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BEST PRACTICES FOR BARRIER PROTECTION OF BRIDGE ENDS

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16. Abstract

A general problem occurs at many bridge locations along highways where the required length of need for bridge approach rails cannot be met within the existing right-of-way limits. These conflicts occur when existing driveways, roads, or other objects are within the ROW. It is not unusual to have less than 15 feet length between the end of the bridge and conflict. Solutions to this problem have included using short radius guardrail, a shortened guardrail section, or a crash attenuator. Typically, these solutions are not practical for the site location or are not cost effective.

The purpose of the study is to identify the best practices used to alleviate problems where length-of-need requirements for bridge approach rails cannot be met. The guide document was developed through a literature review and survey of State DOTs. The survey addressed data concerning: practices or standards for bridge barriers when LON cannot be met, practices variation according to design speed, different types of crash cushions used, and installation of a short radius guardrail in front of a slope.

From the information collected, it appears that use of short radius guardrail practice at bridge locations where LON cannot be met is generally the option preferred by the DOTs. Although few States indicated that their DOTs make somewhat frequently use of crash cushions at bridge locations where LON cannot be met, their employment is very limited by other States due to their higher installation and maintenance costs. Also, use of crash cushions might become not practical and undesirable on road sections with multiple drives and side roads, considering their size. Some State DOTs prefers to relocate the obstacle/ drive access to a point beyond the proposed length of need. When that is not feasible, DOTs have different preferences on how to shield the obstacle, which includes use of short radius guardrail, crash cushions, but also Wood Post Controlled Release Terminal (Alaska DOT), T-Intersection or adjustment of the LON equation (Louisiana DOT), and nested thrie beam transition from concrete bridge rail end block, then attachment of short radius rail as necessary (South Dakota).

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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CHAPTER 1. INTRODUCTION

INTRODUCTION

A general problem occurs at many bridge locations along highways where the required length-of-need for bridge approach rails cannot be met within the existing right-of-way (ROW) limits. These conflicts occur when existing driveways, roads, or other objects are within the ROW. It is not unusual to have less than a 15-ft length between the end of the bridge and the conflict. Solutions to this problem have included using short radius guardrail, a shortened guardrail section, or a crash attenuator. Typically, these solutions are not practical for the site location or are not cost effective. This project is intended to identify the best practices used to alleviate problems where length-of-need requirements for bridge approach rails cannot be met. The scope of this study will include a literature review and survey of State Departments of Transportation (DOT) to develop a best practices guideline.

OBJECTIVES / SCOPE OF RESEARCH

The purpose of the study is to identify the best practices used to alleviate problems where length-of-need requirements for bridge approach rails cannot be met. The guide document was developed through a literature review and survey of State DOTs.

CHAPTER 2. LITERATURE REVIEW

BACKGROUND

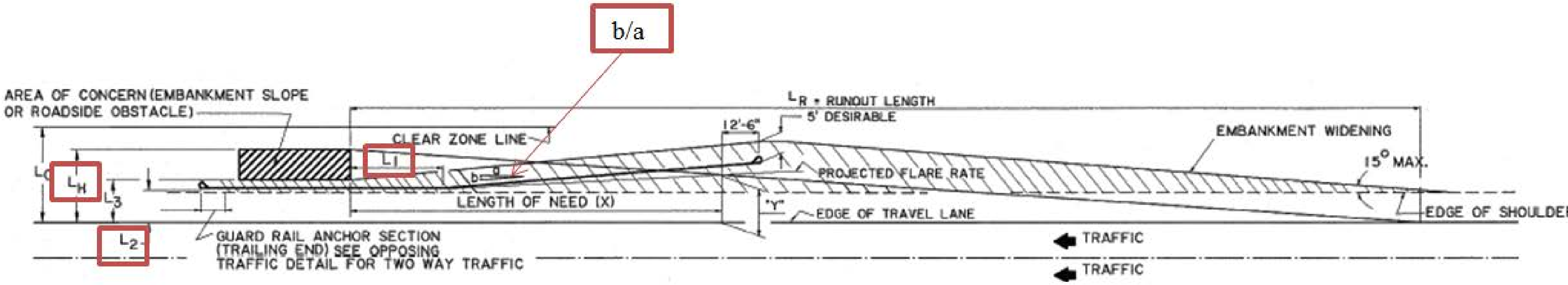
Typically, a rigid longitudinal barrier is used to contain errant traffic at a highway bridge location. These rigid longitudinal barriers present an obstacle at their terminations for oncoming traffic. There are several methods designers use to alleviate these obstacles. Often a guardrail terminal system is used as an approach rail to the bridge location; however, a general problem occurs at many bridge locations along highways where the required length-of-need (LON) for the bridge approach rail cannot be met. The length-of-need is defined as the length needed for a traffic barrier typically used to protect and shield fixed features or hazards. A typical equation used to determine the length-of-need is the following *(1)*:

$$x = \frac{L_H + \frac{b}{a} L_1 - L_2}{\frac{b}{a} + \frac{L_H}{L_R}} \qquad (3.1)$$

where L_H lateral extent of hazard, L_R represents the runout length, L_1 represents the length of tangent section of rail advance of hazard, L_2 represents the distance from edge of pavement to tangent section of guardrail, b/a represents the flare rate of guardrail. These variables and the equation can be seen in Figure 2.1. Alternate solutions to these obstacles include using short radius guardrail, a shortened guardrail section, or a crash attenuator. Historically, short radius guardrails have been used at most locations as crash attenuators might not always represent a feasible or economical solution.

Crash cushions or impact attenuators are devices used to shield and protect fixed features. They are typically employed in areas where use of a long barrier installation is not feasible. When impacted by the errant vehicle, crash cushions absorb the impacting energy by deformation and decelerate the vehicle, leading it eventually to a stop or redirecting the vehicle.

There are two main types of classifications for crash cushions: temporary and permanent. Temporary crash cushions are generally employed in work zone areas. Crash cushions can also be classified as redirective or non-redirective, gating or non-gating, and self-recoverable or non-self-recoverable (Table 2.1). Redirective crash cushions absorb the kinetic energy of the impacting vehicle and deflect the vehicle back in the opposite direction. On the contrary, non-redirective crash cushions do not have this ability. Instead, non-redirective crash cushions allow the vehicles to penetrate the system while at the same time reducing the vehicle's speed. Gating crash cushions allow the vehicle to penetrate the crash cushion for part of the length. In contrast, non-gating crash cushions do not allow penetration and have the capability to redirect an errant vehicle. Self-recoverable crash cushions are able to restore themselves with little or no maintenance after an impact. Crash cushions are selected based on these classifications as well as their reusability.



NOTES:

1. ON TWO-WAY TRAFFIC "Y" IS MEASURED FROM THE CENTERLINE OF THE ROADWAY TO THE GUARD RAIL FOR THE OPPOSING TRAFFIC. THEREFORE, "Y" FOR GUARD RAIL ON THE LEFT SIDE OF A BRIDGE WITH TWO-WAY TRAFFIC IS MEASURED FROM THE CENTERLINE OF THE ROADWAY.
2. EQUATIONS FOR COMPUTING LENGTH OF NEED (X) AND OFFSETS (Y&Z). (ALL DIMENSIONS ARE IN FEET)

$$X = \frac{L_H + (\frac{b}{a})(L_1) - (L_2)}{(\frac{b}{a}) + (\frac{L_H}{L_R})}$$

$$\text{"Y"} = L_H - (\frac{L_H}{L_R})(X)$$

$$\text{"Z"} = \text{"Y"} + \frac{b}{a}(12.5') + 9'$$

L_1 - LENGTH OF TANGENT SECTION OF RAIL IN ADVANCE OF HAZARD.

L_2 - DISTANCE FROM EDGE OF TRAVEL LANE TO TANGENT SECTION OF RAIL.

L_3 - DISTANCE FROM EDGE OF TRAVEL LANE TO OBSTACLE. IF $L_3 > L_C$ NO GUARD RAIL IS REQUIRED FOR ONCOMING TRAFFIC.

L_R - RUNOUT LENGTH

L_C - REQUIRED CLEAR ZONE (TABLE 1)

L_H - IS THE DISTANCE FROM THE EDGE OF THE TRAVELED WAY (EOP) TO THE LATERAL EXTENT OF THE HAZARD.

L_H - L_C FOR BRIDGE APPLICATION, EXCEPT IN SPECIAL CASES SEE SHEET 1 OF 10 FOR DETAILS.

⊞3. FLARE RATES SHOWN FOR BARRIERS INSIDE THE SHY LINE ARE DESIRABLE RATES AND MAY BE WAIVED IF THE GUARD RAIL LENGTH BECOMES TOO LONG FOR A GIVEN SITUATION.

⊕4. SEE SHT. NO. 5 OF 10 FOR FORMULAS FOR COMPUTING GUARD RAIL IN A CURVE.

5. FOR FURTHER INFORMATION CONCERNING TABLES 1-4, REFERENCE LATEST EDITION OF AASHTO ROADSIDE DESIGN GUIDE.

Figure 2.1. Length of Need *(1)*.

Table 2.1. Classification of Crash Cushions.

<table>
<tr><td>
</td><td></td></tr>
<tr><td>(a) Redirective</td><td>(b) Non-redirective</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td>(c) Gating</td><td>(d) Non-gating</td></tr>
<tr><td>
</td><td></td></tr>
<tr><td>(e) Self-recoverable</td><td>(f) Non-self-recoverable</td></tr>
</table>

Several studies and tests have been conducted by Southwest Research Institute (SwRI), Midwest Roadside Safety Facility (MwRSF), and Texas A&M Transportation Institute (TTI) on various short radius guardrail systems *(2)*. These were evaluated under multiple performance criteria including American Association of State Highway and Transportation Officials (AASHTO) *1989 Guide Specification for Bridge Railings*, National Cooperative Highway Research Program (NCHRP) *Report 230*, and *NCHRP Report 350 (3, 4, 5)*. Currently, these systems are limited to test level 2 (TL-2) under *NCHRP Report 350* performance criteria *(5)*.

CHAPTER 3. POLICIES/STANDARDS

The researchers prepared a survey intended for State Departments of Transportation concerning barrier protection bridge ends and aimed at gaining information regarding State standards, practices, or methods for bridge barriers when the length-of-need cannot be met.

The survey addressed data concerning:

- Practices or standards for bridge barriers when LON cannot be met;
- Practices variation according to design speed;
- Different types of crash cushions used;
- Installation of a short radius guardrail in front of a slope.

A copy of the survey sent to the DOTs is attached to this report as Appendix A. Also, complete answers from the DOTs to survey questions are reported in Appendix B.

Out of the 50 States contacted, a total of 12 States participated in this research study and answered either partially or fully the questions of the survey. Table 3.1 reports the names of State Agencies which responded to the survey. Although California, Nebraska, North Carolina, and South Dakota did not participate in the survey, they provided valuable information to this study through email correspondence with the researchers.

Table 3.1. States and Agencies which Responded Partially of Fully to the Survey.

Agency	State
Alaska DOT&PF	AK
Arizona DOT	AZ
Kansas DOT	KS
Louisiana DOT	LA
New Mexico DOT	NM
Ohio DOT	OH
Pennsylvania DOT	PA
South Carolina DOT	SC
Tennessee DOT	TN
Texas DOT	TX
Washington State DOT	WS
Wyoming DOT	WY

The first part of the survey aimed at collecting State practices, treatments, or methods when design exception is needed for shielding bridge approach rails where the length-of-need cannot be met. From the survey answers collected, it resulted that out of the 12 States that participated in the survey, a total of 11 states (91.7%) answered they had documentation regarding their practices and methods, and only 1 state (8.3%) reported they do not have pertinent documentation. States were also asked to provide a copy of the state standards and policies. State answers, standards, and policies are summarized in Table 3.2.

Table 3.2. Summary of State Answers Pertinent to DOT Existing Practices for Bridge Approach Shielding When LON Cannot Be Met.

State DOT	Does your State have any existing practices, treatments, or methods when design exception is need for shielding bridge approach rails where the required LON cannot be met?	Do you have any documentation you could share regarding your practices and methods?	Please provide a copy of your state standards and policies?
AK	Yes	Yes	http://www.dot.state.ak.us/stwddes/dcsprecon/assets/pdf/stddwgs/eng/g25_21w.pdf
AZ	Yes	Yes	http://www.azdot.gov/Highways/Roadway_Engineering/Roadway_Design/Design/Memos/index.asp For short radius guardrail, we develop project specific details following FHWA Technical Advisory T5040.32 and publication FHWA-HI-97-026, pages 4.5.14 and 4.5.15.
CA	N/A	N/A	N/A
KS	Yes	Yes	http://kart.ksdot.org/
LA	Yes	Yes	We have a policy that adjusts the LON equations (EDSM II.3.1.3):http://webmail.dotd.la.gov/ppmemos.nsf/0/F339A6FE4D97D6CA86256F1E00423865/$file/EDSM.htm. We also allow for a short radius guardrail detail: http://www.dotd.la.gov/highways/standardplans/Standard%20Plans/Guardrails/GR200-06.pdf
NC	N/A	N/A	N/A
NE	N/A	N/A	N/A
NM	Do Not Know	Yes	http://dot.state.nm.us/en/PSE/Standards.html
OH	Yes	Yes	http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/roadway/Pages/locationanddesignmanuals.aspx

Table 3.2. Summary of State Answers Pertinent to DOT Existing Practices for Bridge Approach Shielding when LON cannot be met (Continued).

State DOT	Does your State have any existing practices, treatments, or methods when design exception is need for shielding bridge approach rails where the required LON cannot be met?	Do you have any documentation you could share regarding your practices and methods?	Please provide a copy of your state standards and policies?
PA	Yes	Yes	ftp://ftp.dot.state.pa.us/public/bureaus/design/pub13m/Chapters/Appendix_A_Chap12.pdf This is to Appendix A of Chapter 12 in our highway design manual (DM-2). Pub 72M & Pub 652 ftp://ftp.dot.state.pa.us/public/PubsForms/Publications/PUB%2012.pdf
SC	No	No	N/A
SD	N/A	N/A	N/A
TN	No	Yes	http://www.tdot.state.tn.us/Chief_Engineer/engr_library/design/StdDrwgEng_PDFs/SGR46_000000.pdf
TX	No	Yes	http://www.dot.state.tx.us/business/standardplanfiles.htm
WS	Yes	Yes	WSDOT Design Manual Chapter 1610 http://www.wsdot.wa.gov/Publications/Manuals/M22-01.htm#Individualchapters WSDOT Standard Plans Section "C" http://www.wsdot.wa.gov/Design/Standards/Plans.htm
WY	No	Yes	http://www.dot.state.wy.us/wydot/engineering_technical_programs/manuals_publications/standardplans/Standard_Plans

STATE STANDARDS/POLICIES

Researchers collected all the document links the states provided and summarized each participating States' standards when shielding bridge approach rails where the length-of-need cannot be met. When asked how often states use short radius guardrails or crash cushions, 9 states out of the 10 (90%) participating states in this particular question reported they use short radius guardrail more often than a crash cushion when the length-of-need cannot be met. 7 out of the 10 states (70%) that participated in this question mentioned they rarely or never use crash cushions. New Mexico was the only state who reported they use both short radius guardrail and crash cushions somewhat frequently. The results for these questions can be found in Table 3.3. Arkansas, Kansas, and

Pennsylvania reported they rarely use crash cushions but use a short radius guardrail very frequently. As stated before, crash cushions are used less frequently than short radius due to economic issues and for the lack of reusability of some of the crash cushions.

