



COLORADO
Department of Transportation

Applied Research and Innovation Branch

EMERGENCY ESCAPE RAMPS (EER)

IMPROVEMENTS

Authors:

Dr. Rodolfo Valdes Vasquez,

Dr. Kelly Strong, and

Dr. Scott Shuler

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16. Abstract The objective of this research is to develop a set of design and operational recommendations to reduce the number of rollover, jackknife, and rollback end positions for trucks entering the emergency ramp. To do so, the research team used several strategies including a review of literature, appraisal of incident reports, conduct field observations at several emergency escape ramps, interviews and surveys of the I-70 corridor stakeholders, perform an analysis of current geometry and material used in emergency ramps, and conduct interviews with other DOTs and CDOT staff about fuel or cargo spills. The study includes six main tasks as shown below, which form the structure of this report: Chapter 1. Introduction and Background Chapter 2. Field Observation Reports Chapter 3. Material and Design Analysis of the Arrester Bed Chapter 4. Interviews with I-70 Mountain Corridor Stakeholders Chapter 5. Ramp Performance Evaluation (Hazmat) Chapter 6. Conclusion and Recommendations			
Implementation The products of this research is a series of recommendations focusing on: a) maintenance/material replacement, b) signage and pavement marking, c) shoulder strengthening/widening, d) new construction, e) lighting, and f) drivers' outreach. Specific recommendations to be implemented by CDOT include improved maintenance and entrance reconstruction of the arrester bed for the Lower StraightCreek Ramp, the new construction of a dragnet system and updating side road as asphalt for Vail ramps, improved signage and lighting at all ramps, and removing vegetation and improving clear zones for Upper Straight Creek Ramp. The goal of these recommendations is to keep the driver safe and the truck and trailer upright with minimal fuel spills or cargo loss. The implementation of these recommendations will benefit freight carriers through improved driver safety and freight security, the traveling public through fewer "runaway trucks", and the general public through less hazardous material discharge into the natural environment.			
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EXECUTIVE SUMMARY

As a result of research initiated in 2006, the Colorado Department of Transportation (CDOT) developed a specification for aggregates used in truck arrester beds (Section 703.11).

Emergency truck ramp construction is included as part of CDOT Standard Specifications for Road and Bridge Construction, partly based on condition assessment of existing emergency ramp performance and partly based on recommendations from other transportation agencies. However, CDOT staff have identified at least three serious accidents on emergency ramps resulting in jack knife or roll over of the rig accompanied by fire or hazardous waste spills. Excessive speeds at the emergency ramp entrance, especially on Interstate 70, are also a concern and not necessarily addressed by the current design specifications. Lastly, CDOT engineers have expressed some concerns that tractor-trailer drivers fail to utilize the emergency ramps, perhaps owing to a lack of confidence in the ability of ramps to prevent crashes.

The objective of this research is to develop a set of design and operational recommendations to reduce the number of rollover, jackknife, and rollback end positions for trucks entering the emergency ramp. To do so, the research team used several strategies including a review of literature, appraisal of incident reports, conduct field observations at several emergency escape ramps, interviews and surveys of the I-70 corridor stakeholders, analysis of current geometry and material used in emergency ramps, and interviews with other DOTs and CDOT staff about fuel or cargo spills.

The study includes six main Chapters as shown below which form the structure of this report:

- Chapter 1. Introduction and Background
- Chapter 2. Field Observation Reports
- Chapter 3. Material and Design Analysis of the Arrester Bed
- Chapter 4. Interviews with I-70 Mountain Corridor Stakeholders
- Chapter 5. Ramp Performance Evaluation (Hazmat)
- Chapter 6. Conclusion and Recommendations

Although all Colorado existing emergency escape ramp areas are of interest, the Lower Straight Creek truck ramp west of Eisenhower/Johnson Memorial Tunnel (EJMT) is emphasized as it is utilized the most frequently. It is located near Milepost 211 on I-70 westbound and served as the primary field research site.

Implementation Statement

The products of this research is a series of recommendations focusing on

- *maintenance/material replacement,*
- *signage and pavement marking,*
- *shoulder strengthening/widening,*
- *new construction,*
- *lighting, and*
- *drivers' outreach.*

Specific recommendations to be implemented by CDOT include improved maintenance and entrance reconstruction of the arrester bed for the Lower Straight Creek Ramp, the new construction of a dragnet system and updating side road as asphalt for the Vail ramps, improved signage and lighting at all ramps, and removing vegetation and improving clear zones for the Upper Straight Creek Ramp. The goal of these recommendations is to keep the driver safe and the truck and trailer upright with minimal fuel spills or cargo loss. The implementation of these recommendations will benefit freight carriers through improved driver safety and freight security, the traveling public through fewer “runaway trucks”, and the general public through less hazardous material discharge into the natural environment.

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CHAPTER 1 - INTRODUCTION AND BACKGROUND

The objective of Chapter 1 is to provide an overview of the current body of knowledge and incidents related to Emergency Escape Ramps (EER) in Colorado. This background is used to inform the design and operations recommendations to improve the effectiveness and reduce the number of rollover, jackknife, and rollback end positions for trucks entering emergency escape ramps in Colorado.

1.1 Review of Prior Literature and Current Practice

Emergency Escape Ramps (EER) have proven to be an effective method to control and stop runaway vehicles by transferring the vehicles' energy through gravitational deceleration, rolling resistance or both (Abdelwahab, & Morral, 1997). The need for EERs has been established in previous studies. According to Lill's study (1977) conducted for the American Trucking Association, 16% of truck crashes nationwide and 41% of the mountainous state truck crashes were downgrade crashes. Eck (1983) found that 18% of crashes were identified as runaway truck crashes from fifteen downgrade highway sections in West Virginia. The Synthesis of Highway Practice 178 of the National Cooperative Highway Research Program (Witheford, 1992) describes that many ramps in the US are utilized once a week or more.

Depending on the energy dissipation method, different terminology is used by various agencies such as emergency truck ramps, runaway truck ramps, truck escape ramps, escape lanes, arrester beds, and gravity ramps. In this study, the American Association of State Highway and Transportation Officials' (AASHTO) Green Book (2011) definition of Emergency Escape Ramps (EERs) is used as an accepted definition to include all types. The AASHTO's Green Book defines the need for EERs on long, descending grades and topographic locations where excessive speed poses a risk. Improving a highway through construction of an EER often requires adjusted grades and new alignments for providing a safe deceleration and stoppage of runaway trucks at locations away from the main traffic flow. The first emergency truck ramp in US history was designed and constructed in 1956 in California (Witheford, 1992). In the twenty years following the completion of the first ramp, more than 60 ramps were constructed by 20 different states (Williams, 1979).

The highway downgrades for heavy trucks generate a potential safety risk and disruption for the truck operator, other road users, and the environment. Additionally, steep grades can cause negative effects on the brakes, gears, and power systems that may result in brake overheating, failures, and excessive speed. According to Witheford (1992), the main causes of brake failures on downgrades are insufficient vehicle and brake maintenance, driver faults, driver inexperience with the vehicle, road conditions, and lack of retarder systems. The increase in the number of vehicles and their average weight raises the crash risk on the downgrade areas. Competition among commercial transport companies and reduced profit margins may result in the lack of proper maintenance, which may also increase the crash risk. Before EERs were available, runaway trucks had a potential of breaching roadside barriers that may result in serious damages and injuries (Tye, 1986).

1.1.1 Types of EERs

The AASHTO's Green Book (2011) references three main subcategories in the classification of emergency escape ramps and arrester beds, classified by the grade.

- Gravity
- Sand pile
- Arrester bed
 - Descending-grade
 - Ascending-grade
 - Horizontal-grade

In this research report, categorization for the identification of EER types conforms to the AASHTO's Green Book (2011).

a. Gravity EER

Gravity ramps work by using gravitational forces to slow and stop the runaway truck. Rolling resistance forces do not have a significant role in stopping the vehicle. Additionally, the physical characteristics of gravity ramps are long and steep which is considered costly and inefficient. However, the paved surface of the gravity ramp helps to stop forward motion of the vehicle, it cannot prevent rolling back or jackknifing of the tractor-trailer. Therefore, gravity ramps are defined as the least desirable option in the AASHTO's Green Book (2011).

b. Sand Pile EER

Sand pile ramps help to slow down and stop the truck with rolling resistance provided by loose, dry sand in a manner similar to Figure 1.1 below. Also, the gravity force on the slope of the surface contributes to the slowing process. Compared to the arrester beds, sand piles are less preferable because of their severe deceleration characteristics and lack of functionality in adverse weather.



Figure 1.1. Sand Pile EER Reprinted from AASHTO's *Green Book* (p. 144), by the American Association of State Highway and Transportation Officials, 2011, Washington DC.

c. Arrester Bed EER

Arrester beds are specifically designed with a usage of confined or unconfined loose material such as gravel with a certain depth and aggregate size. Arrester beds have three main categories:

c.1 Descending-grade

Descending-grade arrester beds increase rolling resistance by loose aggregate to slow the vehicle in a manner similar to that shown in Figure 1.2. However, the gravitational effect does not contribute to a reduction in the speed of the vehicle and the gradient resistance controls the direction of vehicle movement. Because rolling resistance is the only contributor to deceleration, descending-grade arrester bed need to be longer than the other types or arrestor bed EERs.

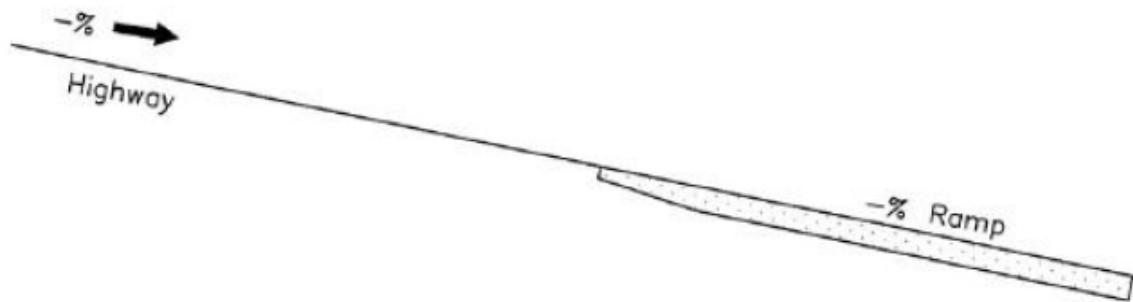


Figure 1.2. Descending Grade EER Reprinted from AASHTO's *Green Book* (p. 144), by the American Association of State Highway and Transportation Officials, 2011, Washington DC.

c.2 Ascending grade

Ascending-grade arrester beds combine gravitational effect and rolling resistance of the loose material for decelerating and stopping the runaway vehicle in a manner shown in Figure 1.3 below. The assistive effect of gravity helps to reduce the length of the arrester bed. Additionally, loose material supports the vehicle to stay in place after it stops. With the effect of all these characteristics, ascending-grade arrester beds are the preferred option in the AASHTO's Green Book (2011). An example of an ascending grade arrestor bed EER is shown in Figure 1.4.

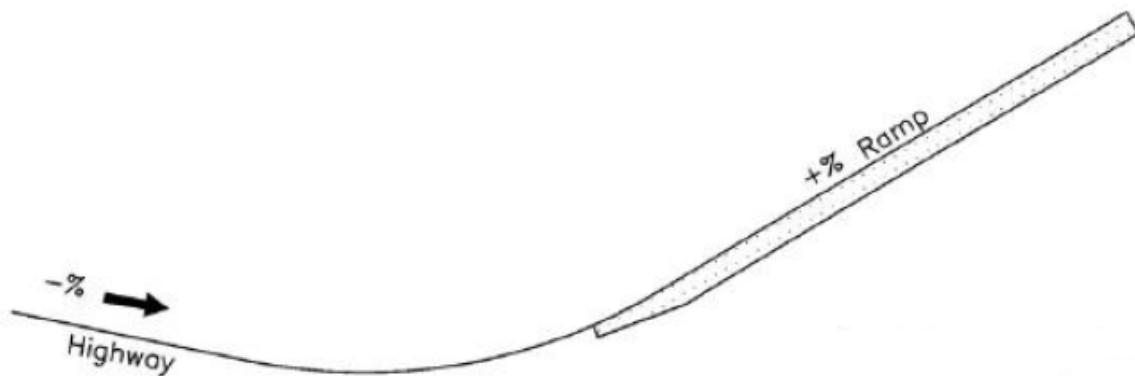


Figure 1.3. Ascending Grade EER Reprinted from AASHTO's Green Book (p. 144), by the American Association of State Highway and Transportation Officials, 2011, Washington DC.



Figure 1.4. Colorado Loveland Pass confined ascending grade arrestor bed EER

c.3 Horizontal-grade

Horizontal-grade arrester beds are designed on a flat gradient compatible with the topography in a manner similar to that shown in Figure 1.5. The rolling resistance of the loose materials decelerates and stops the runaway vehicle. The effect of gravity on the horizontal-grade is minimal which makes its length more than ascending-grade arrester beds. However, vehicle roll-back is less likely on a horizontal grade arrestor bed EER. An example of a horizontal grade EER is shown in Figure 1.6.



Figure 1.5. Horizontal Grade EER Reprinted from AASHTO's Green Book (p. 144), by the American Association of State Highway and Transportation Officials, 2011, Washington DC.

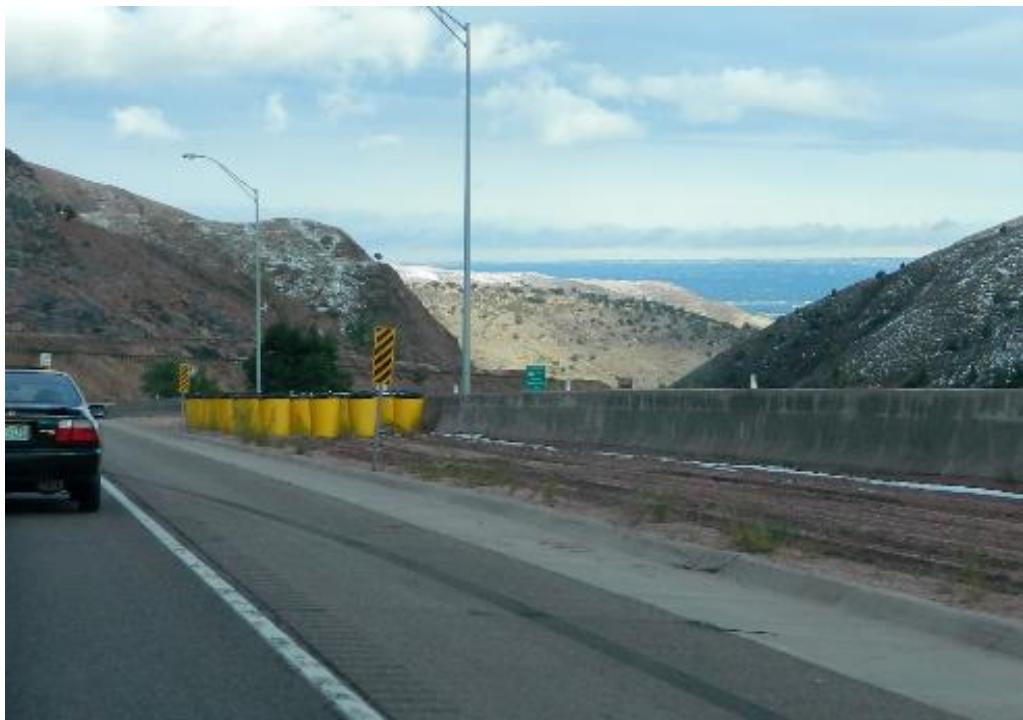


Figure 1.6. Colorado I-70 Eastbound mm 257 horizontal-grade EER

d. Dragnet System

In addition to the EER types described in the AASHTO's Green Book (2011), several new types of emergency escape ramps have been developed. A dragnet truck arrester bed consists of energy absorbers and barrier nets. Concrete median barriers located on each side of the ramp provide mounting and restraining of the steel cable nets and absorbers. The energy absorbers are embedded in the concrete median barriers and the nets are positioned vertically to the ramp (Cushion&Barrier LLC, 2017). Also, the mechanically stabilized earthen wall consists of precast concrete wall panels with an ashlar stone masonry form lined finish. At the end of the ramp, 15 sand-barrel impact attenuators are installed. While not a compulsory aspect of the design, sand-barrel attenuator systems increase the psychological reliability of the ramp for drivers (Hanley, 2010).

In 2008, Connecticut DOT constructed a new ramp near Avon on US Highway 44, which is a part of the National Highway System in Connecticut and a significant connection between Hartford and northwestern Connecticut. The location of the ramp had an Average Daily Traffic (ADT) volume of 19,600 vehicles with a maximum grade of %10. The EER was designed as a dragnet truck arrester bed with mechanically stabilized earthen walls and a sub-surface pavement heating system. Compared to other types of arrester beds, a dragnet system requires less distance and less time to stop the runaway vehicle. The main reasons for choosing a dragnet arrester bed at this location were two recent major runaway vehicle crashes, topographical constraints, upscale suburban neighborhood location, major arterial freight route and, steep, winding grade terminated by a signalized intersection. The US44 dragnet arrester bed is shown in Figure 1.7.



Figure 1.7. Dragnet Arrestor Bed EER with U.44/CT 10/Nod Rd. Intersection in Background Reprinted from Connecticut Department of Transportation's Truck Escape Ramp (TER) (12), 2010, Avon CT.

The net system needs to be removed for maintenance activities and snow removal, which require extra effort and time. After the ramp is utilized by a runaway truck, the expanded metal tapes and tape cartridges need to be changed, and full replacement of the tapes and cartridges costs \$90,000 per incident. The final construction cost of the dragnet arrestor bed EER was reported as approximately \$2.8 million, with an additional cost of \$0.4 million for sub-surface heating system, for a total project cost of \$3.2 million (Hanley, 2010). The heating system is billed at a low rate by the electric utility during the non-heating season, a higher fee is charged for the rest of the year. The effectiveness of the subsurface heating system can be seen in Figure 1.8.



Figure 1.8. Dragnet Arrestor Bed EER after 14" of snow in 72-hour period

Reprinted from Connecticut Department of Transportation's Truck Escape Ramp (TER) (13), 2010, Avon CT.

The dragnet arrestor bed EER has also been implemented on Highway 11 at Thibeault Hill in North Bay, Ontario Canada. A successful full-scale demonstration of the dragnet EER system was performed with a 90 km/hr. speed and 60,000 kg truck in the operation of a live driver. The Ontario 11 dragnet EER is shown in Figure 1.9 and Figure 1.10.



Figure 1.9. Dragnet EER in Highway 11 at Thibeault Hill in North Bay, Ontario Canada

Reprinted from *Web Archive – Internet Archive*. Retrieved June 15, 2017, from: <https://web.archive.org/web/20120506072004/http://www.highway11northbay.com>,

Copyright 2009.



Figure 1.10. Full Scale Demonstration in Highway 11 at Thibeault Hill in North Bay, Ontario Canada Reprinted from Ontario Ministry of Transportation. Retrieved June 15, 2017, from <http://www.mto.gov.on.ca/graphics/english/pubs/highway-construction/northern-highway-2010>, Copyright Queen's Printer for Ontario, 2009.

Another dragnet arrestor bed was installed on US Highway 16 west of Buffalo, Wyoming as shown in Figure 1.11. In August 2007, a tanker truck carrying 80,000 lbs. of sulfuric acid utilized the ramp at a speed of 40 mph. The driver stated that except for the impact of the first net it was a smooth and gradual slow down.



Figure 1.11. Buffalo, WY Dragnet EER Reprinted from Entwistle Co. Retrieved June 15, 2017, from http://www.entwistleco.com/defense/images/dragnet_success_story.pdf, Copyright Entwistle Co, 2007.

The damage from the dragnet system to the truck as shown in Figure 1.12 is limited to the front bumper and cab which makes it possible to back the truck up after being stopped. Also, the system helps to decrease the possibility of saddle tank rupture, jackknifing, and overturning. The driver's view of the entrance to the dragnet EER is shown in Figure 1.13.



Figure 1.12. Wyoming Dragnet EER Crash Damage

Reprinted from Wyoming Department of Transportation. Retrieved June 15, 2017, from <https://www.wyoroad.info/Highway/RunawayTruckRampInfo2013.pdf>, Copyright Wyoming Department of Transportation, 2013.



Figure 1.13. Buffalo, WY Dragnet EER

Reprinted from Wyoming Department of Transportation. Retrieved June 15, 2017, from <https://www.wyoroad.info/Highway/RunawayTruckRampInfo2013.pdf>, Copyright Wyoming Department of Transportation, 2013.

The Nevada Department of Transportation completed a reconstruction of a dragnet EER project on State Route 431 Mt. Rose Highway in 2016 as shown in Figure 1.14 and 1.15. The rock surface of the EER, which was constructed in the late 1970's, was replaced with a heated asphalt surface and a dragnet system of six pre-tensioned nets. The approximate cost of the project was \$4.6 million.



