on I-80 is on a -1.45 percent grade followed by a 0.00 percent grade (19). The upper ramp on SR-9 near Searsburg, Vermont is a horizontal grade arrester bed where the first 100 ft section is on a -8 percent grade and the 450 ft section is on a +1 percent grade (11). The horizontal grade ramp on I-24 on Monteagle Mountain, Tennessee has a -1 percent slope (41).

The steepest descending grade arrester bed is on NY-28 east of Utica, New York. This facility is on a -10 percent grade (23). Williams (11) indicates 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. South Dakota has such a facility on a -5.2 percent downgrade (41); San Diego County, California has one on a -5.9 percent grade (20); and El Paso County, Texas has two descending grade ramps with -8.0 percent and -9.4 percent downgrades (23).

The roadside arrester bed in Oregon's Siskiyou Mountains is constructed on a -5.5 percent grade (24). Colorado's Mt. Vernon Canyon ramp is on a -5.6 percent downgrade (6).

It is evident that some types of truck escape ramps may be found with a variety of grades. Conversely, other types, e.g., a roadside arrester bed, are all built with similar grades.

SECTION III

EVALUATION OF TRUCK ESCAPE RAMP DESIGNS

As illustrated in Section II, the inventory of truck escape ramps in the United States consists of several ramp types, and among these are several different design elements (e.g., length, width, signing, grade, depth, etc.). There are usually variations within each design element. For example where lateral constraints are employed, descending grade arrester beds include triple W-beam guardrails on both sides (22), heavy guardrail (23), or concrete barriers on both sides (41). Because of the many combinations into which the several design elements can be arranged, the number of total designs is larger than the total number of facilities currently existing. Some of these designs are superior to others. In this section, some of the truck escape ramp designs are evaluated.

The ideal truck escape ramp is one that

- can safely stop a runaway truck without a collision regardless of the speed of the heavy truck
- does not produce intolerable deceleration levels on the occupant(s) of the vehicle
- does not eliminate a second vehicle's option to use a truck escape ramp when the ramp is occupied by another vehicle
- can be seen and recognized as a truck escape ramp from a distance that provides adequate time for a driver to decide and properly align the truck for entry into the ramp
- can be safely utilized in all types of weather and in darkness as well as daylight
- is cost-effective
- does not cause any operational or safety problems on the main line
- allows reasonable ease in truck removal
- is designed and constructed in such a manner that it is perceived by the average runaway truck driver as a better alternative than "riding out" the hill.

None of the truck escape ramps discussed in the associated literature meet all of the requirements of an ideal truck escape ramp. The best way to achieve the optimum design for a specific site is by employing the results of appropriate research.

The majority of advances in truck escape ramp technology have come about by states' using the trial-and-error method. However, some formal research has been conducted and has led to usable results.

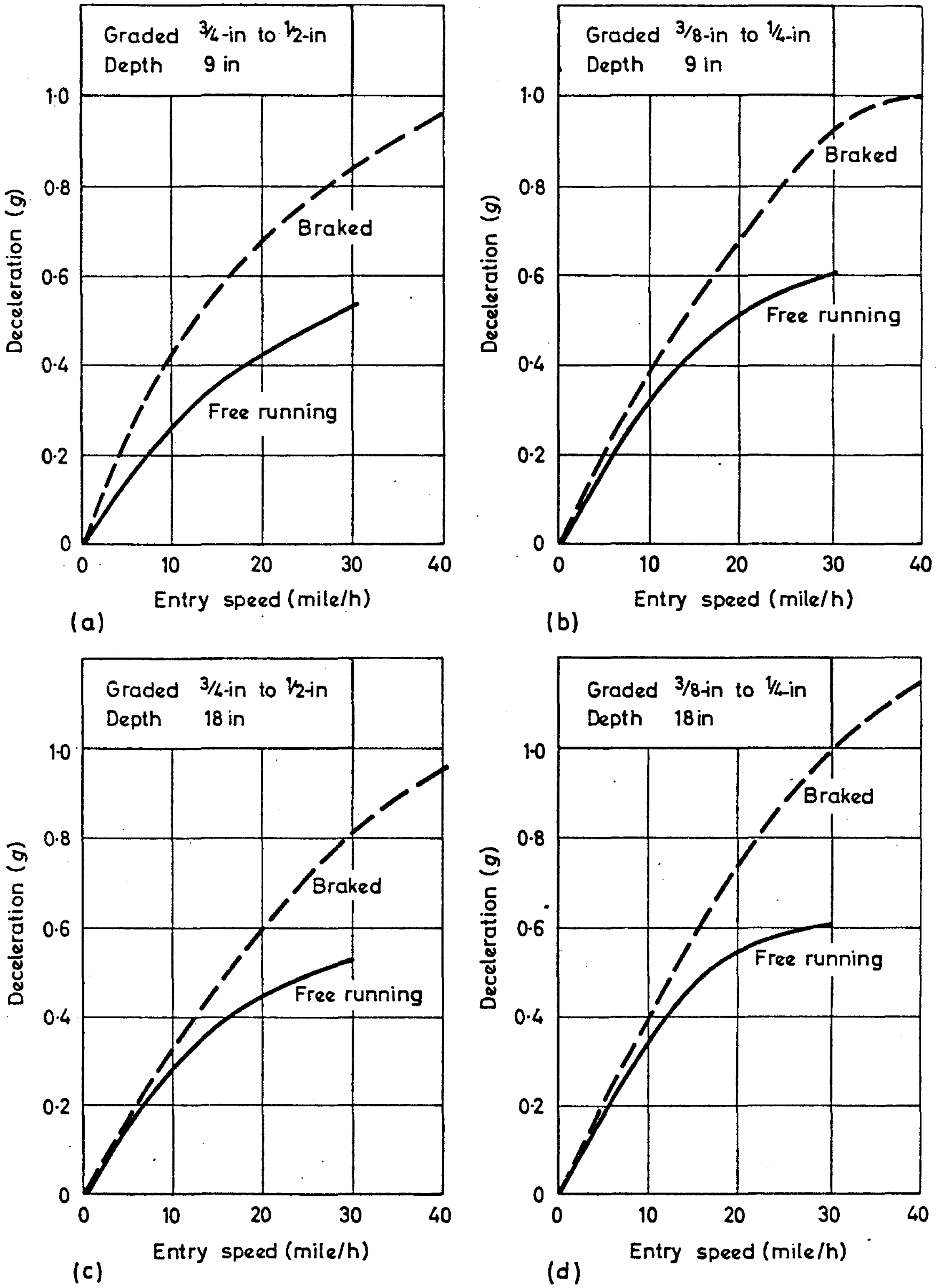
3.1 Formal Research

Among the very few formal research projects was the study conducted by I. B. Laker of Great Britain's Road Research Laboratory (47). This particular research effort's goal was to study vehicle deceleration in beds of loose gravel. Seven short horizontal gravel bed arrangements were constructed and differed in bed depth, size of aggregate, and rounded vs. angular stone. Test speeds ranged from 10 mph to 60 mph, and the 96 test runs included both wet and dry conditions. The results of these tests indicate that gravel beds with small aggregate (0.25 inch to 0.375 inch) decelerate a vehicle slightly better than beds with larger aggregate (0.50 inch to

1.50 inches). Figure 16 shows that the gravel beds with the smaller aggregate created higher decelerations than those with the larger aggregate. The higher deceleration is desirable since it means the vehicle requires a shorter distance to stop. Another finding, illustrated in Figure 16, indicates that two beds, identical in length, width, and aggregate size, but with different aggregate bed depths, imparted slightly different decelerations on the test vehicles. An 18 inch deep bed was only slightly more efficient in decelerating the vehicles than a 9 inch deep bed. In comparing the curves in Figures 16 and 17, the difference between rounded and angular gravel is illustrated in terms of how entry speed is related to vehicle deceleration. It should be realized that the bed depth represented in the latter figure is different than those in Figure 16. Some items to be considered before applying these findings to the design of truck escape ramps are the small weight of the test vehicle (2475 lb), the slow test speeds (10 mph to 60 mph), and the fact that the test vehicle was not articulated.

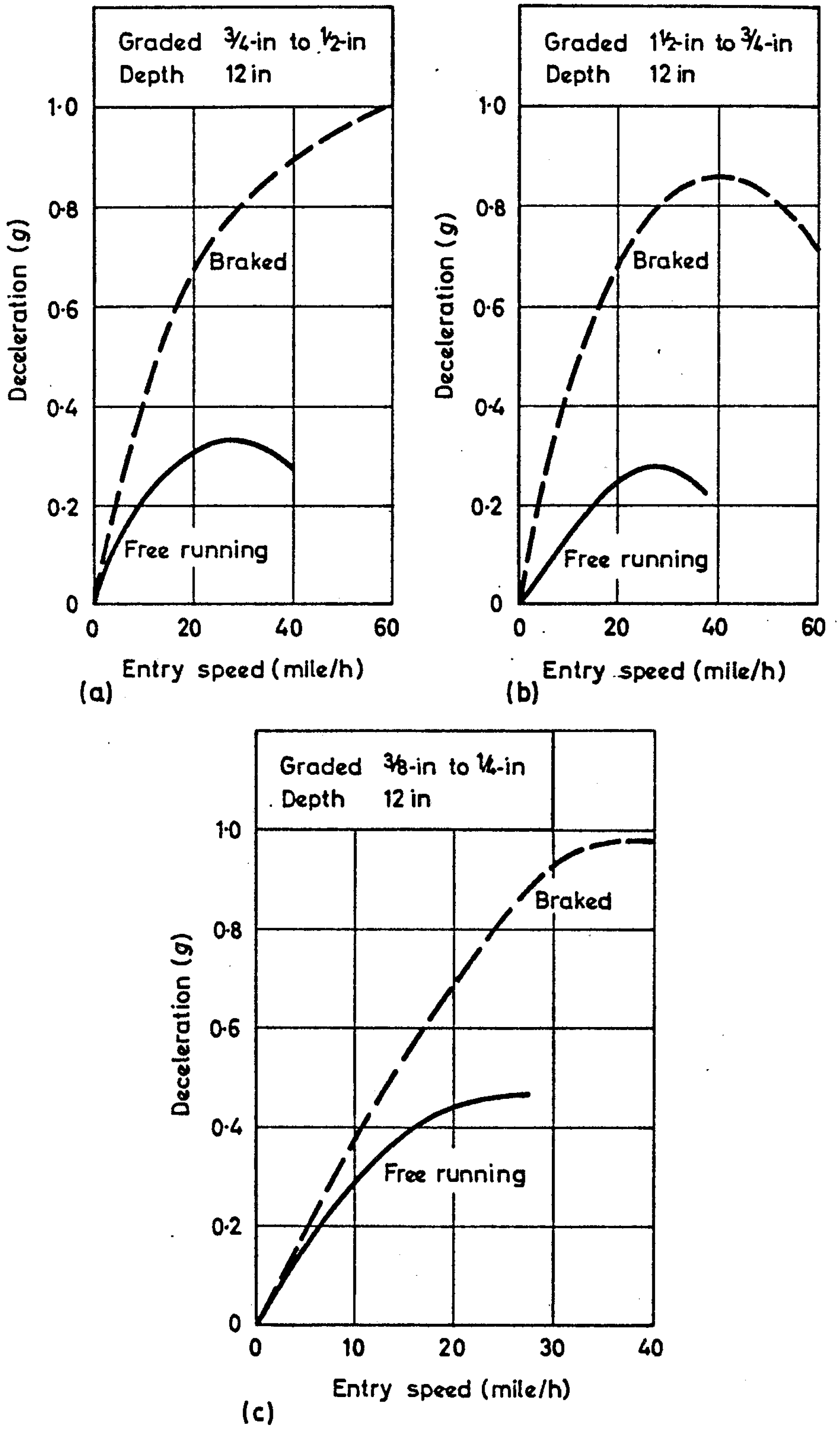
Several years after Laker's study, the New Jersey Department of Transportation conducted a study of gravel beds in which the objective was to stop an automobile traveling at 55 mph, within 100 ft with minimal damage to the vehicle and injury to its occupants (48). With regard to truck escape ramps, this project presents the same limitations as the Laker study, i.e., the test vehicle was not an articulated vehicle and was light weight (3800 lb), and the test speed was only 55 mph. For the purposes of the study, these limitations were acceptable in that the objective of the research was not directly related to runaway trucks on steep grades. Eight different horizontal grade bed configurations with 3/8 inch pea gravel were tested, as shown in Figure 18. These included a bed with a smooth surfaced tapered entry with a full depth of 12 inches; a bed with a 12 inch deep smooth surface without a tapered entry; a bed with a one percent ascending grade smooth surfaced non-tapered entry; three beds with transverse surface ridges of uniform depths of 12 inches, 18 inches, and 24 inches, respectively; a bed with increasing transverse ridge heights from 12 inches to 18 inches to 24 inches; and a bed with 18 inch surface ridges angled at 25 degrees to the lateral direction. Among these, the gravel bed with uniform 18 inch transverse surface mounds was the best design. The smooth surfaced beds required 50 to 200 percent more stopping distance than the bed with 18 inch uniform height transverse surface ridges. In comparing the test results with those of Laker (47) and Jehu (49), New Jersey concluded that the 3/8 inch pea gravel was less efficient than a 3/8 inch artificial aggregate (called Lytag) in that it required a 43 percent greater stopping distance in a similar bed arrangement.