Table 3.3. Summary of State Answers Pertinent to DOT Frequency of Use of Crash Cushion and/or Short Radius Guardrail Practices.

State DOT	Please indicate the frequency of use of the following practices in your State at bridge locations where LON cannot be met.		
	Crash Cushion	**Short Radius Guardrail**	**If 'Other,' please describe.**
AK	Rarely (1-25%)	Very Frequently (76-100%)	
AZ	N/A	N/A	
CA	N/A	N/A	
KS	Rarely (1-25%)	Very Frequently (76-100%)	
LA	Rarely (1-25%)	Somewhat Frequent (26-50%)	Revised Length of Need Equations from the EDSM policy
NC	N/A	N/A	
NE	N/A	N/A	
NM	Somewhat Frequent (26-50%)	Somewhat Frequent (26-50%)	
OH	Never	Very Frequently (76-100%)	
PA*	Rarely (1-25%)	Very Frequently (76-100%)	
SC	N/A	N/A	
SD	N/A	N/A	
TN	Rarely (1-25%)	Somewhat Frequent (26-50%)	
TX	Somewhat Frequent (26-50%)	Frequently (51-75%)	
WS	Rarely (1-25%)	Frequently (51-75%)	
WY	Somewhat Frequent (26-50%)	Very Frequently (76-100%)	

*Received multiple answers

A few States, such as Kansas and Arizona, reported they do not have specific standards to follow when the length-of-need cannot be met, but instead they make decisions based on each situation independently. Others, such as Louisiana, stated that they do have procedures to be followed. 83% of the States stated they use short radius guardrail and 3 of them gave appropriate drawings. Examples provided by States using short radius guardrails can be found in Figure 3.3 and Appendix C. In some cases, however, the DOTs provided general standards and not standards regarding specific situations in which the length-of-need cannot be met. State standards, procedures, and comments (reported in quotation marks) given by the states when the length-of-need cannot be met are reported below.

Alaska

- "At bridge on many roads, minor roads or driveways inhibit length of need for bridge approach rail. Many are on unpaved roads or low speed" *(6)*
- Use short radius guardrail very frequently (76-100%)
- Use crash cushions rarely (1-25%) because "in most locations crash cushions are a higher cost option *(6)*
- "Guardrail and crash cushions are damaged by plows during winter and guardrail is simpler to repair. Stocking proper repair parts is less involved and cheaper when dealing simply with guardrail" *(6)*
- "Use parallel guardrail end treatments where the roadside slope and clear run out are are sufficient" *(6)*
- Use crash cushions "on roads of sufficient volume where the parallel end treatments and short radius don't fit"*(6)*
- Provided a standard drawing of a Wood Post Controlled Release Terminal (Figure 3.1) *(Information obtained from survey)*

Arizona

- Use crash cushions and short radius guardrail
- Provided general procedure for selecting crash cushions
- Follow details in FHWA Technical Advisory T5040.32 and publication FHWA-HI-97-026, pages 4.5.14 and 4.5.15 *(7,8)*

California

- Use crash cushions
- "If there is a private driveway right next to the bridge rail and there is no way to relocate the driveway, how can this problem be solved?" *(9)*

Kansas

- Referred to guardrail standards RD606-RD609 *(Comment obtained from survey results)*
- Do not have a written policy about guardrail that is less than the LON calculation
- Document reasons for decisions made when LON cannot be met, done similar to a design exception process except it is a document to the project records, not something that has to be approved by the FHWA *(Comment obtained from survey results)*
- Use crash cushions rarely (1-25%)

Louisiana

- Use the T-Intersection detail shown in Figure 3.2 *(1)*
- Use "the T-Intersection detail over an impact attenuator" when length of need cannot be met because it is less expensive to install and maintenance costs are low *(10)*
- Use attenuators at bridge ends only when there is no other option *(10)*
- Use of adjusted LON equation is "only allowed on existing roadways and bridge, not new construction and is never allowed on the interstate system" *(10)*

- Provided Equation 3.2, which demonstrates the adjusted LON equation based on a less severe departure angle and results in less guardrail being required *(11)*

$$x = \frac{L_H + \frac{b}{a} L_1 - L_2}{\frac{b}{a} + 0.1763} \quad (3.2)$$

where L_H lateral extent of hazard, L_R represents the runout length, L_1 represents the length of tangent section of rail advance of hazard, L_2 represents the distance from edge of pavement to tangent section of guardrail, 0.1763 represents the tangent of departure angle, 10°.

Nebraska

- Provided layouts when the standard guardrail installation length is shortened (Figure 3.3) *(12)*

North Carolina

- Provided roadway design manual which has allowed more flexibility on Sub-Regional Tier bridge replacement projects *(13)*
- Prefer to "relocate the drive access to a point beyond the proposed length of need" when the driving access is "just off the bridge" *(13)*

New Mexico

- Provided link to standard drawings and specifications *(14)*

Ohio

- Provided pictures of real-world usage of short radius guardrail (Table 3.4(a)) *(15)*
- Typically use short radius guardrail over crash cushions because they can "get more of the length-of-need with the guardrail" *(15)*
- Provided roadside design guidance manual *(16)*

Pennsylvania

- Provided publications 72M and 652 *(17)*
- Provided Appendix for bridge barrier end transitions *(18)*
- Provided pictures of real-world usage of short radius guardrail (Table 3.4(b)) *(19)*

South Carolina

- "Short radius rail is a fairly common installation at intersections and driveways" *(20)*
- "In locations where penetration of the radius rail has extreme consequences (such as at an interstate pass), rigid barrier is sometimes used on radius so that standard guardrail can be attached at the terminal of the rigid barrier along the intersecting ramp/street" *(20)*
- Provided pictures of real-world usage of short radius guardrail (Table 3.4(c)) *(20)*
- Provided more examples that can be found in Table D2 of Appendix D *(20)*
- When the LON cannot be met "due to requirements for additional Right of Way or impractical site grading, the designer should make every attempt to provide a system that covers as much of the LON as the site will accommodate" *(20)*

South Dakota

- Use own design standards to "provide the maximum amount of protection for the length of need" *(21)*
- Use short radius guardrail if moving an approach of obstacle is not feasible *(21)*
- "Use the nested thrie beam transition from our concrete bridge rail end block then will attach the short radius rail as necessary" (Figure 3.4) *(21)*
- Provided design standards for guardrail design *(22)*
- "If any new systems are developed to replace the existing short radius details, we would hope that they are crash tested in accordance with the real world application (not only on flat ground, but with the system placed on flat ground in front of the required guardrail embankment and a breaking slope such as a 6:1 or steeper after the guardrail embankment" *(21)*

Tennessee

- Prefer to use short radius guardrails are over crash cushions due to "cost and space" *(23)*
- Using crash cushions on "road sections with multiple drives and side roads is not practicable and highly undesirable since they are large" *(23)*
- Provided pictures of real-world usage of short radius guardrail (Table 3.4(d)) *(24)*
- Provided more pictures which can be found in Table D3. *(24)*
- Provided standard drawing (Figure 3.5) *(24)*

Texas

- Use crash cushions rarely (1-25%) and short radius guardrail frequently (51-75%)

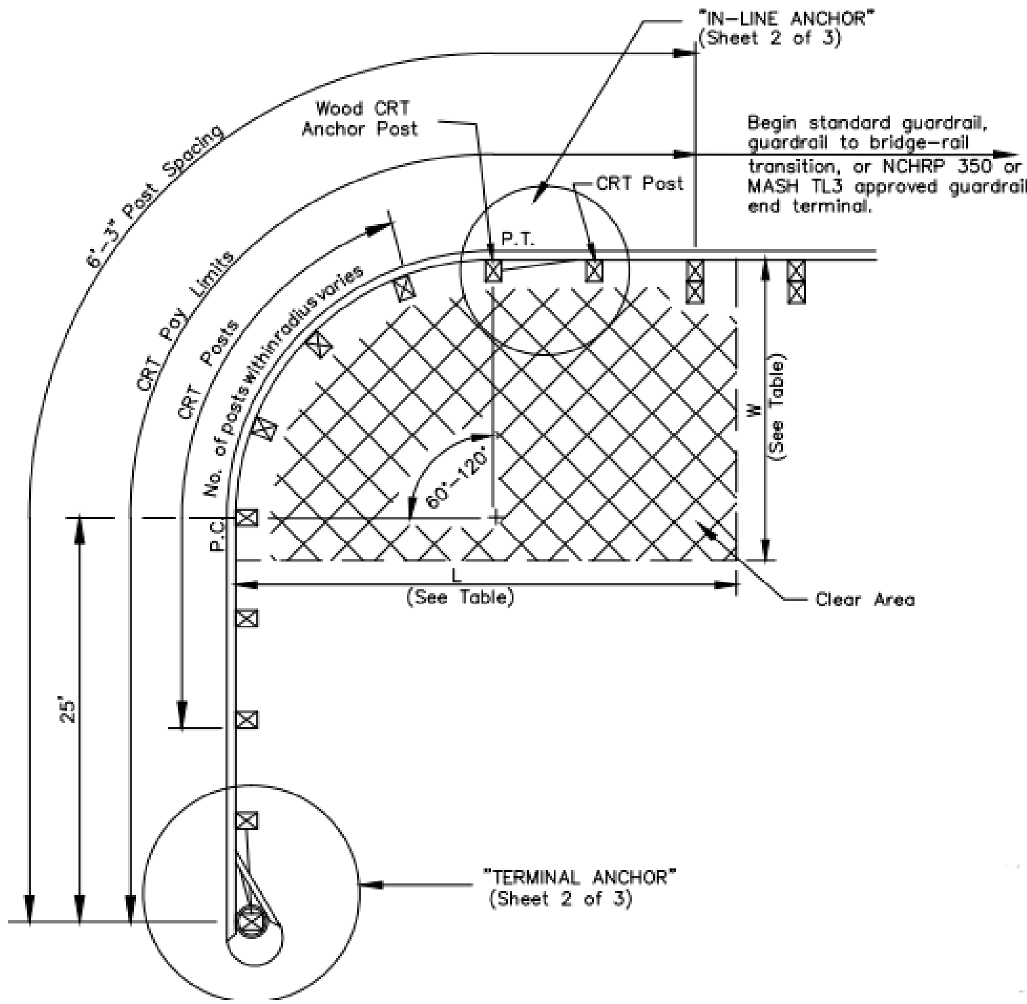


Figure 3.1. Wood Post Controlled Release Terminal (Alaska).

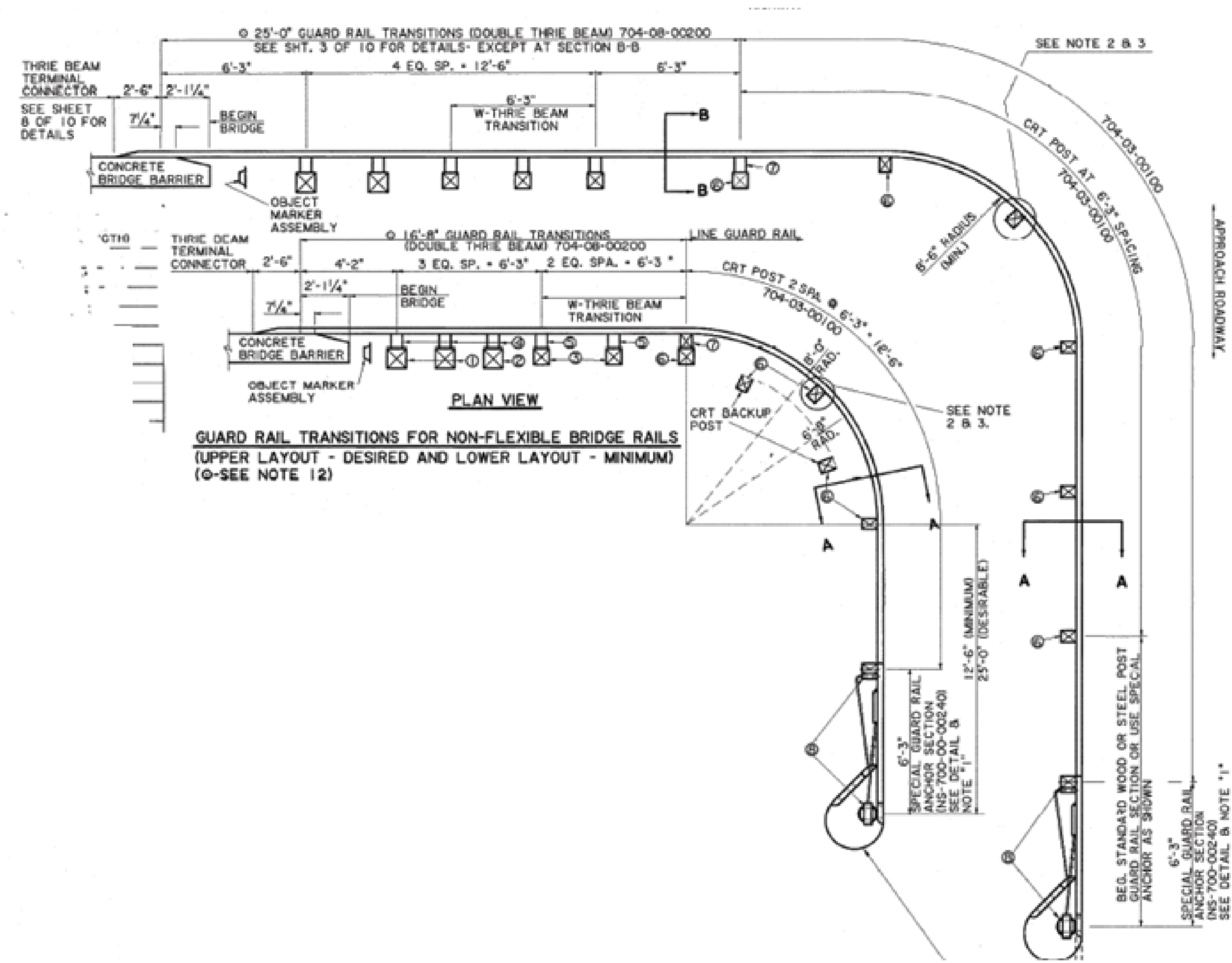


Figure 3.2. T-Intersection Details (Louisiana) *(1)*.