Figure 1.14. The State Route 431 Mt. Rose Highway dragnet EER Nevada

Reprinted from Nevada Department of Transportation. Retrieved June 15, 2017, from <https://www.nevadadot.com/Home/Components/News/News/90/395?arch=1&cftype=SG0ZO3AZ>, Copyright Nevada Department of Transportation, 2016.

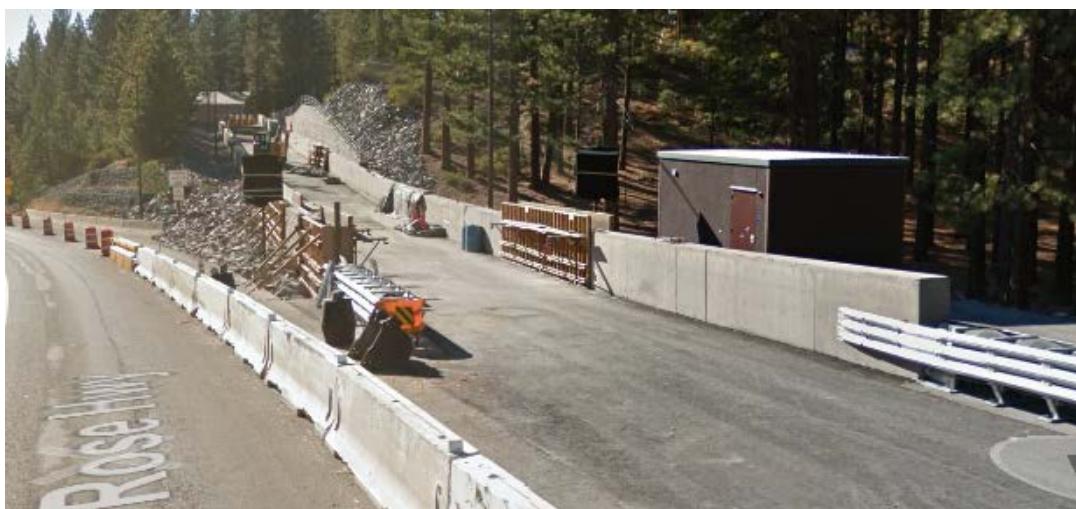


Figure 1.15. The State Route 431 Mt. Rose Highway dragnet EER construction phase Nevada

Reprinted from Google Maps. Retrieved June 15, 2017, from

<https://www.google.com/maps/@39.253927,-119.9704592,3a,75y,278.46h,68.2t/data=!3m6!1e1!3m4!1sf-VjiVL7U-o77ueNUj9Y3Q!2e0!7i13312!8i6656>, Copyright Google Maps.

1.1.2 Location and Need for EERs

The criteria for the selection of the location of an EER is somewhat subjective, as there are many potential locations in any mountain highway corridor. Each location should be considered according to its own characteristics: topography, length, percent grade, potential speed, economics, environmental impact, and crash rate. The two main types of areas which require EERs are steep hills in areas of dense traffic and longer, mountain grades in rural areas (AASHTO's Green Book, 2011). Eck (1979) suggests ten criteria in determining the need for ramps: 1) runaway truck accident rate, 2) length of grade, 3) percent grade, 4) percent trucks, 5) conditions at bottom of grade, 6) average daily traffic, 7) horizontal curvature, 8) accident severity, 9) available right of way (ROW), and 10) topography.

In addition to the analysis of the criteria above, the Grade Severity Rating System (GSRS) from the Federal Highway Administration (FHWA) is a technique for analyzing operations on a grade for determining recommended truck downgrade speed (Bowman, 1989). GSRS uses a brake temperature prediction model which includes steepness and grade of the length, loaded weight and speed of the truck, non-brake resistive forces, heat dissipation, initial brake temperature, and engine revolutions per minute used during the grade descent. Besides these criteria, GSRS is based on the assumption of a five axle truck with a constant descent speed and appropriate gear (Bowman, 1989).

FHWA published the GSRS User's Manual in 1989. The purpose of the study was to improve the mitigation of truck runaways on steep downgrades. The main characteristics of the GSRS mathematical model includes the physical condition of the downgrade, the temperature of the trucks' brakes, and the gross truck weight. According to the gross truck weight and site conditions, the temperature of the brakes can be estimated and a safe downgrade speed can be calculated with the GSRS computer program. With the installation of Weight Specific Speed (WSS) signs at downgrade location, drivers are informed on safe descent downgrade speeds (Bowman, 1989). The procedure of GSRS consists of five main steps: 1) Identifying potential sites in need of WSS, 2) performing field inspection, 3) determining grade severity, 4) determining WSS needs, and 5) installing WSS signs.

In the GSRS, the brake temperature limit is determined as 500 °F (260 °C) for a safe descent grade. This value comes from the calculation of a computer program which uses physical and truck operational characteristics. The brake temperature output helps to identify the possible location of the downgrade brake failure that leads to potential runaways. This output can be used on the decision of location and need of EER (Bowman, 1989).

Abdelwahab and Morral (1997) described the need for warrants, location factors of the ramp on the downgrade, design parameters and the requirements for signing and pavement marking as requirements for EER need assessment. In addition to the needs assessment of EER, their study included design criteria such as design vehicle, road factors, and design driver. Design vehicle criteria include vehicle type, gross vehicle weight (GVW), and vehicle's brakes. Consideration for the road factors focuses on two main aspects: availability of brake-check areas and presence of WSS signs at the break-check area. Lastly, design driver-condition concerns the driver's proper gear selection and checking the brakes at the brake-check area. Additional factors in their study include grade severity, cornering speeds of horizontal curves, accident history, and accident consequences. According to the flow chart of possibilities for each factor, Abdelwahab and Morral present the levels of risk involved in the design of EERs.

The main factors for the selection and length of the ramps are compatibility with the existing location and topographic conditions, the rolling resistance factor of the bedding material and the effect of the gravity (Arizona Department of Transportation, 2003).

1.1.3 Design

AASHTO's Green Book (2011) suggests the minimum entering design speed of the EER as 130 km/h (80mph), with a recommended design speed of 140 km/h (90 mph). For safe deceleration and stopping, the kinetic energy of a runaway vehicle should be dissipated by the ramp, which requires sufficient length, grade, and rolling resistance of the ramp. Also, the ramp should be located tangent to the highway with very flat curvature to ease the entrance of a runaway vehicle traveling at high speed. A width of 26 feet is defined as the minimum value that makes the entrance of two vehicles possible. In the case of infrequent usage and/or high cost, an entrance width of 12 feet is considered the minimum acceptable width. According to Witheford (1992), sand pile EERs

should range in length between 200 and 400 feet, gravity EER length varies between 1200 feet and 1500 feet, and the length of the arrester bed EERs is dependent on their grades.

Liu, Shen, Wand and Zhang (2010) performed a study for determining the design speed on nine EER's on the Yuanmo Expressway in China. From the security point of view, arrester bed length and location were defined as the most critical value for the EER. In this study, a back-analysis method was used that includes field observation, crash records, operation and maintenance records, and traffic volume and composition. After the implementation of the back analysis, the 99% percentile speed was 102.2 km/h. (~61 miles per hour), suggesting that the design speeds recommended in the AASHTO's Green Book (2011) were excessive. The research results were applied to another expressway in China, and no crashes were reported because of improper design speeds of EERs.

Witheyford (1992), suggests using the velocity formula below based on an energy summation procedures:

$$V = 5.469[0.03343 V_o^2 - H - KL - 0.00016 V_m L - (0.0012FLV_n^2 / w)]^{1/2}$$

Where,

V = speed at distance L (mph)

V_o = speed at the beginning (mph)

H = Vertical distance (ft.) corresponding to distance L

K = constant incorporating surface friction and speed- independent part of mechanical loss (0.01675 for pavement, 0.26175 for gravel bed)

L = Grade distance computed from stationing (ft.)

V_m = Average of V and V_o

F = Frontal Area of vehicle (sq. ft.)

V_n^2 = Average of V^2 and V_o^2 , and

W = Vehicle weight (lbs.)

AASHTO's Green Book (2011) recommends a high coefficient of rolling resistance and low shear strength for the arrester bed material. Aggregate should be rounded, uncrushed, evaluated with an appropriate crush test and highly similar in size. Pea gravel is preferred for the bedding material.

On the other hand, loose gravel and sand are commonly used materials for EERs. A maximum size of 1.5 in. (40mm) gradation has proven successful in most of the states. AASHTO gradation No.57 (0-10% passing Number 4 screen opening) is effective in determining cases where fine material needs to be removed.

AASHTO's Green Book (2011) also suggest that the minimum aggregate depth of the arrester bed is 3 ft. (1 m) for construction. In addition to that, the hard surface material should be minimum 12 inch. (300 mm) thickness and the aggregate depth up to 42 in (1100 mm) is advised. On the entrance part of the bed, the depth should be tapered from 3 in. (75 mm). The drainage system with underdrain having transverse outlets or edge drains should be provided for the prevention of freezing and contamination. Between the subbase and the bed materials, geotextiles or paving can be used against contamination and infiltration of fine materials (AASHTO's Green Book, 2011).

Use of an auxiliary lane is advised by AASHTO's Green Book (2011) for the preparation of drivers on entering the ramp. The entrance of the EER should be visible and be convenient for the safe entrance of a vehicle with a high speed. Departure angle should be 5 degrees or less. The location of the ramp lane should be away from the main road, which prevents loose material being thrown through the main lane. Also, greater room on the approach of the ramp helps the driver to feel safe and prepared for the deceleration and stopping stage of the vehicle. A service road, adjacent to the ramp, with a minimum 10 ft. (3 m) width, is recommended for towing and maintenance. Anchors for towing should be placed at intervals ranging from 150 – 300 ft. (50-100 m). Proper signage and pavement markings should be placed for the attention of drivers. In addition, regulatory signage is needed against the improper use of ramps. Lighting for the entrance and ramp is advised for the nighttime.

The deceleration rates of the ramp vary with entering speed of the vehicle. Low deceleration rates increase the length and cost of the ramp. On the other hand, a high deceleration rate may result in freight loss, ramp contamination, vehicle damage, and driver injury (Witheford, 1992).

For the length of the ramp, the equation below is used by the AASHTO's Green Book (2011).

$$L = \frac{V^2}{30 (R \pm G)}$$

Where, L = distance to stop (ft.)
 V = entering velocity (mph)
 G = percent grade divided by 100, and
 R = rolling resistance.

The rolling resistance of the different surface materials are represented in Table 1.1.

Table 1.1. Rolling Resistance Value for Different Surface Materials

VALUES OF "R" FOR
 DIFFERENT MATERIALS

Surfacing Material	"R" Value
Portland Cement	0.010
Concrete	
Asphalt concrete	0.012
Gravel compacted	0.015
Earth, sandy, loose	0.037
Crushed aggregate, loose	0.050
Sand	0.100

According to the Pennsylvania Highway Design Manual (AASHTO's Green Book, 2011) the calculation of bed length is as follows:

$$L = AV + BV + CV^2 + DV^3$$

Where, L = stopping distance or bed length (ft.)
 V = entry velocity (mph)
 A, B, C and D = constants derived in the research

The constants reflect the rolling resistance of the surface material.

1.1.4 Operation & Maintenance

Advance warning of the truck operators for the downgrade conditions, mandatory brake check areas, and weight-specific speed is necessary for EERs. These advance warnings should be implemented with the help of additional signage. The Synthesis of Highway Practice 178 of National Cooperative Highway Research Program (Witheyford, 1992) indicates that 11 of 23 states, which participated in their survey, did not have specific signage plans for EERs, but they followed the signage requirements of The Manual on Uniform Traffic Control Devices for Streets and Highways (Federal Highway Administration, 2012).

“No Parking”, “No Stopping” and “Runaway Vehicles Only” signs and delineators were stated in the NCHRP report for the traffic control near the ramp entrance and on the ramp edges (Witheyford, 1992). The same study reported the misuse and violation of the EER lanes were widespread with more need of enforcement attention. Additionally, a display of the occupation status of the ramp on an electronic board can warn drivers of vehicle removal and maintenance operations.

Mandatory stop areas and brake check areas provide good opportunities for the truck drivers to check the equipment and the temperature of the brakes (AASHTO’s Green Book, 2011). These areas provide a full stoppage for the trucks before the downgrade starts (Witheyford, 1992). On the operational side, Colorado, Nevada and Wyoming Department of Transportations have published flyers to inform drivers about the general concept of EER usage, do’s and don’ts of mountain driving, and the locations of EERs in the state. These documents help to increase the awareness of drivers that will benefit from using EERs in necessary conditions.

AASHTO recommends that after each use, the aggregate should be fluffed and scarified in an appropriate way. On the other hand, to eliminate the effects of compaction over time and to maintain drainage, contamination should be cleaned and scarified periodically. California DOT Guidelines also stress the importance of re-shaping the bed with proper equipment after a vehicle has been removed (Tye, 1986).

According to the synthesis of NCHRP (Witheyford, 1992) cost information for EER maintenance is lower than predicted in previous research, with an average of \$150- \$200 per month for routine maintenance reported by responding states. The same study emphasized the need for random

checks of EERs as well as checks after each use. The manual effort for site maintenance was reported significantly less than equipped maintenance. Winter maintenance of the EER needs special consideration to prevent freezing of moisture in the top layer which will decrease the performance of EER. Periodic salting, periodic litter pickup, putting calcium chloride over the surfaces and the removal of snow on the approach are the main principals of the maintenance during winter. Snow covering, however, can be ignored, as it is generally beneficial (Witheyford, 1992).

1.1.5 Hazardous Material and Aggregate Contamination

Hazardous material and aggregate contamination on the EER have not generally been included in prior research on EERs. NCHRP synthesis pointed out compaction and fines contamination of the arrester beds decreases the effectiveness of EER performance. CDOT reported the effects of melted snow and rain on the sub-surface drainage system and water infiltration. Drainage water from the mountains carries fines into arrester beds, which causes aggregate contamination (Witheyford, 1992).

According to the FHWA's Traffic Incident Management in Hazardous Materials Spills in Incident Clearance Guide Book (2009) there are two types of spill: 1) vehicular fluid spills and 2) hazardous materials cargo spills. The same study mentioned that some states recognize that incidental spills do not have the same threat as larger cargo tank spills. They have adjusted laws and policies to permit quick and proper containment of minor spills.

Arizona Department of Transportation (2003) stated that the contamination of arrester beds come from four main sources:

- 1) Existing Ground
- 2) Surface
- 3) Vehicles
- 4) Gravel Decay.

The following suggestions were provided for each source of contamination:

- Paving the bottom and sides of the arrester bed basin is recommended to prevent contamination of the aggregates from existing material (fines migration).

- An adequate drainage system for roadway and arrester bed is recommended to prevent surface contamination.
- Contamination caused by vehicles is defined as unpreventable, so no specific preventative recommendations were stated.
- Contamination from aggregate decay over time is largely attributed to weather cycles and the natural breakdown of aggregate material. The usage of high quality gravel is recommended for minimizing the contamination from aggregate decay.

The design guide of California Department of Transportation (Tye, 1986) has a similar summary for the contamination resources which includes 1) the ground under the bed, 2) fines blown or carried from the surface, 3) fuel or cargo spills from arrested vehicles, and 4) degradation of the bed material. For preventing the effects of fuel or cargo spills, surface slopes designed to direct runoff away from the bed was suggested. Another suggestion was the usage of a drainage system to separate and contain contaminants before they are released into watercourses.

The synthesis of NCHRP (Witheford, 1992) reported that only two states had followed the guidelines on periodic replacement of material in arrester beds. One state replaced material every three years. The other state removed, washed, screened, and replaced the bed material. Three states mentioned the use of geotextiles or fabric filter under the arrester bed to control fines migration. Surface controls such as a grate system at the approach, earth berms adjacent to the bed and intercept ditches were the other solutions, which were recommended by different states.

Tye (1986) identified the problem of diesel fuel spills with the suggestion of paving the base with cement concrete and the provision of holding tanks to retain spilled material. None of these studies have specific details related to the suggested systems.

1.1.6 Other studies related to EERs

According to the Washington Post's news on June 28, 2018 America's trucker shortage is a significant issue for the country's economy. The same news emphasizes trucking as one of the

most dangerous professions with the U.S. Labor Department citing more than 1,000 fatal incidents of motor vehicle operators in 2016. Family separations and health issues are the main problems that the truckers are facing, thus, the trucking industry has trouble recruiting new drivers and holding them (The Washington Post, 2018). Subsequently, the significance of highway and EER safety is becoming more important within the resource constrained environment of the trucking industry.

Virginia DOT started a rehabilitation project for the truck escape ramp on southbound Interstate 77 in Carroll County at mile marker 1.5. The approximate cost of the project is anticipated as \$300,000. The project includes pavement addition on the left side of the ramp, installation of the new arrestor bed along the right side of the ramp, and replacing the ramp's stone, ditches and guardrail (Virginia DOT, 2017).

Also, the safety study of Massachusetts DOT provides potential safety enhancements for the EER at the intersection of Route 2 (Taconic Trail) at Route 7 (Cold Spring Road) in Williamstown, MA. The observed safety issues are categorized under visibility, horizontal curvature and load shifting, rumble strips, signage, lighting, and driver behavior. The potential safety enhancements include clearing brush along the ramp, realigning and reconfiguring the ramp, relocation of utility poles, removing rumble strips and providing delineators, upgrading the lighting at the entrance, considering overhead signage with flashing beacons, providing additional signage at the flat spot, replacing the signage with diamond grade high intensity yellow sheeting, and installing radar enhanced speed limit signs (Massachusetts DOT, 2012).

1.2 Colorado EER Information and Incident Reports

At the suggestion of the CDOT Technical Advisory Committee for this study, the research team focused the analysis of incident reports on the EERs on Interstate Highway 70. The five ramps are shown in Figure 1.16. The blue highlighted number is the mile marker location of each ramp. The bottom number in yellow represent the total number of incidents reported at that location from 2005 through 2017, and the upper yellow number represents the number of those incidents that involved trucks in the EER. There are incidents such as wildlife in the EER, trees down in the EER, or unauthorized use (e.g. picnics) in the EER which can generate an incident report but do

not involve a truck using the EER. There a total of 341 incidents reported in the thirteen year period between 2005 and 2017 or an average of a little more than two incidents per month. Of these, 263 involved truck usage of the ramp, or an average of about 1.7 uses per month. The same information is shown in bar chart form by location in Figure 1.17, which highlights the significant usage of the EER at mile marker 209 (Lower Straight Creek Ramp) compared to all other EERs along Interstate 70. The Lower Straight Creek Ramp represented 53% of all incidents and 65% of all truck EER usage incidents.

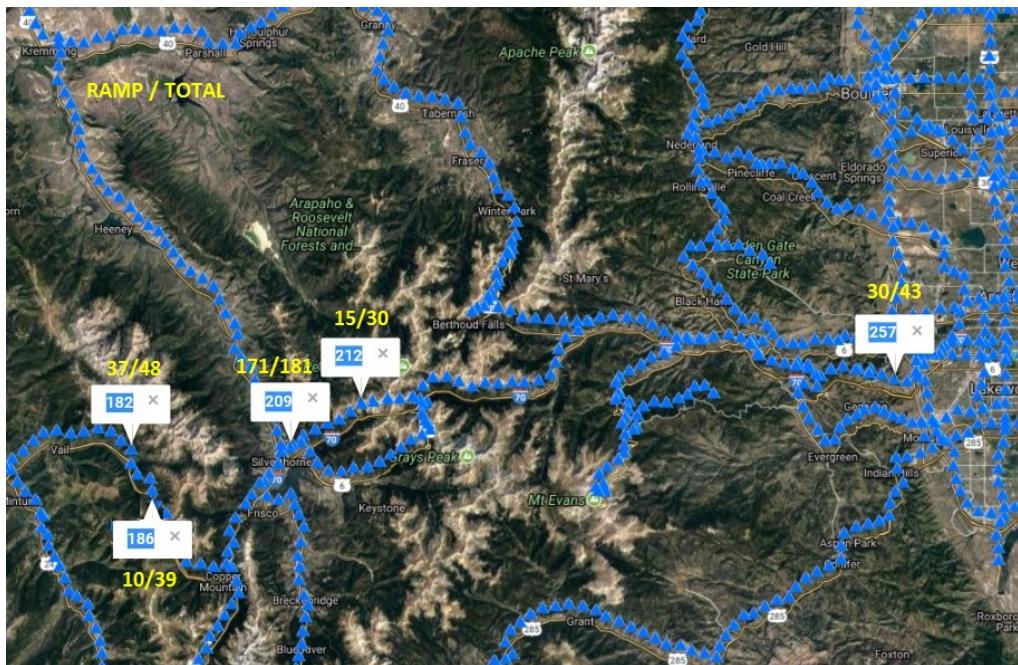


Figure 1.16. Map of Ramp-in-use Incident and Total Incident Reports for EERs on Interstate 70 from 2005 through 2017

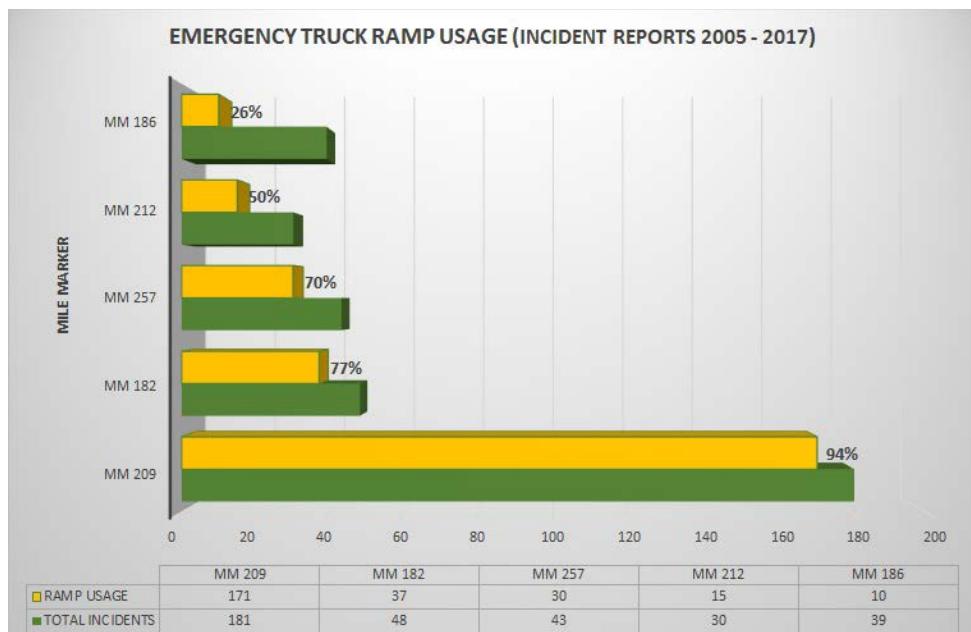


Figure 1.17. Chart of Ramp-in-use Incident and Total Incident Reports for EERs on Interstate 70 from 2005 through 2017

The severity of the incidents is summarized in Figure 1.18. As can be seen, 142 (41.64%) of the incidents did not involve property damage, personal injury or fatality, and 87 incidents (25.51%) involved property damage only. Less than 2% of the incidents over the 13 year period involved serious injury or fatality.