In 1977-78, Oregon undertook tests of gravel mounds in preparation for the construction of the I-5 roadside arrester bed in the Siskiyou Mountains (27). The stated purpose of the field testing was to determine the reaction of trucks impacting transverse gravel mounds of different sizes, shapes, and arresting material gradation. Limitations in the 23 test runs result from the test vehicles, which were two-axle dump trucks loaded with gravel; the impact speeds, which were mostly less



$g = 32.2\ \text{ft/sec}^2$

Figure 16. Vehicle deceleration in rounded gravel.
Source: Reference (47).



$g = 32.2 \text{ ft/sec}^2$

Figure 17. Vehicle deceleration in angular gravel.
Source: Reference (47).

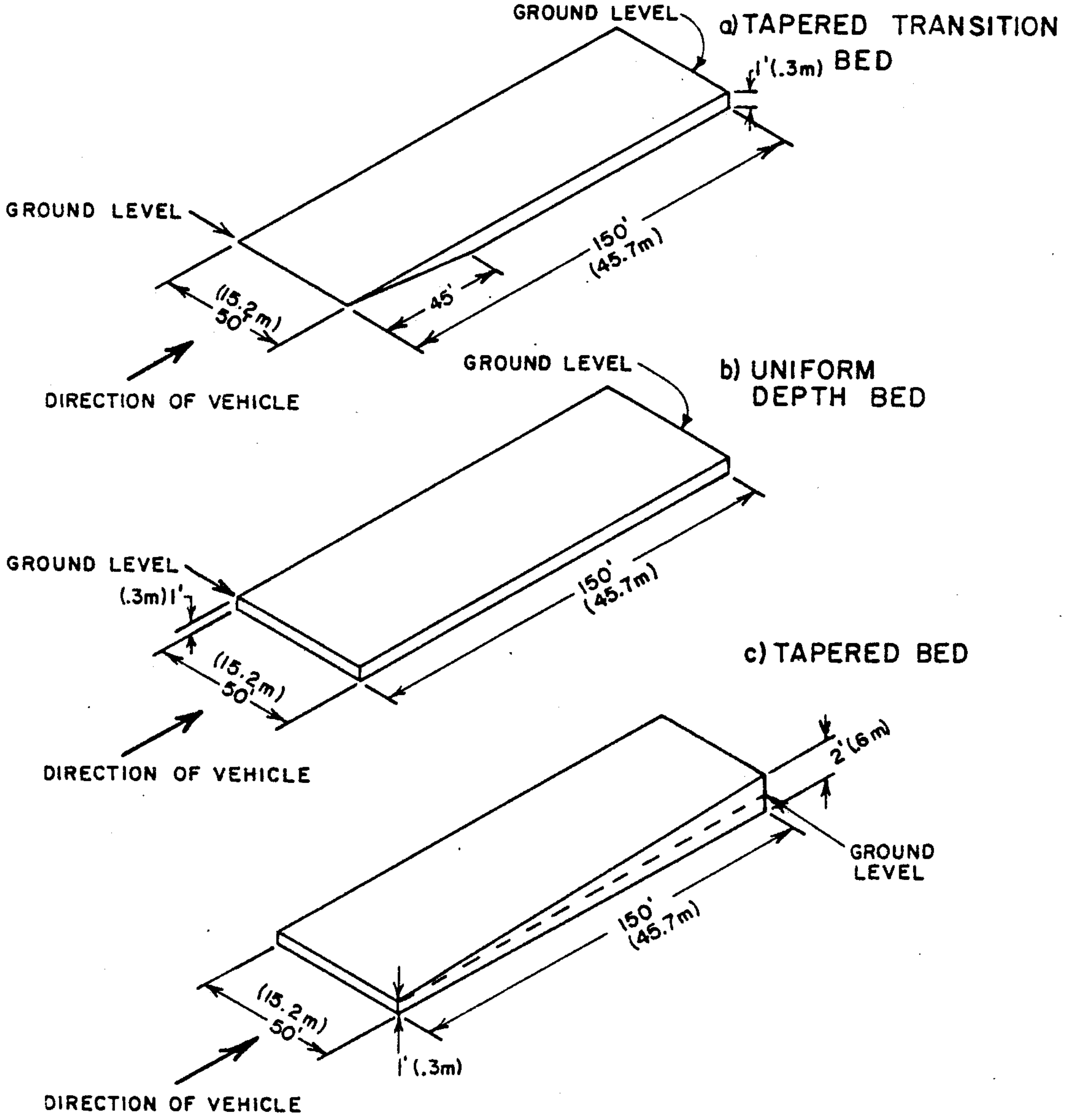


Figure 18. Gravel bed configurations in New Jersey testing. Source: Reference (48).

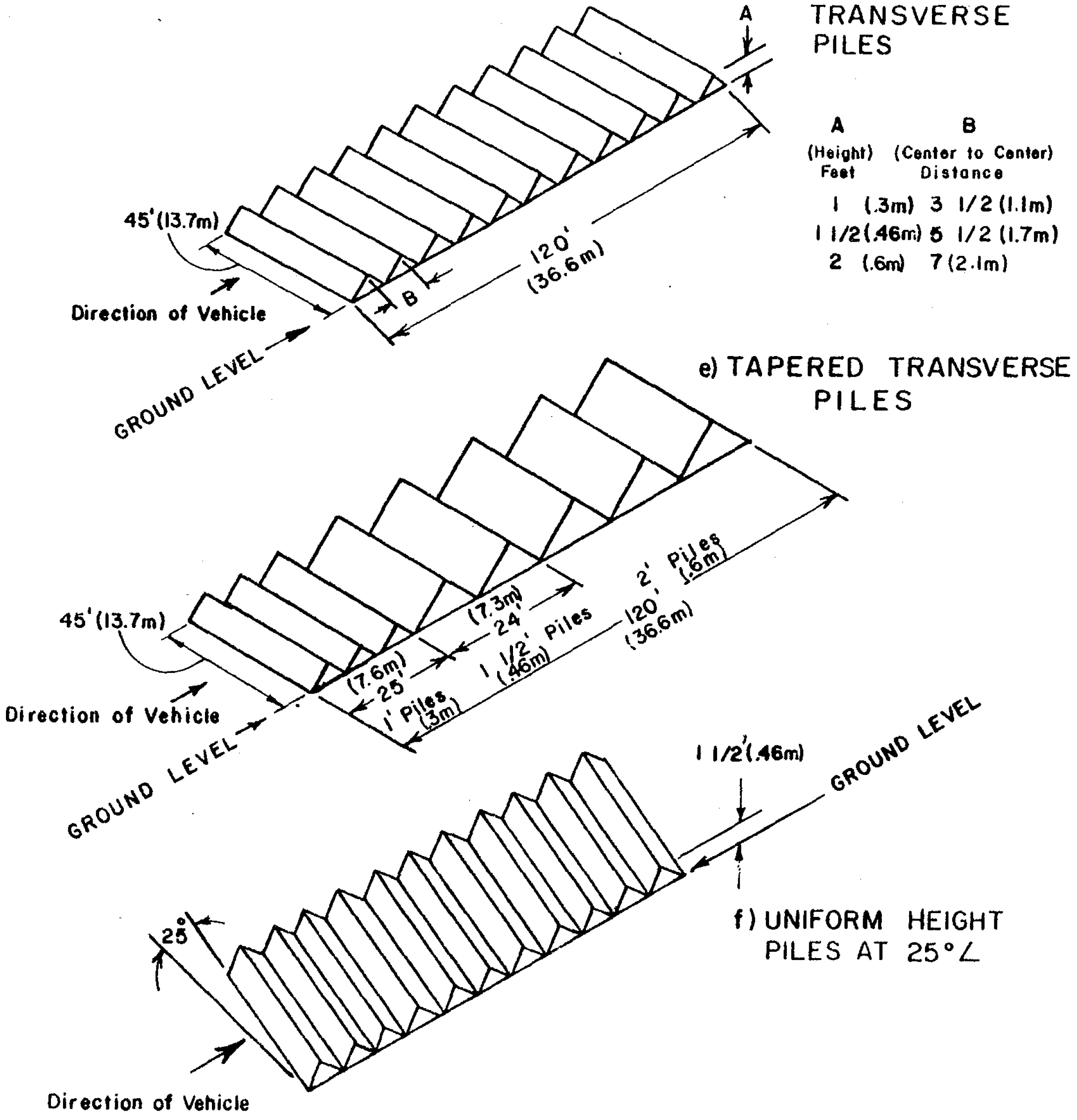


Figure 18. Gravel bed configurations in New Jersey testing (Continued). Source: Reference (48).

than 40 mph; and the gravel configuration itself, which consisted of gravel mounds placed atop a paved surface rather than atop a bed of gravel. The tests consisted of driving the vehicles into transverse gravel mounds in various combinations of 12 inch, 24 inch, and 30 inch high mounds singularly and in groups of three. Mounds with peaks and level tops were tested. Test results indicated the truck reaction to impacting the gravel mounds was more severe than anticipated and damage to the vehicles was noted in 11 of the 23 runs. The effects induced by mounds with flat tops and the high mounds were too severe for practical use in truck escape ramps. Appendix A contains the summaries of Oregon's field tests. The bottom line suggestion by the researcher is that the use of any transverse gravel mounds in truck escape ramps would effectively decelerate a runaway truck yet they should "not be used except under very critical conditions." In addition, gravel berms used as secondary attenuators near the end of truck escape ramps could be used where the consequences of a vehicle traveling beyond the end of the ramp would be nominally probable and "critically hazardous." Oregon also suggests that if gravel mounds are used, they should be "quite low, have front and back slopes of approximately 1.5 to 1, come to a peak at the top," and be closely spaced (probably less than 14 ft apart according to Oregon's experience).

Another formal research project (Idaho Transportation Department's R.P. 94) regarding truck escape ramps was conducted in 1978; Stanley (34) developed an equation and a calculator program designed to aid in determining the minimum length of an arrester bed on a truck escape ramp. The objective of the research was to develop such a procedure and compare its predictions to actual field tests of a particular truck escape ramp. The limitations inherent in the equation, which was presented in Section II, and the calculator program include the following

- vertical curves are approximated by chords
- horizontal curves have been ignored
- the truck is assumed to be out of gear
- the ramp grade is ascending
- the reliability of the constant values of the K parameters is unknown

One implication of ignoring the horizontal curvature of the ramp is that energy loss due to lateral friction on the horizontal curves is not considered, hence the equation's projected length is greater than the true minimum length if the ramp is curved. Another result of ignoring horizontal curvature is that the designer must check the safe cornering speed against the predicted speed at the curve since Stanley's procedure does not check this for the designer. The assumption regarding the truck being out of gear is frequently a good assumption since in the case of most high-speed runaway trucks, either the driver has failed to properly downshift prior to entering the escape ramp or the brakes overheated. If the first explanation applies, then the truck is, indeed, out of gear. Finally, the assumption that the ramp is on an ascending grade is reflected in the negative algebraic sign before the variable, H. For this equation to apply to a descending grade or roadside arrester bed, the sign must simply be changed to a positive sign.

The iterative program was compared to data from field testing performed on pavement instead of gravel beds and on highway grades of -4.0 to -44.3 percent. The test vehicle was a loaded articulated tractor-trailer combination which weighed 61,200 lb and had a frontal area of 82 ft^2. Figure 19 graphically illustrates the field data and the predicted data to show the merits of Stanley's procedure for paved surfaces. It is noteworthy that the research report includes no comparison of this procedure's predictions and field testing for aggregate beds. However, in a memorandum internal to the Idaho Transportation Department (50), results of a followup to Stanley's original project are identified. In the followup, the calculator program's predicted stopping distances were compared to actual field experience of three arrester bed ramps on Idaho's Lewiston Hill. The results of this comparison revealed that in 12 of 35 uses, the actual reported stopping distance exceeding the predicted stopping distance as illustrated in Table 3. Considerations which contribute to the low success rate of the calculator program are the fact that the entry speeds were drivers' estimates rather than electronically measured values and the value of the K parameter does not account for conditions where the gravel was bound together by frost or by deicing salt.