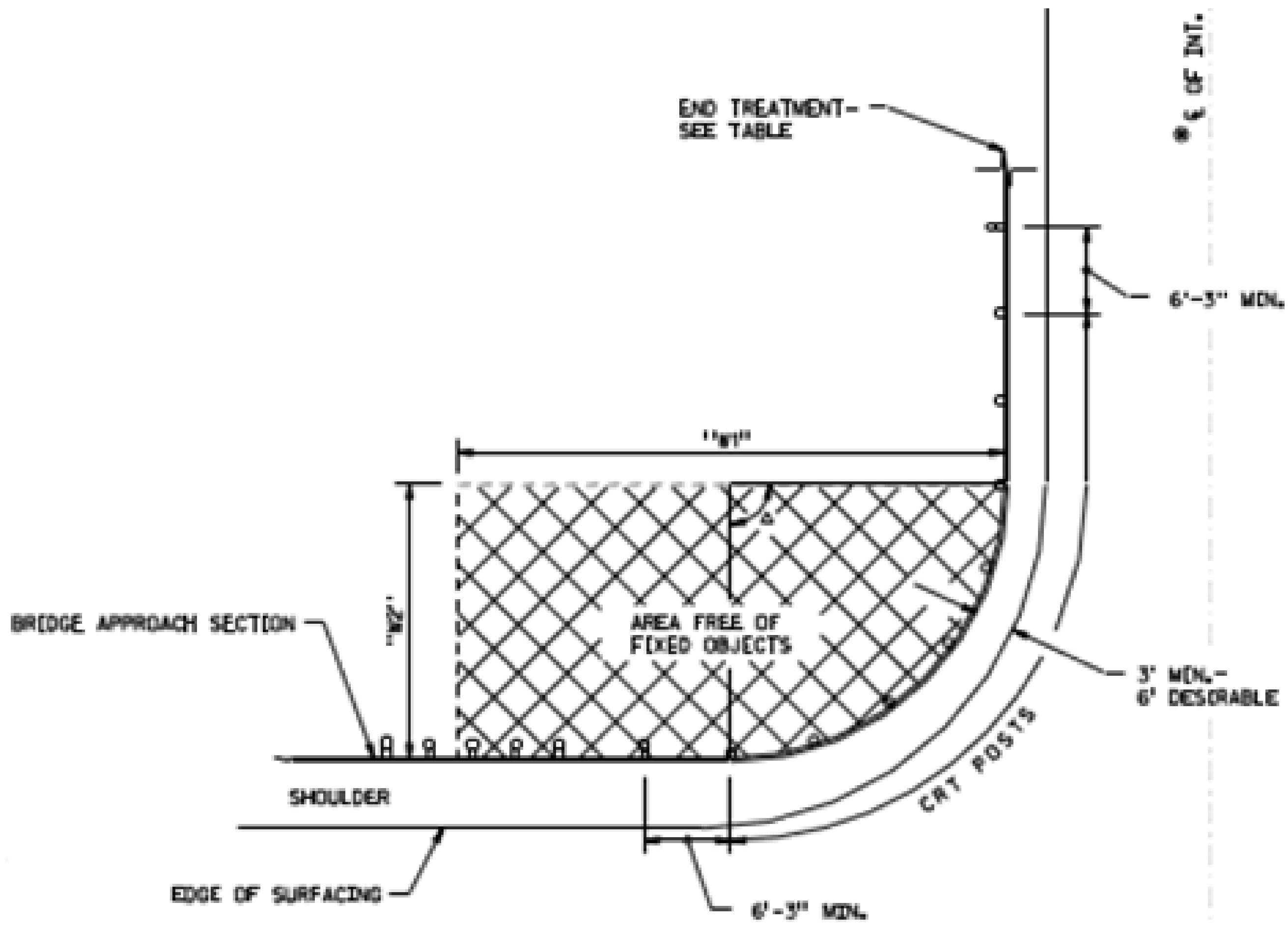


Figure 3.3. Curved Beam Guardrail *(2)*.

Table 3.4. Short Radius Guardrail Examples.

(a) Short Radius Guardrail Example from Ohio DOT

(b) Short Radius Guardrail Example from Pennsylvania DOT

Table 3.4. Short Radius Guardrail Examples (Continued).

(c) Short Radius Guardrail Example from South Carolina DOT

(d) Short Radius Guardrail Example from Tennessee DOT

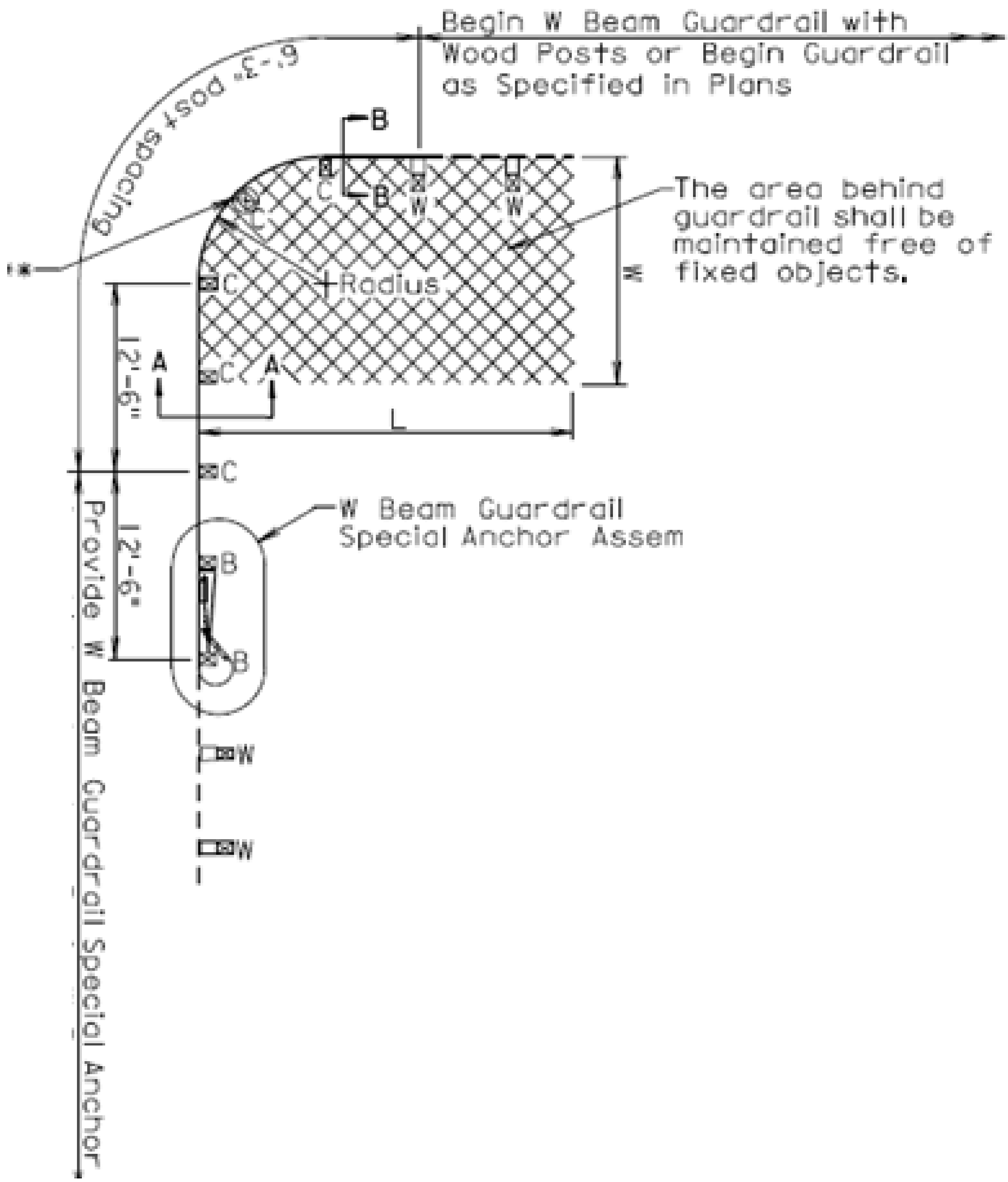


Figure 3.4. Nested Thrie Beam Transition and Short Radius Guardrail *(21)*.

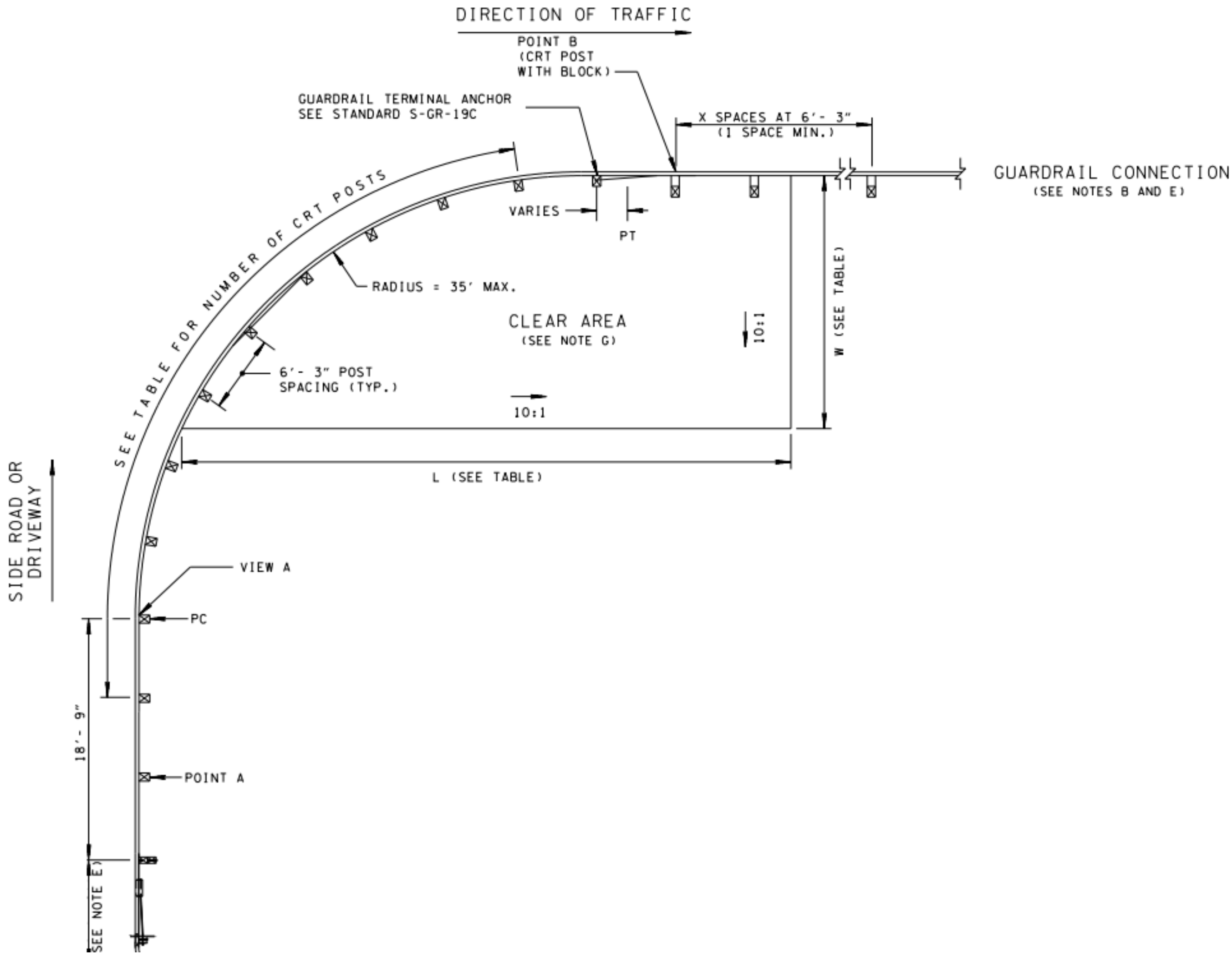


Figure 3.5. Short Radius Guardrail *(24)*.

CRASH CUSHIONS

Crash cushions are an alternative use when the length-of-need cannot be met. As mentioned before, most States prefer to use short radius guardrail over crash cushions when the length-of-need cannot be met. Some States have stated crash cushions are not the best alternative when the length of need cannot be met unless under special circumstances which are explained below according to each state.

The crash cushions included in the survey were the following: ABSORB 350, ADIEM, BEAT-BP, BEAT-SSCC, CAT-350, Compressor, EASI-CELL, HEART, NCIAS, Quadguard System, QuadTrend 350, QUEST, REACT 350, Sand Barrels, SMART Cushion, TAU-II System, Thrie-Beam Bullnose Guardrail System, and the TRACC System. Pictures and a brief description of the crash cushion types included in the survey questions are listed in Appendix C.

In the survey, the DOTs were asked the frequency of use of the included crash cushions types, with the answer choices being Never, Rarely (1-25%), Somewhat Frequently (25-60%), Frequently (51-75%), and Very Frequently (76-100%). Results are shown in Table 3.5. A brief description of each type of crash cushion is included in Table C1 of Appendix C. Some States provided additional information regarding which type of cushions they use that was not included in the survey. Information regarding those additional crash cushions can also be found in Table C1.