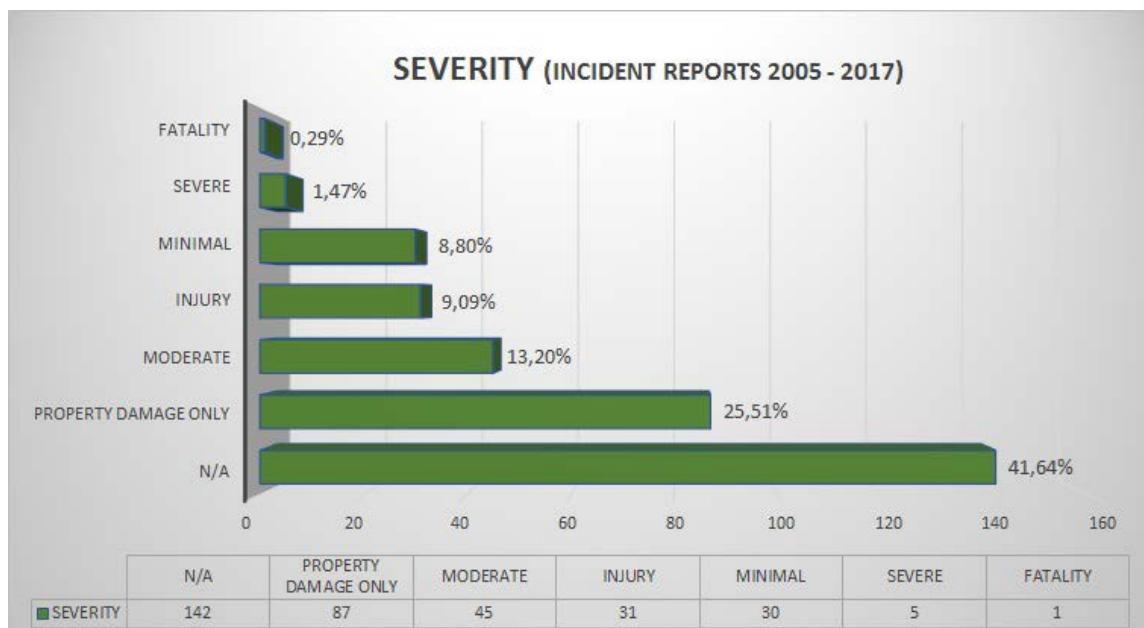


Figure 1.18. Chart of Severity Ratings for Incident Reports on all EERs on Interstate 70 from 2005 through 2017

Seasonal variations appear to be significant as can be seen from Table 1.2 (winter month usage 2015/2016) and Table 1.3 (summer month usage 2016). Winter month usage in 2015/2016 was 4.5 trucks per month and summer 2016 usage was 13 uses per month. Assuming truck volume is relatively constant and allowing for even a modest increase in RV and bus traffic in the summer, it appears that operators are less likely to use an EER in winter months than in summer. It is possible that this variation is due to overall slower speeds and colder temperatures in the winter preventing brake overheating, but further investigation may be warranted to determine if operators are less likely to use an EER in winter because of greater safety concerns related to EER performance.

Table 1.2. Incident Reports for EERs on Interstate 70 for Winter 2015/2016

DATE	VAIL	LOWER STR CRK	UPPER STR CRK	MT.VERNON	
9/2/2015	1				car
September		5			
October	1	3		1	
November	1	1			
December				1	
January	2	1		2	
February	1	7			
TOTAL	6	17	0	4	27

Table 1.3. Incident Reports for EERs on Interstate 70 for Summer 2016

Month/Yr	VAIL	LOWER STR CRK	UPPER STR CRK	MT.VERNON	
May		5	1		
June		5		2	
July	2	13		2	
August	4	15		1	
September	4	8		3	
TOTAL	10	46	1	8	65

Long term longitudinal usage data was not analyzed, but a cursory review of Table 1.2 (Winter usage 2015/2016) and Table 1.4 (Winter usage 2016/2017) reveals that the 6 trucks per month in winter 2016/2017 was slightly more than the 4.5 trucks per month in the previous winter, and both of these numbers are significantly higher than the 13 year average frequency of 1.7 trucks per month. Although no definitive finding can be reported on long term trends in EER usage it appears that truck use of EERs on Interstate 70 has increased steadily in the last 15 years.

Table 1.4. Incident Reports for EERs on Interstate 70 for Winter 2016/2017

DATE	VAIL 185.69	VAIL 182.17	LOWER STR CRK	UPPER STR CRK	MT.VERNON	
October	1		4			
November			2	1		
December	1		3			
January	1		3	2		
February			4	1		
March	1		5	2	3	
April	1		5	2		
TOTAL	5	0	26	8	3	42

Table 1.5. Incident Reports for EERs on Interstate 70 for Summer 2017

DATE	VAIL 185.69	VAIL 182.17	LOWER STR CRK	UPPER STR CRK	MT.VERNON	
May		2	4	2		
June			8	1		
July			14	4		
August			4	5		
September			3	3		
TOTAL	0	2	33	15	0	50

Table 1.6. Incident Reports for EERs on Interstate 70 for Winter 2017-2018

DATE	VAIL 185.69	VAIL 182.17	LOWER STR CRK	UPPER STR CRK	MT.VERNON	
October			7	1		
November			3	1		
December			7	5		
January			3	3		
TOTAL	0	0	20	10	0	30

Table 1.5 and Table 1.6 show the frequency of trucks entering I-70 EERs in summer 2017 and winter 2017-2018. The summer 2017 numbers of Lower Straight Creek and Vail ramps are lower than in summer 2016. However, summer 2017 numbers of Upper Straight Creek are higher than summer 2016.

CHAPTER 2 - FIELD OBSERVATION REPORTS

Part of the study involved a field observation of operations and video monitoring capabilities at the Eisenhower Tunnel along with a visual observation of the conditions at the Upper Straight Creek Ramp and Lower Straight Creek Ramp on westbound Interstate 70 as well as the US 6 EER at Loveland and the Vail Pass ramps. Chapter 2 provides a summary report of those observations.

2.1 Field Observation August 1, 2017

The field observation occurred on Tuesday, August 1, 2017 attended by the following individuals:

- Kelly Strong, CSU
- Rodolfo Valdes Vasquez, CSU
- Deniz Besiktepe, CSU
- David Reeves, CDOT
- John Wheatley, CDOT (at Eisenhower tunnel)
- Clint Moyer, CDOT

The field observation began with a review of operations at the Eisenhower Memorial Tunnel. John Wheatley provided an overview of the operations, maintenance, and video monitoring of the I-70 corridor, including westbound emergency truck ramps at mile markers 212 (Upper Straight Creek) and 209 (Lower Straight Creek) and eastbound emergency truck ramp at mile marker 257 (Mt. Vernon Canyon).

The camera used to observe the Lower Straight Creek emergency truck ramp utilizes a simple contact switch to activate on entry to the ramp. The camera has no infrared capability, so monitoring at night, especially in snowy conditions, is limited. The camera also operates on simple Wavetronix radar technology, with little or no capability for data recording, storage, or transmission. There are no sensors at the Upper Straight Creek Ramp, the eastbound ramp at mile marker 257, nor at the catchment ramp on US 6.

The tunnel operations team can deploy static signage and variable message dynamic signage when escape ramps are closed. John explained the event audit report coding and incident severity

ratings. John also explained the procedure followed when a truck has entered the ramp and the maintenance procedures for the escape ramps. It is also possible to set up an alarm at the tunnel operations center if a truck enters an escape ramp. Currently, trucks in the ramp are visually identified only (no alarm).

When a truck enters the escape ramp, all calls are sent to Colorado State Patrol (CSP), including hazardous material spills or loss of cargo. The event audit report contains details on location, roadway closure durations, ramp closure duration, date, and the user who entered the data. CSP crash reports would contain more detailed information, but they are only generated in the case of property damage, injury or fatality.

The Upper Straight Creek Ramp is 24 feet wide and approximately 300 feet long. It is an ascending grade arrestor bed EER with a steep uphill grade and sand attenuator barrels at the end of the ramp. There is a story sign approximately $\frac{1}{2}$ mile before the ramp instructing truckers to use the ramp if their brakes are overheating and warning of steep grades ahead. The ramp is relatively poorly lit with one fixture off the shoulder at the entry of the ramp. The upper 2/3 of the ramp is overgrown with vegetation and appears to not have been utilized by trucks in the recent past. It appears that almost all trucks were able to stop within the first 100 feet of the ramp. The ramp is unconfined on both sides for most of the length, with some concrete barriers at the creek location. As a result, the pea gravel in the arrestor bed is crowned down the center line of the ramp. There was evidence of significant fines intrusion at the lower end of the ramp, with less than two inches of pea gravel depth at the entrance to the ramp. The Upper Straight Creek Ramp is used much less frequently than the Lower Straight Creek Ramp.

The Lower Straight Creek Ramp is 36 feet wide and approximately 300 feet long. It is an ascending grade arrestor bed EER, with a steep grade and sand attenuator barrels at the end of the ramp. The ramp is relatively poorly lit with one fixture off the shoulder at the ramp entrance. The Lower Straight Creek ramp is much less vegetated than the Upper Straight Creek ramp and has evidence of longer escape runs by trucks, with approximately 2/3 of the ramp length appearing to have been utilized. The Lower Straight Creek ramp is confined for most of its length on the south side with concrete barriers and natural grade on the north side. The aggregate in the arrestor bed is

moderately crowned down the centerline of the ramp at the entrance, where the natural confinement on the north is less pronounced. There is evidence of significant fines intrusion at the entry to the ramp and over the first 100 feet of the arrestor bed, with less than 2 inches of pea gravel depth at some locations.

The EER on US 6 is designed for much lower entry speeds than the Upper and Lower Straight Creek EERs. Because US 6 is the primary east-west freight route for hazardous and flammable material that are not allowed through the Eisenhower tunnel, the US 6 ramp has a catchment system that prevents hazardous material from discharging into the nearby streams. The function of the catchment system was not apparent by field observation, but a concrete basin with a hand operated sluice gate was located parallel to the ramp.

All three ramps appear to be maintained with a tow-behind gravel rake with deep tines spaced approximately 12 inches apart. Evidence of fines is more pronounced in the rake path as seen in Figure 2.1.



Figure 2.1. The Lower Straight Creek Ramp after Maintenance

2.2 Field Observation June 14, 2018

The field observation occurred on Thursday, June 14, 2018 attended by the following individuals:

- Kelly Strong, CSU
- Rodolfo Valdes Vasquez, CSU
- Deniz Besiktepe, CSU
- David Reeves, CDOT
- Emmalee Bender, CDOT

The field observation began with participation in the I-70 Mountain Corridor stakeholder meeting at the Eisenhower Memorial Tunnel. More details about this meeting are provided in Chapter 4.

The research team inspected the Lower Straight Creek ramp to assess the feasibility of improvements in shoulder surface, ramp entry alignment, pavement marking, and visibility. Several pictures were taken. It appears that the LSC ramp entry could be straightened by strengthening the shoulder and moving signage. Several vehicles were observed using the far right “lane” to pass slower traffic, so development of a dedicated ramp entry lane would require signage, pavement markings, and warning lights to designate no traffic in the ramp entry lane. One of the challenges with a dedicated ramp entry and shoulder strengthening will be the potential need to reroute water drainage. Snow removal issues will also need to be considered.



Figure 2.2. Panoramic View of the Lower Straight Creek Ramp



Figure 2.3. The Lower Straight Creek Ramp Entrance

In addition, the research team observed the two Vail Pass escape ramps. Both ramps appear to utilize the old roadbed from the former US Highway 6 and did not appear to be specifically designed as escape ramps. The location of the upper Vail Pass ramp was not ideal, with a sharp angle of departure at the ramp entry, exposed rock formations that reduce visibility of the ramp, curved alignment, and a steep embankment on the left. There were no guardrails or confinement structures at the perimeter of the ramp, and a sediment capture basin is immediately adjacent to the ramp entry, which narrows the entry lane. There is no median at Interstate 70 at this location, increasing the risk of a shut down in both directions in case of a catastrophic left roll-off. These issues can be seen by manipulating the views on the following Google link:

<https://www.google.com/maps/@39.5866336,-106.2456844,3a,60y,90t/data=!3m6!1e1!3m4!1sOncfq3RRc8VZpUFE9QWBCg!2e0!7i13312!8i6656?hl=en>

The location of the lower Vail Pass ramp is reasonably good, with relatively flat terrain immediately adjacent to the arrester bed, good visibility, and a better departure angle than the upper Vail Pass ramp. Interstate 70 has a median separating the east and west bound lanes at this location. There are no hydraulic structures near the ramp, and the ascending grade reduces the distance needed for deceleration. The major issue with the lower Vail Pass ramp is that the curvature of the arrester bed begins immediately after entering the ramp.



Figure 2.4. Lower Vail Ramp



Figure 2.5. Upper Vail Ramp

CHAPTER 3 - MATERIAL AND DESIGN ANALYSIS OF ARRESTER BED

3.1 Background

The length of arrester beds is obviously an important attribute when designing these structures. Too short, and vehicles may exit the bed before coming to a stop. Too long, and materials and valuable real estate are wasted, not to mention the cost of adding to a roadway alignment. Therefore, research has been done over the years to determine how to best estimate the length of these arrester features so they can be accommodated into existing alignments. The first attempt at estimating this distance reasoned that the distance required to stop a moving vehicle would be a function of the velocity of the vehicle, the rolling resistance of the material or materials in the arrester bed, and the gradient of the arrester bed. The result of this early research was the relationship shown below (Teragin, A. 1945):

$$L = \frac{V^2}{0.3 (R + G)}$$

Where,

L = Stopping Distance, ft.

V = Approach Speed, mph

R = Rolling Resistance from Figure 1 (AASHTO 1990)

G = Grade of Ramp (+ up; - down)

Table 3.1. Rolling Resistance for Various Materials

Materials	R, rolling resistance
PCC Pavement	1
HMA Pavement	1.2
Uncrushed, Compacted Gravel	1.5
Sandy, Loose Earth	3.7
Crushed, Loose Rock	5.0
Uncrushed, Loose Gravel	10.0
Sand	15.0
‘Pea’ Gravel (90-100% -3/8”)	25.0

As described in Chapter 1, the AASHTO Green Book (2011) expresses the stopping distance equation slightly different by dividing by 30 instead of 0.3, and then using rolling resistance and grades 10 times less than shown in Table 3.1. Results for L are the same.

So, for example, given a tractor trailer entering an escape ramp filled with uncrushed, compacted gravel on a 6 percent downgrade at 90 mph, the stopping distance would be:

$$L = \frac{90^2}{0.3 (1.5 + 5)} = 4154 \text{ ft.}$$

And for the same conditions, but with the escape filled with pea gravel, the stopping distance would be:

$$L = \frac{90^2}{0.3 (25 + 5)} = 900 \text{ ft.}$$

A more recent experiment conducted by the Pennsylvania Transportation Institute and published by PennDOT (PennDOT 2015) using pea gravel in the EER resulted in the third order equation below:

$$L = A + BV + CV^2 + DV^3$$

where:

L	=	Basic bed length, ft.
V	=	Entry speed, mph
A,B,C,D	=	Constants given in Table 3.2.

Table 3.2. Values for Constants to Calculate TER Length

CONSTANT	30 TO 60 mph						
	PERCENT GRADE OF BED						
	-5	0	5	10	15	20	25
A	-49.78	3.2552575	-16.14589169	-5.92049487	1.61678158	4.78170653	23.30369173
B	4.13	0.16944534	1.39562086	0.62431019	-0.05600296	-0.21110752	-1.60118449
C	-0.051	0.04329616	0.01592913	0.03164279	0.04807917	0.04769312	0.07884436
D	0.00165	0.00065202	0.00067035	0.00043730	0.00020949	0.00016497	-0.00012045

Table 3.2(continued). Values for Constants to Calculate TER Length

CONSTANT	61 TO 90 mph						
	PERCENT GRADE OF BED						
	-5	0	5	10	15	20	25
A	-926.9208	-285.1744293	-73.54089126	-77.36637125	-99.16972295	-13.9597750	-9.93858798
B	45.53989258	14.49087202	4.19421811	3.8908948	4.41882161	0.93742345	0.49591149
C	-0.70598725	-0.19635557	-0.02899535	-0.01748326	-0.02055797	0.02526466	0.03336147
D	0.00512399	0.00200734	0.00090754	0.00068014	0.00057884	0.00030885	0.00021004

Depending on the speed of the vehicle entering the EER, the constants vary, significantly. Comparing the length of the EER required to that determined from the Teragin formula for a 5% up grade, we get:

$$L = -73.54 + 4.19 (90) - 0.03 (90)^2 + 0.0009 (90)^3 = 716.7 \text{ feet}$$

This length is relatively close to that calculated using the Teragin relationship assuming pea gravel is contained within the EER. And, since the PennDOT relationship is valid only for pea gravel, the Teragin relationship should provide reasonable stopping distances if other materials are contained in the EER.

Since the space available for placement of many escape ramps is limited, there is an obvious incentive to use materials with high rolling resistance within the ramp. Unfortunately, this leads to the consequence of rapid deceleration as a vehicle enters the escape ramp. The higher the deceleration, the greater the chance of human and vehicle damage. Since drivers of commercial vehicles know the risk facing them upon entering the escape ramp, they have a tendency to avoid the ramp. When the deceleration is high, there is also a chance for the vehicle to jackknife or for the trailer to run over the tractor in the ramp since the trailer is still accelerating as the tractor is coming to a rapid stop. If this happens, there is significant risk of human injury as well as vehicular damage and possible fuel spills.

3.2 Material Type, Size, and Depth

Much work has been done to determine types of materials, depth of materials and length of truck escape ramps (Witheyford 1992). Research (Wambold 1988) indicates that an AASHTO No. 57 aggregate gradation (AASHTO 2013) was the best of all materials tested for arresting vehicles in EERs. The report states that this gradation used with uncrushed, rounded, and smooth river gravel made the best arrester beds. It goes on to recommend that the depth of the arrester bed be increased by 6 inches if the No. 57 aggregate is not washed.

Depth of the EER affects arresting ability. The deeper the bed, the faster the deceleration. However, as the EER becomes contaminated with dust and other fines, the bottom of the bed can become very stiff, almost like stabilized soil. This reduces the EER effectiveness for slowing vehicles since the depth of the EER is now shallower. The recommended minimum depth found in the literature varied, but 36 inches appears to be the most commonly used depth (Witheyford 1992). One report suggested the EER be tapered from 3 inches at the beginning of the ramp to the maximum depth after 100 to 200 feet (Arizona DOT 2003). The premise for the taper was to prevent stopping the vehicle too abruptly. To evaluate how much deceleration occurs as a vehicle stops in an EER, two scenarios shown below are compared. Scenario 1 is the situation described above with uncrushed, compacted gravel where the stopping distance was shown to be 4154 feet from 90 mph (132 fps). Scenario 2 is the same EER but containing pea gravel where the stopping distance was found to be 900 feet. The deceleration experienced by an individual under these two scenarios is as follows:

$$a = (Vf^2 - Vi^2) / 64.4 L$$

Where,

- a = Acceleration, gravity units
- Vf = Final velocity, fps
- Vi = Entering velocity, fps
- L = Stopping distance, ft.