These research projects illustrate the scarcity of formal research in truck escape ramp technology. However, other advances have been made by means other than formal research.

3.2 Operationally Successful Design Elements

As noted previously, most of the advances in truck escape ramp designs have come from states' trial-and-error experimentation. Some of these designs have been proven to be less than optimal. Others have provided useful additions to truck escape ramp technology despite their not coming from formal research projects. In this subsection, some operationally successful design elements are discussed.

In 1973, Virginia built its first sandpile (10). This facility is on US-52 on Fancy Gap Mountain in Carroll County. The objective of the design was simply to "help drivers of out-of-control trucks." As part of the design, the 200 ft sandpile had a smooth surface. After a runaway truck was driven into the facility and continued through the far end, the Virginia Department of Highways and Transportation decided to create a "lumpy" surface on the sandpile such that the undercarriage of the truck would drag against the sand. Because this proved successful, Virginia has included such transverse surface ridges in other sandpiles.

North Carolina went through the same experience in 1974 when the second truck to use a sandpile on US-70 traveled through the entire length of the sandpile and stopped on the backslope (26). The North Carolina Department of Transportation then reworked the sandpile's surface into irregular mounds which were about 3 ft in height and spaced at 15 ft centers. North Carolina reports that this

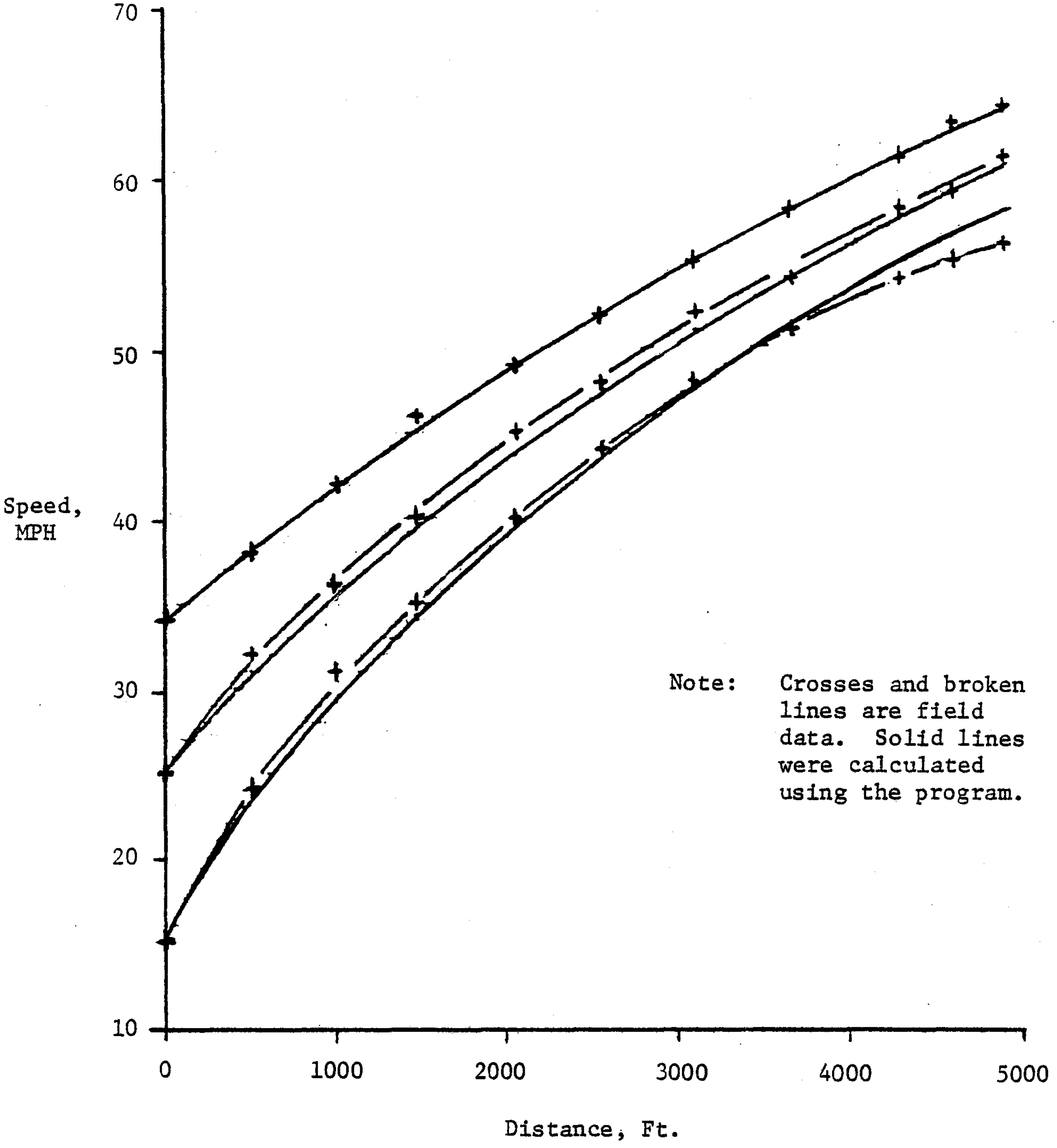


Figure 19. Calculator-predicted results vs. actual field data. Source: Reference (<u>34</u>).

Table 3. Reported stopping distances vs. R.P. 94 program distances.

RAMP LOCATION	DISTRICT INCIDENT #	REPT WT	REPT SPEED	REPT DIST.	PROGRAM DIST.
Lewiston Hill #2	45	40,000	25	98	125
"	47	26,000	55	472	525
"	51	25,000	40	98	275
"	59	80,000	40	1000*	275
"	71	75,000	35	372*	225
"	76	52,000	50	247	450
"	77	80,000	35	260*	225
"	81	79,000	50	738*	450
"	86	80,000	45	192	350
"	91	78,000	50	500*	450
"	92	78,000	60	100	625
"	94	80,000	50	784*	450
"	98	72,320	45	384*	350
Lewiston Hill #3	13	78,000	52	365	500
"	15	78,000	80	510	775
"	17	50,000	35	96	225
"	20	80,000	60	329	600
"	21	80,000	30	186*	175
"	22	80,000	40	250	275
"	24	77,000	45	185	350
"	31	75,480	80	855*	775
"	33	70,000	50	430	450
"	36	46,000	75	700	725
"	38	45,000	40	258	275
"	39	80,000	45	185	350
"	48	26,000	55	473	500
"	63	80,000	50	140	450
"	87	78,000	35	275*	225
Lewiston Hill #4	18	78,000	40-45	245	275 (40 mph)
"	26	60,000	60	440	625
"	41	62,000	60	850*	625
"	42	72,000	65	475	725
"	80	66,390	30	175	175
"	95	68,000	35	248*	225
"	97	16,500	50	231	425
"	103	46,000	40	189	275

Note: An asterisk next to a reported stopping distance indicates that the reported distance exceeds the distance estimated by the program.

Source: Reference (50).

modification has been very successful.

It is noted that the use of surface mounds on Virginia's and North Carolina's sandpiles is reported to be successful while Oregon's study of gravel mounds for arrester beds showed them to be more damaging to the vehicle and, therefore, not recommended except in extreme cases.

Limited operational success has been reported in the side entry use of roadside arrester beds (41,51). The feature which makes roadside arrester beds unique is that they may be entered from the side. Because very few trucks have entered these facilities from the side, there is very little data available to determine the merits of roadside arrester beds. Oregon constructed a truck escape ramp of this type in the Siskiyou Mountains in 1978 and performed a field test with a two-axle dump truck, which weighed 26,400 lb, entering the gravel bed from the side. The truck's front right tire was abruptly pulled in and straightened out by the gravel in a manner that allowed the entire truck to enter and travel in a path along the longitudinal axis of the bed. This action resulted in the driver losing control momentarily, but the vehicle was stopped safely (5,41,51). As a result, Oregon recommends that the apron on the ramp's approach be squared off, as shown in Figure 20, so that an entering truck's front wheels will enter simultaneously. However, based on the same field testing, Newton (5) recommends that roadside arrester beds, providing side entry capability, be considered for installation only where the other designs are not feasible.

Nevada's two roadside arrester beds are on US-50. One of these employs a 6 inch asphalt dike with 1:1 side slopes, which was designed to prohibit or discourage side entry. However, there has been at least one side entry by a 5-axle tractor-trailer combination. The truck entered the gravel bed at its halfway point, crossed the bed, struck the concrete barrier which was on the right side of the bed, was redirected, and stopped. Because there was no accident report, it is assumed that the truck sustained little or no damage (5).

Although these accounts of one field test and one actual use of roadside arrester beds form a small sample, they do serve to point to the feasibility of such designs without any documented research program.

A third truck escape ramp design element which has not been formally studied in its application to truck escape ramps is the crash cushion. There are numerous research reports which extol the abilities of various crash cushion designs. Consequently, only slight mention of them is made in this report. New York has, like some other states, installed a conventional crash cushion at the end of the ramp for use as a secondary attenuator in the event that a truck has not stopped prior to that point. New York has also installed a crash cushion at the gore area where the escape ramp approach departs from the main line. New York felt this was necessary since a hazardous guardrail end is located in the gore (22).

A very important design element for which very little research has been conducted is in the determination of

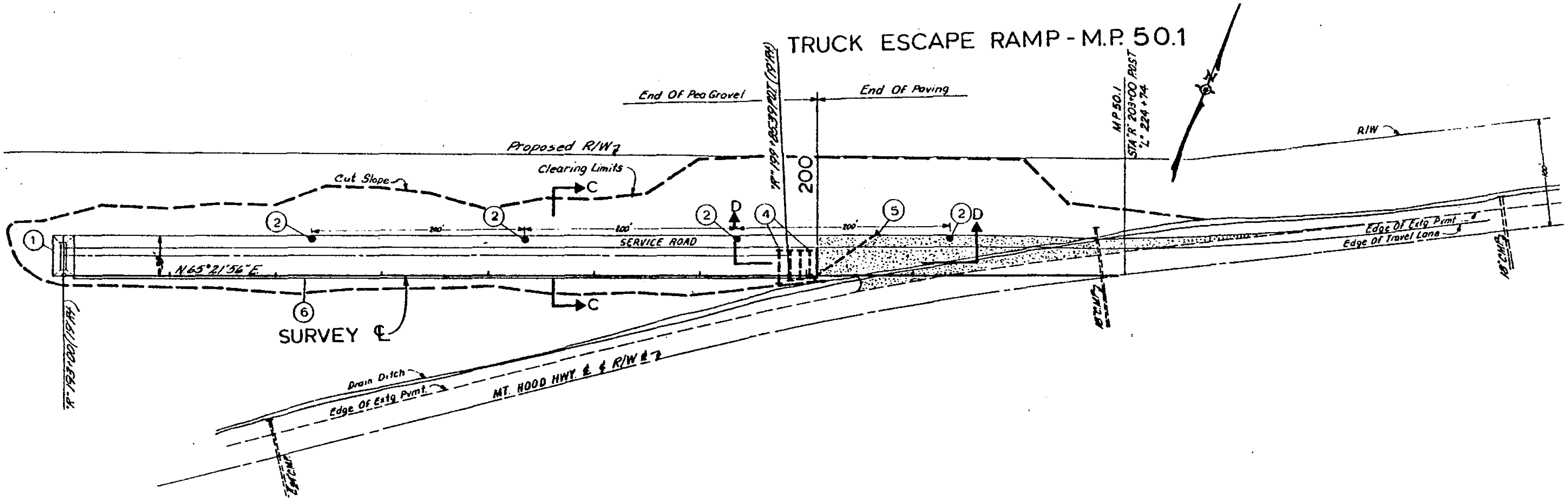


Figure 20. Example of a squared-off entry.
Source: Reference (<u>52</u>).

minimum acceptable arrester bed depths. Some indication of adequate depth was given by Hayden (12). Colorado's arrester beds have full depths of 12 inches, 18 inches, and 24 inches. Hayden states that these seem adequate since the measured rut depths in the field were about 12 inches.