Alaska

- Rarely (1-25%) uses crash cushions
- Use other 250- or MASH- compliant crash cushions not listed in the survey *(Comment obtained from survey results)*
- Consider the "nature of the hazard behind the cushion and the ability to perform maintenance" and weather conditions when deciding what type of crash cushion *(6)*
- "We have some challenges with snow and gravel on the roads affecting performance of crash cushions that use ground level track systems" *(6)*
- Do not use sand barrels due to freezing *(Comment obtained from survey results)*

Arizona

- Provided memorandum regarding the crash cushion procedure *(25)*

Kansas

- Rarely (1-25%) uses crash cushions

Louisiana

- Rarely (1-25%) uses crash cushions
- Do not have specific policy when using attenuators *(10)*
- Decision on which attenuator to use is left to the designer's criteria on the best approach *(10)*

Nebraska

- Use impact attenuators in tight locations *(12)*

North Carolina

- Provided typical end treatments “Structure Anchor Unit with a GRAU-350 attached (TL-2 or TL-3), Structure Anchor Unit transitioning to W-beam guardrail with a small radius into the driveway of –Y- line, and Impact Attenuator Unit only (TL-2 or TL-3)” *(13)*

Ohio

- Never uses crash cushions *(Comment obtained from survey results)*
- Does not have specific criteria when determining what crash cushion to use but has a list of approved impact attenuators from which the contractor may choose which crash cushion will be used
- List of approved impact attenuators: Brakemaster 350, CAT, and FLEAT-MT as permanent impact attenuators, QuadGuard, TAU-II, TRACC, REACT 350, QuadGuard, ELITE, SCI, and HEART may be used for permanent or work zone locations, and ABSORB 350 and SLED for work zones only.
- Decision on which attenuator to use is usually based on price
- QuadGuard crash cushions are the most commonly used

Pennsylvania

- Rarely (1-25%) uses crash cushions
- Besides the crash cushions stated in Table 3.5, Pennsylvania also uses ET-2000 and SKT-350

South Carolina

- Distinguishes impact attenuators from crash cushions as follows: “An installation attenuator requires semi-rigid guardrail directly behind the end treatment and then can be stiffened to a bridge connection type rail system,” while a crash cushion installation can “be connected directly to the bridge barrier” *(20)*
- CAT-350 has the largest percentage of impact attenuators installation, about 80% *(20)*
- Brakemaster makes up about 20% of impact attenuators used *(20)*
- FLEAT-MT was recently added to Standards *(20)*
- QuadGuard systems are the most used about 90% of the time *(20)*
- TRACC systems are frequently used *(20)*

Tennessee

- Criteria for selecting which type of crash cushion to use is based on site characteristics, structural and safety characteristics of the systems, system costs, and maintenance characteristics *(23)*

Table 3.5. DOT Frequency of Use of Crash Cushions for Bridge End Protection When LON Not Met.

State DOT	 ABSORB 350	 ADIEM	 BEAT-BP	 BEAT-SSCC	 CAT-350	 Compressor	 EASI-CELL	 HEART	 NCIAS
AK	Rarely	Rarely	Rarely	Rarely	Rarely	Rarely	Rarely	Rarely	Rarely
AZ	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
CA	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
KS	Never	Never	Never	Never	Never	Never	Never	Never	Never
LA	Rarely	Never	Never	Never	Never	Never	Never	Never	Never
NC	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
NM	Rarely	Rarely	Rarely	Rarely	Rarely	Rarely	Rarely	Rarely	Rarely
OH	Never	Never	Never	Never	Frequently	Never	Never	Never	Never
PA*	Rarely	Never	Never	Somewhat Frequently	Rarely	Rarely	Never	Never	Never
TN	Rarely	Never	Rarely	Rarely	Rarely	Rarely	Never	Never	Never
TX	Never	Never	Never	Rarely	Never	Never	Never	Rarely	Never
SC	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
SD	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
WA	Never	Never	Never	Never	Rarely	Never	Never	Never	Never
WY	Never	Never	Never	Rarely	Never	Never	Never	Never	Never

*Received multiple answers.

Table 3.5. DOT Frequency of Use of Crash Cushions for Bridge End Protection when LON not met (Continued).

State DOT	Quadguard System	QuadTrend 350	QUEST	REACT 350	Sand Barrels	SMART Cushion	TAU-II System	Thrie-Beam Bullnose	TRACC
									
AK	Rarely	Rarely	Rarely	Rarely	Never	Rarely	Rarely	Rarely	Rarely
AZ	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
KS	Somewhat Frequently	Rarely	Never	Never	Never	Very Frequently	Rarely	Never	Never
LA	Very Frequently	Never	Never	Rarely	Never	Rarely	Rarely	Never	Rarely
NC	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NM	Rarely	Rarely	Rarely	Rarely	Somewhat Frequently	Rarely	Rarely	Somewhat Frequently	Rarely
OH	Somewhat Frequently	Never	Never	Rarely	Rarely	Rarely	Rarely	Somewhat Frequently	Rarely
PA*	Rarely	Never	Rarely	Somewhat Frequently	Rarely	Rarely	Rarely	Never	Rarely
TN	Somewhat Frequently	Never	Rarely	Somewhat Frequently	Never	Rarely	Rarely	Never	Rarely
TX	Somewhat Frequently	Never	Rarely	Rarely	Somewhat Frequently	Rarely	Somewhat Frequently	Never	Rarely
SC	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SD	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WA	Rarely	Rarely	Never	Rarely	Never	Rarely	Rarely	Never	Never
WY	Rarely	Never	Never	Never	Rarely	Never	Rarely	Never	Rarely

*Received multiple answers.

SPEED-DEPENDANT GUIDELINES

The DOTs were asked if guidelines for selection varied depending on the design speed of the roadway and what is the common percentage of low and high speed roadways identified for bridge locations where the LON is not met (Table 3.6). High speed roadways were defined as "a roadway with a posted speed of 50 MPH or greater," while a low speed roadway is denied as a roadway has a "posted speed less than 50 MPH".

Table 3.6. Speed-Dependence of State Guidelines with Design Speed of Roadway.

State DOT	Do your guidelines for selection or placement vary with design speed of roadway?			For bridge locations where the LON cannot be met, please indicate the percentage of high speed and low speed roadways.	
	Yes	No	Do Not Know	% High Speed	% Low Speed
AK		X		N/A	N/A
AZ	X			N/A	N/A
CA	N/A	N/A	N/A	N/A	N/A
KS	X			5	95
LA	X			70	30
NC	N/A	N/A	N/A	N/A	N/A
NM	X			50	50
OH		X		N/A	N/A
PA*			X	N/A	N/A
TN		X		N/A	N/A
TX	X			25	75
SC	X			N/A	N/A
SD	N/A	N/A	N/A	N/A	N/A
WA	X			70	30
WY	X			30	70

*Received multiple answers

Alaska, Ohio, and Tennessee reported that guidelines for selection or placement did not vary with the design speed of roadway. Alaska DOT prefers to use short radius controlled release terminal (CRT) regardless of speed. However, Arizona, Kansas, Louisiana, New Mexico, Texas, South Carolina, Washington, and Wyoming reported that their guidelines for selection or placement do vary with the design speed. South Carolina stated "crash cushions are typically reserved for higher speed, higher volume roads where the length-of-need is mainly addresses as well as gore areas and medians where guardrail approaches are not practical" *(20).*

States were also asked how often they encountered high speed and low speed roadways where the length of need cannot be met. Answers from the DOTs varied significantly. South Carolina uses crash cushions for higher speed or higher volume roads. In the case of low speed or low volume the designers use lower test level components such as shorter end treatments. For Tennessee, the length of guardrail must be at least 50 feet when the design speed is 45 mph or under. For 45 mph or above, the minimum length of guardrail is 75 feet.

SLOPE-DEPENDENT GUIDELINES

DOTs were questioned about installation of short radius guardrail in front of a slope. Survey responses are shown in Table 3.7.

Table 3.7. Slope-Dependence of State Guidelines with Slope of Roadway.

State DOT	If your State uses Short Radius Guardrail, has it been installed in front of a slope?			Do you know the Slope Dimensions?	What is the typical slope?
	Yes	No	Do Not Know		
AK	X			No	2H:1V
AZ	N/A	N/A	N/A	N/A	N/A
CA	N/A	N/A	N/A	N/A	N/A
KS	X			Yes	4H:1V
LA	X			No	3H:1V
NC	N/A	N/A	N/A	N/A	N/A
NM			X	N/A	N/A
OH	X			No	2H:1V
PA*	X			No	2H:1V
TN		X		N/A	N/A
TX		X		No	N/A
SC	N/A	N/A	N/A	N/A	N/A
SD	N/A	N/A	N/A	N/A	N/A
WA	X			No	2H:1V
WY	X			No	2H:1V

*Received multiple answers

Alaska, Kansas, Louisiana, Ohio, Pennsylvania, Washington and Wyoming reported they have installed a short radius guardrail in front of a slope.

The typical slopes given by the States varied from 2H:1V to 4H:1V. Alaska, Ohio, Pennsylvania, Washington, and Wyoming stated the typical slope for their state is 2H:1V, Louisiana 3H:1V, and Kansas 4H:1V.

CHAPTER 4. SUMMARY AND CONCLUSIONS

A general problem occurs at many bridge locations along highways where the required length of need for bridge approach rails cannot be met within the existing right-of-way limits. Solutions to this problem have included using short radius guardrail, a shortened guardrail section, or a crash attenuator.

The study aimed at identifying DOTs best practices used to alleviate problems where length-of-need requirements for bridge approach rails cannot be met. A survey was prepared and targeted to collect data concerning DOTs best practices or standards for bridge barriers when LON cannot be met (including use of short radius guardrail and/or crash cushions), and possible practices variation according to design speed and slopes. A total of 16 States participated in this research study by either completing the survey or by sending valuable information through email correspondence with the researchers. Best practices used by DOTs that participated to this study are summarized in Appendix E.

From the information collected, it appears that use of short radius guardrail practice at bridge locations where LON cannot be met is generally the option preferred by the DOTs. Although few States (New Mexico, Texas and Wyoming) indicated that their DOTs make somewhat frequently use of crash cushions at bridge locations where LON cannot be met, their employment is very limited by other States due to their higher installation and maintenance costs. In the State of Alaska, for example, crash cushions and guardrail can be severely damaged by use of plows during the winter season: although both of these systems need to be repaired, the guardrail results to be a simpler and cheaper option than the crash cushions. Also, use of crash cushions seem to be not practical and highly undesirable on road sections with multiple drives and side roads, considering the needed size of the crash cushions.

Some State DOTs prefers to relocate the obstacle/ drive access to a point beyond the proposed length of need, such as North Carolina and South Dakota stated. When that is not feasible, DOTs have different preferences on how to shield the obstacle.

Alaska DOT, for example, makes use of the Wood Post Controlled Release Terminal. Alaska uses parallel guardrail end treatments where the roadside slope and clear run out are sufficient and employs crash cushions on roads of sufficient volume where the parallel end treatments and short radius don't fit. When deciding what type of crash cushion to use, AKDOT gives considerations to the nature of the hazard behind the cushion, the ability to perform maintenance. Considerations are also given to possible weather conditions consequences in that region. In fact, AKDOT has encountered some challenges with snow and gravel on roads, which affects the performance of crash cushions that use ground level track systems. Alaska never uses sand barrels due to freezing-related problems.

Louisiana DOT uses an adjusted LON equation, which is only allowed on existing roadways and bridge, but not on new construction. The adjusted LON is never allowed on the interstate system. LDOT also makes use of the T-Intersection and employs attenuators at bridge ends only when there is no other feasible option. LADOT does not have a specific policy when using attenuators in these situations: decision on which attenuator to use is left to the designer's criteria on the best approach.

South Carolina DOT uses rigid barrier sometimes on radius, so that standard guardrail can be attached at the terminal of the rigid barrier along the intersecting ramp/street (in locations where penetration of the radius rail has extreme consequences, such as at an interstate pass). South Dakota DOT employs nested thrie beam transition from concrete bridge rail end block, then attachment of short radius rail as necessary.

Tennessee DOT rarely uses crash cushions at bridge locations where LON cannot be met, preferring employment of short radius guardrail for those circumstances. The criteria for crash cushion type selection are based on site characteristics, structural and safety characteristics of the systems, system costs, and maintenance characteristics.

Alaska, Ohio, and Tennessee reported that guidelines for selection or placement did not vary with the design speed of roadway. Alaska DOT prefers to use short radius controlled release terminal (CRT) regardless of speed. However, Arizona, Kansas, Louisiana, New Mexico, Texas, South Carolina, Washington, and Wyoming reported that their guidelines for selection or placement do vary with the design speed.

States were also asked how often they encountered high speed and low speed roadways where the length of need cannot be met. Answers from the DOTs varied significantly. South Carolina uses crash cushions for higher speed or higher volume roads. In the case of low speed or low volume the designers use lower test level components such as shorter end treatments. For Tennessee, the length of guardrail must be at least 50 feet when the design speed is 45 mph or under. For 45 mph or above, the minimum length of guardrail is 75 feet.

Alaska, Kansas, Louisiana, Ohio, Pennsylvania, Washington and Wyoming reported they have installed a short radius guardrail in front of a slope. The typical slopes given by the States varied from 2H:1V to 4H:1V. Alaska, Ohio, Pennsylvania, Washington, and Wyoming stated the typical slope for their state is 2H:1V, Louisiana 3H:1V, and Kansas 4H:1V.

South Dakota DOT strongly suggest that in the event a new concept is designed to replace the existing short radius details, that new system would be crash tested in accordance with real world application, that is not only on flat ground, but with the system placed on flat ground in front of the required guardrail embankment and a breaking slope such as a 6:1 or steeper after the guardrail embankment.

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APPENDIX A – SURVEY – BEST PRACTICES FOR BARRIER PROTECTION OF BRIDGE ENDS

Scope of the survey

Texas Transportation Institute is conducting a survey for Roadside Safety Research Program Pooled Fund Study TPF-5 (114), "Best Practices for Barrier Protection of Bridge Ends."

This survey is intended for State Departments of Transportation (DOT) and aims to gain information regarding practices used to alleviate problems where length-of-need requirements for bridge approach rails cannot be met.

The results of the survey will be used to develop a best practices document. This document will provide state DOTs with a reference for how others handle installations where the required length-of-need cannot be met for bridge approach rails.

It is very important that all states are accurately represented in this survey. Your participation in the survey is very important.

Thank you for your time in helping with this research effort.

Contact Information

***1. Please enter your contact information.**

Name:

Title:

Agency:

Address:

City/Town:

State:

ZIP:

Email Address:

Phone Number:

In this first part of the survey, you are asked to respond to a few questions regarding your State's best practices for barrier protection of bridge ends (if any).