So, for scenario 1: acceleration = 0.065 g

And scenario 2: acceleration = 0.300 g

The time required to stop the vehicles in the two scenarios is given by:

$$t = (V_f - V_i) / a$$

which for scenario 1 = 136.6 seconds

and scenario 2 = 13.7 seconds

Neither of these scenarios would be sufficiently traumatic to injure a driver if wearing a seatbelt as demonstrated in field experiments for NASA where decelerations in the x-direction of 4.0 were measured over sustained periods of 100 or more seconds (NASA, 2015).

3.3 Lower Straight Creek

A CDOT report (Outcalt, 2008) evaluated the aggregate contained in all thirteen of the Colorado EERs. Observations made by the researchers at the time of the evaluation in 2006 indicated the material in the Lower Straight Creek EER was “like walking on a hard, gravel road”. A heavy loader used for sampling made imprints in the material only about two inches deep.

In summer 2018, CDOT performed a ramp aggregate test collecting samples from the Upper Straight Creek, Lower Straight Creek, Upper Vail pass, and Lower Vail pass EERs in July 2018. Samples of the material in the EERs were taken at three depths, near the top, middle and bottom of the layer. The results of the test are shown in Appendix A. A summary of this sieve analysis is shown in Figure 3.1 compared with the gradation of the current 703.11 specification for EER aggregate.

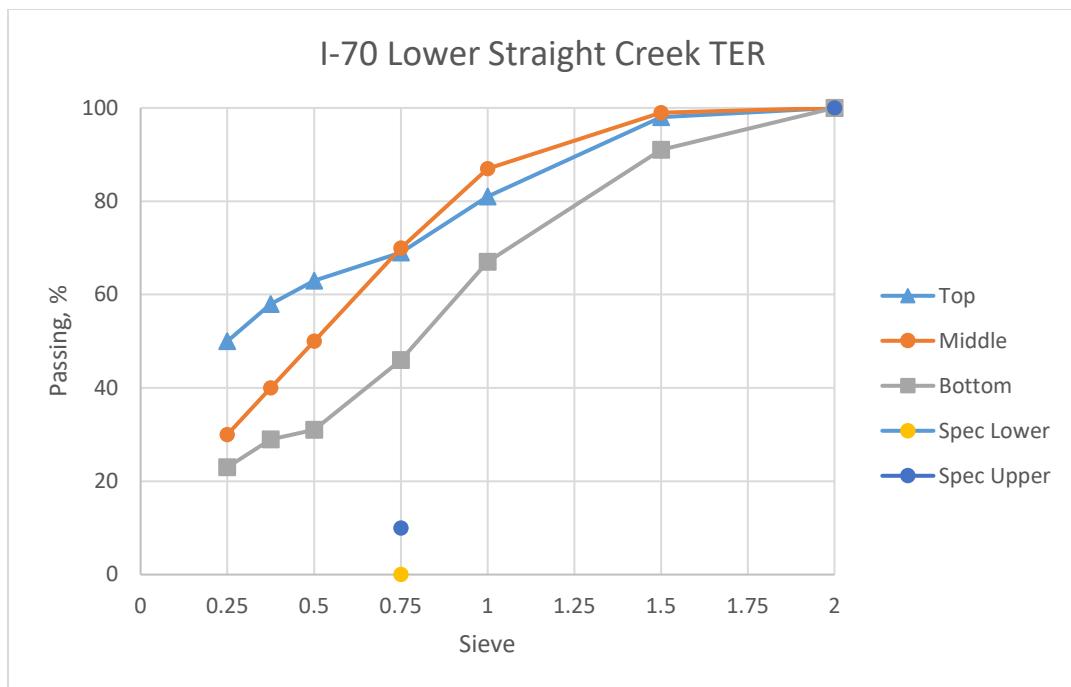


Figure 3.1. Aggregate Gradation in Lower Straight Creek and Current 703.11 Specification

Based on this comparison, the aggregate in the Lower Straight Creek EER is significantly finer than the limits of the 703.11 specification. Of course the gradation shown in Figure 3.1 was measured in 2006 and could be different today. But, if the aggregate has not been removed and replaced, it is likely further contamination has occurred. If so, the gradation of the material today would be expected to be even finer than in 2006. A finer aggregate gradation means the material could be even more compact than it was in 2006. If so, trucks entering the EER would probably travel farther into the escape ramp. According to the CDOT report (Outcalt 2008) at least one truck had gone completely past the end of the ramp. Chapter 6 includes specific recommendations based on this previous analysis.

CHAPTER 4 – INTERVIEWS WITH I-70 MOUNTAIN CORRIDOR STAKEHOLDERS

The study also involved attendance to the I-70 Mountain Corridor Meeting in January and June, 2018, as well as phone interview with a representative of the Colorado Motor Carriers Association (CMCA). Chapter 4 provides a summary of these meetings.

4.1 I-70 Mountain Corridor Coordination Meeting January 11, 2018

The I-70 Mountain Corridor Monthly Meeting occurred on Thursday, January 11, 2018 at the Mountain Residency Straight Creek Conference Room. After the meeting, Dr. Valdes-Vasquez spoke with the following individuals:

- Patrick Chavez, CDOT
- Patti Hestekin, CDOT
- Captain Richard Duran, CSP

The main questions of the discussion are below.

- Law enforcement response to ramp usage- what is the process?
- Are local jurisdiction involved or just state patrol?
- Are operators fined, either by law enforcement or the freight companies?
- Why is the upper straight creek ramp used so much less than the lower ramp?
- How effective would shoulder improvements, lighting, or signage be?
- Why do drivers choose not to utilize emergency ramps in general?
- What design improvements would you suggest to make the ramps more effective?

In summary, Captain Duran explained that the state patrol is responsible for reporting any incidents related to the escape ramps. Ms. Hestekin shared some data in regard to the recent *Hot Brakes and Runaway Truck Ramp Report*. Mr. Chavez explained that operators are not fined, and that more awareness, as well as education, can benefit in helping them to use the escape ramps. Also, everyone was really supportive of horizontal signage improvements as shown in Figure 6.4 under Chapter 6. Based on the suggestion of Mr. Chavez, we scheduled a conference call with Tracy Sakaguchi from Colorado Motor Carriers Association (see next section).

4.2 Meeting Minutes with CMCA representative (Conference Call)

The conference call was on Monday, February 19, 2018. The following individuals were part of the call:

- Tracy Sakaguchi – CMCA
- Dr. Rodolfo Valdes-Vasquez – CSU
- Deniz Besiktepe – CSU

During the conference call, several questions were asked (see Appendix B). In sum, according to Tracy Sakaguchi's knowledge, there is no specific training related to the emergency escape ramps in the state of Colorado. Additionally, none of the CMCA's training includes information related to the EERs and hazmat carrying. As a requirement of federal regulations, drivers need to carry hazmat labels and emergency response guidebooks, and the carrier companies are responsible for the clean-up of hazmat spills resulting trucks entering to the emergency escape ramps.

In the remaining part of the conversation Dr. Valdes-Vasquez gave information about the overall goal of the research project. Tracy Sakaguchi indicated that the Lower Straight Creek ramp is the most frequently used escape ramp in the state. The drivers that used this ramp averaged less than five years of experience.

In addition, Dr. Valdes-Vasquez gave information related to the collaborations of the California Trucking Association with other associations and the idea of having online education related to emergency escape ramps in the state of Colorado. Dr. Valdes-Vasquez asked if the rules of the CMCA are mandatory by law. The answer was they are not mandatory by law, but they are needed by regulations. The training of CMCA are not certified programs, they provide a certificate of completion.

Furthermore, Dr. Valdes-Vasquez asked if Tracy Sakaguchi had some specific suggestions for the signage improvements on the emergency escape ramps. She talked about their recommendation for signage of weight-in-motion, which gives the overall weight of the truck in the tunnel and what should be the recommended speed for its current weight.

On the last part of the conversation, Dr. Valdes-Vasquez shared that CDOT and CMCA published a flyer for the emergency escape ramp usage in the past.

4.3 I-70 Mountain Corridor Coordination Meeting June 14, 2018

The second meeting with the I-70 Mountain Corridor occurred on Thursday, June 14, 2018 at the Mountain Residency Straight Creek Conference Room. The meeting minutes are included in Appendix C. The goal of attending this meeting was to request feedback about preliminary design alternatives. The research team benefitted from the dialogue and feedback of the various stakeholders present including CDOT, Colorado State Patrol, design consultants, regional law enforcement officers, ski area representatives, and freight carrier associations.

The agenda included introductions, description of the study, general discussion of recommendations, and a survey. The general discussion included the following topics: the higher frequency of usage of the Lower Straight Creek EER, the lack of maintenance schedules for EERs, the lack of reporting of hazmat spills, the need for questions related to EERs on the commercial driver license test, and the need for dynamic speed signage and flashing signage for hot brakes.,.

After the general discussion, a survey consisting of two sections was conducted with the attendees to get their feedback related to the preliminary recommendations and views about runaway truck ramps. The first section focused on recommendations related to maintenance/material replacement, signage and pavement marking, shoulder strengthening/widening, and lighting and drivers outreach. The survey instrument is attached as Appendix D. The survey was designed based on a seven-point scale in a range of agree and disagree answers. The key of the seven-point scale is shown in Table 4.1.

Table 4.1. The seven-point scale of the survey

Strongly Disagree	-3
Disagree	-2
Somewhat Disagree	-1
Neither Agree or Disagree	0
Somewhat Agree	1
Agree	2
Strongly Agree	3

Results of the Survey

Eight participants of the meeting completed the survey. The answers of the participants are represented in Table 4.2 and Table 4.3.

Table 4.2. The answers of the participants for the preliminary recommendations

	P1	P2	P3	P4	P5	P6	P7	P8	MEAN
Q1	3	3	N/A	0	2	2	-1	Don't know	1,50
Q2	3	3	N/A	0	2	2	-1	Don't know	1,50
Q3	3	3	N/A	0	2	1	0	Don't know	1,50
Q4	3	3	1	0	2	2	0	Don't know	1,57
Q5	1	1	2	2	2	-1	1		1,14
Q6	2	3	2	2	2	3	0	exists	2,00
Q7	3	3	2	2	2	2	1	-3	1,50
Q8	3	3	2	2	2	2	1	exists	2,14
Q9	2	3	3	2	2	1	1	3	2,13
Q10	2	2	2	1	2	3	1	-3	1,25
Q10-A			3						3,00
Q11	2	3	1	1	2	0	0	-3	0,75
Q12	-1	2	N/A	2	0	0	0	0	0,43
Q13	0	0	-2	0	0	1	0	-3	-0,50
Q14	2	3	2	2	1	1	1	-2	1,25
Q15	3	3	3	2	2	3	2	3	2,63
Q16	3	3	3	2	2	2	2	3	2,50

Q10-A = Decrease curve of truck ramps I70 WB MM182

Maintenance/Material Replacement

The mean of the answers suggested that replacing or recycling existing material to meet AASHTO 57 gradation standards, installing geo-fabric, and improving drainage were agreed recommendations.

Signage and Pavement Marking

Including ramp entry directional signage, story signs ahead of the tunnel, designated ramp entrance, and adding guardrails or other type of channeling method (e.g. barrels) were agreed recommendations with a higher average. Additionally, one participant provided a recommendation of decreasing the curve of the truck ramp at I70 MM 182 with a highest point.

Shoulder Strengthening/Widening

The recommendation of widening the shoulder had the highest average among the others of eliminating shoulder cross-slope and paving for traffic. However, the average of the answers for widening shoulder were between zero and one, five out of eight answers were above one. Eliminating the cross-slope recommendation was answered with a mean in the range of zero and one. The mean for the recommendation of paving for traffic was below zero.

Lighting and Drivers Outreach

Adding lights at ramp entry had a mean in the range of one and two. Trucker outreach (posting a digital flyer on CDOT website) and including commercial driver's license test questions had the highest averages among all other recommendations in the survey that were in the range of two and three.

Table 4.3. The answers of the participants for the views of EERs

	P1	P2	P3	P4	P5	P6	P7	P8
Q1	F	E/B/A		B	E	A	E	C/D
Q2	F/C	A/B		B	E	E	A/E	C/D
Q3	C	A/D/B		B	A	C	F	
Q4	A			B	E	F	F	
Q5	A	D/B		B	E	A	D	

According to the participants' answers, ascending arrestor bed ramps with concrete side barriers, an access road, and barrels on the top are the best designs for the future emergency escape ramps and are more inviting for the drivers. Additionally, these types of ramps are perceived as easy to operate and maintain.

CHAPTER 5 – RAMP PERFORMANCE EVALUATION (HAZMAT)

According to the CDOT staff, throughout the last four years there was no permit issued for a spill in any runaway truck ramp in Region 3 for CDOT. However, permits were issued for incidents that happened near the locations of the truck ramps. In 2011, one major spill accident occurred on the lower Vail ramp as shown in figure 5.1. These images were provided by Emmalee Blender from CDOT.



(a)



(b)

Figure 5.1. Images of the spill accident on the lower Vail ramp in 2011

Another recent accident occurred on July 18, 2018 in the Lower Straight Creek EER. A truck had the brakes fail and hit a barrier on the EER, rupturing the saddle tank and releasing approx. 60 gallons of diesel to the soil and rock. The research team did not have access to all the details of the accident and the clean-up process of this latest event. However, the release was secure and a contractor was hired to clean-up the area.

One task of the study was to better understand the clean-up process and costs, remediation techniques after trucks entering emergency ramps, and auditing/verification process after the clean-up. Thus, Chapter 5 includes three sections as follows:

1. Phone Interviews with Western state DOTs personnel
2. Phone Interviews with the Emergency Responder Companies
3. Phone Interviews with CDOT Hazmat personnel

Each section provides information about the interview process and the summary of the interview.

5.1 Phone Interviews with western state DOTs

The main purpose of the phone interviews was to better understand the following topics from the perspective of the DOTs: types and numbers of the emergency escape ramps in their states, their practice of clean-up processes and costs, remediation techniques after trucks entering emergency ramps, and auditing/verification process after the clean-up. The phone interviews were planned with the following DOTs: Alaska, Arizona, California, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. Appendix E includes the interview instrument that was used and approved by the CSU Institutional Review Board (IRB).

The first step of the phone interview process was to collect the name and contact details of the persons responsible for oversight of the emergency escape ramps from the above mentioned DOTs. The researchers collected the names of possible participants, and, to increase the response rate, David Reeves from CDOT introduced the researchers via email with the potential participants. As a second step, the researchers followed up with the DOTs' personnel via email and scheduled the phone interviews. As a result, out of eleven DOTs, six participated in the phone interviews and two participated with written responses. Four had one participant, and four had more than one participant. Three DOTs did not participate in the study. A total of 17 people from eight DOTs

participated in the study. Table 5.1 shows the distribution of DOTs and the number of participants in the interview process. Additionally, New Zealand's Milford Road Transportation Agency was contacted but the information provided was not relevant to this study.

Table 5.1. Participation of western DOTs

Contacted DOTs	Phone Interviews	Written Participation	Number of Participants
Arizona	x		5
Alaska	-	-	-
California	x		2
Idaho	-	-	-
Montana	x		1
Nevada	x		2
New Mexico	x		4
Oregon		x	1
Utah	-	-	-
Washington		x	1
Wyoming	x		1
TOTAL	6	2	17

The information provided by the DOTs' personnel was limited to their division/district and did not reflect the state-wide or best practice. Appendix F shows the responses of the DOTs summarized by each question.

The information from the DOTs was limited to the knowledge of the personnel even if the questions were shared by the researchers in advance. State wide best practice of EERs related to clean-up and maintenance was not able to be collected. The general practice of clean-up the spills is to remove and replace the contaminated aggregate. However, detailed information of removal and replacement practices could not be provided, and it was only reported as depending on the type of material spilled on the ramp. Additionally, the number of incidents regarding the fuel spills were reported less, and the hazmat spills were zero.

The success and effectiveness of the dragnet system was reported by the two states. Despite the high construction cost of the dragnet system, the ease and low cost of maintenance were emphasized as the benefits in terms of operation. On the other hand, the dragnet system is reported as a superior emergency escape ramp with the advantages of having little damage to the vehicle itself and the prevention of roll over and jack knife.

5.2 Phone Interviews with the Emergency Responder Companies

Based on suggestions from CDOT personnel, the researchers contacted the following three companies:

- a. Cleaning Guys (CG) Environmental,
- b. Custom Environmental, and
- c. Environmental Hazmat Services.

The researchers interviewed the Cleaning Guys Environmental Company and the Environmental Hazmat Services. Additionally, we contacted the Clean Harbors Company, which was mentioned during the phone interview by the state of Nevada. The company representative replied to the questions via e-mail. Appendix H includes a summary of the responses from these companies.

In general, there are three main contacts that the emergency responder companies will use in case of the truck drivers entering the emergency escape ramps, including:

- The trucker company and their insurance company,
- Law enforcement (state or highway patrol), and
- CDOT

In some cases, the trucker companies get in contact with spill brokers who contact with the emergency responder companies.

The typical fuel spill on the emergency escape ramp incidents can be the fuel tank puncture. The reportable amount of the fuel spill in the state of Colorado is over 25 gallons; however, any amount of the spill needs to be cleaned up. Depending on the type of spill and its amount, the clean-up steps are as follows:

1. Keep the site and its environment safe for ongoing traffic and the public with a flagging crew.
2. Prevent the current spill's contamination of the waterways with absorbent materials both on the ramp surface and drainage.
3. Remove the cargo from the truck and then the truck itself.
4. Remove the contaminated aggregate and replacing it with new aggregate.

The average time of the clean-up process can change according to the type and volume of the spill. If a permit from DOT is required, it can take about a week to get the permit and to finalize the cleaning. The typical cost of the clean-up also depends on the type and volume of the spill. The average cost is around \$15,000.

The general recommendations of the participants focused on the drainage and having a pool on the catch basin to keep the possible spills away from the shoulder, roadway, and waterway.

5.3 Phone Interviews with CDOT Hazmat personnel

We contacted Joel Berschauer on July, 17th 2018 and Steven Gillespie on July 27th, 2018, both from CDOT, to better understand the spill clean-up process. Appendix I includes the questions and responses of these two phone interviews.

Overall, the typical spill resulting from a truck entering the emergency escape ramp is the puncture of a fuel tank. CDOT is not responsible for clean-up of the spills. The main responsible party for clean-up is the truck company. The steps that CDOT follows to clean up the escape ramp are as follows:

- According to the location of the incident, the fire department or Colorado State Patrol (CSP) is informed as emergency response authority. CSP is the initial responder to the hazmat incidents and they have hazmat troopers and certified hazmat people to handle the initial response.
- CSP will get in contact with the trucking company about the need of clean-up, and trucking companies contact with the hazmat broker or the emergency responder companies for the initial response of the clean-up.
- After the removal of the truck and the cargo, the spill is covered and controlled, preventing the spill from migrating from the initial site.
- CDOT issues a hazmat permit for the clean-up process.
- Additionally, the clean-up companies need to be in contact with the insurance companies to confirm their payments.

The general time frame for the clean-up of the spills in the emergency escape ramps depends on the location and the volume of the spill. The clean-up of a tank puncture spill may take two weeks including permit and clean-up process.

The recommendations of the CDOT hazmat personnel on the design and operation of the ramps can be summarized as below:

- Containment system for the spills under the ramp.
- Concrete surface of the ramps in terms of easy clean-up purposes.
- Increasing the signage and awareness.
- Adding a section on the Commercial Driver's License test for the proper brake usage in the mountain areas.
- Increasing the awareness of the drivers driving on the mountain area.
- Using the simulators on the driver's license process.

Chapter 6 includes specific recommendations related to fuel and hazmat spills, particularly after finding strong odor in the arrester bed aggregates as described in Appendix A.

CHAPTER 6 – CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The review of the literature suggests that the EERs along Interstate 70 in Colorado were originally constructed using the state-of-the-art designs at the time of their initial implementation and have performed well over their lifespan. There has been only one fatality and five severe injury incidents over the last 13 years. There were no reports of significant hazardous spills in the incident reports, although the long term impact of a series of spills below the reporting threshold requires further investigation. There is little guidance in the literature on best practices for mitigating the impact of repeated low-volume fuel spills over the long term. The incident reports suggest that the Lower Straight Creek Ramp is by far the most used EER on Interstate 70 and, therefore, is the best candidate for design and operations improvement.

The observations on the Upper Straight Creek Ramp, the Lower Straight Creek Ramp, and the EER on US 6 provided that the pea gravel in the arrestor beds are crowned down the centerline of the ramp and that significant fines have intruded at the entry and lower end of the ramp. In addition, the research team observed the two Vail Pass escape ramps. The main issues on the Vail Pass escape ramps are sharp angle of departure at the ramp entry and the curvature of the arrestor bed beginning after the ramp entry.