In Pennsylvania a lesson was learned regarding gravity ramps. In 1966, a 1125 ft gravity ramp was constructed uphill from the town of Hopwood in Fayette County, Pennsylvania. Truckers expressed displeasure with the ramp because they would roll backwards after coming to a stop. As a result of the rollback, the truck would jackknife and lose its load. Consequently, many truckers elected to bypass the safety facility and risk their chances on "riding out" the hill. This attitude led to some serious accidents in Hopwood. In 1980 the Pennsylvania Department of Transportation added 36 inches of pea gravel to transform the gravity ramp into an ascending grade arrester bed. Since then, there have been no serious accidents and truckers are no longer reluctant to use the escape ramp (53).

3.3 Untried Design Ideas

Most preliminary design ideas which are never implemented are seldom discussed in technical literature. An exception to this involves three preliminary ideas for the Siskiyou Mountains truck escape ramp in southern Oregon. Because the terrain negated the option of constructing a conventional ascending grade ramp, one idea was to establish a large fill such that an uphill ramp could be built. Another idea was to build a grade separation where the runaway truck would exit to the right and travel over the main line and onto the uphill ramp on the left. These ideas were discarded because of the anticipated high costs. The third preliminary idea required a switch in the traffic flow uphill from the escape ramp exit so that the downhill lanes would be on the cut side, i.e., left side, of the roadway where there would be an exit to the escape ramp. This idea was discarded because of it highly irregular nature (24).

Another untired design is in regard to the arresting material. In correspondence internal to the Arizona Department of Transportation (42), it is indicated that blow sand, fly ash, and cinders were each considered for use as the arresting material. Each was dismissed in favor of pea gravel on the Materials Services' advice that internal friction would develop among these materials when placed under the heavy design loads.

3.4 Arrester Beds vs. Sandpiles

Much of the truck escape ramp literature addresses both arrester beds (i.e., ascending grade, horizontal grade, descending grade, and roadside arrester beds) and sandpiles. However, the literature is unclear regarding the functional differences between these two classes of escape ramps, i.e., is one better than the other? Some kind of difference is suspected since states with sandpiles are only in the eastern United States in the Smokey Mountains. Eck (4) recognized a related phenomenon in noting that truck escape ramps on interstate highways are heavily used in the West whereas they are infrequently used in the East. Eck suggests this is due to the good alignment on the eastern interstates and the fact that the primary grades in the East are typically shorter than those in the West (3 to 4 miles as compared to 10 to 12 miles).

Versteeg (51) stated that arrester beds and sandpiles are so different that they almost defy comparison. An arrester bed provides "almost guaranteed success" for trucks up to 80,000 lb at 85 mph with only up to $20 damage, whereas sandpiles are sufficient only for speeds up to half that amount.

Three reports (7,26,28) from North Carolina which provide accident experience related to sandpiles indicate that this type of truck escape ramp inflicts damage and often injury in instances where the truck's entry speed is greater than 50 or 60 mph. For North Carolina sandpile usage, see Appendix B. Indeed, Crowe (7) reported that "only when the entry speeds were greater than 50 mph did property damage estimates climb materially on these two ramps [two sandpiles on North Carolina's US-70]."

A list of escape ramp usages in Colorado from December 16, 1976, to April 28, 1981, show that there have been instances in which trucks traveling 100 mph have been brought to a stop without damage or injury (54). However, there have also been instances where the entry speeds were 85 to 100 mph and minor damage was incurred. Appendix C contains the ramp use accounts for one of Colorado's arrester beds. Comparing the accident experiences of North Carolina's sandpiles with Colorado's arrester beds clearly exhibits the difference between these two classes of truck escape ramps.

3.5 Evaluation of Specific Truck Escape Ramps

Some truck escape ramp literature incorporates enough information concerning specific truck escape ramps that these facilities' attributes can be classified as good or bad. Many truck escape ramps are not sufficiently discussed in the literature to allow such a segregation of their characteristics. Some ramps that have been evaluated are listed in Table 4. The facilities listed in this table do not include all truck escape ramps in the United States and the positive and negative features associated with these escape ramps do not represent exhaustive lists. The features listed are only those which could be gleaned from the literature sources, and in reviewing the negative features of these facilities, it is important to note that some researchers tend to highlight the positive aspects of truck escape ramps while many negative aspects are omitted or glossed over.

Some elaborative comments are needed in conjunction with the keys associated with Table 4. Unless otherwise noted, these truck escape ramps include the following attributes: hard-surfaced service lane, tow anchors spaced approximately 300 ft apart, minimal maintenance requirements, and MUTCD advance signing. Additionally, unless otherwise noted, the arrester beds use rounded pea gravel.

Some amplification of cost-effectiveness in relation to two Colorado ramps listed in Table 4 is necessary. The ascending grade arrester bed at Rabbit Ears Pass is reported to have a 10.1 benefit-cost ratio (31). In

Table 4. Positive and negative features of various truck escape ramp designs.

Ramp and Reference	Ramp Type	Positive Features	Negative Features
US-421, North Carolina (7)	Sandpile	A,F,I,N,W	b,y
US-70, North Carolina (28)	Two Sandpiles	A,E,F,G	b,y
US-16, second of three between Buffalo and Tensleep, Wyoming (17,45)	Ascending Grade Arrester Bed	E,G	k,l,x
US-40, Rabbit Ears Pass, Colorado (40)	Ascending Grade Arrester Bed	J,K,M,X	
Beattyville-Zachariah Road, Lee County, Kentucky (15)	Ascending Grade Arrester Bed	B,C	i
I-80, Parleys Canyon, Utah (19)	Horizontal Grade Arrester Bed	K,N,P,Q	c,e,k
Hyden Spur, Leslie County, Kentucky (15)	Descending Grade Arrester Bed	A,K,N	j
NY-28, Vickerman Hill, New York (22)	Descending Grade Arrester Bed	A,D,G,K,L,O	e
I-90, Mullan Hill, Idaho (30)	Descending Grade Arrester Bed	B,D,L,N,Y	m,n
I-5, Siskiyou Mountains, Oregon (24)	Roadside Arrester Bed	A,B,C	a,i
I-70, Mt. Vernon Canyon, Colorado (33)	Roadside Arrester Bed	A,C,H,I	d,f,g,h
US-50, Carson City, Nevada, (upper ramp) (38)	Roadside Arrester Bed	A,B,C,K,L	e,o,p
US-50, Carson City, Nevada, (lower ramp) (38)	Roadside Arrester Bed	A,B,K,L	e
General Comments (32)	Gravity Ramps	R,S,T	q,r,s
General Comments (5)	Roadside Arrester Beds	A,C,F,L,P,U,V	a,b,t,u,v w

KEY TO POSITIVE FEATURES

A - Can be used where uphill ramps cannot
B - Good drainage via pipe system
C - Longitudinal barrier on one side of arrester bed
D - Longitudinal barriers on both sides of arrester bed
E - Backup measure included*
F - Inexpensive to construct
G - Brake check area uphill from escape ramp
H - Includes a television monitoring system
I - Illuminated
J - Prevents rollbacks after the complete stop
K - Depth at entry is tapered
L - Depth at far end is tapered
M - Cost-effective
N - MUTCD delineation
O - Crash cushion is present in the gore area
P - Little or no additional right-of-way is required
Q - Squared-off entry
R - No special truck removal equipment is required
S - Not adversely affected by snow
T - Almost no maintenance is required
U - Allows side entry into arrester bed in case of blocked approach
V - Lends itself to construction of several intermittent installations along grade as a backup measure*
W - Well located on grade
X - Satisfactory performance under snow blanket
Y - Snow poles are present for winter delineation

KEY TO NEGATIVE FEATURES

a - Easily mistaken for a rest area, main line, etc.
b - Expensive truck removal and restoration costs
c - Ramp is too long
d - Expensive
e - No backup measure*
f - Gravel is not rounded
g - Narrow service lane
h - Not cost-effective
i - Depth at entry is not tapered
j - Arrester bed is too deep
k - Left-hand exit
l - Not illuminated
m - Occasionally requires "recycling" of aggregate
n - Width narrows at the far end
o - A 6 in. asphalt dike intervenes between the main line and the gravel bed
p - Greater than 300 ft spacing between tow anchors
q - Limited application due to topography restrictions
r - Difficulty in maintaining ramp usage records
s - Rollbacks and jackknifing may occur
t - Somewhat excessive maintenance requirements
u - May complicate highway drainage
v - Aggregate may be expelled onto main line easily
w - Truck removal and maintenance personnel are in close proximity to main line
x - Special signing is required
y - Effectiveness limited to lower entry speeds

*Note: A backup measure is an option available to the driver in the event that the escape ramp is already occupied.

contrast, the Mt. Vernon Canyon facility is not considered cost-effective because its $1,000,000 initial cost, which includes a television monitoring system, requires approximately 8-1/3 years to recover (33). Donnelly believes this period is beyond the estimated design life of the system. This is based on the facility being used to avert 30 percent of the accidents which might occur in the area.

After reviewing findings of formal research, operationally successful design elements, and existing designs, it is readily evident that no ideal truck escape ramp exists. For example, some are not cost-effective, some cannot safely stop a runaway truck at very high speeds, some eliminate the chance of a second vehicle's using the facility while the first vehicle occupies it, etc. Because an ideal truck escape ramp has not been attained, it behooves the designer to consider the requirements of an acceptable design. The designer of a truck escape ramp should strive to incorporate as many attributes of an ideal design as possible. An acceptable design is one that saves the lives of and prevents debilitating injury to the driver and occupants of the runaway truck, the innocent motorists on the main line in the area of the hazardous grade, and the local inhabitants along and at the bottom of the grade. All truck escape ramps in use today meet the standard of acceptability in that they reduce the number of deaths and seriousness of injuries which result from runaway trucks on long steep downgrades. However, there is a general lack of data to identify which escape ramp designs prevent the greatest number of deaths and serious injuries. For this reason, the decisions in design element choices are often subjective, with exceptions in the areas where research has shown which choices are superior (e.g., small, rounded aggregate is superior to large, angular aggregate in arrester beds). In the following chapter, suggested guidelines are presented and are based on findings in the literature review.

SECTION IV

INTERIM DESIGN GUIDELINES

The designers of a truck escape ramp should be able to choose particular design elements (e.g., length, width, depth, presence of a lateral constraint, etc.) for the site based on proven research and field testing. Indeed, this can be done for a few design elements, but many must be chosen according to other means including subjective judgment. This chapter identifies some suggested design guidelines for use until research efforts have produced some procedures and design element choices which have been verified by research.

In determining the need for a truck escape ramp, the Institute of Transportation Engineers (25) suggests the following items be considered:

- presence of a community at the base of the grade
- frequent use of the downgrade by school buses
- consequences of the absence of a truck escape ramp.

The best site for construction of a truck escape ramp must be chosen in light of available usable right-of-way. Other criteria for site selection are subsequently discussed.

After determining the need and the best location for a truck escape ramp, the first concern should be deciding whether to construct a sandpile, gravity ramp, or some type of arrester bed. Based on the accident experiences of sandpiles and arrester beds (7,54), it is recommended that an arrester bed be built if there is a relatively high probability of runaway trucks attaining speeds greater than 50 mph. Otherwise a sandpile is recommended because it will function adequately, is less expensive, and requires less right-of-way than other truck escape ramp types. Because sandpiles require less length than other ramp types, topography less frequently limits the choices of location. Gravity ramps are not recommended herein simply because their shortcomings (e.g., rollbacks and severe limitations in placement due to terrain restrictions) have largely been overcome with their replacement by other types of truck escape ramps.

4.1 Sandpiles

The following guidelines for sandpile escape ramps are suggested. Although the literature does not detail the development of Virginia's guidelines, it is recommended that the the length should be determined according to the Virginia formula (11) because it is the only proven method today that provides guidance for designing the length of sandpiles. The width should be at least 26 ft to allow more than one vehicle to occupy the facility simultaneously (2). The surface of the sand should be horizontal since this design has proven successful and those with ascending grades have been reported to cause more truck damage than horizontal grade surfaces (36). The surface shape should include transverse surface ridges (see Section 2.1.4) since this has been used successfully (7,10). The sand itself should be of a predominantly single size (see Section 2.1.3) to minimize the potential for freezing (36).

For ease in truck removal, the sandpile site should incorporate tow anchors and a service lane (see Section 2.2.6). The tow anchors should be spaced approximately 300 ft apart as experience has shown this to be adequate. Service lanes are also helpful in maintenance operations. The exit from the main line to the sandpile should be on the right unless the only feasible locations require a left-hand exit. In this case, a sandpile with a left-hand exit should be considered for an undivided roadway only if the traffic volume is low, i.e., less than 1000 vehicles per day (43).

A brake check area at or near the summit above the first critical point of the downgrade is desirable, particularly if the grade has a history of runaway trucks. It is desirable that the brake check area be equipped with a diagrammatic sign which illustrates the grade and location of the sandpile.