***2. May we contact you if more information is desired?**

Yes

No

Contact

***3. Please Contact:**

***4. Does your state have any existing practices, treatments, or methods when design exception is needed for shielding bridge approach rails where the required length-of-need cannot be met?**

- Yes
- No
- Do Not Know

***5. Do you have any documentation (e.g. standard drawings, guidelines, etc.) you could share regarding your practices and methods?**

- Yes
- No
- Do Not Know

***6. Please provide a copy of your state standards and policies (you may provide the URL address where your policies can be accessed and/or appropriate contacts for further follow up)**

***7. Have these treatments been crash tested?**

- Yes, under NCHRP Report 350 criteria
- Yes, under MASH criteria
- No
- Do Not Know

Other (please specify)

*8. What test level?

- [ ] TL-1
- [ ] TL-2
- [ ] TL-3
- [ ] TL-4
- [ ] TL-5

Other (please specify)

A high speed roadway is defined as a roadway with a posted speed of 50 MPH or greater. A low speed roadway has a posted speed less than 50 MPH.

*9. Do your guidelines for selection or placement vary with design speed of roadway?

- ( ) Yes
- ( ) No
- ( ) Do Not Know

*10. For bridge locations where the Length Of Need (LON) cannot be met, please indicate the percentage of high speed and low speed roadways.

Percent High Speed

Percent Low Speed

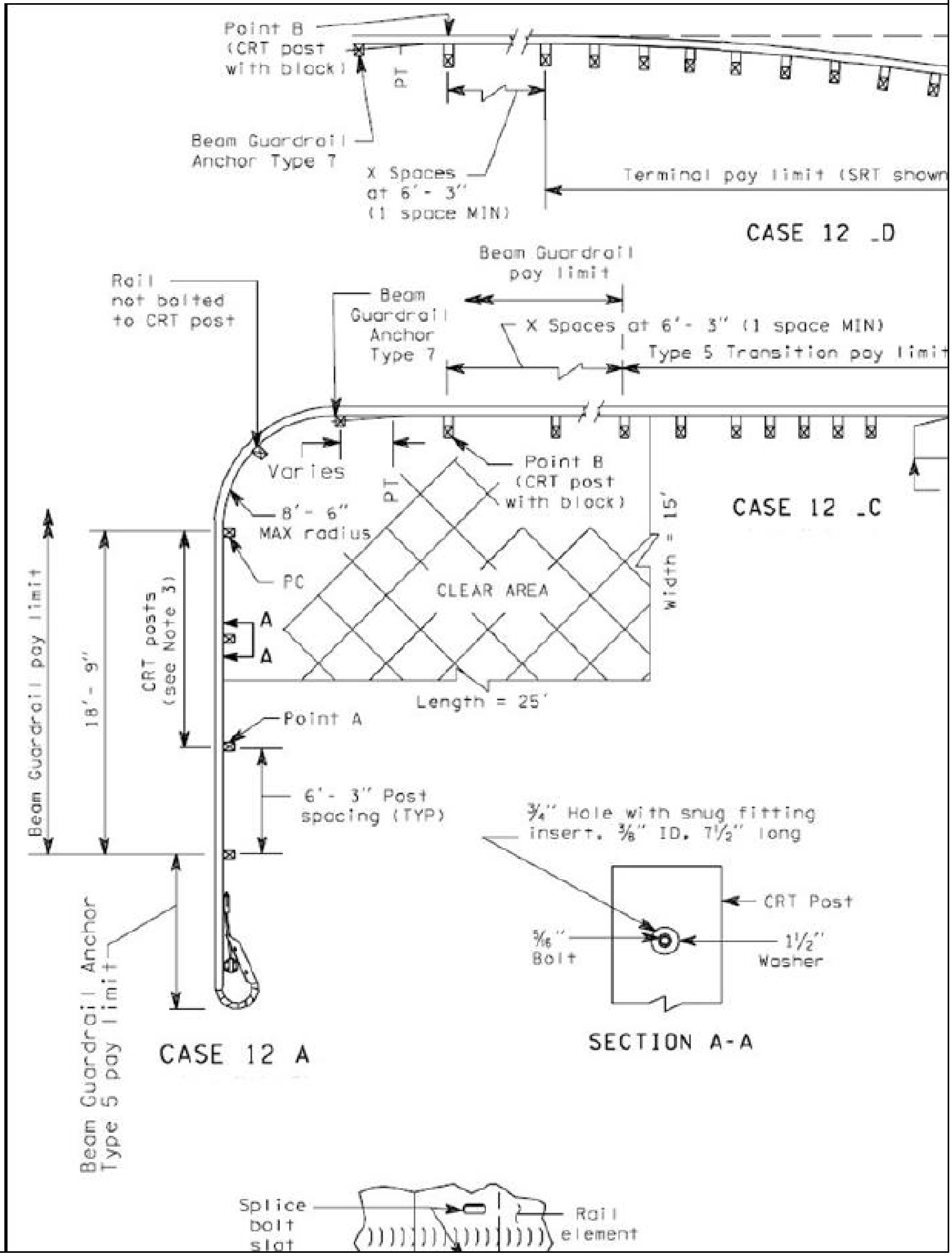
*11. What percentage of bridge locations where the Length Of Need (LON) cannot be met are due to the close proximity of private intersecting roads or driveways?

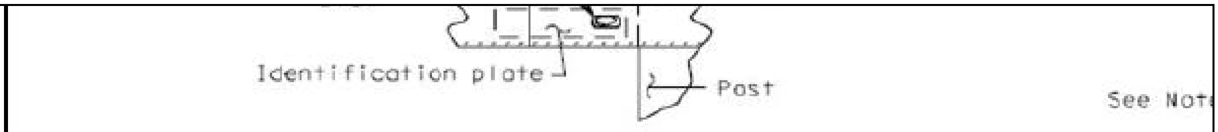
Percent

Short Radius Guardrail

Common alternatives to a properly designed guardrail Length Of Need (LON) at bridge sites where the proper LON cannot be met are a shortened guardrail design, a curved or T-intersection guardrail design, or to relocate the obstruction. The curved guardrail design is known as the short radius guardrail.

Short Radius Guardrail drawing (C-2f) from WsDOT





IDENTIFICATION PLATE
MOUNTING DETAIL

***12. Please indicate the frequency of use of the following practices in your State at bridge locations where LON cannot be met.**

	Never	Rarely (1-25%)	Somewhat Frequent (26-50%)	Frequently (51-75%)	Very Frequently (76-100%)
Crash Cushion	○	○	○	○	○
Short Radius Guardrail	○	○	○	○	○

If 'Other', please describe (you can include description, pictures, drawings, links, etc... any information that you think it might be relevant))

***13. If a crash cushion is used to shield motorists from bridge ends in close proximity to an intersecting roadway, please indicate the frequency of use of the following crash cushion types.**

	Never	Rarely (1-5%)	Somewhat Frequently (26-50%)	Frequently (51-75%)	Very Frequently (76-100%)
ABSORB 350	○	○	○	○	○
ADIEM	○	○	○	○	○
BEAT-BP	○	○	○	○	○
BEAT-SSCC	○	○	○	○	○
CAT-350	○	○	○	○	○
Compressor	○	○	○	○	○
EASI-CELL	○	○	○	○	○
HEART	○	○	○	○	○
NCIAS	○	○	○	○	○
Quadguard System	○	○	○	○	○
QuadTrend 350	○	○	○	○	○
QUEST	○	○	○	○	○
REACT 350	○	○	○	○	○
Sand Barrels	○	○	○	○	○
SMART Cushion	○	○	○	○	○
TAU-II System	○	○	○	○	○
Thrie-Beam Bullnose Guardrail System	○	○	○	○	○
TRACC System	○	○	○	○	○

If 'Other', please describe (you can include description, pictures, drawings, links, etc... any information that you think it might be relevant))

***14. If your State uses Short Radius Guardrail, has it been installed in front of a slope?**

- ○ Yes
- ○ No
- ○ Do Not Use Short Radius Guardrail
- ○ Do Not Know

***15. Do you know the slope dimensions?**

- ○ Yes
- ○ No

***16. What is a typical slope?**

Horizontal

Vertical

APPENDIX B. SURVEY RESULTS – BEST PRACTICES FOR BARRIER PROTECTION OF ENDS

*Please note the percentage reported for each question is related to the number of states that answered that particular question

4) Question: Does your state have any existing practices, treatments, or methods when design exception is needed for shielding bridge approach rails where the required length-of-need cannot be met? (12 out of 12 States answered this question)

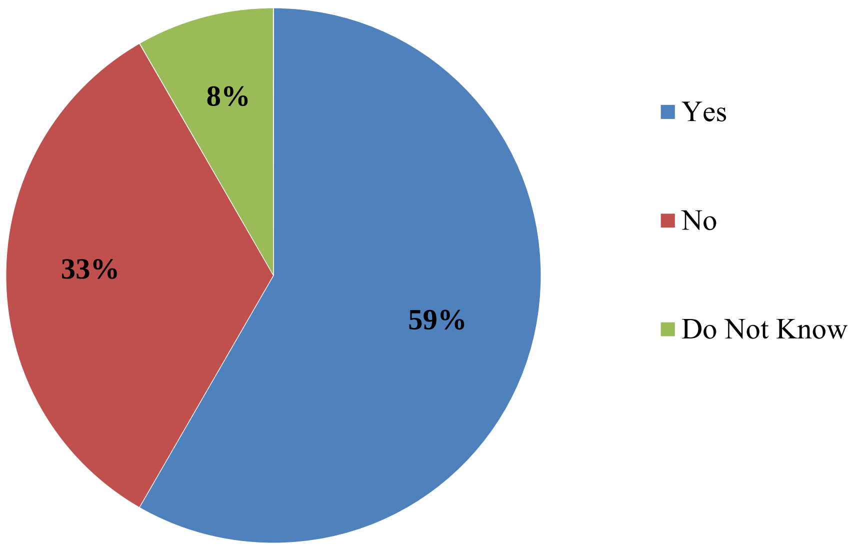


Figure B1. Reponses Regarding Existing Practices, Treatments, or Methods When Length-of-Need Cannot Be Met.

5) Question: Do you have any documentation (e.g. standard drawings, guidelines, ect.) you could share regarding your practices and methods? (12 out of 12 States answered this question)

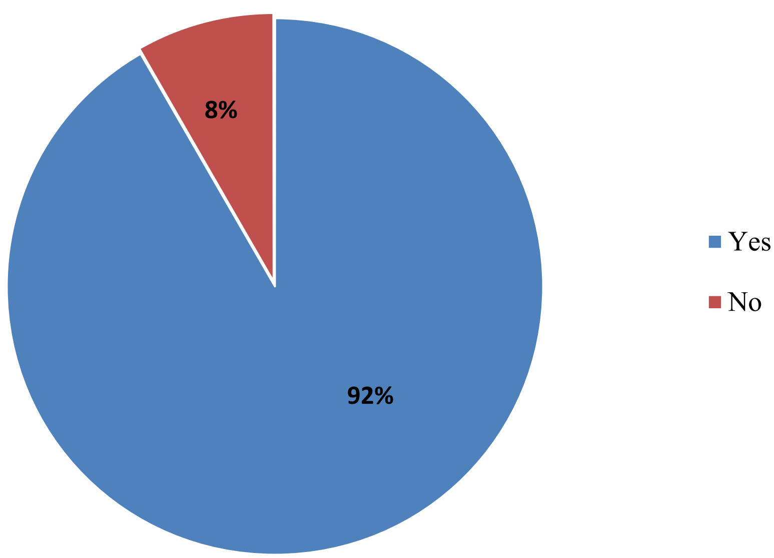


Figure B2. Responses to Providing Documentation Regarding State Practices and Methods.

6) Please provide a copy of your state standards and policies (you may provide the URL address where your policies can be accessed and/or appropriate contacts for further follow up). (11 out of 12 States answered this question)

Alaska:

Link to pdf of three page Standard Drawing G-25.21 Wood Post Controlled Release Terminal: http://www.dot.state.ak.us/stwddes/dcsprecon/assets/pdf/stddwgs/eng/g25_21w.pdf

Arizona:

We don't have a written procedure for when LON can't be met, but in practice we use crash cushions and short radius guardrail. Our general procedure for selecting crash cushions is at: http://www.azdot.gov/Highways/Roadway_Engineering/Roadway_Design/Design/Memos/index.asp For short radius guardrail, we develop project specific details following FHWA Technical Advisory T5040.32 and publication FHWA-HI-97-026, pages 4.5.14 and 4.5.15.

Kansas:

http://kart.ksdot.org/ Our design manual and standard drawings can be found at this location. Our guardrail standards are RD606 - RD619. RD619 is our side-road wrap around guardrail installation. We also utilize the RDG. We don't have a written policy about guardrail that is less then LON calcualation as per the RDG. Instead we document the reasons why the decision was made. This is done in a manner similar to a design exception process except it is a document to the project records, not something that has to be approved the FHWA.

Louisiana:

We have a policy that adjusts the LON equations (EDSM II.3.1.3):
http://webmail.dotd.la.gov/ppmemos.nsf/0/F339A6FE4D97D6CA86256F1E00423865/$file/EDSM.htm
We also allow for a short radius guard rail detail:
http://www.dotd.la.gov/highways/standardplans/Standard%20Plans/Guardrails/GR200-06.pdf

New Mexico:

http://dot.state.nm.us/en/PSE/Standards.html This is a link to all of our standard drawings and our standard specifications can be found in the same area. I may be contacted.

Ohio:

See pg 52/75
http://www.dot.state.oh.us/Divisions/Engineering/Roadway/roadwaystandards/Location%20and%20Design%20Manual/Section_600_Apr_2012.pdf

Pennsylvania:

Pub 72M & Pub 652 ftp://ftp.dot.state.pa.us/public/PubsForms/Publications/PUB%2012.pdf ftp://ftp.dot.state.pa.us/public/bureaus/design/pub13m/Chapters/Appendix_A_Chap12.pdf This is to Appendix A of Chapter 12 in our highway design manual (DM-2).