Based on the sieve test results of CDOT on July 2018, the aggregate in the Lower Straight Creek EER is significantly finer than the limits of the 703.11 specification. A finer aggregate gradation means the material could be even more compact than it was. If so, trucks entering the EER would probably travel farther into the escape ramp.

The I-70 Mountain Corridor Coordination Meeting on June 14, 2018, provided the feedback of more awareness as well as education of truck drivers that can help them to use the escape ramps. Ramp improvements include, horizontal signage improvements, and dynamic speed signage. Additional recommendations of the survey were replacing the existing material on the arrestor beds, improving drainage, widening the shoulders on EERs, adding lights at the ramp's entry,

truckers outreach (posting a digital flyer on CDOT's website), and including commercial driver's license test questions.

The phone interviews of the DOTs provided limited and did not reflect state-wide or best practice. The general practice of cleaning up the spills is to remove and replace the contaminated aggregate, depending on the type of material spilled on the ramp.

The dragnet system was reported as an effective and successful system with the advantages of having little damage to the vehicle itself and the prevention of roll over and jack knife. Despite its higher construction cost, the ease and low cost of the maintenance were emphasized as the other benefits of the system.

The emergency responder companies and CDOT's hazmat personnel recommended drainage improvements with a pool on the catch basin, concrete surface under the ramps for easy clean-up purposes, increasing the signage and awareness of driving on the mountain area, and using simulations for truck driver's training. In addition to design and operation improvement recommendations for the Lower Straight Creek ramp, an investigation is warranted into the reasons why operators fail to utilize the Upper Straight Creek EER and whether its continued operation is justified.

6.2 Recommendations

The research team decided to move forward with design and operation alternatives based on interviews with I-70 corridor stakeholders, CDOT staff, aggregate analysis, field observations, and interview with other DOTs. The recommendations focus on the following categories: maintenance/material replacement, signage and pavement marking, shoulder strengthening/widening, new construction, lighting, and driver outreach.

- **Maintenance/Material replacement**
 - Aggregate replacement - Lower Straight Creek Ramp
 - Update side road to asphalt road – Vail ramps
 - Remove vegetation and improve clear zones – Upper Straight Creek Ramp
 - Develop a maintenance schedule for arrester beds

- Add a camera at the entrance of the EER that records the incidents and takes photos of the license plate.
- PID (photoionization detector) unit, grid soil sampling
- Add a spill kit at the end of the EER
- **Signage and Pavement Marking**
 - Add story signs ahead of tunnel
 - Designated ramp entrance and pavement marking
 - Add guardrails and other type of channeling method
- **Shoulder Strengthening/Widening**
 - Improve shoulder strength and width
- **New Construction**
 - Dragnet system - Vail ramps
- **Lighting**
 - Add lighting at the EER entrance and on the sideways or access roads
 - Added lighting at the overhead sign could incorporate flashing beacons
- **Drivers' Outreach**
 - Post a digital flyer at CDOT's website with a scannable barcode that will lead drivers to a YouTube link including a short video regarding EERs.
 - Update CDOT website regarding EERs.
 - Prepare a flyer that will be distributed at the port entry to truck drivers.
 - Suggest Colorado Department of Revenue add questions regarding EERs on Commercial Driver's License (CDL) test.

The following sub-sections contain more details about these recommendations.

6.2.1 Maintenance/Material Replacement

Aggregate replacement - Lower Straight Creek Ramp

Based on the research conducted by Outcalt (2008), the aggregate gradations in many of the EERs in Colorado are unacceptable with respect to reducing vehicle velocity. Therefore, for those EERs suspected of not meeting the current CDOT 703.11 specifications, aggregate should be sampled at

three locations, near the entrance, midway and near the end. The thickness of the aggregate in the EER should be measured. Samples should be taken at third points within the thickness at each location. Other sieve and particle shape analyses should be completed and compared with the 703.11 specification. If the material meets the specification requirements, nothing more is needed. However, if the material does not meet the specification, the location of the material violating the specification should be determined and that material should be removed and replaced with materials that meet the specification.

Remove the fines from the arrestor beds using mobile screening equipment such as a Powerscreen Chieftain or Warrior Series mobile screening application or similar application. See <https://www.powerscreen.com/screens/> for examples and descriptions of available options. The local contact for technical assistance is Powerscreening LLC in Henderson, Colorado. Because the historical review of incident reports indicates adequate performance, the screening specifications can be written to meet the original construction specifications. However, suggested improvements in aggregate mix as suggested by Outcalt in 2008 should be considered as well.

Update side road to an asphalt road - Vail ramps

Adjacent access to the EER on Vail Pass is currently difficult. This makes recovery of vehicles that have entered the EER difficult. Therefore, the road currently in place adjacent to the EER should be upgraded to an asphalt pavement, or as a minimum, a compacted aggregate base course to accommodate recovery vehicles.

Remove vegetation and improve clear zones - Upper Straight Creek Ramp

All EERs along the I-70 corridor need to have vegetation cleared from the arrestor bed, including removal of root mass. In addition, all EERs should have an established clear zone of at least three feet from the perimeter of the arrestor bed to improve visibility of reflector poles, Jersey barrier positions, signage, and edge conditions. See the Figure 6.1 of the Upper Straight Creek for examples of vegetation issues.



Figure 6.1. Vegetation in the Upper Straight Creek Ramp

Develop a maintenance schedule for arrester beds

The time required for EER aggregate to be contaminated with fine aggregate, soil and dust and consequently become consolidated and compacted, will vary by location. Therefore, if a regular maintenance schedule is developed based on time, some EERs will need maintenance and some may not. However, because development of a specific custom schedule for maintenance would require sampling and testing the aggregates in each EER, our recommendation is to use a time-based schedule where each EER is scarified and, during the scarification process, the character of the aggregate in the EER is evaluated to determine efficacy as an arresting medium. Scarification should be done using conventional rippers attached to motor graders or crawler tractors. Crawler tractors are preferred due to low contact pressure and they are less likely to become stuck in the arrester aggregate.

Add a camera at the entrance of the emergency escape ramp (EER) that records the incident and takes photos of the license plate.

The Lower Straight Creek (LSC) ramp is utilized significantly more than any other EER in the state. Long term performance improvements in the LSC ramp will require improved data collection, including video records of vehicle behavior in the ramp and perhaps improved incident reporting (e.g. fuel tank rupture, estimated speed at entry, driver interviews). Based on discussions with CDOT personnel, it appears the existing camera at the LSC entrance incorporates simple wavetronics radar that serves only to initiate a signal that a truck has entered the ramp. The camera

should be upgraded to an ITS-Series Dual Automatic Incident Detection system as manufactured by FLIR or similar (<https://www.flir.com/products/its-series-dual-aid/>). The camera should have both thermal and digital imaging capabilities along with data collection and transmission. The new camera can be mounted in the same location as the existing camera, but would perhaps provide better information if mounted at the top of the ramp. ITS professionals within CDOT should be consulted for camera location options to provide optimal data collection for future EER performance studies. Data collected should include, at a minimum, vehicle speed and angle at entry, pitch, roll or trailer jack knifing, vibration or instability of the tractor, and stopping distance.

PID (photoionization detector) unit and grid soil sampling

A photoionization detector measures the volatile organic compounds (VOC) and other gases during manufacturing processes, waste handling, and hazmat contamination control. It uses ultraviolet (UV) rays to detect a wide range of VOCs providing a reading that indicates the presence of compounds in the site. Wireless, portable, and transportable versions are available that have common usage among the first responders. Figure 6.2 shows the different types of PIDs.



Figure 6.2. PID examples

Reprinted from *RAE systems*. Retrieved July 15, 2018, from
<https://www.raesystems.com/solutions/photoionization-detectors-pids>.

Grid soil sampling is a technique used for determining the hazmat contamination of a defined site involving a sampling grid of the site and collection of soil samples from the center of each grid. The first step of the grid soil sampling is to have the knowledge of the nature and the magnitude of the hazmat that contaminates the site. Sample depths depend on the characteristics of site and

the contaminant type. According to Environmental Protection Agency (EPA) Supplemental Guidance to Risk Assessment Guidance for Superfund (RAGS) (1992) the minimum number of samples is ten, regardless of site size. The maximum grid size should not exceed a residential lot, specified to be 1/5 acre (about 8700 square feet). The site size and number of sample locations are shown in table 6.1. Grid sizes vary depending the characteristics of the site. (Wyoming Department of Environmental Quality [DEQ], 2000)

Table 6.1. Number of Sample Locations for Grid Soil Sampling

Site Size	Minimum # of Sample Locations
5 acres	25
10 acres	50
30 acres	150
100 acres	500

For the data analysis of the sampling, direct comparison and statistical analysis methods are used. The direct comparison method is the comparison of the soil sample result to the soil clean up level at each grid. Statistical analysis is the comparison of the 95 percent upper confidence limit (UCL) of mean to cleanup levels. The 95 percent UCL is EPA's concentration term in the calculation of risk assessments under Superfund (EPA, 1992). Statistical analysis requires more than 10 sample locations in the data collection. Laboratory analyses of the grid soil sampling should include volatile organic compounds, semi-volatile organic compounds, total petroleum hydrocarbons - gasoline range organics (TPH GRO), total petroleum hydrocarbons - diesel range organics (TPH DRO), and priority pollutant metals (DEQ, 2000).

Add a spill kit at the end of EER

Spill kits are prompt response and clean-up instruments containing absorbent material, containment devices and personal protective wear used to prevent the contamination of fuel/hazardous materials spills into the environment. The capacity of the spills kit varies from an indoor workplace to a general environmental spills. According to the type of material and volume of the spill the content changes. The key products the spill kits contain are booms, pads and socks, plugs and dikes, waste disposal bags, and personal protective equipment. Figure 6.3 shows the different types of the spill kits according to the size of spill.



5 Gallon Bag

20 Gallon Kit

50 Gallon Kit

Figure 6.3. Spill kit examples

Reprinted from *Uline*. Retrieved July 15, 2018, from <https://www.uline.com>

6.2.2 Signage and Pavement Marking

Add story signs ahead of tunnel

Placement of new story signs before and immediately after the tunnel entrance should reflect changes to ramp entrance configuration and pavement markings. Consider dynamic speed-warning signs after the tunnel.

Designated ramp entrance and pavement marking

This research began with one objective: to hypothesize a solution for reducing or eliminating fuel spills from trucks entering truck escape ramps. During the course of the research some theories have evolved that suggest possible solutions to this problem. One theory is that if trucks decelerate too rapidly upon entering the EER there is a high probability that human and equipment damage will ensue. Although this is a possibility, based on the analysis of deceleration rates, it appears the level of deceleration is not very high, even when pea gravel is the aggregate in the EER. Another theory is that if the EER was more inviting, truck drivers might be more inclined to use them, thereupon entering the EER at a slower rate and reducing the risk of damage. An example of a more inviting EER is shown in Figure 6.4.



Figure 6.4. Truck Escape Ramp in Switzerland

These escape ramps offer several advantages over current ramps. First, they narrow towards the end. This makes it more difficult for the vehicle to roll upon entering. This also provides the perception to the driver that rolling over is less likely, making the driver more likely to use the ramp in the first place. Second, they have guardrails and concrete barriers on each side of the ramp. This also provides some insurance that rolling over will be less likely. This also provides a more inviting escape. Contrast the ramp in Figure 6.4 with the ramp in Figure 6.5. Although the ramp in Figure 6.1 is not necessarily a bad looking ramp, there are no guardrails to lead the vehicle into the ramp and no barriers to rolling over.



Figure 6.5. Truck Escape Ramp in Colorado

It is proposed that CDOT conduct a relatively simple experiment to evaluate deceleration rates, deceleration distance, and potential for vehicles to roll over. The experiment would utilize the aggregate gradation described in CDOT 703.11, Truck Escape Ramp Aggregate, placed in depths, of 18, 24 and 36 inches over distances to be determined based on the speed and mass of the vehicle and the gradient of the EER. Guardrails and concrete barriers would be constructed on either side of the EER as the EER narrows near the end to provide lateral support to reduce rollover potential. The objective of this experiment would be to measure the actual distances travelled by a vehicle entering the three depths of material in the EER to determine if the equations developed by Teregin and PTI are valid in Colorado.

Add guardrails and other type of channeling method

Guardrails are safety barriers that help to reduce the impact of runaway vehicles. The potential benefits of the guardrails on EERs are preventing roll over and jackknifing, providing a more inviting escape, and eventually lessening the severity of crash. Channeling methods to be considered include wire rope safety barriers, drums, cones, or tubular markers. More permanent channelizing devices such as guardrails or jersey barriers should not be placed in positions where they would increase safety risk to the driver.

6.2.3 Shoulder Strengthening/Widening

Improve shoulder strengthening

The shoulder can be strengthened and designated as the ramp entry lane with red and white checkerboard marking along with a sign designating the lane as “Escape Ramp Entrance; No Traffic” or similar language. A chevron or “V” shaped guard cable or wire-rope safety barrier should be placed with the point of the chevron at the entry to the ramp with one side parallel to the south edge of the ramp and the other side parallel to the northern most lane of Westbound I-70. This will further demark the ramp entrance and should provide visual guidance to improve vehicle alignment at the entry to the ramp. See figure 6.6 for the design concept.

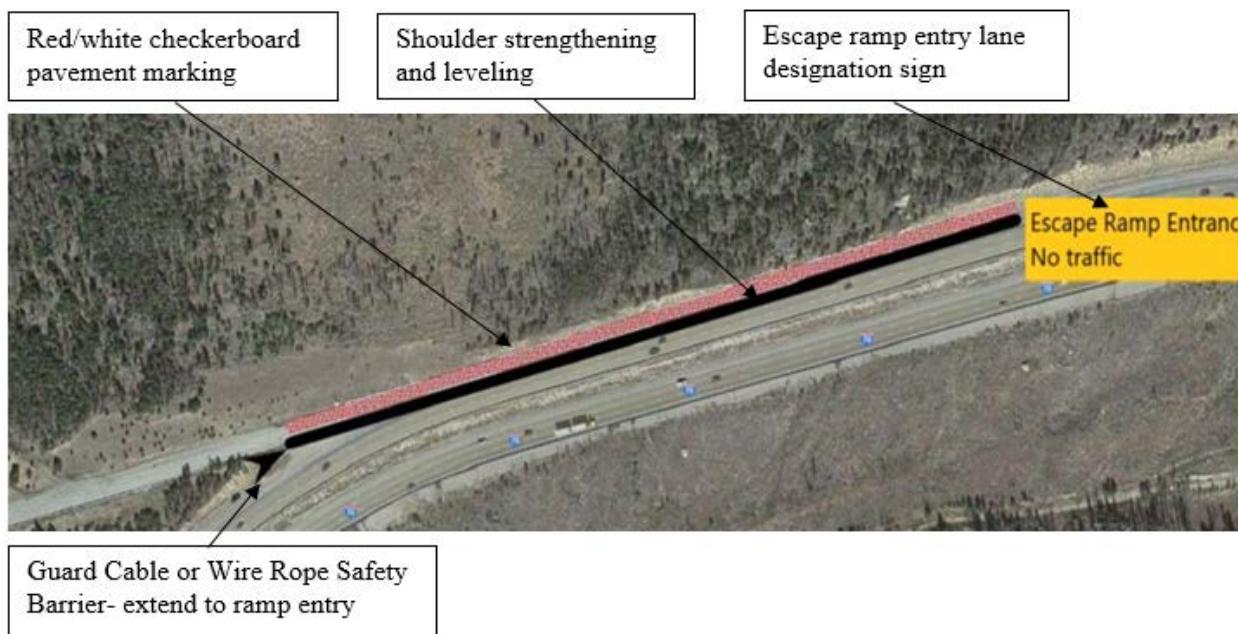


Figure 6.6. Design Concept for Lower Straight Creek

6.2.4 New Construction

Dragnet system - Vail ramps

As mentioned under Chapter 1 and Chapter 5, a dragnet system including energy absorbers, steel barrier nets, and concrete median barriers that provide mounting and restraining of the nets and absorbers requires less distance and less time to stop the runaway vehicle. The final construction cost of the dragnet system varies between \$3.2 million to \$4.6 million with an additional cost of

\$0.4 million for a sub-surface heating system. The system helps to decrease the possibility of saddle tank rupture, jackknifing, and overturning.

The Upper Vail Pass ramp rests on the roadbed of old U.S. Highway 6 and was not specifically designed as an emergency escape ramp. The alignment is poor with a sharp angle of departure from Interstate 70, and the ramp curves gradually to the north for the first portion of the ramp and then turns abruptly to the left at the top. Interstate 70 turns sharply to the left just after the ramp entrance, with no median separating the eastbound and westbound lanes. The alignment, curvature, proximity to, and relationship to Interstate 70 make this a high risk situation. This situation could be mitigated by implementation of a dragnet system at the location shown in Figure 6.7. A similar system has recently been installed in Nevada. This would be an expensive option. If the dragnet is not installed the ramp should be straightened and a dedicated entrance lane added similar to that proposed for Lower Straight Creek.



Figure 6.7. Dragnet system for Upper Vail Pass Ramp

6.2.5 Lighting and Drivers Outreach

Add lighting at the EER entrance and on the sideways

To the extent possible, given environmental regulations, all of the EERs on the I-70 corridor should have improved lighting at the ramp entrance and, more importantly, path demarcation lights along the perimeter of the EER. The lights can be ground mounted or mounted on the Jersey barrier and shielded to reduce light transmission. Low pressure sodium vapor or low intensity LED strip fixtures with low luminous efficacy can also be considered. The demarcation lights are not intended to illuminate the escape ramp but can provide improved guidance at night or in poor visibility conditions.

Added lighting at the overhead sign could incorporate flashing beacons

The overhead signs with flashing beacons are effective ways of attracting drivers' attention. The EERs on the I-70 corridor should have lighting at the overhead sign that could incorporate flashing beacons. The Rabbit Ears Pass EER has flashing beacons on the advance signings with solar powered panels as shown in Figure 6.8. Solar panels absorb sunlight with photovoltaic cells and convert it direct current (DC) power. With the help of a solar battery, the system stores electricity.

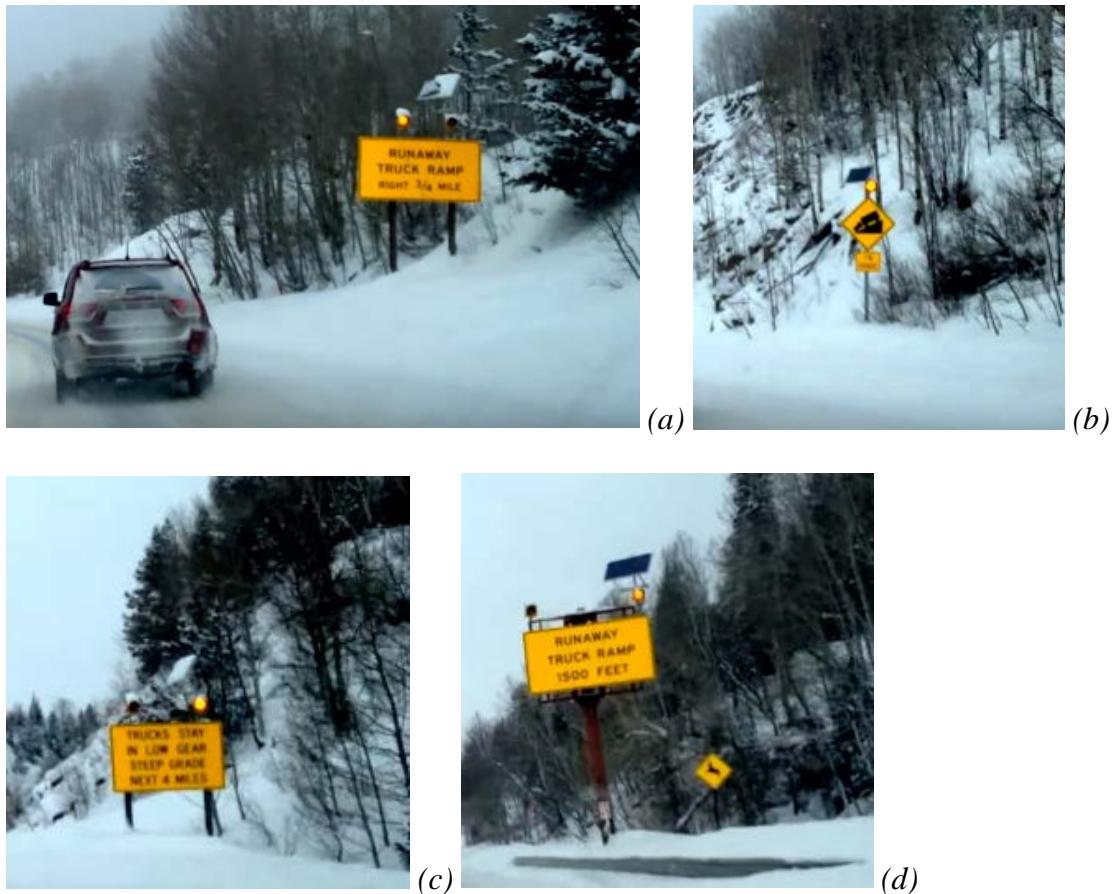


Figure 6.8. Flashing beacons on the advance signing of Rabbit Ears Pass EER
 Images retrieved from YouTube <https://www.youtube.com/watch?v=gLog9dnA3ck&t=226s>

6.2.6 Drivers' outreach

Post a digital flyer and short video regarding EERS at CDOT's website

Printed flyers are one of the efforts to attract drivers' attention. However, online communication tools such as digital flyers are the easiest, most cost effective, and sustainable way of attracting drivers. Additionally, digital flyers reach out to more recipients than printed versions. Posting a digital flyer at CDOT's website containing the locations and main benefits of EERs in the I-70 mountain corridor will help to increase the drivers' awareness of EERs.