Signing for the sandpile should be in accordance with the MUTCD. This includes a supplemental sign with the word "Sand" below the warning sign. If the sandpile is too narrow for multiple occupancy and is the only one on the grade, then there is no backup measure; a foldup "Occupied" sign is recommended to be located in advance of the sandpile (20). Until further research is done in relation to red delineators, it is suggested that MUTCD gore markings, object markers, snow poles, and white or amber delineators be used (45). For good visibility in darkness, it is recommended that sandpiles be illuminated at the approach and the sandpile itself (2,3).

4.2 Arrester Beds

Arrester bed escape ramps offer the designer four types from which to choose. Ascending grade arrester beds have gravity working in their favor and should be the first considered. If topography prohibits the construction of an ascending grade ramp, then a horizontal grade arrester bed should be the next choice. If the terrain precludes this type, then a descending grade arrester bed is the third choice. Roadside arrester beds are recommended only as an alternative where other arrester beds are not feasible (5).

Once the decision to design an arrester bed facility has been made, then other design questions must be answered. The following guidelines apply to arrester beds.

The length should be determined by one of the design equations suggested by Stanley (34,50) or the FHWA (2). Each of these equations have problems in adequately predicting the necessary length: Stanley's equation was shown to predict insufficient lengths in 12 of 35 cases (50) and FHWA equation's rolling resistance values are suspect. Because of the fallibility of each of these design equations, the ITE Technical Committee's (25) recommendation of increasing the calculated length by 25 percent is a wise safeguard.

The width of the arrester bed ramp should be at least 26 ft to provide the opportunity for multiple occupancy (2). If the ramp is a roadside arrester bed and is part of a pair of ramps on the grade, a width of 15 ft is all that is necessary since the backup provision can be met by intermittent duplication of escape ramps along the grade in the hazardous area (5).

The recommended arresting material on all arrester beds is pea gravel since it meets the small and rounded criteria recommended by the Road Research Laboratory (47) (see Section 2.1.3). The optimal gradation of arresting material is not known. However, predominantly single sized gradations are desired and those on the order of 1/4 inch to 3/4 inch have been successfully used and are recommended (24,37). The surface of the bed should be smooth and not contain any surface mounds (27) (see Section 2.1.4). The depth of the aggregate bed is another parameter which lacks definitive research results. Because Colorado (12) reported that rut depths are usually 12 inches, and many successful truck escape ramps (24,31,37,39) have depths of 12 inches to 24 inches, it is recommended that a bed have a minimum depth of 12 inches and a desired depth of 18 inches. The reason for this desired depth is that the 12 inch rut depths which were measured in Colorado were in arrester beds of 18 inches and 24 inches and the extra 6 inches to 12 inches may have been of some benefit in the arresting process.

The entry to the arrester bed may or may not be tapered in depth. FHWA (2) suggests a taper from 3 inches to full depth in at least 100 ft. The purpose for a tapered depth is to allow for an acceptably slow deceleration of a lightweight vehicle, e.g., passenger vehicle or pickup truck, upon its entrance into the arrester bed. If the aggregate depth is full depth at the entrance, a vehicle can decelerate too abruptly and possibly cause injury to passengers. However, the inclusion of a tapered entry, as opposed to a full depth entry, requires a truck to travel further into the bed. If the available length is severely limited, the tapered entry may not be allowable. Tapered entries are desired and recommended if they do not infringe on the length requirements of the arrester bed design.

Lateral constraints (e.g., concrete barriers, steel guardrails, and gravel longitudinal berms) should be installed if the consequences of their absence are severe (36). In most cases, the decision to include lateral constraints is a matter of safety and economics as with conventional longitudinal barriers in the highway system. In the case of roadside arrester beds, one concrete barrier is necessary on the side of the bed which is farthest from the main line, provided that the bed is on the fill section (5) (see Section 2.2.5). With the inclusion of lateral constraints, the designer must be aware of the potential problem of snow buildup against the barrier and the lack of adequate safety research on occupant injury potential.

Adequate drainage is usually a result of predominantly single sized, free-draining aggregate. This is sufficient in most areas; however, where there are frequent cold, wet conditions, some additional drainage provisions may be necessary. This usually takes the form of perforated pipe networks (see Section 2.2.2).

For ease in truck removal from the aggregate bed, tow anchors should be installed and spaced at a distance such that local tow truck operators can have access to one while they are anywhere along the arrester bed. Typically, spacings of 300 ft accomplish this task and are recommended. In addition to the tow anchors, a hard-surfaced service lane is recommended. This is needed for truck removal and maintenance of the arrester bed (2,3). Roadside arrester beds do not need a separate service lane because the main line shoulder serves the function. However, the shoulder should be widened in the area of the arrester bed (5).

Some existing facilities have a positive attenuation device at the end of the gravel bed (15,20,22,31). If the consequences in conjunction with the probability of a truck traveling beyond the end of the arrester bed are more severe than those of a loaded truck impacting an attenuation device, then such a device should be installed. The problem with a loaded truck impacting a secondary retarder is in the possibility of the load shifting into the cab and harming the occupants. It may be expected, however, that by the time the truck reaches the impact attenuator at the end of the bed, its speed has decreased substantially and the degree of shift in the load may not be great enough to cause significant damage. It is recommended that such secondary retarders be part of the design of the arrester bed escape ramp if the bed is shorter than desirable and the consequences and probability of a vehicle's traveling beyond the end of the escape ramp outweigh those of the load shift problem (2,25). It should be pointed out, however, that safety research on the use of these devices is lacking; and as such, their occupant injury producing potential is unknown. Facilities that are designed with the intention that the vehicle may return to the main line from the bed's end should not have any secondary attenuator at the end (5). If it is determined that a secondary attenuator is justified at an ascending, horizontal, or descending grade arrester bed, then the type of attenuator should be either standard crash cushions or gravel berms. Current literature provides no indications regarding the good and bad attributes of these two classes of attenuators in truck escape ramp applications. Consequently, either is recommended.

The location on the grade where an escape ramp has the potential for doing the most good is a problem-specific determination. The distance between the summit and the escape ramp should be determined according to the specific characteristics of the runaway truck problem on the grade being considered (4). However, it is recommended that consideration be given to the following general locations:

- immediately uphill from a horizontal curve that cannot be safety negotiated by a high-speed runaway truck (2,25)
- below the halfway point on the grade and above the base (4)
- immediately after a critical point on the grade where many drivers first realize they are runaway, e.g., after a grade change from 6 to 7 percent (31).

Truck escape ramps can have several positions with respect to the main line: parallel, angled, or tangent to the main line immediately preceding a curve. It is recommended that the arrester bed ramp be tangent to the main line immediately preceding a curve. This is advantageous in that the driver performs only a minimum of maneuvering to position the truck for its entry to the facility. A drawback to this arrangement is that the ramp entrance is more likely to be mistaken for the main line by other motorists. However, Oregon engineers claim that the misuse of truck escape ramps is insignificant compared to the lives and property saved (56). Roadside arrester beds must be parallel to the main line to allow side entry (5). As with sandpiles, arrester beds should have right-hand exits from the main line unless all right-hand exit options are infeasible. In such a case, a left-hand design should be considered for a divided highway. If the roadway is an undivided, two-way highway, a left-hand exit is recommended only if the traffic volume is less than 1000 vehicles per day (43) and all right-hand exit designs are infeasible.

The approach to the arrester bed should be a squared-off apron which allows the front wheels of the entering vehicle to contact the aggregate bed simultaneously. The alternative of allowing one wheel to enter the bed before the second wheel can create unnecessary erratic motion to the vehicle (25).

Again, as with sandpiles, arrester beds should be preceded with brake check areas between the escape ramp and the summit or at the summit itself. It is preferable that the brake check area be located at the summit since it is here that the trucker is safest from the runaway condition and is still uncommitted to beginning the descent. It is recommended that the brake check area include a diagrammatic sign outlining the route of the downgrade as well as the percent and length of grades, the location(s) of the arrester bed(s), and an admonition to the driver to use an appropriate low gear during his descent (11).

Signing and delineation for arrester beds should be the same as for sandpiles with the exception of the MUTCD's supplemental panels reading "sand." Uniformity in signing and delineation is important. This includes "No Parking" and "Occupied" signs where they are needed. Where left-hand exits are necessary, Wyoming's "Runaway Truck Crossing" signs (17) are currently recommended (see Section 2.2.12) because they are the only signs in use today which are designed for the purpose of warning drivers in the opposing lane(s) of the potential hazard. Delineation for roadside arrester beds needs to be different than the current MUTCD conventional highway delineation. Because these facilities abut against the main line's shoulders, some special delineation is recommended. Some suggestions are a distinctive cross-hatching to guide other motorists away from both ends and wide barrier stripe along the shoulder edge (5).

Illumination is recommended at the site such that both the arrester bed and the approach (and exit in the case of a roadside arrester bed) can be recognized as a safety measure for runaway trucks from a distance adequate for the appropriate drivers to identify it.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

In the United States today, there are many truck escape ramps and these can be segregated into six types: sandpiles, gravity ramps, ascending grade arrester beds, horizontal grade arrester beds, descending grade arrester beds, and roadside arrester beds. Although truck escape ramps have been present in this country since 1956 (11), it has been only recently that the state-of-the-practice has seen accelerated advances. Most of these have been produced by state transportation agencies using the trial-and-error method. A consequence of this has been a lack of much uniformity across the nation. Complete standardization of truck escape ramp design is not possible due to factors such as differences in topography and distances between the summit and the desirable ramp site (41). However, better uniformity among the different escape ramps is attainable and desirable. Uniformity allows truck drivers to know something of what to expect when approaching the entrance to truck escape ramps. Albeit some formal research has been performed in this area (27,34,47,48,49,50), there is still a need for bona fide research in truck escape ramp technology. Specifically, research is recommended in the following areas.

1. There is a need for field testing roadside arrester beds. Colorado, Idaho, Nevada, and Oregon have similar designs, but there has not been a sufficient number of side entries to yield conclusions about the adequacy of the design concept.

2. Because side entry is a possibility with roadside arrester beds, investigation into the optimal side slopes of the aggregate bed is needed.

3. One of Nevada's roadside arrester beds has a 6 inch asphalt dike "barrier" between the roadway shoulder and the gravel bed. Despite its presence, the facility has experienced side entry in which the runaway truck was successfully stopped. Research is required to determine the value of a low barrier designed to keep other motorists out of the safety facility.

4. Because many uses of truck escape ramps involve trucks with faulty brake equipment, many truckers who use these facilities are issued traffic violation citations. It is recommended that research be undertaken to determine if this practice fosters a reluctance among drivers to use the truck escape ramp.

5. There is a general lack of documentation regarding the operating experiences of most truck escape ramps. The designers of new escape ramps would benefit from learning of the experiences of other facilities. It is suggested that a single source with standardized report forms for data gathering from the various state agencies might alleviate this lack of documentation somewhat.

6. There is a need for safety research in the area of secondary retarder applications in truck escape ramps. The potential for increased rather than decreased occupant injury needs to be determined. Articulated vehicles tend to jackknife upon striking impact attenuators in the highway system (57). Another hazard in connection with

secondary retarders may occur if a heavily loaded truck strikes a secondary attenuator. If this happens, the load may shift causing truck damage and possible injury. Consequently, secondary retarders in connection with truck escape ramps is an area in which there is a need for additional safety research.

7. The Idaho (34) and FHWA (2) design equations presented in Section 2.2.1 (2,34) include, as parameters, measures of rolling resistance. These values are not known with great accuracy. Hence, they should be validated or more reliable quantitative measure of rolling resistances for various materials should be ascertained.

8. It is suggested that research be conducted to investigate a possible relationship between truck weight and friction factor that may be responsible for an apparent decrease in the amount of displaced gravel in arrester beds as entering velocity increases (51). The product of such research may not be immediately and directly applicable to bettering truck escape ramp technology; however, this kind of research will allow engineers to better understand the mechanics of the vehicle-arrester bed interface. This, consequently, may indirectly lead to improved designs.

9. There is a need to determine the best alternatives for delineation and at-ramp signing for all types of truck escape ramps. Some states currently use standard MUTCD delineation for use in truck escape ramp design. There is evidence that such an application may not be the most effective type of delineation since other motorists are sometimes inadvertently led off of the main line and into the escape ramp. Currently, on-going research is investigating the use of red delineators for special application in truck escape ramp delineation. Similarly, at-ramp signing above and beyond current MUTCD standards should be researched to reduce the likelihood of motorists mistakenly entering an escape ramp. Special conditions often require special signing. Consequently, additional research may be useful in developing such signing.