Tennessee:

http://www.tdot.state.tn.us/Chief_Engineer/engr_library/design/StdDrwgEng_PDFs/SGR46_000000.pdf

Texas:

http://www.dot.state.tx.us/business/standardplanfiles.htm

Washington:

WSDOT Design Manual Chapter 1610 http://www.wsdot.wa.gov/Publications/Manuals/M22-01.htm#Individualchapters
WSDOT Standard Plans Section "C" http://www.wsdot.wa.gov/Design/Standards/Plans.htm

Wyoming :

http://www.dot.state.wy.us/wydot/engineering_technical_programs/manuals_publications/standardplans/Standard_Plans

7) Question: Have these treatments been crash tested? (12 out of 12 States answered this question)

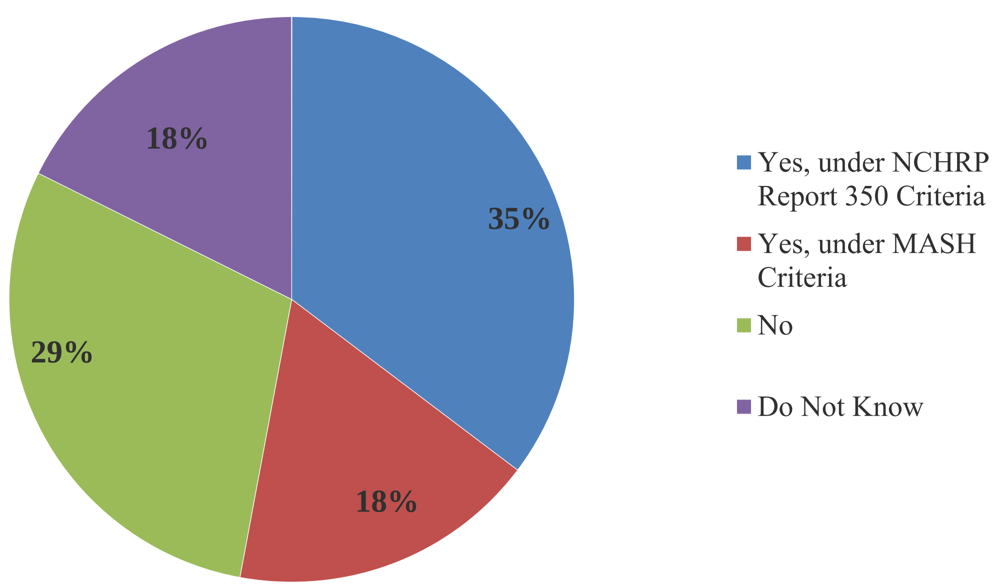


Figure B3. Treatments Crash Tested.

8) Question: What test level? (6 out of 12 States answered this question)

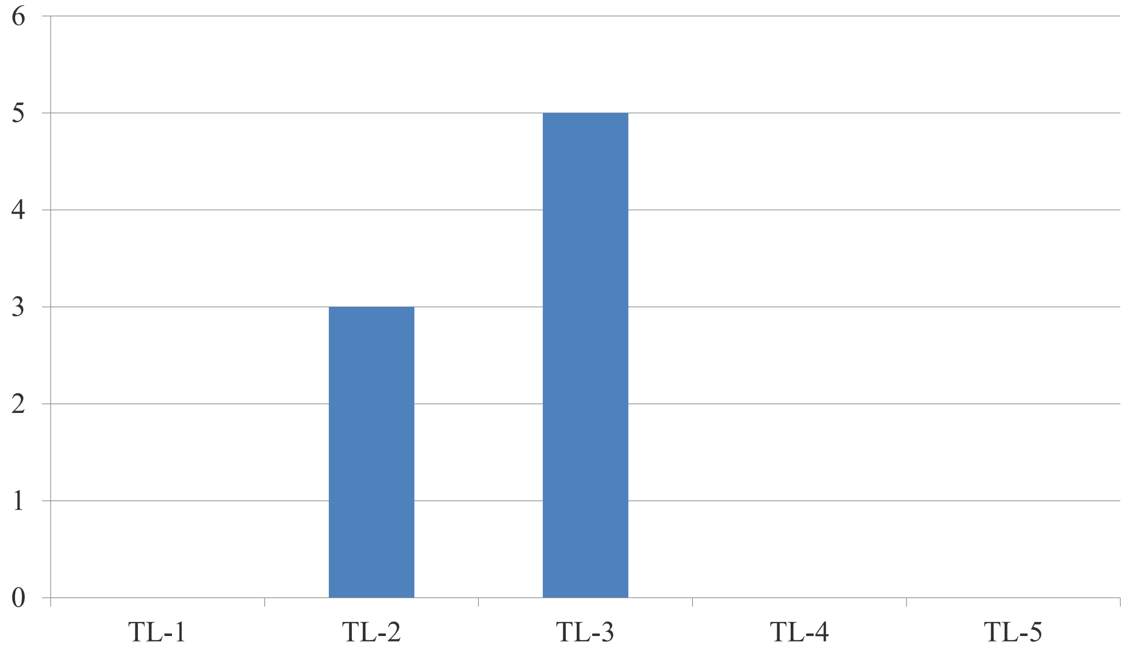


Figure B4. Test Level Treatments Have Been Tested For.

9) Question: Do your guidelines for selection or placement vary with design speed of roadway? (12 out 12 States answered this question)

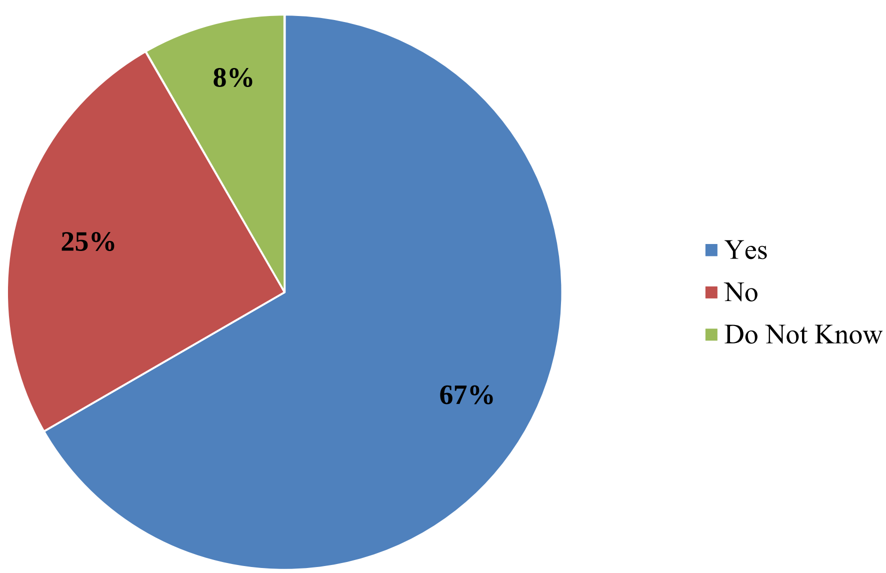


Figure B5. Variation of Speed.

10) Question: For bridge locations where the Length of Need (LON) cannot be met, please indicate the percentage of high speed and low speed roadways? (6 out of 12 States answered this question)

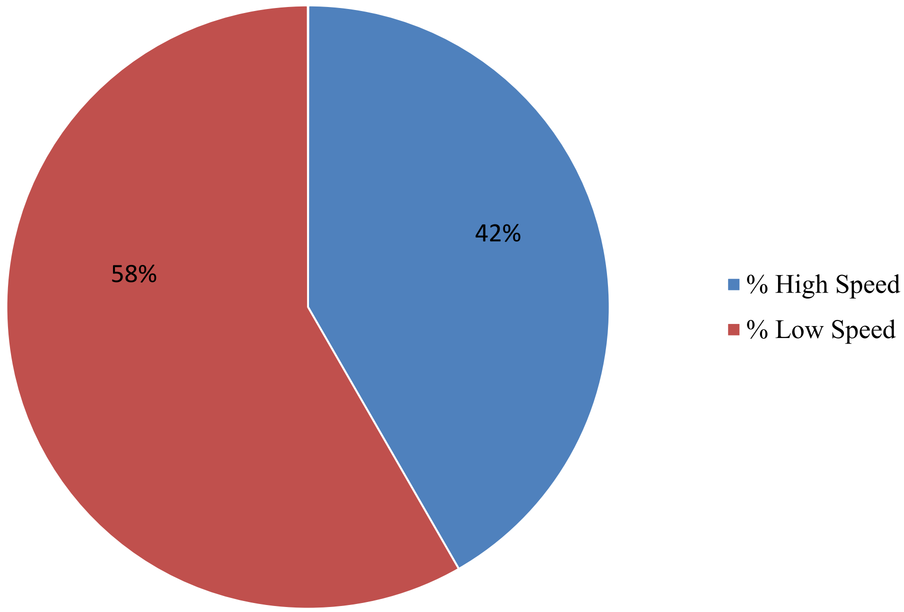


Figure B6. Average Percentage of High Speed and Low Speed Roadways.

11) Question: What percentage of bridge locations where the Length of Need (LON) cannot be met are due to the close proximity of private intersecting roads or driveways? (9 out of 12 States answered this Question)

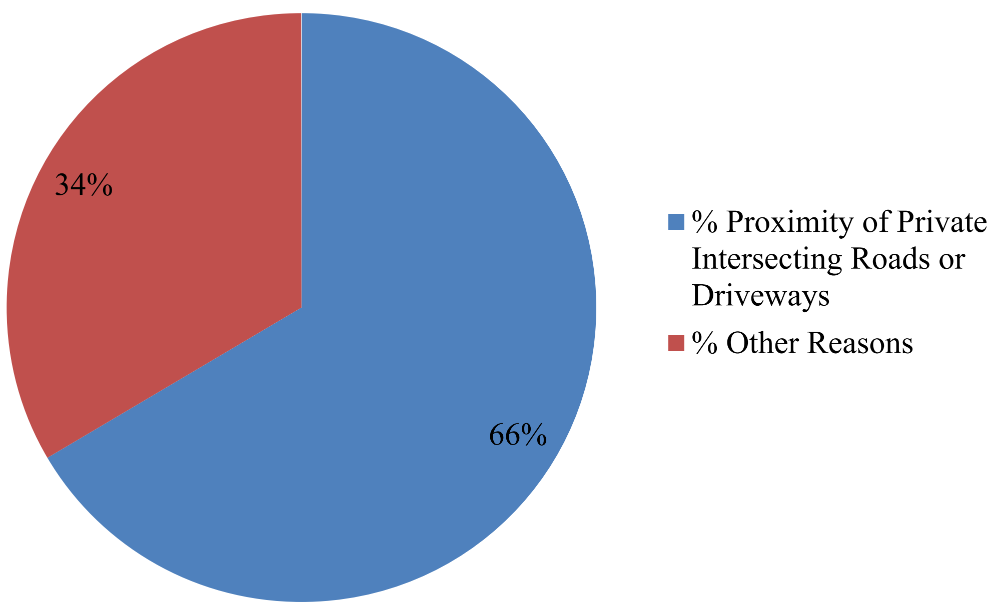


Figure B7. Reasons for LON Cannot Be Met.

12) Question: Please indicate the frequency of use of the following practices in your state at bridge locations where LON cannot be met. (10 out of 12 States answered this question)

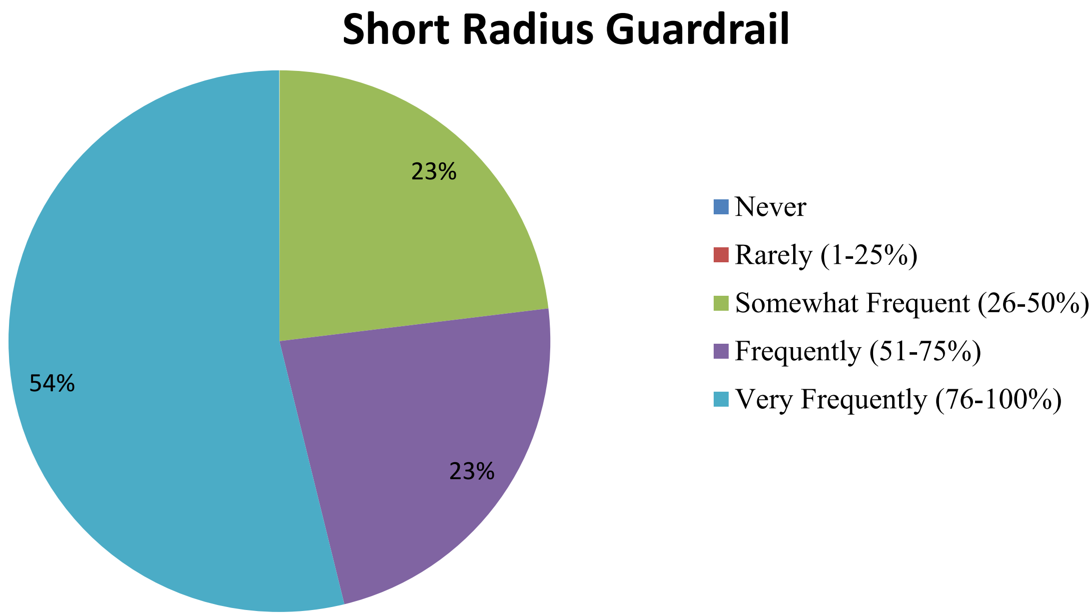


Figure B8.a Short Radius Guardrail.

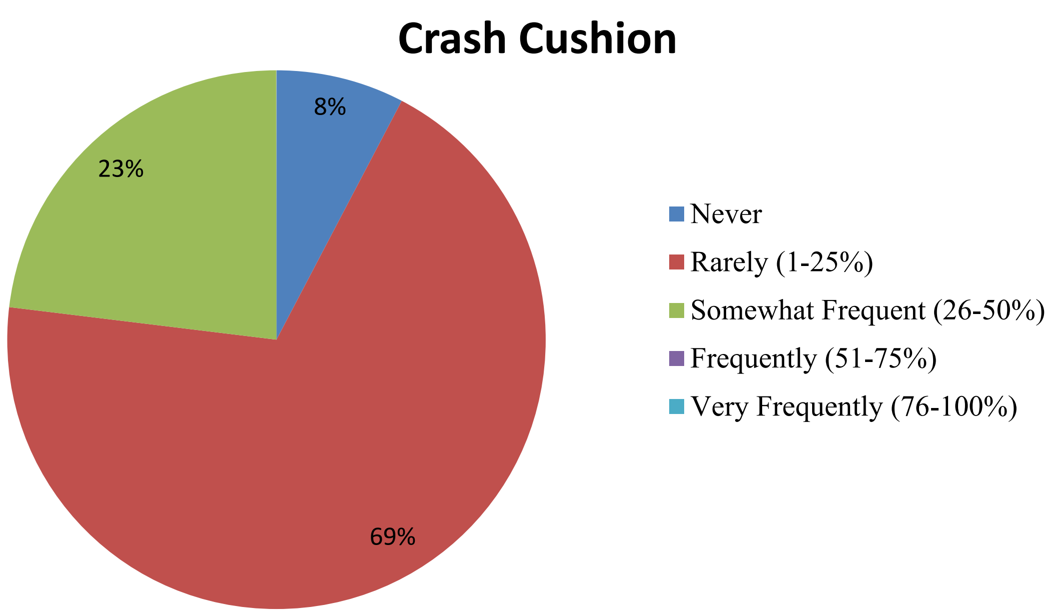


Figure B8.b Crash Cushion.