Since the latest developments in information technology allow numerous ways of communication, scannable barcodes of mobile phones enable pop up audio-visual tools that help to better reach targeted groups. A tool of a scannable barcode that will pop up a 1-2 minute informative You Tube video, including EER locations and their benefits, will increase the awareness of drivers.

Update CDOT website regarding EERs

The websites of the Arizona DOT, Nevada DOT, and Wyoming DOT include informative links, documents, and videos related to EER and dragnet systems. The informative documents and audio-visual tools should be added to CDOT's website.

Prepare a flyer for truck drivers that will be distributed at the port entry

As mentioned on the above recommendations, flyers will help to increase the drivers' awareness of EERs. Appendix J shows the flyer from CDOT that needs to be updated, and Appendix K includes flyer examples from Nevada and Wyoming DOTs.

Suggest Colorado Department of Revenue add questions on Commercial Driver's License (CDL) test regarding EER's

In the state of Colorado, a Commercial Driver's License (CDL) is required for operating any commercial motor vehicle (CMV) with a Gross Vehicle Weight Rating (GVWR) of 26,001 pounds or more, or that is designed to transport 16 or more passengers including the driver, or is transporting hazardous material and is required to be placarded in accordance with 49 CFR Part 172, Subpart F (Colorado Department of Revenue, 2018). The Colorado CDL test does not include questions regarding EERs. Addition of EER related questions to the CDL test will help to raise the recognition of the locations and the advantages of EERs.

6.2.7 Summary of Recommendations

The recommendations of the research group are categorized under time frame, cost, and potential impacts. Table 6.2 shows the estimated time frame and costs under each category. Additionally the potential impact of the each recommendation is categorized low, medium, or high, describing a qualitative judgment of the research group regarding recommended improvements. Table 6.3 summarizes the recommendations of the research group.

Table 6.2. Time Frame and Costs of Recommendations

Time Frame	Costs		
Short-term	< 1 year	Low	< \$10K
Mid-term	1-3 years	Medium	\$10K-\$50K
Long-Term	> 3 years	High	> \$50K

Table 6.3. Summary of Recommendations

Type	Recommendations	Time Frame	Cost	Potential Impact
Maintenance/Material Replacement	Aggregate replacement - Lower SC	Short-term	Medium	High
	Update side road as asphalt road - Vail ramps	Mid-term	Medium	Low
	Remove vegetation and improve clear zones - Upper SC.	Short-term	Low	High
	Develop a maintenance schedule for arrester beds	Short-term	Medium	High
	Add cameras at the entrance of the EERs that record the incidents and take photos of license plates.	Mid-term	Low	High
	PID (photoionization detector) unit, grid soil sampling	Short-term	Low	Medium
	Add spill kits at the end of EERs	Short-term	Low	High
Signage and Pavement Marking	Add story signs ahead of the Eisenhower-Johnson tunnel	Short-term	Low	Medium
	Designated ramp entrance and pavement marking	Short-term	Low	Medium
	Add guardrails and other types of channeling methods	Medium-term	Medium	Medium
Shoulder Strengthening/Widening	Improve shoulder strength	Medium-term	Medium	High
New Construction	Dragnet system - Vail ramps	Long-term	High	High
Lighting	Add lighting at the EER entrances and on the sideways	Medium-term	Medium	Medium
	Add lighting at the overhead signs that could incorporate flashing beacons	Medium-term	Medium	Medium
Drivers' outreach	Post a digital flyer at CDOT's website/Add a scannable barcode to the flyer that will lead drivers to a youtube link including a short video regarding EERs	Short-term	Low	Medium
	Update CDOT's website regarding EERs	Short-term	Low	Medium
	Prepare a flyer for truck drivers that will be distributed at the port entry	Short-term	Low	Medium
	Suggest Colorado Department of Revenue add questions on Commercial Driver's License (CDL) test regarding EERs	Medium-term	Low	High

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Appendix A. CDOT ramps sieve analysis results

COLORADO DEPARTMENT OF TRANSPORTATION PRELIMINARY SOIL SURVEY				Page 1	Date Drilled:		7/17/2018	
				Highway Number:		I 70		
				Start & End Mileposts:		Straight Creek		
				Location:		Truck Escape Ramps Denotes R-Value Sample		
MILEPOST, LANE & THICKNESS	TEST NO.	MATERIALS	DESCRIPTION	SULFATE %	PERCENT PASSING			
					#3	#1"	#3/4"	#5/8"
					#4	#10	#20	#40
					#60	#100	#200	
Upper Straight Creek	Top Pit	0"-6" Screened Rock						
		6" - 24" Base			100	51	7	
		Subgrade @ 24" Strong Odor						
Upper Straight Creek	Middle Pit	0" - 2" Screened Rock						
		2" - 18" Base						
		Subgrade @ 18" Strong Odor						
Upper Straight Creek	Bottom Pit	0" - 12" Screened Rock						
		12" - 24" Base						
		Subgrade @ 24" Strong Odor						
Lower Straight Creek	Top Pit	0" - 2" Screened Rock						
		2" - 18" Base			100	98	28	16
		Subgrade @ 24" Strong Odor						
Lower Straight Creek	Middle Pit	0" - 24" Screened Rock						
		Subgrade @ 24" Strong Odor						
Lower Straight Creek	Bottom Pit	0" - 12" Screened Rock						
		Subgrade @ 12" Strong Odor						

CDOT Form #655 Rev. 07/11

COLORADO DEPARTMENT OF TRANSPORTATION PRELIMINARY SOIL SURVEY				Page 2	Date Drilled:		7/17/2018	
				Highway Number:		I 70		
				Start & End Mileposts:		Vail Pass		
				Location:		Truck Escape Ramps Denotes R-Value Sample		
MILEPOST, LANE & THICKNESS	TEST NO.	MATERIALS	DESCRIPTION	SULFATE %	PERCENT PASSING			
					#3"	#1"	#3/4"	#5/8"
					#4"	#10	#20	#40
					#60	#100	#200	
Upper Vail Pass	Top Pit	0" - 10" Screened Rock			96	23		
		10" - 24", 1-1/2" Base						
		Subgrade @ 24" No Odor						
Upper Vail Pass	Middle Pit	0" - 10" Screened Rock						
		10" - 24", 1-1/2" Base						
		Subgrade @ 24" No Odor						
Upper Vail Pass	Bottom Pit	0" - 10" Screened Rock						
		10" - 24", 1-1/2" Base						
		Subgrade @ 24" No Odor						
Lower Vail Pass	Top Pit	0" - 24", 2" Screened Rock						
		Subgrade @ 24" Slight Odor						
	Middle Pit	0" - 24", 2" Screened Rock						
		Subgrade @ 24" Strong Odor						
	Bottom Pit	0" - 24" 2", Screened Rock						
		Subgrade @ 24" Strong Odor						

CDOT Form #655 Rev. 07/11

Appendix B. Meeting Minutes with CMCA representative

The conference call was on Monday, February 19, 2018. The following individuals were part of the call:

- Tracy Sakaguchi – CMCA
- Dr. Rodolfo Valdes-Vasquez – CSU
- Deniz Besiktepe – CSU

During the conference call, the following questions were asked, and their responses are shown below each question.

Q1. Do you know of any specific training related to the emergency escape ramps in the State of Colorado? If so, what are the specifics of this training?

A1. No.

Q2. Does any of CMCA's training include information including emergency escape ramps, including

- What is an emergency escape ramp and what is the purpose of it?
- Where are the emergency escape ramps located in the State of Colorado?
- In what type of emergency situations drivers should use an emergency escape ramp?
- What is the process that should be followed up by drivers after using the ramp? (e.g., how do they need to report the incident? If so, to which department?)

A2. No.

Q3. Does CMCA have any specific training related to the hazmat carrying in the State of Colorado? If so, we would like to know the details related to the content of this training.

A3. No.

Q4. Do drivers have any informative documentation for the hazmat carrying?

A4. Yes. As a requirement of federal regulations, they need to carry hazmat documentation such as hazmat labels and emergency response guidebooks.

Follow up Q: Do you know the name of any specific laws and regulations?

A: No.

Q: If you find something related to the name of the laws and regulations can you send us by e-mail.

A: Yes absolutely.

Q5. If a hazmat spill occurs in one of the emergency escape ramps what is the process to be followed up for the clean-up of the area?

A5. The carrier will probably call their emergency responder that they would have on file with the company. They would respond up for the cleanup.

Follow up Q: Is there a list of emergency responders in the State of Colorado?

A: It is a federal law that they have to have emergency responders.

Q: Who are the companies that normally do this job?

A: Belfor Environmental and Custom Environmental

Q: Do you think it is a good idea to contact them?

A: Absolutely, they will give you lots of information.

Q: Who pays for these cleanups?

A: The carrier company pays for the cleanup.

Q6. Does CMCA have any collaborations with other related organizations for training and educational purposes? (e.g., California Trucking Association or any other states' trucking/motor carriers associations)

A6. No.

Q7. Who is responsible for the approval of CMCA's training content and the selection of the training instructor?

A7. Patty Gillette. Vice President of CMCA.

Follow up **Q:** Can we get in contact with her?

A: Absolutely.

Q: Since there is no specific training for emergency escape ramps in the State of Colorado, do you think something should be included related to the emergency escape ramps into the training content?

A: If we can find somebody who is qualified enough to develop the training such as safety managers who may implement the content to the drivers.

Q: So the main concern for the training of emergency escape ramps is finding somebody qualified enough to do the training.

A: Yes.

Q8. Are operators fined, either by law enforcement or the freight companies after using the emergency escape ramps?

A8. No, they are not.

Follow up **Q:** So you don't think there is an issue for them missing the escape ramp.

A: There should be no issue and there should be no penalty for them missing the emergency escape ramp.

Q9. How effective should shoulder improvements, lighting, or signage be on the ramps? Do you have any specific suggestion for the signage improvement on the ramps?

A9. It should be very effective and it should also speak to passenger vehicles. Passenger vehicles will park right in front of the escape ramps not knowing what they are. The signage and the lighting is very important.

Appendix C. Minutes from the I-70 Mountain Corridor Coordination Meeting June 14, 2018

The second meeting with the I-70 Mountain Corridor occurred on Thursday, June 14, 2018 at the Mountain Residency Straight Creek Conference Room with the following attendees:

- Patrick Chavez, CDOT
- Gloria Jones, CDOT
- David Millar, HDR
- Patti Hestekin, CDOT
- Richard Duran, CSP
- Solomon Haile, CDOT
- Bill Crawford, CDOT
- Martha Miller, CDOT
- Tracy Sakaguchi, CMCA
- David Reeves, CDOT
- Kelly Strong, UNI
- Rodolfo Valdes-Vasquez, CSU
- Deniz Besiktepe, CSU
- Two representatives from the port of entry

The goal of attending this meeting was to request feedback about preliminary design alternatives. The research team benefitted from the dialogue and feedback of the various stakeholders present including CDOT, Colorado State Patrol, design consultants, regional law enforcement officers, ski area representatives, and freight carrier associations.

Agenda:

- Introductions
- Project Description
- General discussion about possible recommendations
- Survey

General Discussion:

1. Dr. Strong: Is there an option of flashing signage for hot brakes? A: There is a monitor but it is too small. There are large mobile monitors which trucks need to go over with a low speed. It is not for high speeds and for hot brake recognition it does need a lot of IT work.
2. Dr. Valdes: How does it work during the winter and is there any influence of season. A: It is a year round issue.
3. Dr. Strong: The Lower Straightcreek ramp is the most used one in the state of Colorado. The picture of the emergency escape ramp on the CDOT website is not inviting. The hot brake enforcement should be one of the potential options. There are a lot of fines into the aggregate and it is sticky. There is no video evidence of truck going into the ramp. Just as a guess if a truck enters to the ramp with an 85 mi/h speed and stops in 200 ft. that is a fast deceleration.

4. CDOT: I don't think that the maintenance guys have a schedule for changing the aggregate on the ramps. Dr. Strong: We didn't find any reports showing the change of aggregates but it doesn't mean that it has never been changed. CDOT: They are fluffing it up.
5. Dr. Valdes: We are looking for the level of contamination after the fuel spill happens. We couldn't find any good data about it. It is another concern about the area especially because there is a creek down the road. There is only one catch basin on the one at Loveland pass. CDOT: Catch basin should be a good recommendation for the ramps. Dr. Strong: We mostly look the incident data on the ramps of the I70 corridor. We didn't find any record of incidents having a hazardous material spill on the ramp. Which means the spills were under the amount of the reportable amount or someone estimated that it is under the reportable amount.
6. Dr. Strong: How effective is the CMCA in communicating the out of state drivers? A: However we are working with other states' motor trucks associations, it is very difficult.
7. Dr. Valdes: It seems that there are no questions on the CDL tests related to the emergency escape ramps. That might be something that we are looking into. CDOT: Department of Revenue is open to the suggestions. Driver training schools can also show some videos. CDOT David Reeves: As part of the report there will be an implementation plan.
8. CDOT: As a part of your problem statement are you looking at design and signage? Dr. Strong & Dr. Valdes: Yes. CDOT: Wolf creek pass may have a dynamic-speed sign.
9. Dr. Strong: Upper straight creek ramp, the drivers are already going in higher speed and they don't have enough time to decide to use the ramp.
10. CDOT: Road Safety Audit is another recommendation. Wolf creek pass had 5 fatalities. Dynamic warning, dynamic signage which tells the driver that the truck is going too fast can be good recommendations. There is a report of Wolf Creek Pass of FHWA and Evaluation of Downhill truck speed warning system.

Other notes:

- Hot brake system and Infrared systems
- Contacting Department of Revenue for adding the questions related to EERs in CDL test.
- Outreach: Effective flyers, sending messages to truck drivers when they are going too fast, a barcode for the truck drivers on the port entry which pop ups a You tube link showing a video of EERs.

Appendix D. Survey of I70 Mountain Corridor Coordination Meeting June 14, 2018

I-70 Stakeholder Meeting Survey

Goal: To request feedback about preliminary design alternatives

Project Description:

This study aims to provide recommendations to alternative design and construction specifications for runaway truck ramps. The alternative design and construction specifications will be reviewed and evaluated by CDOT engineers and freight carriers to identify concerns and benefits. Based on the results of this research, further design and testing will be identified for Phase II research if requested by CDOT. Although all Colorado existing emergency truck ramp areas are of interest, the Lower StraightCreek truck ramp west of Eisenhower/Johnson Memorial Tunnel (EJMT) will be emphasized as it is utilized the most frequently.

Summary of Alternatives: The research team has developed preliminary design alternatives focusing on signage, pavement marking, and ramp entry geometry (including potential shoulder upgrades), along with materials upgrades such as geotextiles that can stabilize the pea gravel and mitigate the fines intrusion that has been observed.

The investigators would like to know your opinion about them, please following instructions:

- Please answer the below questions to the best of your ability.
- "Neither Agree nor Disagree" means you are indifferent to the statement.
- "N/A" means you feel the statement does (did) not apply based on your experience.
- Reference your current or most recent experience about Runaway Truck Ramps when responding to questions.

SECTION 1 – Preliminary Recommendations

Evaluate the following recommendations in regard to Maintenance/Material Replacement.

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree	N/A
Replace or recycle existing material to meet AASHTO 57 gradation standards	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Improve confinement of the aggregate material	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Install geo-fabric	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Improve drainage	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other _____	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Evaluate the following recommendations in regard to **Signage and Pavement Marking**.

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree	N/A
No automobiles on the shoulder after the tunnel	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Include Ramp entry directional signage	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Story signs ahead of the tunnel	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Designated ramp entrance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Adding guardrails or other type of channeling method (e.g. barrels)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Striping/checkerboarding at the entrance- decrease departure angle	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other _____	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Evaluate the following recommendations in regard to **Shoulder strengthening/widening**.

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree	N/A
Widen shoulder	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Eliminate shoulder cross-slope	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Pave for traffic	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other _____	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Evaluate the following recommendations in regard to **Lighting and Drivers Outreach**.

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree	N/A
Add lights at ramp entry and at top of the ramp	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Truckers Outreach (posting a digital flyer on CDOT website), see attached example	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Including commercial driver's license test questions	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other _____	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

SECTION 2 – Your views about Runaway Truck Ramps

Please review the following images before answering the questions below:



A)



B)



C)



D)



E)



F)

1. Which image(s) represents the best design for future Runaway Truck Ramps in CO? _____
2. Which image(s) looks more inviting to be used by Truckers? _____
3. Which image(s) is more cost effective to be built in CO? _____
4. Which image(s) is easier to operate/maintain in CO? _____
5. Which image(s) will facilitate the clean-up process after fuel spill on the ramp? _____

SECTION 3 - General Comments

Do you have any extra comments about Runaway Truck Ramps that you would like to share with us? For instance, do you have any specific concerns about these preliminary recommendations? Do you have alternative recommendations that were not included above? Please provide your feedback in the space provided below.

If you would like the research team to contact you to clarify some of your comments, please provide your contact information below

Name: _____

Email: _____

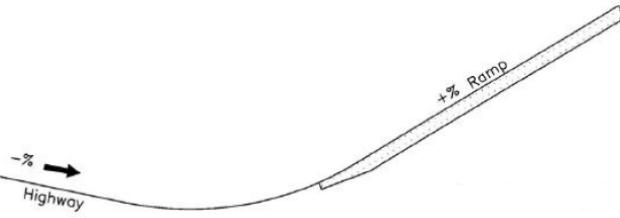
Phone #: _____

We thank you for your time spent taking this survey.

Appendix E. Research Instrument used when interviewing Western States DOTs personnel

1. Please select the types of emergency escape ramps and provide their numbers currently in use in your State:

1. _____ Gravity
2. _____ Sand Pile
3. _____ Arrester Bed
 - 3.1 _____ Descending grade
 - 3.2 _____ Ascending grade
 - 3.3 _____ Horizontal grade

TYPES OF EMERGENCY ESCAPE RAMPS (AASHTO Green Book)		
1	Gravity Emergency Escape Ramp	
2	Sand Pile Emergency Escape Ramp	
3.1	Arrester Bed - Descending Grade Emergency Escape Ramp	
3.2	Arrester Bed - Ascending Grade Emergency Escape Ramp	
3.3	Arrester Bed - Horizontal Grade Emergency Escape Ramp	

2. Please provide the numbers of incidents on the emergency escape ramps in your State between 2016– 2018:

3. Please provide the numbers of **fuel spills** on the emergency escape ramps in your State between 2016 – 2018:

4. Please provide the numbers of **hazardous material** (any item or chemical which is a "health hazard" or "physical hazard") spills on the emergency escape ramps in your State between 2016 – 2018:

5. Please select the responsible party for the clean-up of the emergency escape ramps after **fuel spills** resulting trucks entering emergency escape ramps?

- A. _____ DOT
- B. _____ Carrier company involved in the incident
- C. _____ Other (_____)

If the DOT is responsible, who is in charge of cleaning? Please provide the name of the companies.

If a carrier company is responsible, who is in charge of cleaning? Please provide the name of the companies.

6. Please select the responsible party for the clean-up of the emergency escape ramps after **hazardous material spills** resulting from trucks entering emergency escape ramps?

- D. _____ DOT
- E. _____ Carrier company involved in the incident
- F. _____ Other (_____)

If the DOT is responsible, who is in charge of cleaning? Please provide the name of the companies.

If a carrier company is responsible, who is in charge of cleaning? Please provide the name of the companies.

7. What are the typical remediation techniques for clean-up of the emergency escape ramps after **fuel spills** resulting from trucks entering the ramps?

8. What are the typical remediation techniques for clean-up of the emergency escape ramps after **hazardous material spills** resulting from trucks entering the ramps?

9. Please provide the average cost of the clean-up of the emergency escape ramp after fuel spills or hazardous material spills resulting from trucks entering emergency escape ramps.

US \$ _____ (for **fuel spills**)

US \$ _____ (for **hazardous material spills**)

10. What is the auditing/verification process of the emergency escape ramp after the cleaning, from the perspective of the DOT?

11. What are the specific requirements and regulations related to the clean-up of fuel/hazardous material spills resulting from trucks entering emergency escape ramps in your State?

12. What are the design features for making the containment of spills easy to clean/remove? Can you provide any examples of the design features?