10. Arrester bed depth is quite varied among today's truck escape ramps. Research is needed to determine the effects arrester bed depth has on decelerating runaway trucks and identifying the optimum depth of aggregate for various ramp type and aggregate combinations.

11. Because freezing and packing can result from an arresting material's becoming too contaminated with fine material, it is necessary to develop a procedure to determine what percentage of fines necessitates the replacement of arresting material. Such a procedure would be useful in the initial installation of arresting material to determine if a particular aggregate is suitable. Additionally, this procedure could be used periodically in the life of the escape ramp to determine if the arresting material required replacement. An alternate approach would be to determine recommended replacement intervals for various aggregates.

12. What is the service life of an arrester bed, a sandpile, or a

gravity ramp? This question must be answered before an accurate cost-effectiveness analysis can be made for a given facility.

13. If all else is equal, two designs involving different ascending grades will need to be of different lengths. Because steeper grades require less length, it seems to be to the advantage of the designer to use the maximum allowable grade on the ascending ramp. Research is necessary to determine the maximum grade. It is noted that Colorado has an arrester bed which has as its third section a +42.8 percent grade, and there have been no problems with rollbacks (12); however, Colorado's Design Manual (35) recommends grades no steeper than 20 percent.

14. There is a general lack of data regarding which escape ramp designs prevent the greatest number of deaths and serious injuries. Such data would be useful in identifying the best truck escape ramp designs.

15. The human factors aspects in truck escape ramp usage should be research further. Although Eck (4) has reported findings from a survey of truck drivers, more in-depth research of truck drivers' thoughts would be useful. Truck escape ramp design technology could benefit from a better understanding of why some truck drivers are more apt to enter certain facilities than others.

16. Several truck escape ramp installations include pipe networks to facilitate good drainage. Other escape ramps rely solely on the drainage characteristics provided by the aggregate gradation and slope. To avoid retrofitting pipe networks into the escape ramp system, it would be desirable for research to determine the conditions when such elaborate drainage provisions are needed.

17. There is a need to identify the extent to which the freezing of aggregate is a problem. If the extent is significant, research should show how much of the bed must be frozen to cause appreciable operational problems.

18. The location of a truck escape ramp is usually identified by the distance between it and the summit of the downgrade. The various truck escape ramp installations throughout the United States differ with respect to location on the respective grades. Research should be conducted to identify the point or section on the grade at which the escape ramp placement would be optimum. This point or section could, perhaps, be defined in terms of grade, distance, horizontal curvature, and speed capabilities of the escape ramp type.

19. Because of the few truck escape ramps which are accessed via left-hand exits from the main line, it is recommended that further research be directed toward the advisability and design guidelines for such facilities. The escape ramps include both those requiring traffic to cross lanes of opposing traffic and those which are in the median of divided highways.

20. There is a need for research in the area of brake check areas. Specifically, it is recommended that research be conducted to determine the effects of high and low type brake

check areas on reducing runaway truck occurrences and minimizing the severity of runaway truck accidents.

21. Illumination on highway facilities is often desirable, but not always cost-effective. Consequently, research in the area of illumination benefits as applied to truck escape ramps could produce useful information.

22. In light of the potential problem of uncontrolled rollbacks on smooth surfaces, and the resultant possibility of jackknifing or overturning, research regarding the advisability of future construction of gravity ramps as opposed to escape ramps employing aggregate beds or sandpiles is recommended.

23. Generally, some form of lateral constraint, e.g., guardrailing, is useful in minimizing jackknifing and overturning by channelizing the truck within the ramp. However, most lateral constraints have the potential to entrap snow drifts in the bed. Because this seems to have the potential to impair the function of the truck escape ramp, it is recommended that safety research dealing with the placement and design of lateral constraints be conducted.

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APPENDIX A

TEST CONDITIONS AND SUMMARY OF TRUCK REACTION TO MOUNDS

Source: Reference (<u>27</u>)

Test No.	Mound shape, number, and spacing	Height ft.	Material	Peak, Front hub, ft.		Peak, Front target, ft.		Peak, Rear hub, ft.		Peak, Rear target, ft.		In/Out Radar MPH	Comments
				Vert	Horiz	Vert	Horiz	Vert	Horiz	Vert	Horiz		
1	1.5:1 Peak Single	1	3/4-1/2" Gravel	+0.45	0	+0.16	+4.6	+0.19	0	+0.17	+2.0	25/24	Mild reaction.
2	1.5:1 Peak Single	1	3/4-1/2" Gravel	+0.57	0	+0.17	+5.2	+0.17	+0.6	+0.23	+3.2	34/33	Front wheels left ground.
3	1.5:1 Peak Single	1	3/4-1/2" Gravel	+0.67	+0.6	+0.23	+4.6	+0.23	+0.6	+0.23	+5.2	43/42	Front wheels left ground.
4	3:1 Peak Single	1	3/4-1/2" Gravel	+0.45	0	+0.40	+5.8	+0.20	±0.6	+0.46	+0.6± 0.3	28/27	Front wheels left ground. Battery came out of mount; Broke radiator hose.
6	1.5:1 Peak 3 @ 30' c-c	1	3/4-1/2" Gravel	+0.46	0	+0.12	+4.9± 0.3	+0.17	0± 0.3	+0.23	+0.6	26/24	End pile 3; Each berm reduced speed 1/2 mph.
				+0.38	0	+0.21	+6.0	+0.15	0	+0.18	+1.4		End pile 1; 3 separate impacts - no carry-over.
7	1.5:1 Peak 3 @ 30'	1	3/4-1/2" Gravel	+0.48	0	+0.29	+7.2	+0.35	+0.3	+0.40	+4.9	35.5/33	End pile 3; 1st Target ±0.3 below bar on approach.
				+0.53	0	+0.23	+7.5± 0.1	+0.18	+0.6	+0.14	+4.0		End pile 1; Rear wheel leaves ground.

TEST CONDITIONS AND SUMMARY OF TRUCK REACTION TO MOUNDS (continued)

Test No.	Mound shape, number, and spacing	Height ft.	Material	Peak, Front hub, ft.		Peak, Front target, ft.		Peak, Rear hub, ft.		Peak, Rear target, ft.		In/Out Radar MPH	Comments
				Vert	Horiz	Vert	Horiz	Vert	Horiz	Vert	Horiz		
8	1.5:1 Peak Single	2	3/4-1/2" Gravel	+0.54	+0.9	+0.52	+5.5 ± 0.3	+0.35	+0.9 ± 0.3	+0.69	+1.2	25.5/ 22.5	Axle spread gravel 50' downstream. Broke both front shock mountings, radiator leak, bent steering wheel.
9	3:1 Peak Single	2	3/4-1/2" Gravel	+0.60 (est.)	+2.3	+0.63	+7.5 ± 0.3	+0.48 (est.)	+0.6	+0.60	+4.9	36.5/ 32.5	Driver nearly lost control of truck. Bent front axle or broke kingpins. Truck out of action.
10	3:1 Peak Single	2	3/4-1/2" Gravel	+1.01	+5.5	+1.15	+6.9 ± 0.6	+0.84	+4.0	+1.32	+0.6 ± 0.6	26/ 22.5	Softer than #8 and #9. No truck damage.
11	1.5:1 Peak 3 @ 30'	2	3/4-1/2" Gravel	-	-	-0.71	-5.8	-	-	-	-	25±	Data is for low point prior to impact of berm #3.
				+0.58	+5.2	+0.64	+1.2	+0.79	+1.7	+1.12	+0.86		Data for berm #3 after impact.
				+0.46	-0.6	+0.29	+3.5 ± 1.2	+0.37	-0.3	+0.60	0		Berm #1 data; Scattered gravel over test area. Tie rod and axle skims tops of piles, bent tie rod. Out of action.
12	1.5:1 Peak 3 @ 30'	2	1/2-2" Rubber Tire Chips			-0.35	-2.3					38.5/ 23.5	Data for low point prior to impact of berm #3.
				+0.37	0	0	-0.6	+0.31	+1.4	+0.32	+2.3		Berm #3, after impact.
				+0.59	0	+0.25	+1.7	+0.26	+0.6	+0.43	+0.6		Piles compress, moderate reaction. No front axle damage, berm #2 data.

TEST CONDITIONS AND SUMMARY OF TRUCK REACTION TO MOUNDS (continued)

Test No.	Mound shape, number, and spacing	Height ft.	Material	Peak, Front hub, ft.		Peak, Front target, ft.		Peak, Rear hub, ft.		Peak, Rear target, ft.		In/Out Radar MPH	Comments
				Vert	Horiz	Vert	Horiz	Vert	Horiz	Vert	Horiz		
13	1.5:1 Peak 3 @ 30'	2	1/2-2" Rubber Tire Chips			-0.35	-9.2					38/33	Data for low point prior to impact of berm #3.
				+0.69	+0.3± 0.3	-0.37	-2.3	+0.46	+0.3	+0.58	+1.44		Berm #3 after impact.
				+0.67	+0.3	+0.29	+5.2± 0.3	+0.38	+0.9± 0.3	+0.60	+2.9		Camera pan - berm #2. Truck jumps over each berm.
14	1.5:1 5' Flat top Single	2	1/2-2" Rubber Tire Chips	+0.81	+1.7	+1.06	+6.9	+0.89	+2.9	+1.35	+1.2	26/22	Camera fixed - end pile.
				+0.62	+1.7± 0.3	+1.01	+6.0± 0.9	+0.73	+4.0	+1.35	+2.0		Camera pan - nose landing, shifted load forward.
15	1.5:1 8' Flat top Single	2.9	1/2-2" Rubber Tire Chips	+2.01	+8.1	+2.28	+6.9	+1.61	+5.8	+2.24	+3.2	25.5/ 20	Camera fixed - end pile.
				+2.04	+7.5	+2.24	+6.9	+1.55	+4.9	+2.23	+2.9		Camera pan - truck climbed up and through pile. Leaped over downstream end, dumped part of load. No damage.
16	1.5:1 Peak 3 @ 30'	2	3/4-1/2" Gravel			-0.59	-4.6± 0.6					23.5/ 13	Data for low point, before impact - berm #3.
				+0.40	+2.3	+0.53	+2.9± 0.6	+0.46	+0.6	+0.48	0± 1.2		Berm #3 after impact.
				-	-	-	-	+0.51 (est.)	+1.2 (est.)	+0.44 (est.)	+0.9 (est.)		Camera pan Berm #2 - tie rod bent (partly damaged after second berm). Right wheel turned out after third berm resulting in tire drag frictional stoppage.

TEST CONDITIONS AND SUMMARY OF TRUCK REACTION TO MOUNDS (continued)

Test No.	Mound shape, number, and spacing	Height ft.	Material	Peak, Front hub, ft.		Peak, Front target, ft.		Peak, Rear hub, ft.		Peak, Rear target, ft.		In/Out Radar MPH	Comments
				Vert	Horiz	Vert	Horiz	Vert	Horiz	Vert	Horiz		
17	1.5:1 6' Flat top Single	2	3/4-1/2" Gravel	+1.29± 0.23	+4.0	+1.27	+4.3	+1.16	+1.4	+1.50	-0.9	22.5/16	Camera fixed - end pile. Truck climbed through berm, breaking out on backside. Tie rod bent.
18	1.5:1 Peak 3 @ 14' c-c	2	3/4-1/2" Gravel	-	-	-0.53	-1.7	-	-	-	-	24/10	Camera pan - data for low point prior to impact of berm #2.
				-	-	+0.26	+5.2	-	-	-	-		Camera pan - data for high point after impact with berm #2.
				-	-	-0.63	-1.4	-	-	-0.3	-7.5		Camera fixed - data for low point before impact with berm #3.
				-	-	+0.12	+3.5	-	-0.9± 0.3	+0.52	-3.5		Camera fixed - data for high point after impact with berm #3. Tie rod damage began at first berm and worsened with each succeeding impact. Truck barely cleared 3rd berm before stopping, little jump.
19	1.5:1 Peak Single	2.5	3/4-1/2" Gravel	obscured		+1.00	+5.2± 0.6	+0.70	+3.5	+1.09	+1.4	25/19	Camera pan.
				obscured		+1.00	+6.3± 0.6	+0.71	+2.0	+1.10	+0.3		Camera fixed. Tie rod bent. Climbed through pile, not much jump.