13) Question: If a crash cushion is used to shield motorists from bridge ends in close proximity to an intersecting roadway, please indicate the frequency of use of the following crash cushion types. (10 out of 12 States answered this question)

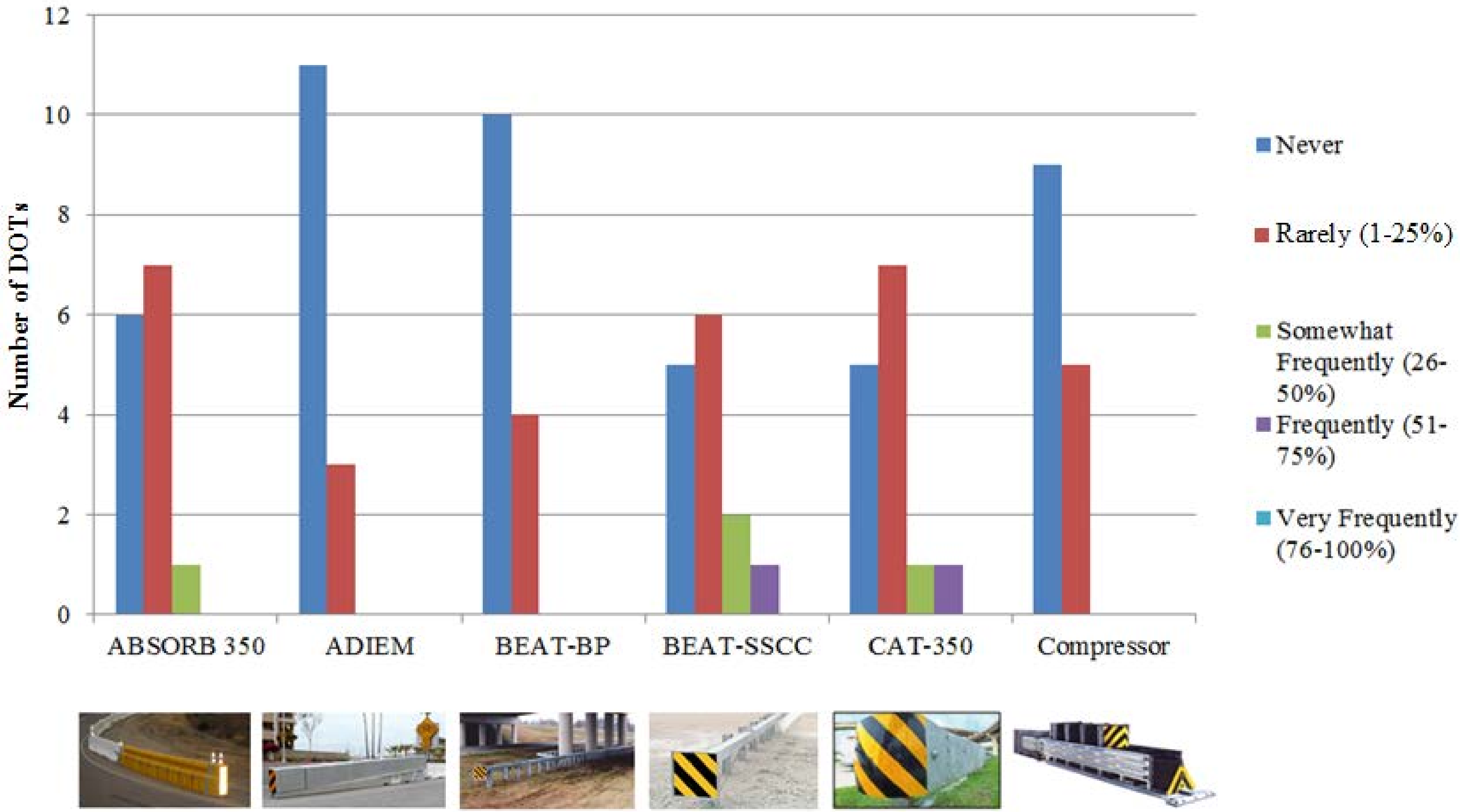


Figure B9. Types of Crash Cushions.

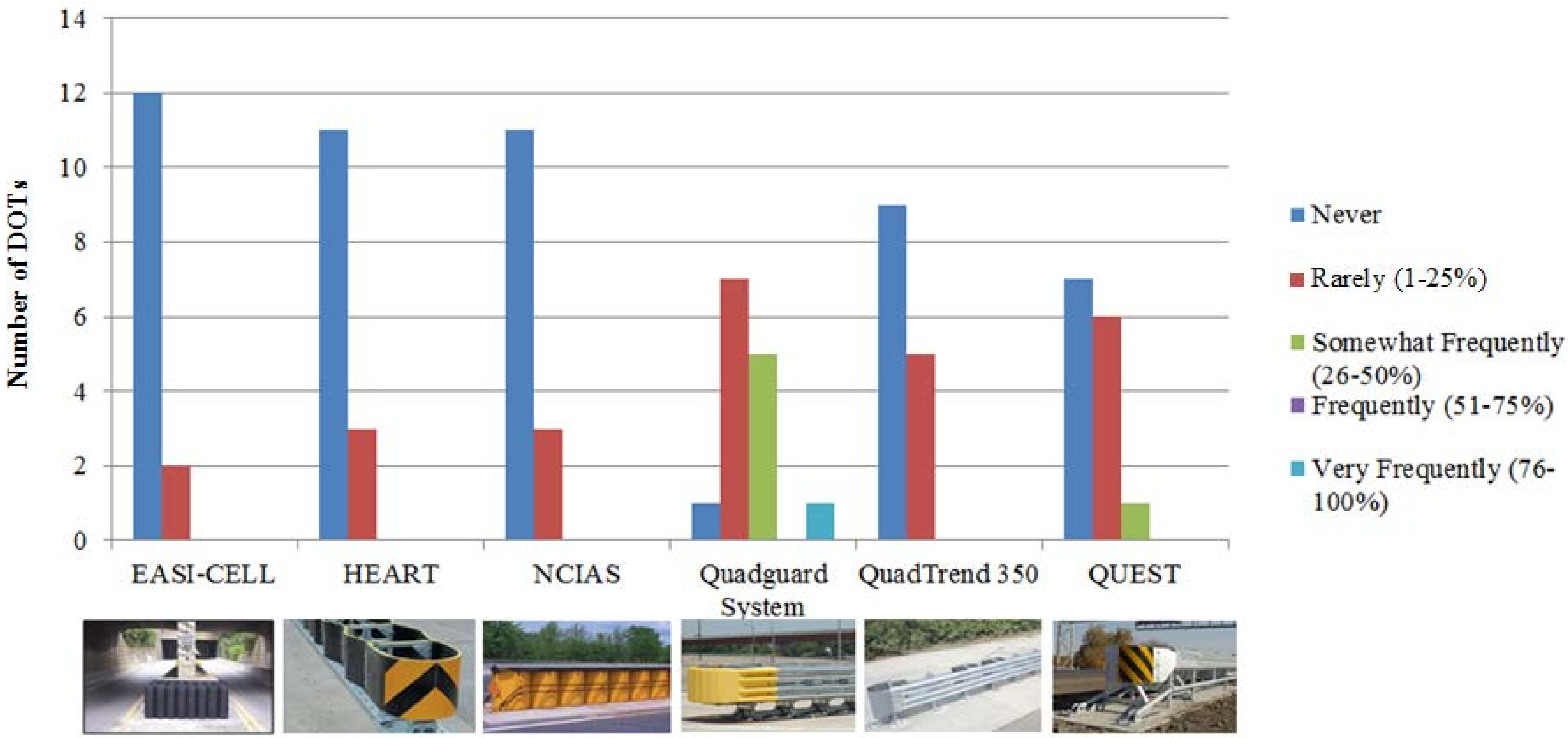


Figure B9. Types of Crash Cushions (Continued).

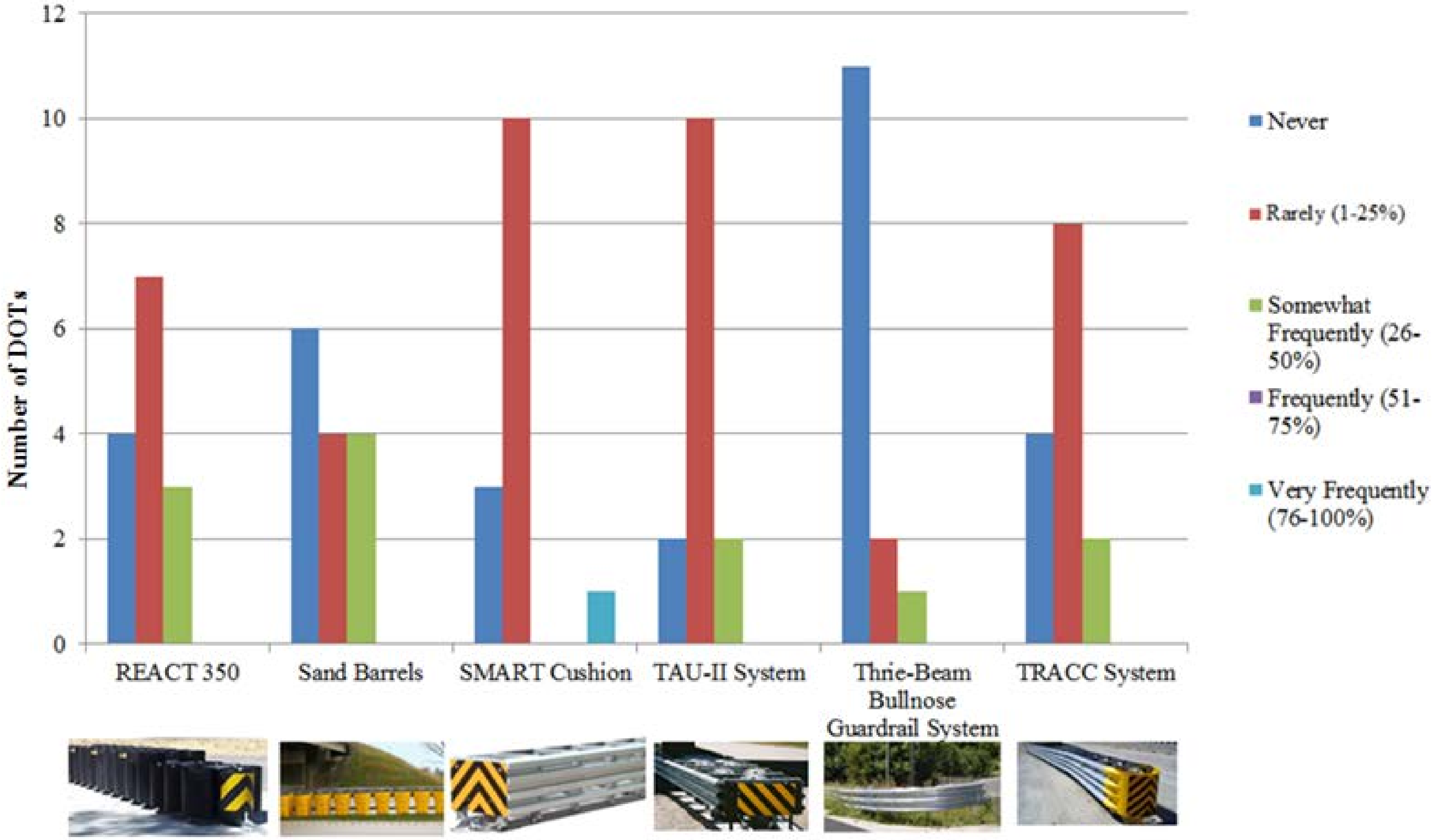


Figure B9. Types of Crash Cushions (Continued).

14) Question: If your state uses Short Radius Guardrail, has it been installed in front of a slope? (10 out of 12 States answered this question)

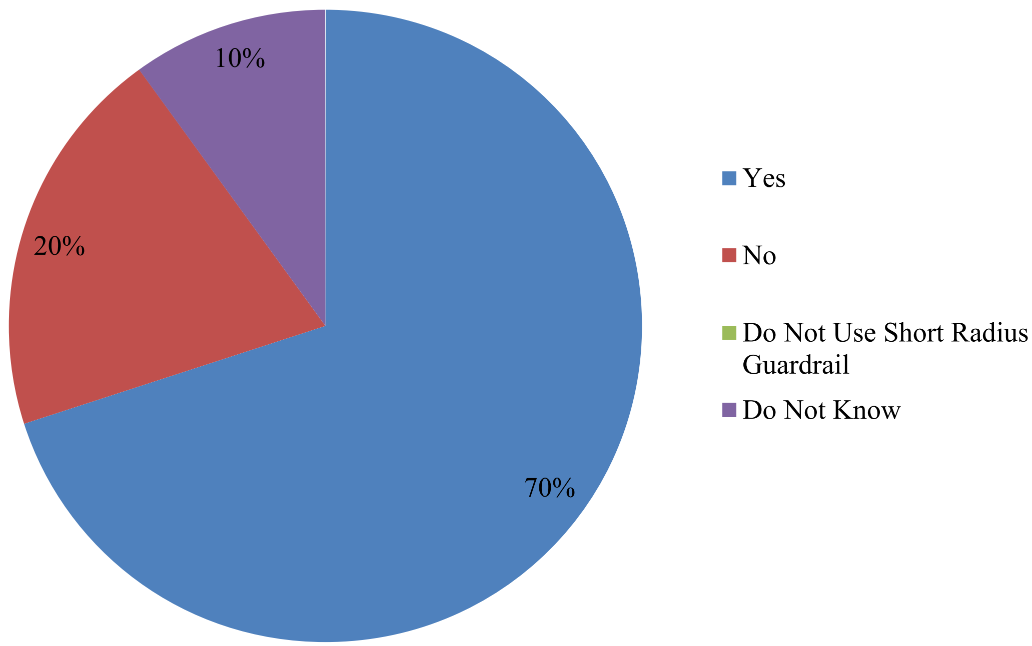


Figure B10. Installation in Front of Slope.