Appendix F. Summary of Interviews with Western DOTs' staff

Q1. Type and the number of Emergency Escape Ramps (EERs) in their states

Out of eight, four DOTs (Arizona, Nevada, Washington, and Wyoming) provided the exact number and types of the EERs in their states. The others only provided the number and types of the EERs in their districts, and they did not have the state wide information. The state wide numbers of EERs are nine (9) in Arizona, four (4) in Nevada, five (5) in Washington, and eleven (11) in Wyoming. The majority of the EERs were ascending arrester beds, and two DOTs (Nevada and Wyoming) reported that they have dragnet systems.

Q2. Number of incidents on the EERs in their State between 2016-2018

The state of California and Arizona reported 80 and 100 incidents per year per ramp. The state of Oregon recorded 72 incidents per year. The other reported numbers of incidents were below six. Except for one state (California), the majority of the incidents were reported as caused by trucks. The state of California reported 75% of the incidents caused by cars on the EER located in the left lane. Also, the state of California shared a truck escape ramp form, which was completed by law enforcement after the truck entering the EER. The form is shown in Appendix G.

Q3 and Q4. Number of Fuel or Hazmat spills on the EERs in their State between 2016-2018

Two states (Wyoming and New Mexico) reported minor fuel spills on their EERs. The state of Wyoming reported two fuel spills on their dragnet system, and the state of New Mexico could not provide any numbers. None of the states reported any hazmat spills on their EERs during the last two years.

Q5 and Q6. Responsible party for the clean-up of EERs after Fuel or Hazmat spills resulting from trucks entering the EERs.

The general response was from private emergency responder companies. Typically, trucker companies have contract with an emergency responder company. Law enforcement and the trucker companies are the first contact of DOTs when trucks enter the ramps. Two states (New Mexico and Montana) reported that their environmental crews/departments are responsible for the clean-up process. The reportable amount of the fuel spills was 25 gallons in general practice. Two states (Arizona and New Mexico) mentioned that any amount is reportable.

Q7 and Q8. Typical remediation techniques for clean-up the EER's after fuel / hazmat spills resulting from trucks entering the EERs.

Since the general trend of responsible party for the clean-up is a private emergency responder company, the DOTs' personnel could not provide detailed information about the remediation techniques and clean-up process. The common information provided was removing the contaminated aggregate and replacing it with new aggregate compatible with the state specifications. One state reported the use of spill kits on the ramps, which include absorbent socks or blankets, pads, pillows, proof seals, gloves, goggles, and disposal bags. Overall, the information provided was that the remediation technique depends on the type of material contaminated and best practice of the emergency responder company.

Q9. The average cost of the clean-up of the EERs after fuel/hazmat spills resulting from trucks entering the EERs.

The general information provided by the states was that the cost of clean-up varies from case to case and depends on the contaminated material. The state of California reported \$120,000 for the general maintenance, which includes clean-up of the arrester bed, screening the aggregate, and putting the aggregate back in place. One state reported man hours as four hours per ramp for the clean-up of fuel/hazmat spills. The state of Arizona reported their maintenance practice as roughly 2-3 hours with 2-3 persons with a back-loader and the cost of this maintenance activity was around \$2,000 - \$3,000 per ramp.

Q10. The auditing/verification process of the EERs after the cleaning, from the perspective of the DOT.

The general practice for the auditing/verification process of the EERs after the clean-up was visual inspection of the site by maintenance personnel of the DOTs or environmental crew of the state. Also, the clean-up company is responsible to provide a certification of the clean-up process to the DOT. The state of Montana reported having local inspectors who check the clean-up performance according to the states guidelines.

Q11. Specific requirements and regulations related to the clean-up of fuel/hazmat spills resulting from trucks entering the EERs.

The general practice for the specific requirements related to the clean-up of fuel / hazmat spills is requesting a documentation from the company responsible for clean-up and visual inspection of the ramps by DOT personnel or environmental crew after the cleaning.

Q12. Design features for making the containment of spills easy to clean and remove.

The dragnet system was recommended by two DOTs because of ease of clean-up and less maintenance required. The bed of the dragnet system is a hard surface, and if there is a spill, it is possible to capture the fluid before it leaves the ramp. The construction cost of dragnet system with heating system is around \$4.5 million, and, if there is a pavement heating system, the total heating cost per month during the winter is around \$3,000 - \$4,000. Other than the heating cost no other maintenance cost was reported. The dragnet system requires only trash and snow removal in terms of maintenance. The cost of replacing the nets after the dragnet system used is around \$100,000 and this cost is billable to the insurance party of the trucker company. In addition, having an asphalt road right next to the ramp for the ease of clean-up and towing was reported by one state. Use of the local materials for arrester beds was another recommendation.

Q13. Other recommendations or comments.

One state reported the use of cameras in the ramps, and when a truck enters the ramp the maintenance supervisors and law enforcement get email notifications. Also, the system takes the photo of the vehicle and it is possible to track the plate of the vehicle. Another benefit of having a camera is giving the opportunity to track the entrance speed of the vehicle. Another practice that was recommended by one state is having a lighting system prior to the ramps that shows it is occupied in case of incident. Keeping the runaway truck on the EER away from ongoing traffic was a safety related recommendation that prevents flying aggregate from going onto the highway. The flyers for drivers' outreach was recommended for informing the truck drivers. Panel boards at the edges of the EERs, horizontal ramp-ahead signage and the arrow sign, which shows the entrance of the ramp, were other general recommendations.

Appendix G. Truck Escape Ramp Form of California Department of Transportation

TRUCK ESCAPE RAMP SURVEY

To: California Department of Transportation
 Division of Traffic Operations, MS-36
 1120 N Street
 Sacramento, CA 95814
 Attn: Manuel L. Fonseca
manuel.fonseca@dot.ca.gov

Date: 02-26-2018

From: Department of California Highway Patrol San Bernardino Area 860

LOCATION							
Date of Incident 02-26-2018	Time 2055	Weather: <input type="checkbox"/> Clear <input type="checkbox"/> Raining <input checked="" type="checkbox"/> Wind <input checked="" type="checkbox"/> Cloudy <input type="checkbox"/> Snowing <input type="checkbox"/> Fog			Roadway Surface: <input checked="" type="checkbox"/> Dry <input type="checkbox"/> Snowy - Icy <input type="checkbox"/> Wet <input type="checkbox"/> Slippery		
County SBDO	Route I-15	Milepost	Name of Ramp		<input type="checkbox"/> East Ramp	<input type="checkbox"/> West Ramp	
DRIVER							
Name			License Number		State CA		
Age	Driving Experience (yrs) (mos) N/A	Experience on Route (yrs) (mos) MINIMAL					
VEHICLE							
Type of vehicle: <input type="checkbox"/> Auto/ Pick up <input type="checkbox"/> Motorhome <input type="checkbox"/> 3-axle truck <input checked="" type="checkbox"/> Truck Tractor <input checked="" type="checkbox"/> Doubles <input type="checkbox"/> Auto w/ trailer <input type="checkbox"/> 2-axle truck <input type="checkbox"/> Truck w/ trailer <input type="checkbox"/> Tractor w/ semi <input type="checkbox"/> Other							
Registered Owner	Address				License Plate & State		
Gross Weight N/A	Distance Traveled in Ramp (Beg. of gravel to steering axle) APPROX 400'				Speed Entering Ramp N/A		
Type of Truck: <input type="checkbox"/> Van <input type="checkbox"/> Tanker <input type="checkbox"/> Flatbed <input checked="" type="checkbox"/> Bulk			Cargo: EMPTY				
BRAKE ADJUSTMENT							
Right							
	Front	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6
Left							
RAMP							
Condition: <input type="checkbox"/> Smooth <input checked="" type="checkbox"/> Rutted <input type="checkbox"/> Dry <input type="checkbox"/> Wet <input type="checkbox"/> Snow <input type="checkbox"/> Ice					Damage: DISPLACED GRAVEL		
Advisory Signs: <input checked="" type="checkbox"/> Visible <input type="checkbox"/> Not Visible <input type="checkbox"/> Damaged	Approach Markings:		<input checked="" type="checkbox"/> Visible <input type="checkbox"/> Not Visible <input type="checkbox"/> Obscured				
SUMMARY							
<p>HE WAS UNFAMILIAR WITH THE ROADWAY AND THOUGHT THE ESCAPE RAMP WAS AN EXIT. HE DROVE ONTO THE ESCAPE RAMP GRAVEL WHERE HE GOT STUCK. HE NOTIFIED HIS EMPLOYER, WHO ARRANGED FOR A PRIVATE TOW TO ASSIST</p>							
Preparer's Name:	I.D. Number:	Mo. Day Yr.	Reviewer's Name:	I.D. Number:	Mo. Day Yr.		
02-27-18							

Appendix H. Summary of Interviews with Hazmat Cleaning Companies

Q1. How do the drivers get in contact with your company? Could you provide detailed information about your agreement with the carrier companies?

Typically, there are three ways to contact the clean-up company: 1) Colorado State Patrol, 2) CDOT, and 3) Individual trucking company. In some cases, spill brokers get in contact with the emergency responder company that provides service for the area. Spill brokers are companies that have a previous arrangement with the trucker company, and, by checking the zip code of the emergency call, they identify which local company could help with responding to the incident.

Clean Harbors has a 24/7 Emergency Response Hotline 1-800-OILTANK. A customer would call into their Emergency Operations Center (EOC) and they will route the call to the appropriate branch. Clean Harbors has locations all over the country, in Canada, and Puerto Rico and they may have Standby Emergency Response Agreement (SERA) with particular carriers where they are basically required to respond. If not, the customer will need to sign our Emergency Response Agreement to pay for emergency response rates and payment terms.

Q2. What are the typical incidents that your company deals with in emergency escape ramps?

The fuel tank puncture can be the majority of incidents. Any amount of spill, which is over 25 gallons is reportable. However, the companies mention that even if it is five gallons or one gallon it still has to be cleaned up, but reporting it to the state is not necessary. If there are hydrocarbons coming out of the escape ramps that are able to get into the waterway, even if it is a detention pond, it is reportable. Any amount on the highway or on the emergency escape ramps needs to be cleaned up. Typically, CDOT reports the spill to the clean-up company if they carrier company has not taken care of it. Emergency escape ramps are basically treated as any other roadside spill. If there is oil or fuel on the ground, it will be contained, removed (either washed with a pressure washer and degreaser if on the pavement, or excavated if in the soil). Clean Harbors indicates that they will contain the waste for disposal.

Q3. What are the steps that your company follows for clean-up of the escape ramp based on the type of incident?

Depending on the material, the aggregate on the ramp is excavated and removed. All hydrocarbons are cleaned from the site. Some of the escape ramps have a very steep incline and the spilled material will run down the hill. Thus, the spill has to be chased and contained back into the escape ramp. Micro Blaze and bio bugs are products used to clean the area. Micro Blaze is an enzyme activated by the hydrogen molecules in the water. So, if it is mixed with water it activates. Bio bugs can be used for the outside spills, but they are extremely expensive, and they have to be maintained in a climate-controlled area. They are generally used in ocean spills and water treatment facilities, though. Additionally, the contaminated aggregate or soil goes to certified landfills.

Clean Harbors indicated that they do not have a particular Standard Operating Procedure (SOP) in regard to escape ramps. This would be like any other roadside spill where they are getting a flagging crew to shut down traffic as needed and work with the local agency in regard to traffic control. If there is a waterway nearby it needs to be protected first. Then, they focus on the

containment of the release. Their overall steps can be summarized as public safety, containment, and protecting the waterways. If there is a drainage on the ramps they put some absorbent material to keep the contamination from running into the drainage and creek. Finally, the product or the cargo will be offloaded from the truck and a permit will be provided from CDOT.

Q4. Do you have any idea based on your other experience, what is the average time period that is defined for clean-up of the area, depending on the type of incident?

Depending on the incident, typically we are going to be on an average tank spill around half a day replenishing the material. Additionally, if the incident happens during the winter time and it will be cleaned up during the summer, the spill can be located by PID (photoionization detector) units. These unit pick up the levels of hydrocarbons and other products. Then, the incident can be documented with the insurance company. Depending on the extent of the spill, they could last several hours or several months.

Q5. What is the typical cost for one of these cleanups?

It depends on the removal of soil, hauling up soil, disposal of soil, and the proper documentation back to the state showing that it was handled properly. Under the Cradle-to-Grave federal act, the clean-up company and the trucker company have to have documentation showing the cleanup process. Additionally, every incident is different, and costs vary from case to case. The longer the spilled material sits on the surface, the larger the clean-up. Overall, it depends on the extent of the spill. Excavators, roll-off trucks, flagging personnel, transportation and disposal, all add up very quickly. The average estimate can be anywhere between \$10,000 to \$20,000. For instance, the clean-up of the big spill, which happened in Vail in 2011, probably ended up with \$100,000.

Q6. Do you have any other thoughts or final recommendations about design or clean-up processes on the emergency escape ramps?

Having the concrete ramps for the slower speed ones and having a pool on the catch basin will be perfect. The clean-up on the concrete surface is really quick and easy. If there is a spill on the escape ramp there should be a drainage to contain and to keep the spill away from the waterway.

Appendix I. The summary of the phone interviews with CDOT Hazmat personnel

Interview with Joel Berschauer

Q1. What are the typical spill incidents that CDOT deals with on emergency escape ramps?

Most of the time the truck should stop on the ramp and there will be no puncture on the fuel tank. If it happens, it is basically the same as what happens on the road except that the fuel gets into the gravel or the surface material. Ninety percent (90%) of the trucks have less than 100 gallons of diesel fuel tanks; other oil from the truck can be motor or transmission oil. Anytime a truck jackknifes, it will poke hole in the fuel tank. The landing gear from the trailer pokes a hole on the aluminum fuel tank and then, depending on the size of the fuel tank the fuel is drained across the road or shoulder.

Follow up Question: Is the minimum reportable amount of the spill 25 gallons?

The reportable quantity of the diesel fuels and gasoline is 25 gallons. Most importantly, the reportable amount depends on the type of the material and the UN ID number of the material. Hydraulic oil, transmission oil, and motor oils are not considered as hazardous materials per Colorado State Patrol specifications because there is not a net amount to be reported. But, fuel leaks are most of the time over 25 gallons. The UN ID can be found in the National Response Guidelines – Emergency Response Guidebook (yellow book), and it shows all the reportable quantities. The UN numbers are assigned by the United Nations Committee of Experts on the Transport of Dangerous Goods and range from UN0001 to about UN3534.

Q2. What are the steps that CDOT follows for clean-up the escape ramp based on the type of incidents?

CDOT is not responsible for clean-ups. The trucker company is responsible for the clean-up and they have or should have insurance. The steps are as follows:

- 1) After the incident happens, initial response and emergency response are handled by the fire department if within the town or city limits. They determine if there is a fuel or hazmat leak on the incident site depending on the location.
- 2) If it is on an emergency escape ramp, Colorado State Patrol (CSP) is informed, and they are the designated emergency response authority. Typically, CSP is the initial responder to the hazmat incidents, and they have hazmat troopers and certified hazmat people to handle the initial response. They get into the incident site, try to stop it and make sure it is safe. If the incident site is inside the town or city limits, the first initial responder is the city or town fire department. But, if the incident is on the highway or outside of the limits, then CSP is the first initial responder. Normally, all of the emergency escape ramps are outside of the city limits on the I-70 corridor, thus CSP is the first initial responder of the incidents in the emergency escape ramps.
- 3) CSP get in contact with the trucking company and inform them about the need of clean-up on the ramp. Most of the trucking companies have hazmat brokers. After the trucker company gets the information about the incident, they call the hazmat broker. The hazmat broker calls the local or Colorado certified clean-up company. The clean-up company does the initial response of clean up.
- 4) The clean-up company tries to get out the people and the freight material from the truck. After unloading the freight material, the truck is towed. The clean-up company covers the

spill with plastic and keeps it in the area. They basically try to contain the spill where it stays. Unless it is a ton of fuel or oil it is hard to get into the water and the material will basically stay into the ground. Then, the samples will be taken from the soil to see where the extent of spill goes.

- 5) CDOT approves the clean-up company by issuing a hazmat permit.
- 6) The clean-up company needs to make sure that they will get paid by the insurance company.

My job is to permit the job of the clean-up company. Ninety-five percent (95%) of my job is the utility permits and 5% includes the hazmat permits.

Q3. What is the typical time frame for the clean-up if it happens around emergency escape ramps?

I do not know, but I would not expect anything different from any of the other spills. The only difference on the emergency escape ramps is the amount of gravel that needs to be cleaned up and how they clean it. I have not been involved one of those yet, but they will pull out the contaminated gravel/soil to a disposal site and they will replace it with the new material. There was an 8,000 gallon spill that was a 5 months process, but another 8,000 gallon spill on Highway 50 was a 4-week process. It depends on the location, the amount of traffic control, and the work the clean-up company has to do. Spills under 100 gallons take a day but it generally takes two weeks for them to get the funding and to make sure that they have to get paid. For a 100 gallons spill, it usually takes one full dump truck to remove the contaminated material. I would not expect more than two weeks for the spill cleanup on the emergency escape ramp.

Q4. What is the range of cost for clean-up on the emergency escape ramps?

I do not get involved to the money and I do not have any idea. We do not pay for it unless it is an abandoned spill. That is something that the clean-up companies will know better.

Q5. How many permits per year do you approve?

I had around 40 permits last year. Now you got to realize the type of year we had. It depends on the winter, and if we have a strong winter with a lot of snow we have more wrecks. Also, it depends on the year, the location, and the drivers. This year I am only up to 10-12 permits.

Q6. Do you have any incident data that is located close to or between the ramps?

Last year, I had one permit right below the LSC truck ramp on the MM 208. But it changes in time. Custom Environmental Services was the clean-up company for this incident.

Follow up Question: Can provide us more details about the incident that happened on MM 208?

The clean-up company was the Custom Environmental Services. Brooke and Marty Green were working in the company at that time. You can have more details from them. They were the initial responders. Then, a different company took it over which is Environmental Restoration. The spill happened January 3rd, 2017. The truck tried to enter the emergency escape ramp but missed it. It was loaded with heavy steel drill pipes. The trucking company was a Texas-based company called GB Transport.

Q7. Do you have any recommendations for improving the design of emergency escape ramps for expediting the clean-up process? What will be your take on having a different type of escape ramp instead of a gravel base?

I do not know the different types of emergency escape ramps. But the first thing that came into my mind is having a containment system underneath the ramp whatever the type of material is. The gravel and sand can be removed easily, especially over the concrete surface. There should be a drain and some sort of valley to go to a containment area. The containment area should not be accessible to air and it can be an underground holding tank or a concrete-lined pond with a chemical material resistant wire. The best scenario would be to have some sort of catch or containment system underneath the ramp. It should be kept away from any waterway. If the ramp sits on the top of the soil or ground the fuel/hazmat gets into the soil and the soil needs to be dug. If the ramp sits on something solid like concrete, it is easy to remove the contained gravel and the concrete surface would be washed.

Interview with Steven Gillespie

Q1. What are the typical spill incidents that CDOT deals with on emergency escape ramps?

The typical incident generally up on the mountain corridor is the loss of brakes that makes commercial motor vehicles (CMV) access emergency escape ramps whether it is a mechanical malfunction, or it is a driver's error. Especially on the I70 mountain corridor, we have a lot of truck drivers of transcontinental transport who are not familiar with driving on the steep grades; on the incline and decline. They are overusing their brakes; the brakes heat up and they lose their brakes. This is typically seen on the Upper Straight Creek and Lower Straight Creek emergency escape ramps. The Lower Straight Creek is the most used truck ramp in the country. This is a statistical data shared on the national level. The Straight Creek ramps are the highest elevation ramps in the country. They are on 10,000 – 11,000 foot levels with 7% - 7.5% steep grades. A mechanical failure or a driver error are the main causes of the typical incidents. The other direction on eastbound I-70 coming out of the mountains through the Golden and Lakewood area, there is only one runaway truck ramp right after MM 257. Trucks bypass this ramp because they start coming out of the steep decline and they figure that they are down, but their brakes are so heated we have six, seven, or eight commercial truck semi fires per year due to overheated brakes. On the eastbound decline there is not a lot of opportunities for EERs. The truckers do not realize how bad their brakes are and they just bypass the truck ramp at MM 257.

Q2. What are the steps that CDOT follows for clean-up of escape ramps based on the type of fuel/hazmat spill incidents?

The most common type of spill is fuel tank rupture. Fuel and hazmat spills are coded and classified the same. When you have a fuel spill, you have a hazardous material release. The first step is the life safety of the occupants and the driver. The next step is the protection of the environment. The type and volume of the release, the weather conditions, and the debris or aggregate removal are other important factors. If there is an excessive amount of the release or the pulling of the fuel, the following step will be to repair the leak in the saddle tank. The CMV is removed from the truck ramp. The trucker company has to have a private contractor. The large carrier companies have private contractors. The driver will contact the dispatch center and the clean-up process will begin depending on the size of the incident. If the trucker company does not have a private contractor for clean-up then CDOT will assign its clean-up crew. The clean-up will be billed to the trucker company. These are the two primary methods to mitigate and clean-up any release on the truck ramps.