TEST CONDITIONS AND SUMMARY OF TRUCK REACTION TO MOUNDS (continued)

Test No.	Mound shape, number, and spacing	Height ft.	Material	Peak, Front hub, ft.		Peak, Front target, ft.		Peak, Rear hub, ft.		Peak, Rear target, ft.		In/Out Radar MPH	Comments
				Vert	Horiz	Vert	Horiz	Vert	Horiz	Vert	Horiz		
20	1.5:1 Peak 3 @ 30'	2	3/8-#10 Gravel	-	-	-0.63	-3.7	-	-	-	-	20.5/ 8.5	Camera pan - data for low point prior to impact of berm #2.
				+0.58	+4.2± 0.6	+0.99	+3.7	+0.56	+0.3± 0.3	+0.56	-2.0		Camera pan - data for high point after impact with berm #2.
				-	-	-0.69	-7.8	-	-	-	-		Camera fixed - data for low point before impact with berm #3.
				+0.52	-1.7	+0.48	-1.4	+0.46	-0.3± 0.3	+0.59	-3.7		Camera fixed - data for high point after impact with berm #3. Less violent than with coarse aggregate. No vehicle damage.
21	1.5:1 Peak 3 @ 30'	2	3/8-#10 Gravel	-	-	+0.25	-1.2	-	-	-	-	32/20	Camera fixed - data for low point before impact with berm #3.
				-	-1.2± 0.3	+0.29	+2.0	-	+2.0	+0.98	0		Camera fixed - data for high point after impact, bent axle, tie rod okay. Truck swerved left.

TEST CONDITIONS AND SUMMARY OF TRUCK REACTION TO MOUNDS (continued)

Test No.	Mound shape, number, and spacing	Height ft.	Material	Peak, Front hub, ft.		Peak, Front target, ft.		Peak, Rear hub, ft.		Peak, Rear target, ft.		In/Out Radar MPH	Comments
				Vert	Horiz	Vert	Horiz	Vert	Horiz	Vert	Horiz		
22	1.5:1 Peak 3 @ 14' c-c	2	3/8-#10 Gravel	-	-	-0.35	0	-	-	-	-	26/ 14.5	Camera pan - data for low point prior to impact with berm #2.
				-	-2.3	+0.14	+7.5	-	-0.6	+0.3	-0.9		Camera pan - data for high point after impact with berm #2.
				-	-	-0.37	-1.7	-	-	-	-		Camera fixed - data for low point prior to impact with berm #3.
				obscured		+0.23	+4.3	-	0± 0.6	+0.81	-2.3		Camera fixed - data for high point after impact with berm #3. Three close berms stop truck faster. Tie rod and axle bent up at spindle and shackle and exposed tie rod ends.
23	1.5:1 5' Flat top Single	2	3/8-#10 Gravel	+1.09	+1.2	+1.07	+4.6	+1.44	+2.3	+2.01	+0.9± 0.9	25/17	Camera pan - front end of pile.
				+1.09	+2.3	+1.27	+5.2	+1.55	+1.7	+2.08	0		Camera fixed - truck climbed through berm and jumped. Dodge axle higher than Ford thus giving better protection to tie rod. Tie rod still bent. Gravel thrown up grille.

APPENDIX B

"SANDPILE" ACCIDENT HISTORY
Source: Reference (26)

US 421, Wilkes County
May 15, 1974 thru August 31, 1975

1. 1-16-74: Truck brakes failed. Drove into sandpile. No injuries, no damage to rig. Estimated entry speed of 40 mph. Total distance of travel into sandpile was 120 feet.

2. 7-22-74: 9:00 a.m., clear, warm. Truck brakes failed. Drove into sandpile. No injuries, no damage to rig. Estimated entry speed of 25 mph. Total distance of travel into sandpile was 103 feet.

3. 8-28-74: 12:30 a.m. Truck brakes failed. Drove into sandpile. No injuries, minor damage to rig. Estimated entry speed of 35 mph. Sand packed tightly, stopping force due to "ridges." Total distance of travel into sandpile was 150 feet.

4. 12-17-74: Truck brakes failed. Drove into sandpile. No injuries, $500 damage to truck. Estimated entry speed of 35 mph. Total distance of travel into the sandpile was 150 feet.

5. 1-29-75: Truck brakes and transmission failed. Drove into sandpile. One Class A injury. Dump truck and flatbed trailer were both demolished. Estimated entry speed in excess of 60 mph. Truck traveled 210 feet through entire sandpile and stopped on the back edge.

6. 5-21-75: Truck brakes failed. Drove into sandpile. One Class B injury, minor damage to rig. Estimated entry speed of 40 mph. Truck traveled 200 feet into sandpile (see newspaper clipping).

7. 8-20-75: Driver stopped truck up the mountain to make repairs. Driver unhooked tractor from trailer and drove down mountain in an effort to jump start the tractor. When engine didn't start, the driver drove into sandpile. Upon impact, the flip up cab came completely over, crushing the driver. Driver killed, tractor demolished. Estimated entry speed of 45 mph. The tractor traveled 175 feet into sandpile (see newspaper clipping).

8. 8-26-75: 2:15 p.m., clear. Truck brakes failed. Truck drove into sandpile with right side wheels only. No injuries, $300 estimated damage to vehicle. The truck traveled 120 feet into sandpile.

9. 8-29-75: 6:00 a.m. Truck brakes failed. Drove into sandpile. No injuries, no damage to truck. Truck traveled 100 feet into sandpile. The entry speed is not known.

NOTE: A twelfth truck has been stopped by a dirtpile at this site. The truck's brakes failed and the driver drove into a dirtpile from the excavation for the sandpile area. The accident occurred May 6, 1974, nine days prior to the completion of the sandpile. There were no injuries or truck damage involved in the low speed impact.

"SANDPILE" ACCIDENT HISTORY (continued)
Source: Reference (7)

US 70 - Black Mountain, McDowell County
Sandpile #1
From February 1, 1974 (Installation Date)

Accident No.	Date	Estimated Speed of Entry	Estimated Damage to Vehicle	Injuries	Out or In State Driver	Weight of Vehicle
1	5-3-74	25 mph	None	None		40,000
2	5-16-74	70 mph	Demolished	One Class A		
3	9-4-74	25 mph	None	None		70,000
4	9-25-74	40 mph	None	None		70,000
5	1-17-75	20 mph	None	None		
6	1-30-75	Details not known		None		
7	1-30-75	Details not known		None		
8	2-3-75		Minor	None		38,000
9	4-4-75		None	None		
10	4-20-75	75 mph	$5,000	One Class C		
11	7-14-75	20 mph	None	None		
12	7-18-75	60 mph	$25,000	None		
13	D.O.T. Not Notified					
14	D.O.T. Not Notified					
15	D.O.T. Not Notified					
16	D.O.T. Not Notified					
17	D.O.T. Not Notified					
18	D.O.T. Not Notified					
19	D.O.T. Not Notified					
20	D.O.T. Not Notified					
21	D.O.T. Not Notified					
22	D.O.T. Not Notified					
23	D.O.T. Not Notified					
24	2-22-76	20-25 mph	None	None	Out	Unknown
25	3-4-76	20-25 mph	$25	None	Out	73,000
26	3-5-76	35-40 mph	$300	Minor cuts	In	78,000

"SANDPILE" ACCIDENT HISTORY (continued)

Accident No.	Date	Estimated Speed of Entry	Estimated Damage to Vehicle	Injuries	Out or In State Driver	Weight of Vehicle
27	3-21-76	30-40 mph	None	No	Out	78,000
28	3-27-76	45 mph	None	No	In	68,000
29	3-31-76	50 mph	$3,000	None	Out	72,400
30	5-14-76	40 mph	None	None	In	Unknown
31	5-16-76	60 mph	$2,000	None	Out	72,000
32	5-18-76	25 mph	None	None	In	72,000
33	6-8-76	25 mph	None	None	Out	72,000
34	6-16-76	60 mph	$2,000	None	Out	28,000
35	D.O.T. Not Notified					
36	6-28-76	15 mph	None	None	Out	72,000
37	7-17-76	20 mph	None	None	In	72,000
38	8-7-76	35 mph	None	None	In	68,000
39	8-11-76	50 mph	$300	None	Out	72,000
40	8-12-76	20 mph	None	None	Out	15,000
41	8-13-76	45 mph	$800	None	Out	7,300
42	8-15-76	50 mph	$1,200	None	In	7,300
43	8-18-76	45 mph	None	None	In	56,000
44	8-27-76	40 mph	None	None	Out	73,000
45	8-29-76	25 mph	None	None	Out	31,000
46	9-1-76	50 mph	None		Out	65,000
47	9-7-76			None		
48	9-9-76	50 mph	None	None	Out	73,000
49	10-21-76	50 mph	None	None	Out	73,000
50	10-28-76	40 mph	$1,000	None	In	60,000
51	12-9-76	25 mph	None	None	Out	73,000
52	12-14-76	30 mph	None	None	In	73,000
53	12-17-76	50 mph	None	None	Out	69,000
54	12-29-76	30 mph	None	None	Out	7,300
55	2-17-77	35 mph	None	None	Out	68,000
56	D.O.T. Not Notified					
57	4-8-77	D.O.T. Not Notified				

"SANDPILE" ACCIDENT HISTORY (continued)

Accident No.	Date	Estimated Speed of Entry	Estimated Damage to Vehicle	Injuries	Out or In State Driver	Weight of Vehicle
58	4-21-77	20 mph	None	None	Out	73,000
59	4-28-77	60 mph	None	None	Out	71,000
60	5-6-77	80 mph	$15,000	None	Out	73,000
61	5-20-77	D.O.T. Not Notified				
62	5-27-77	30 mph	None	None	In	72,000
63	6-3-77	60 mph	None	None	In	72,000
64	6-8-77	60 mph	None	None	Out	74,000
65				None		
66	7-16-77			None		
67	7-17-77	35 mph	None	None	Out	73,000
68	7-27-77	45 mph	None	None	Out	73,000
69	7-28-77	45 mph	None	None	Out	74,000
70	8-12-77	30 mph	None	None	Out	67,000
71	8-16-77	30 mph	None	None	Out	69,000
72	8-17-77			None		
73						
74	9-5-77	35 mph	None	None	In	30,000
75	9-6-77	25 mph	None	None	Out	79,000

"SANDPILE" ACCIDENT HISTORY (continued)

US 70 - Black Mountain, McDowell County
Sandpile #2

From December 15, 1975 (Installation Date)

Accident No.	Date	Estimated Speed of Entry	Estimated Damage to Vehicle	Injuries	Out or In State Driver	Weight of Vehicle
1	D.O.T. Not Notified					
2	D.O.T. Not Notified					
3	2-18-76	40-45 mph	$25	None	Out	63,000
4	3-27-76	38 mph	None	None	Out	72,000
5	4-14-76	40 mph	$25	None	Out	73,000
6	6-7-76	30 mph	None	None	Out	68,000
7	7-1-76	20 mph	None	None	Out	72,000
8	7-19-76	30 mph	None	None	Out	70,000
9	8-4-76	20 mph	None	None	Out	36,000
10	8-11-76	45 mph	None	None	Out	73,000
11	8-27-76	45 mph	None	None	Out	73,000
12	9-2-76	50 mph	$1,200		Out	60,000
13	9-3-76	D.O.T. Not Notified		None		
14	9-15-76	40 mph	None	None	Out	72,000
15	9-20-76			None		
16	9-22-76	45 mph	None	None	Out	73,000
17	9-26-76	50 mph	None	None	Out	69,000
18	10-3-76	50 mph	$125	None	Out	40,000

APPENDIX C

RUNAWAY TRUCK ESCAPE RAMP USAGE

Source: Reference (54)

Rabbit Ears Pass - US 40
Cost - $302,000
Date opened - December 1976
Length - 1300 ft., Gravel 800 ft.