15) Question: Do you know the slope dimensions? (8 out of 12 States answered this question)

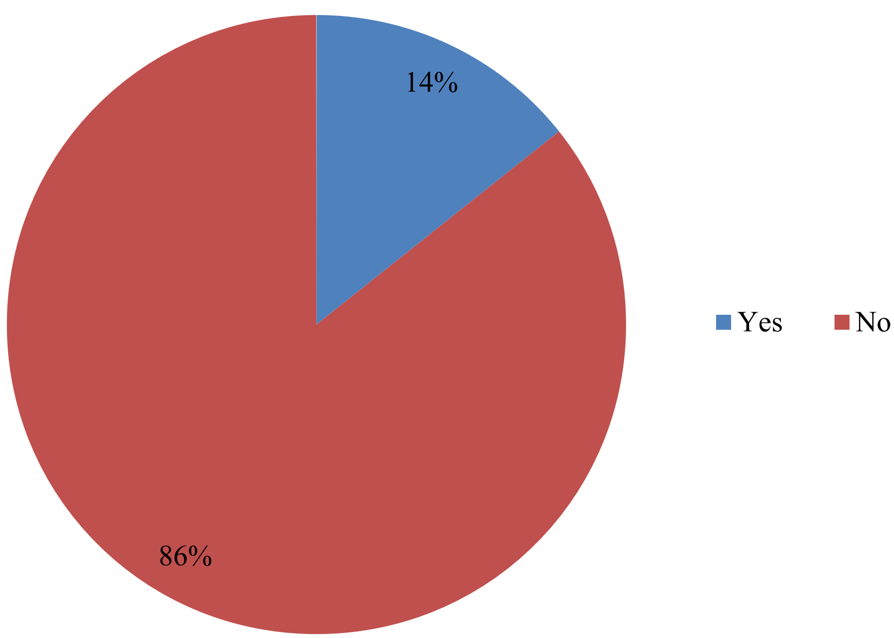


Figure B11. Slope Dimensions.

16) Question: What is a typical slope? (7 out of 12 States answered this question)

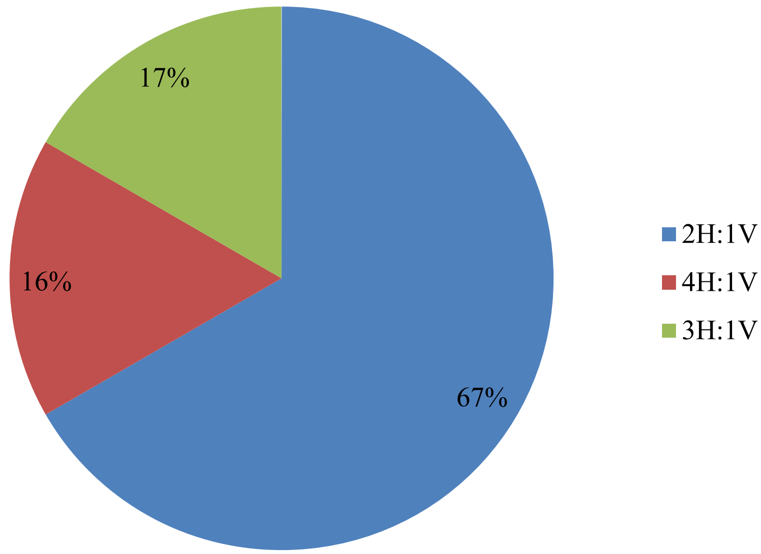


Figure B12. Percentage of Typical Slope.

APPENDIX C: CRASH ATTENUATORS

Below are crash cushion types used in the survey along with other suggested or preferred crash cushions from other States. Information about each crash cushion is also provided.

Table C1. Crash Cushions Included in the Survey.


ABSORB 350 – Non-redirective, meets TL-1, Tl-2, & TL-3 test criteria, approved for permanent and work zone locations, simple and cost effective maintenance after an impact, quick and easy development, and low cost.

ADIEM (Advanced Dynamic Impact Extension Module) – Cost effective, redirective energy absorbing crash cushion. Meets TL-3 test criteria.

BEAT-BP (Box Beam Bursting Energy Absorbing Terminal Bridge Pier) – energy absorbing crash cushion used to shield bridge piers, meets TL-1, TL-2, & TL-3 test criteria.

Table C1. Crash Cushions Included in the Survey (Continued).


BEAT-SSCC (Box Beam Bursting Energy Absorbing Terminal Single-Sided Crash Cushion) -

BREAKMASTER 350 – a gating, redirective crash cushion system, used to shield guardrail ends at wide median and roadside sites with clear zones. Meets TL-3 test criteria.

CAT 350 (Crash Cushion Attenuating Terminal) – energy absorbing attenuator, TL-3 test criteria.

Table C1. Crash Cushions Included in the Survey (Continued).


Compressor – a self-recoverable crash cushion, meets TL-3 test criteria.

EASI-CELL – composed of 32, energy absorbing, reusable cylinders, can self-recover after impacts up to about 90% of its original shape without maintenance. Meets TL-1.

ET-2000

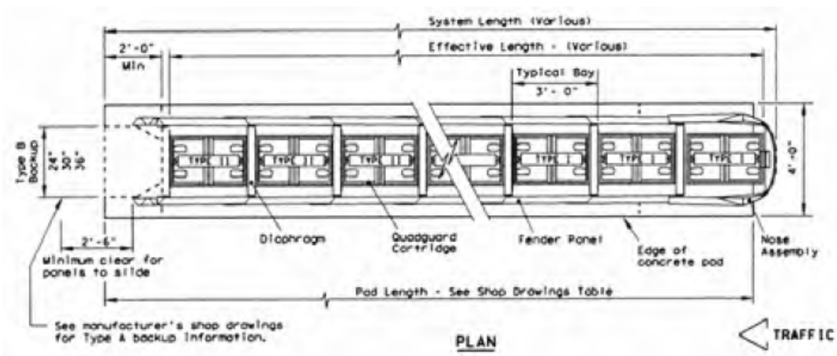
Table C1. Crash Cushions Included in the Survey (Continued).


FLEAT-MT – a median terminal commonly used in wide medians. Depending on the severity of the impact, vehicle can be stopped before reaching the second impact head. Meets TL-3 test criteria.

HEART – reusable, restorable, non-gating, re-directive crash cushion. Meets TL-3.

NCIAS (Connecticut Impact Attenuation System) – redirective, non-gating crash cushion, consists of 8 steel cylinders. Meets TL-3 test criteria.

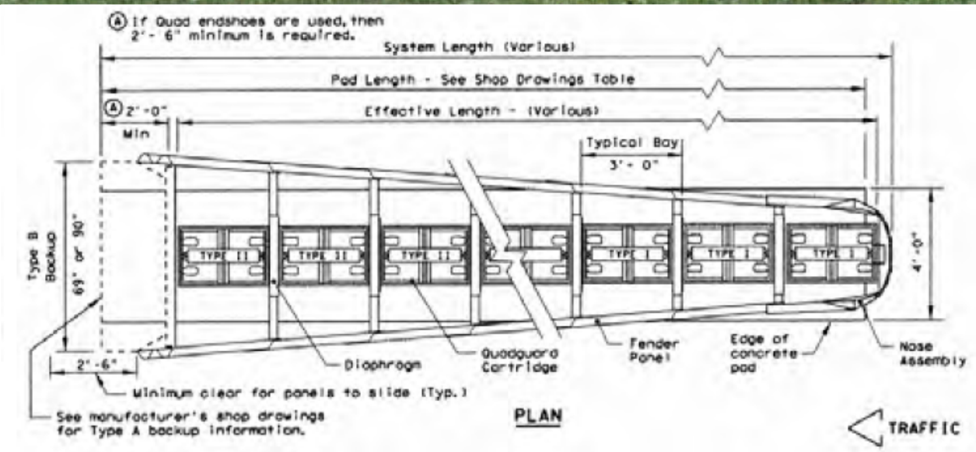
Table C1. Crash Cushions Included in the Survey (Continued).



Quadguard System – redirective, non-gating crash cushion that consists of crushable, energy absorbing cartridges. Meets TL-3 criteria.

Quadguard II – A redirective, non-gating crash system, 25% shorter than the original QuadGuard. Meets TL-2 and TL-3 test criteria.

Table C1. Crash Cushions Included in the Survey (Continued).

 
QuadGuard ELITE – non-gating, redirective crash cushion system, reusable cylinders. Meets TL-2 and TL-3 criteria.

QuadTrend 350 – a gating redirective end treatment designed to protect the ends of concrete barriers. Meets TL-3 criteria.

Table C1. Crash Cushions Included in the Survey (Continued).

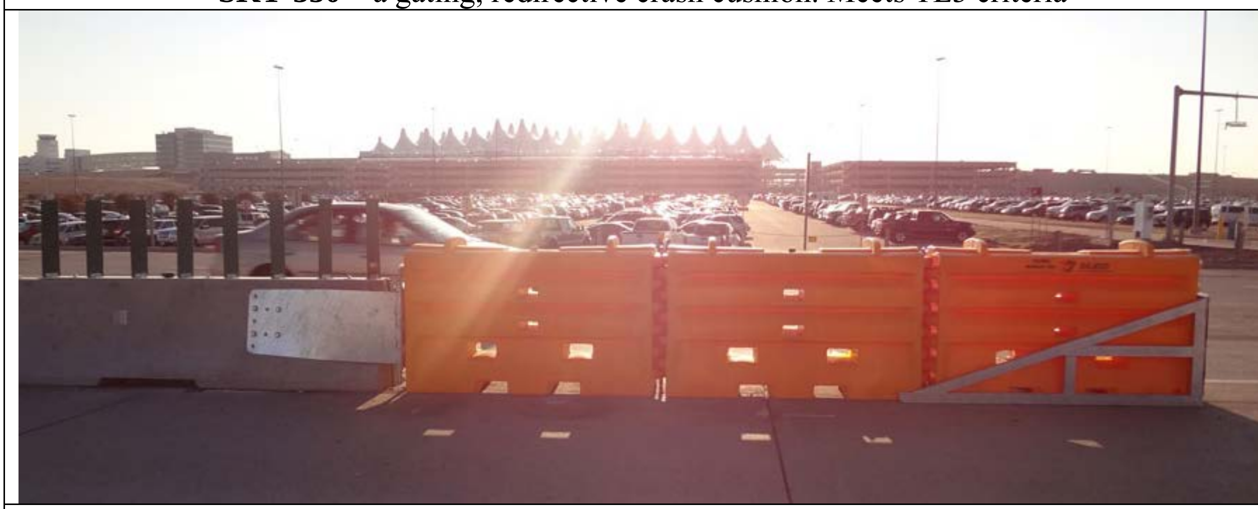
QUEST – simple redirective, non-gating crash cushion. Meets TL-2, TL-3 test criteria.

REACT 350 – a non-gating, redirective, reusable crash cushion with cylinders that can regain up to 90% of their original shape. Reusability if up to 99%.

Sand Barrels – non-redirective, gating sand filled crash cushion. Common set up consists of 12 barrels, typically a single file of four barrels followed by 4 rows of 2 barrels in each.

Table C1. Crash Cushions Included in the Survey (Continued).

SKT-350 – a gating, redirective crash cushion. Meets TL3 criteria



SLED – non-redirective gating crash cushion

SMART Cushion – a speed-dependent crash cushion that varies stopping resistance during an impact.

Table C1. Crash Cushions Included in the Survey (Continued).

TAU II System – a non-gating, redirective system ideally for roadway hazards such as bridge piers or ends of rigid concrete barriers. Can be installed as permanent or temporary. Cheap maintenance after impacts.

Thrie-Beam Bullnose Guardrail System

TRACC System – redirective, non-gating crash cushions available in a variety of lengths for a variety of highway speeds, requires low maintenance. Meets TL-2 & TL-3 test criteria.

Table C1. Crash Cushions Included in the Survey (Continued).

SLED

APPENDIX D – EXAMPLES OF STATES

Table D1. Examples When LON Cannot Be Made By Ohio.

(a) Example #1

(b) Example #2

(c) Example #3

Figure D1. Example of Short Radius Guardrail from Pennsylvania.

Table D2. Examples Provided by South Carolina.


(a) “Bridge immediately adjacent to railroad crossing and intersection”

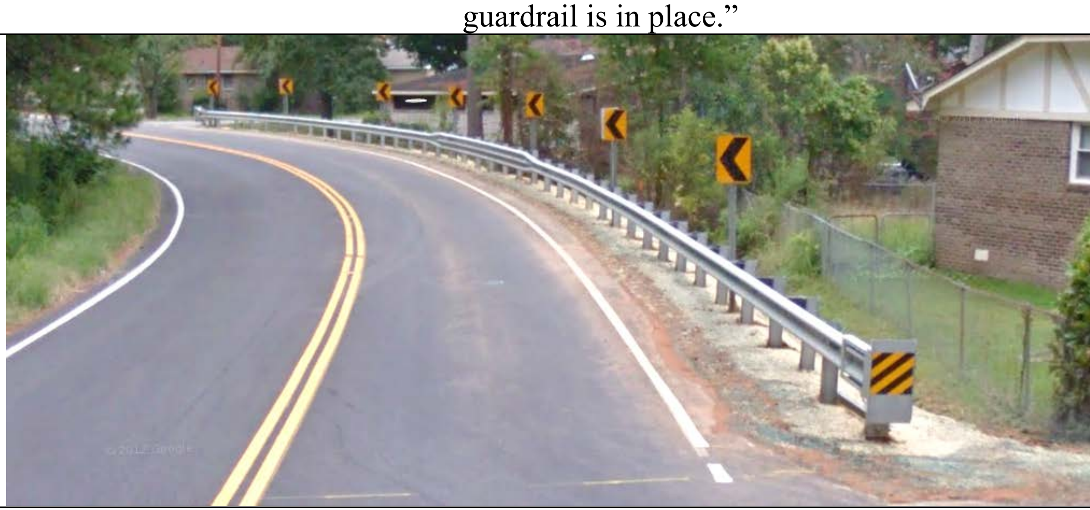
(b) “Bridge immediately adjacent to barrier on interchange ramp.” The bridge is expected to be raised 2 feet in a future project. “Barrier wall will also be adjusted and lengthened for the new fill conditions and may be extended to wrap around the radius where the existing guardrail is in place.”

(c) A high volume, 35 mph in a horizontal curve & crossing a culvert.

Table D2. Examples Provided by South Carolina (Continued).

(a) Common crash cushion installation Example 1

(b) Common crash cushion installation Example 2

(c) Less common crash cushion installation Example 1

(d) Less common crash cushion installation Example 2

Table D3. Examples Provided by Tennessee.

(a) Short Radius Guardrail Example #1

(b) Short Radius Guardrail Example #2

(c) Short Radius Guardrail Example #3