Follow up Question: Are hydraulic oils, transmission oils and motor oils considered as hazardous materials? Since they are below 25 gallons of reportable threshold how do you measure the amount of these?

Yes, those are all considered as hazardous materials. It is just a rule of thumb. CSP and the hazmat crew can tell according to the size of the vehicle, or the truck driver can say how big the capacity of the oil storage is. In theory, if the oil is environmentally friendly, there is no need to clean it up. Additionally, CMV's have this information as a requirement of the US DOT information to be displayed on the truck.

Q3. Is there any regulatory process that needs to be followed up for clean-up the escape ramp or surrounding areas?

The only regulatory process is to remove the hazardous material. The biggest concern is the contamination of the material into the surface ground, the aggregate, and waterways. Depending on the size of the leak, the removal of the aggregate will be done till the contaminated ground.

Q4. Is there any average time period that is defined for clean-up the area depending on the type of incidents?

It is mostly as long as it takes. Depending on the size and magnitude of the incident it can be an hour or a day.

Follow up Question: As my understanding, CDOT will have to approve the process of third party company, is that correct?

Yes. As long as the CMV company has a contractor of hazmat clean-up crew, they have limited scope and good to go there. If there are any issues about the coordination of the contractor company, CSP hazmat suggests them working with other contractors.

Q5. What is the average cost range according to the type of incidents?

I do not have that information. We do not track that information. CDOT does not have any costs other than traffic controls, which are indirect costs.

Q6. How often do you get calls for emergency escape ramp incidents?

It is like any other emergency. On average it is three to five a month on the Mountain Corridor.

Follow up Question: How many of them are related to fuel/hazmat spills?

Twenty percent (20%) is related to that type of spills. Most of them there is no damage to the trucks.

Q7. Do you have any statistical data on the incidents? (The type of incident, frequency, causes, driver information, other)

CSP will have that type of data. We don't necessarily capture that information but they do.

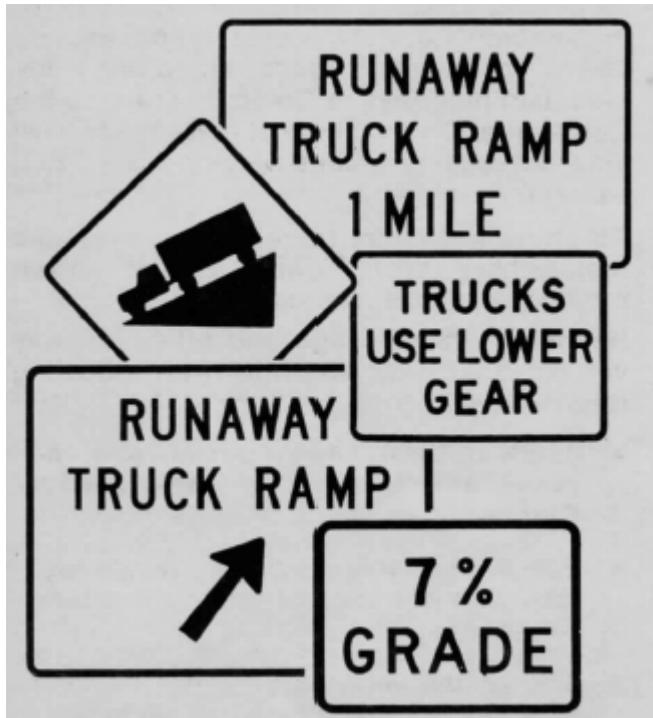
Q8. Do you have any other recommendations on the design or operation maintenance of the truck ramps that will benefit the clean-up process such as having a pavement access road...etc.?

The biggest thing that I will recommend is increasing signage and awareness. Especially for the drivers who are traveling through the area and the interstate system. If there is an initial

training as part of the CMV driver's license for the proper brake usage in the incline and decline areas and the use of truck ramps, it will be excellent. On the CMV traffic, drivers are hesitant to use truck ramps. It is important to break this cultural barrier and make them aware that it is safe to use truck ramps instead of their trucks catching on fire. Increasing the awareness of the drivers driving on the mountain area and the training as far as preemptive of how to properly traverse to the area with significant grades. Using the simulators on the driver's license process will be really beneficial in the commercial trucking industry. You can mimic it in the virtual environments and the simulator will mimic the visual stimulus of how to use brake pedals. Simulation trainings work in other industries. Especially in the scenario of the mountain area driving, there is no chance to train drivers. There are no CDL programs that have an opportunity of mountain area driving.

Appendix J. EER flyer from Colorado DOT

RUNAWAY TRUCK RAMPS



Presented by:

Colorado Motor Carriers Association

Colorado Department of Highways Division of Highway Safety

Colorado Department of Public Safety Colorado State Patrol

Colorado Department of Revenue Ports of Entry

(It needs to be confirmed and approved)

RUNAWAY TRUCK RAMPS

(check overall narrative)

Colorado's Interstate highways and state roadways are lifelines for the people of this State. Coloradoans use highways often in their daily lives – and they rely on the materials and goods moved by trucks using these roads. In Colorado, the trucking industry moves more goods through the State than any other transportation form.

With the increasing volume of trucks operating on Colorado roads, there has been an increase in the number of truck accidents and runaway trucks on mountain roads. There are many mountain highways in Colorado crossing the Continental Divide. Some of these roads have long descending grades ranging from 5 to 8 percent.

To prevent runaway truck accidents, escape ramps have been constructed at known problem locations (see map).

Reports of ramp usage and other runaway vehicle incidents provide the following information: (Update stats)

- 67.5% of the runaway trucks using the ramps are registered in states east of Colorado.
- 20% of the drivers utilizing the ramps have less than one year of mountain driving experience.
- 55% of the vehicles entering the ramps were in the 70 to 80 thousand pound gross vehicle weight range.

These statistics show a need for a greater awareness among truck drivers about the causes and prevention of runaway truck incidents and of the design and proper use of an escape ramp.

WHAT CAUSES RUNAWAYS?

Generally, **brake fade** (the loss of braking power.)

Q. What is brake "Fade"?

A. It is loss of braking power. It occurs when heat build-up causes the brake lining to glaze or deteriorate at high temperatures. This decreases the effectiveness of the brakes, and, in the extreme cases makes them nearly worthless.

Q. Are runaways becoming more prevalent?

A. Yes, for several reasons. These include:

- improper brake adjustment
- reduction in natural vehicle retardation as vehicles are designed to reduce frictional resistance (i.e. radial tires, vehicle design, wind deflectors, etc.)
- changes in brake lining material, have lowered levels of braking power,
- over-reliance on the vehicle or trailer braking systems,
- disregard for the posted regulatory and warning signs – and the limitations of the vehicle and operator, and
- increases in traffic volumes.

Q. What can be done to prevent runaways?

A. These precautions will help:

- comply with posted regulatory and warning signs,
- operate a safe vehicle with a properly maintained braking system,
- when appropriate, descend the grade, **in a low gear**, utilizing the braking capabilities of the engine. (The common rule that says to go down a hill in the same gear you came up no longer applies, due to the increased horsepower in truck engines. The ability of your brakes to stop you on a downhill has not kept up with the engine's ability to take you up the hill.)
- drive "ahead of yourself" to avoid the need for excessive use of the braking system, and
- operate the vehicle retarder

TYPES OF RUNAWAY TRUCK

RAMPS

There are four basic types of runaway truck escape ramps- sandpile, horizontal grade, descending grade, and ascending grade. Of the four types of the Colorado Department of Highways has elected to use the ascending grade for nine locations and the descending grade type ramp for two locations. Research done by other states utilizing sandpile and windrow type arrestor beds indicated some evidence of damage; therefore, these designs were not employed. All ramps constructed in Colorado employ smooth arrestor beds of gravel 18 to 24 inches in depth.

ASCENDING GRADE

The ascending grade type ramps utilize both the arresting bed and the slowing (or up-hill) effect of gravity. These reduce the length of the ramp needed to stop the vehicle.



DESCENDING GRADE

For the descending grade type ramps the arrester bed is longer because gravity is not an element in reducing the speed of a vehicle. Any increase in rolling resistance to stop and slow the runaway vehicle is supplied by this longer gravel arresting bed.



Update Pic



Update Pic

USING A RUNAWAY RAMP?

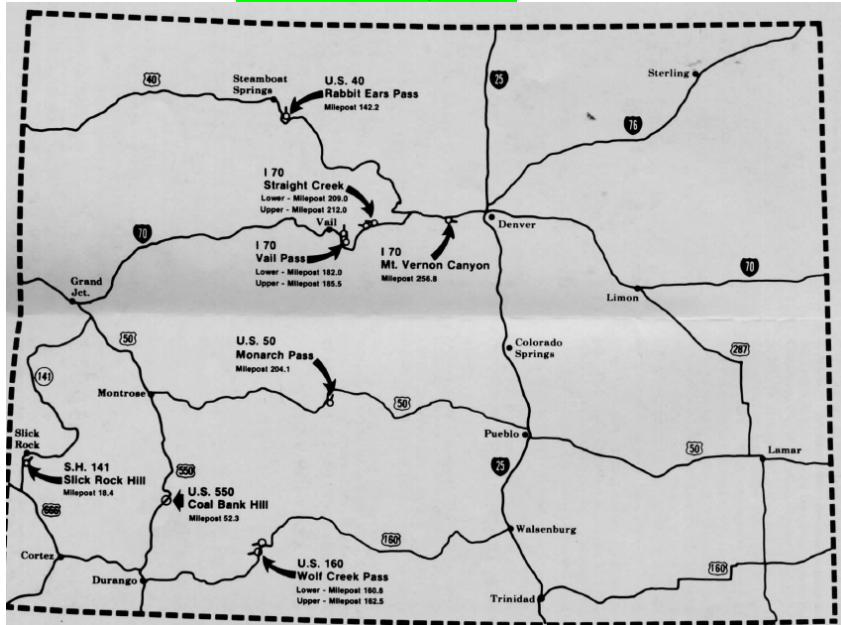
All ramps in Colorado are located on the right side of the roadway, are clearly identified with road sign advisory information and allow the driver a clear view of the entrance area.

When approaching the entrance, be certain the vehicle is centered on the ramp. Maintain a firm grip on the steering wheel during entry and keep the vehicle in the center of the ramp at all times. DO NOT HESITATE IN USING THE RAMP. It has been designed to save your life. The ramp will stop your vehicle. The ramps have been used successfully by your fellow drivers.

The time to make your commitment is now-not under the stressful conditions during a runaway. The runaway truck escape ramps can save your life-and the live of other people.

The escape ramps in Colorado have been designed to provide a direct access point where trucks can enter. There are special problems at the Mt. Vernon location (on I-70 just west of Denver). It is advisable to access this ramp from the entrance; however, if this is not possible (heavy volumes of traffic exist on this road) it has been used successfully by entering the ramp from the side. If this is necessary, it is recommended you try to go in as close to the entrance as possible to take the greatest advantage of the decelerating capabilities of the gravel arrestor bed. (It needs to be confirmed)

Please study this map and determine the locations of the ramps along your route of travel and
DRIVE WITH CARE. (It needs to be updated)



LOCATION MAP - COLORADO TRUCK - ESCAPE RAMPS

UPSLOPE STOPPING SYSTEM (It needs to be updated)

US 40 Rabbit Ears Pass
I 70 Vail Pass (Lower)
I 70 Vail Pass (Lower)
I 70 Straight Creek (Lower)
I 70 Straight Creek (Upper)

US 160 Wolf Creek Pass (Lower)
US 160 Wolf Creek Pass (Upper)
US 50 Monarch Pass
US 550 Coal Bank Hill

***FLAT STOPPING SYSTEM (It needs to be confirmed)**

I 70 Mt. Vernon Canyon
SH 141 Slick Rock Hill

*These ramps are built on a grade that is the same or almost the same as the existing roadway. They utilize a gravel arrestor bed to slow down and gradually stop the truck. **Check the language.**

A truck driver will not be charged any restoration fees by the Colorado Department of Highways for any responsible use of a truck escape ramp, nor will a truck driver be cited by the Colorado state Patrol for using the ramp, except in the most aggravated conditions involving unsafe driving or equipment. **(It needs to be confirmed)**

FOR FURTHER INFORMATION CONTACT: (It needs to be updated)

Colorado Motor Carriers Association
4060 Elati
Denver, CO 80216
433-3375

Denver, CO 80222
757-9381

Colorado Department of Highways
Division of Highway Safety
4201 E. Arkansas Avenue

Appendix K. Example of flyers from different state DOTs

1. NEVADA DOT

The Four Nevada Truck Escape Ramps

NEVADA TRUCK ESCAPE RAMPS

For more information, contact:
WWW.NEVADADOT.COM
(775) 888-7000

NEVADA DOT

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TRUCK ESCAPE RAMPS

WWW.NEVADADOT.COM

What is a Truck Escape Ramp?

- It is an emergency area located adjacent to a downgrade roadway to provide a location for out-of-control vehicles to slow and stop away from other vehicles on the road.
- They are generally located near the middle or the end of long, steep downgrades.
- The two most common types of truck escape ramps are:
 - **Gravity Ramps** are built with an upgrade to use the forces of gravity to slow a runaway vehicle.
 - **Aggregate Arrestor Bed Ramps** use special sized rock in a gravel bed to slow a runaway vehicle. These ramps may have either an upward or downward grade.



Who should use a Truck Escape Ramp?

- **ANY VEHICLE** experiencing braking problems or the inability to slow downhill speed. **Truck escape ramps are not just for trucks.** If you feel your vehicle is losing its braking ability, for your safety and those vehicles around you, consider using a truck escape ramp before total brake loss occurs.

Dos and DON'Ts of Using a Truck Escape Ramp

Dos

- **DO** use a truck escape ramp if you are having difficulty slowing your vehicle or experience brake loss.
- **DO** enter the gravel bed in line with the ramp and as close to center as possible.
- **DO** contact Nevada DOT after you have used a Nevada truck escape ramp.
- **DO** contact a tow truck company after you have used a truck escape ramp to remove your vehicle from the gravel bed, and have the faulty vehicle's brakes repaired before driving again.

DON'Ts

- **DO NOT** avoid using a truck escape ramp because you fear possible damage to your vehicle. Damage to vehicles from gravel beds is negligible compared to the potential damage caused by not using a truck escape ramp.
- **DO NOT** try and drive out of the gravel bed yourself. The gravel beds are designed to stop runaway vehicles. Trying to drive out may only cause further damage to your vehicle.
- **DO NOT** wait in your vehicle while it is in the aggregate bed.
- **DO NOT** use the truck escape ramp paved entry as a rest stop or parking area. Runaway vehicles are traveling at very high speeds and have limited ability to avoid parked vehicles in their path.
- **DO NOT** use the gravel bed as a recreational area for your off-road vehicle.



Avoid Needing a Truck Escape Ramp

- Have your vehicle serviced and maintained regularly.
- Use provided brake check areas located near mountain summits and tops of steep grades to verify that your equipment and vehicle is in proper working condition.
- Be familiar with the road and grades and load your vehicle accordingly.
- Operate your vehicle on downgrades using recommended gears and speeds to help avoid excessive brake temperatures.



NEVADA TRUCK ESCAPE RAMPS

2. WYOMING DOT 2012



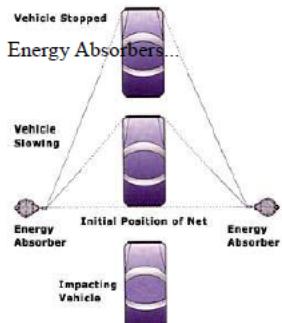
IMPACT ABSORPTION

Dragnet Vehicle Arresting Barriers

The Dragnet Truck Escape System is comprised of a series of nets set up along a truck escape ramp. The array of nets is arranged in such a manner so as to stop the vehicle in the distance allowed, while minimizing the deceleration forces. These nets, which are made of aircraft cable, can have one or two energy absorbers connected on each side. The energy absorbers, in turn, are mounted within the concrete walls of the truck escape ramp.



The variables involved with determining the stopping distance of a "g" load response of a system are vehicle weight, vehicle speed, and net width. Dragnet Truck Escape Systems have been designed to stop a wide range of vehicles weighing up to and including 90,000 pounds and traveling up to 60 mph. A 1,800 pound vehicle impacting a 30-foot wide net at a speed of 63 mph will stop in approximately 39 feet with an average deceleration of approximately 3.3 g's. A 4,500 pound vehicle impacting a 30-foot wide net at a speed of 62 mph will stop in approximately 83 feet with an average deceleration of approximately 1.6 g's.



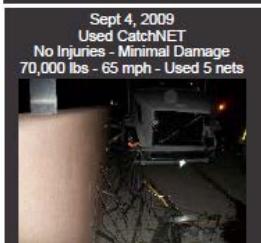
Dragnet's energy absorbers use a patented "metal bender" principle for absorbing energy, which provides the means to stop vehicles of varying weights and speeds. The absorbers are primarily comprised of a chamber, a length of metal tape, and a series of offset pins.

As the metal tape is pulled through the series of offset pins, the tape is bent back and forth beyond its yield point. The process of bending the metal beyond its yield point is the principal mechanism for absorbing the energy of impact.

The absorbers utilize few moving parts, making them virtually maintenance free. Following an arrestment, the system can be quickly returned to service by replacing the metal tapes with minimal time and effort.

Trucks that used the Runaway CatchNET

6 Trucks/RVs - No Injuries - Minimal Vehicle Damage



Runaway Truck CatchNET System

US Highway 16 west of Buffalo, WY

	# of Trucks & RV's	Injuries	Fatals
Used CatchNET	6	0	0
By passed CatchNET and wrecked below	5	1	4



September 2012

By passed CatchNET and wrecked below

5 Trucks - 1 Major Injury and 4 Fatalities



3. WYOMING DOT 2013





a WYDOT publication

100% successful when used

Dragnet Vehicle Arresting Barriers

The Dragnet Truck Escape System is comprised of a series of nets set up along a truck escape ramp. The array of nets is arranged to stop the vehicle in the distance allowed, while minimizing the deceleration forces. These nets, made of aircraft cable can have one or two energy absorbers connected on each side. The energy absorbers, in turn, are mounted within the concrete walls of the truck escape ramp.



The variables involved with determining the stopping distance and 'g' load response of a system are vehicle weight, vehicle speed and net width. Dragnet Truck Escape Systems have been designed to stop a wide range of vehicles weighing up to 90,000 pounds and traveling up to 90 mph.

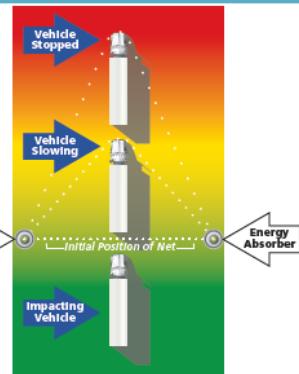
A 4,500-pound vehicle hitting a 30-foot wide net at a speed of 62 mph will stop in approximately 83 feet with an average deceleration of approximately 1.6 g's.

Energy Absorbers

Dragnet's energy absorbers use a patented "metal bender" principle for absorbing energy, which provides the means to stop vehicles of varying weights and speeds. The absorbers are primarily comprised of a chamber, a length of metal tape and a series of offset pins.

As the metal tape is pulled through the series of offset pins, the tape is bent back and forth beyond its yield point. The process of bending the metal beyond its yield point is the principal mechanism for absorbing the energy of impact.

The absorbers utilize few moving parts, making them virtually maintenance free. Following an arrestment, the system can be quickly returned to service by replacing the metal tapes with minimal time and effort.

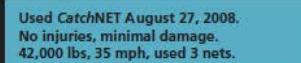


	Trucks & RVs	Injuries	Fatals
Used CatchNET	6	0	0
Bypassed CatchNET and crashed	4	1	4

Trucks and RVs that used CatchNET



Used CatchNET August 31, 2007.
No injuries, minimal damage.
80,000 lbs, 40 mph, used 5 nets.



Used CatchNET August 27, 2008.
No injuries, minimal damage.
42,000 lbs, 35 mph, used 3 nets.



Used CatchNET August 26, 2010.
No injuries, minimal damage.
15,000 lbs, 60 mph, used 1 net.



Used CatchNET May 29, 2012.
No injuries, minimal damage.
55,000 lbs, 70 mph, used 7 nets.

Runaway truck CatchNET System is found on U.S. 16 west of Buffalo. There is a brake check area at milepost 83.45 when traveling eastbound on U.S. 16. The runaway truck CatchNET can be found at milepost 85.

Trucks that bypassed CatchNET



Bypassed CatchNET September 23, 2008.
Crashed at milepost 86. Fatal injuries.
Hauling bags of bentonite powder.



Bypassed CatchNET April 4, 2011.
Crashed at milepost 86. Major injuries.
Hauling bags of bentonite powder.



Bypassed CatchNET April 1, 2012.
Crashed at milepost 86. Fatal injuries.
Hauling bags of powdered sugar.



Bypassed CatchNET September 4, 2012.
Crashed at milepost 86. Fatal injuries.
Hauling bags of bentonite gravel.