Partial record of use:

Date	Time	Comments
12/16/76	12:05 pm	Truck-semi(tank) experienced failure to drive train. Minor damage to vehicle resulted from running over striped vertical panel. Driver responded to a questionnaire, "I want to express my appreciation to the State of Colorado for the fine job they did of constructing the ramp. In fact I think so much of it every time I cross Rabbit Ears Pass I am going to get out and kiss it about five times before I proceed on my way." Entered ramp at estimated speed of 55 mph, coasting in 917 ft.
12/28/76	7:00 pm	Tractor towing 40-ft. flat bed trailer loaded with 40,000 lbs. of steel entered ramp at estimated 90 mph and stopped at top of ramp. Gear shift lever had broken off leaving truck in neutral and air brakes failed. Minor damage to vehicle resulted from collision with two vertical panels and one delineator. "Ramp probably saved two lives."
05/16/77	10:00 am	Tractor towing trailer loaded with steel pipe fittings had brake failure and entered ramp at estimated 80 mph traveling 954 ft. Driver was well satisfied with the ramp. No damage.
06/22/77	5:45 pm	Pickup truck towing four-wheel trailer loaded with a forklift and having gross combination weight of estimated 25,000 lbs. could not reduce speed when trailer brakes became hot. Driver turned into ramp and traveled 541 ft. Electric brakes on trailer were out of adjustment and driver was cited for inadequate brakes on a towed trailer. No damage.
07/17/77	7:10 pm	Motor home towing pickup truck developed smoking brakes which went out altogether above the ramp. Driver turned into ramp and traveled 354 ft. No damage. Driver unhooked pickup and drove both vehicles off ramp under their own power.
07/25/77	7:00 pm	Mobile crane weighing 48,000 lbs. blew engine and lost air pressure to brakes. Driver entered at estimated 50 mph and traveled 776 ft. Driver was quite pleased with the ramp and could think of no suggestion that could improve it. No damage.
08/15/77	5:30 pm	Truck-semitrailer entered ramp at estimated 100 mph and traveled to within 8 ft. of end of ramp. Engine had blown and brakes had gone out. Driver stated that he had stopped at top of pass and tightened all the brakes. However, inspection indicated that the brakes had not been touched for several weeks; the front driver wheel brakes were completely unhooked and missing parts; and the rear drivers were leaking oil and were probably skipping all the way down until they burned out. Scuff marks indicated that vehicle had probably gone around last two curves on nine wheels. It took three wreckers four hours to remove this vehicle from ramp. No damage to vehicle or load.

RUNAWAY TRUCK ESCAPE RAMP USAGE (continued)

Date	Time	Comments
08/17/77	8:45 pm	Truck-semitrailer weighing about 60,000 lbs. entered the ramp at estimated 80 mph and traveled 15 ft. beyond the end of the ramp. Undercarriage was damaged severely by gravel berm at end of ramp. The pea gravel had apparently packed too hard as vehicle sank in only about 6 inches near top of ramp.
11/15/77	--	Ramp was raked after an unreported usage.
02/05/78	1:30 pm	Truck-semitrailer weighing 80,000 lbs. lost braking power and entered ramp at estimated 60 mph. Vehicle traveled 680 ft. into the ramp before stopping in 4 ft. of snow. Front of tractor received moderate to severe damage with no damage to trailer.
05/24/78	12:05 pm	Truck-semitrailer lost air pressure to brakes and entered truck ramp at estimated 50-55 mph. Vehicle traveled 288 ft. into ramp and was undamaged.
07/03/78	11:00 am	Tractor-trailer carrying 44,400-lb. load lost brakes and entered ramp. No damage to vehicle.
07/12/78	--	Incident report not received.
09/16/78	3:15 pm	Tractor-semitrailer loaded with railroad ties developed hot brakes and entered ramp using 339 ft. of the gravel before stopping. After being towed off the ramp, the vehicle continued on its way.
09/17/78	8:05 am	Driver of a truck-tractor with trailer and piggy-back trailer, loaded with furniture and having gross weight of 57,000 lbs., felt brakes beginning to be spongy. Vehicle entered ramp at estimated 35-40 mph and traveled 366 ft. into the gravel. No damage to vehicle.
09/21/78	12:01 pm	Truck driver stopped at the false top parking area to check brakes--truck had no Jake brake. Driver started down pass in third gear at approximately 35 mph. After brakes failed, vehicle built up speed and driver entered ramp with vehicle traveling 392 ft. into the gravel. Driver of truck #2, the same type as the first truck, started down the pass in fifth gear and was following the first truck. When truck began picking up speed, driver down shifted to fourth gear. When truck still picked up speed, driver was unable to down shift and realized he had no brakes. Driver followed truck #1 into the ramp traveling 292 ft. into the gravel. Driver of truck #2 was able to drive out of the ramp without needing a tow.
09/22/78	7:30 am	Truck tractor with trailer loaded with packing units and having gross weight of 72,000 lbs. entered the ramp at approximately 55 mph traveling 396 ft. into the gravel. Driver had stopped at false top to check brakes and then proceeded down the pass in low gear. When he applied brakes, they felt hard and air gauge indicated that he had lost all the air. He also stated that he knew the air leak was there but could not find it.
10/01/78	10:45 pm	Truck-semitrailer loaded with furniture and having gross weight of 51,500 lbs. entered the ramp at about 65 mph and stopped 750 ft. from the end of the ramp. Driver was going about 30 mph and had just passed the first ramp sign when he realized that he did not have total braking power. It was the driver's first trip over the pass. No damage to vehicle.

RUNAWAY TRUCK ESCAPE RAMP USAGE (continued)

Date	Time	Comments
10/23/78	5:29 pm	Driver of truck tractor towing a 14x75 ft. mobile home stopped at top of pass to check brakes. On descent the trailer brakes went out and then truck brakes began to smoke. Driver used ramp to avoid ruining his brakes, entering at approximately 25 mph and traveling 224 ft. into the gravel. Driver was able to remove truck and mobile home from ramp without damage to either. Driver had traveled the pass approximately 25 times before, towing mobile homes.
11/19/78	1:23 pm	Driver of truck-trailer hauling load of steel and having gross weight of 63,000 lbs. had stopped at summit to check brakes and started down pass at approximately 25-30 mph. Brakes lost air pressure and driver entered the ramp at unknown speed with vehicle traveling 588 ft. into gravel. Vehicle had no Jake brake.
05/20/79	2:30 pm	Tractor-trailer hauling 55,000 lbs. of fuel with a gross weight of 80,000 lbs. lost brakes and driver entered truck ramp traveling 325 ft. into the ramp. No damage to vehicle. The truck had no Jake brake and driver had stopped at the west summit to check brakes. Driver had driven over Rabbit Ears Pass numerous times. He "had a very positive attitude towards the truck ramp."
05/31/79	3:00 am	Tractor-trailer with load of grass sod experienced engine failure and brakes overheated causing driver to use the ramp. Vehicle traveled 547 ft. into the ramp. No damage caused to vehicle from use of the ramp.
06/13/79	9:00 pm	The driver of a truck having gross weight of 71,750 lbs. used the truck ramp after brakes overheated and then failed. Vehicle traveled 470 ft. on the gravel. Vehicle was towed off ramp and left the scene under its own power. "No Jake brakes and inexperience of mountain driving were contributing factors."
06/15/79	11:30 am	Truck towing tanker loaded with gasoline and having gross weight of 85,000 lbs. (a special transport permit allowed vehicle to carry that amount of weight) experienced failure of the Jake brake and the driver was unable to control the speed. A speedometer graph in the vehicle indicated that the driver had begun the descent at 28 mph and entered the ramp at approximately 58 mph. The vehicle traveled 592 ft. into the ramp before stopping. The speed was too great for the engine compression and the engine suffered apparent interior damage. The vehicle owner stated that he had personally trained this driver over this road and had advised him to descend the pass at 18 mph in order to maintain control. It was the officer's opinion that the driver did not allow a margin of safety in the speed at which he began the descent considering the weight of the vehicle and cargo.
06/22/79	2:40 pm	Truck-trailer loaded with lumber and having gross weight of 75,000 lbs. entered the ramp at 65 mph and traveled 747 ft. into the gravel. The brakes had overheated and the driver missed when he attempted to split shift so that the vehicle was freewheeling. The vehicle was towed from the ramp and proceeded under its own power. The driver stated that he had topped the pass at more than 25 mph and that he did not apply Jake brakes until vehicle was freewheeling.

RUNAWAY TRUCK ESCAPE RAMP USAGE (continued)

Date	Time	Comments
07/12/79	9:30 am	Tractor-trailer hauling 50,000 lbs. of gasoline began descent at estimated 25 mph and entered the ramp at estimated 60 mph (speedometer was broken). Vehicle traveled 393 ft. into the newly surfaced gravel ramp. Driver did not stop at Pass summit to inspect brakes which failed to hold on the descent. Driver was cited for inadequate brakes.
07/26/79	9:30 pm	Tractor-trailer loaded with furniture and having a gross weight of approximately 40,000 lbs. was descending the Pass when the air line to the trailer brakes dropped onto the drive shaft and was severed. The trailer brakes failed to lock and the vehicle entered the ramp at approximately 45 mph, traveling 408 ft. into the ramp. The furniture was loaded in the front of the trailer and apparently caused some sideslip by the vehicle in the ramp.
07/27/79	10:11 am	Tractor-trailer loaded with 42,200 lbs. of assorted groceries and having a gross weight of 74,200 lbs. began the descent at too high speed and driver was unable to slow the vehicle which traveled 701 ft. into the ramp. Inexperience in mountain driving and disregard of highway signs were believed to be causes of this usage of the ramp.
08/15/79	11:30 am	Tractor-trailer loaded with steel and having a gross weight of 59,000 lbs. experienced smoking brakes when driver entered the ramp at 30-35 mph. Vehicle traveled 414 ft. into the ramp before stopping.
08/24/79	10:30 am	Tractor-trailer loaded with steel products and having gross weight of 72,200 lbs. entered the ramp when the air pressure continued dropping. Vehicle traveled 670 ft. into the ramp before stopping. Brake shoes on the trailer were found to be in poor condition.
09/17/79	11:40 am	Tractor-trailer loaded with more than 54,000 lbs. of explosives started down the Pass in 5th gear at 30 mph and lost its brakes. The vehicle entered the ramp at 70 mph and traveled 1032 ft. into the ramp before stopping. Traffic in both directions on the Pass was stopped while the vehicle was removed.
09/30/79	9:15 pm	Tractor-trailer loaded with 6000 lbs. of furniture and with overheated brakes entered the ramp at 75 mph and traveled 730 ft. into the gravel, stopping 63 ft. from the end of the ramp. Two vertical panel markers were damaged. The truck which had no Jake brake had begun the descent in 4th gear and lost air pressure when the brakes were applied.
03/13/80	1:15 pm	School bus with 33 passengers and having gross weight of 30,000 lbs. was descending the Pass when the brakes overheated and faded and the automatic transmission would not hold. The vehicle entered the ramp at estimated 60 mph and traveled 170 ft. into the ramp before stopping; the last 50 ft. were in deep snow. There were no injuries to the occupants nor damage to the vehicle. Less than one year mountain driving experience, first trip over this route.
05/21/80	9:30 am	Tractor-trailer loaded with drill pipe collars and having gross weight of 66,860 lbs. entered the ramp at estimated 50 mph and traveled 430 ft. into the ramp before stopping. The driver thought he could have made it to the bottom of the hill, but elected to use the ramp rather than chance it. No mountain driving experience; first trip over pass.

RUNAWAY TRUCK ESCAPE RAMP USAGE (continued)

Date	Time	Comments
05/22/80	7:05 am	Tractor-trailer loaded with steel I-Beams was two miles above the ramp when driver became aware of the problem and entered the ramp at estimated 90 mph, traveling 975 ft. into the ramp before stopping. Less than one year mountain driving experience; two trips over pass.
06/14/80	9:06 am	Tractor-trailer loaded with furniture and having gross weight of 50,220 lbs. experienced problems 0.5 mile above the ramp and entered at 50 mph, traveling 341 ft. into the ramp before stopping. No mountain driving experience; first trip over pass.
06/18/80	5:30 pm	Truck loaded with feed supplements and having gross weight of 31,800 lbs. lost its clutch and began freewheeling about two miles east of the ramp. Vehicle entered the ramp at 70 mph and traveled 601 ft. into the ramp before stopping. Fifteen years mountain driving experience; 11 trips over pass.
07/01/80	4:20 pm	Tractor-trailer hauling furniture was 1 mile above the ramp when driver noted brakes overheating. The vehicle entered the ramp at 30-35 mph, stopping at end of the paved approach. Seven years mountain driving experience in eastern states; first trip over this route.
07/02/80	3:00 pm	Tractor-trailer hauling household goods and having gross weight of 42,840 lbs. was 1.5 miles above ramp when brakes overheated. Vehicle entered ramp at 50-55 mph and traveled 532 ft. in the gravel. Driver cited for careless driving as he failed to stop on top of pass before descending and stated that he had started down at 40 mph. Less than one year mountain driving experience; first trip over this route.
09/15/80	12:00 pm	Tractor-trailer loaded with furniture and having gross weight of 47,480 lbs. was 1/2 mile above the ramp when the brakes overheated and faded. Vehicle entered ramp at 50-60 mph and traveled 483 ft. in the gravel. Two years mountain driving experience; first trip over this route.

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

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* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.

DEPARTMENT OF TRANSPORTATION ★ UNITED STATES OF AMERICA ★

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