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Memorandum

U.S. Department of Transportation
Federal Highway Administration

:t: INFORMATION: Guidelines for the Selection of Crash Cushions

Date: January 3, 2000

From: Vincent F. Schimmoller
Program Manager, Infrastructure

Reply to Attn. of: HMHS

To: Resource Center Directors
Division Administrators
Federal Lands Highway Division Engineers

Section 1402 of the 1998 Transportation Equity Act for the 21st Century required the Secretary of Transportation "... to issue guidance regarding the benefits and safety performance of redirective and nonredirective crash cushions in different road applications ...," and to provide "... recommendations on the most appropriate circumstances for utilization of redirective and nonredirective crash cushions." The attached guidelines include the crash cushions that have been currently accepted for use on the National Highway System under the test evaluation criteria contained in NCHRP Report 350 and provide general information on the characteristics of each, including relative initial costs, maintenance and repair characteristics, and performance limits. Within these general guidelines, a State transportation agency may select any design that is compatible with the site at which it will be installed. The attenuators thus covered include:

- Crash Cushion Attenuating Terminal (CAT)
- Brakemaster
- ADIEM
- TRACC
- Narrow Connecticut Impact Attenuation System (NCIAS)
- REACT-350
- QuadGuard
- Sand Barrels
- Connecticut Impact Attenuation System (CIAS)
- QuadGuard 69-90
- QuadGuard LMC and QuadGuard Elite
- Wide-REACT

All of the above crash cushions, except sand barrels and the Connecticut Impact Attenuation System (CIAS), are classified as redirectional, i.e., vehicles impacting on the *sides* of these units will generally be directed back towards the roadway. Sand barrels and the CIAS will generally slow and stop ("capture") most impacting vehicles with little or no redirection. However, if the

CIAS is struck near the rear of the steel cylinders, it is designed to guide a vehicle past the shielded object. In other words, the CIAS becomes a redirectional attenuator when the impact point is close to the rear of the array. The CIAS and the NCIAS are currently the only non-proprietary crash cushions that meet NCHRP Report 350 guidelines.

Additional information on these devices can be found at http://safety.fhwa.dot.gov/roadside. If you have further questions, please call Mr. Richard Powers at 202 366-1320 or contact him at richard.powers@fhwa.dot.gov.

Attachment

GUIDELINES FOR THE SELECTION OF CRASH CUSHIONS

1. Introduction

Crash cushions or impact attenuators have gained widespread acceptance in the United States since their introduction in the early 1960's and have proven to be highly effective in reducing the severity of many crashes. According to NHTSA's Fatal Accident Reporting System (FARS) data, there were 249 total fatalities nationwide from 1988 through 1998 in which the first harmful event was reported as an impact with a crash cushion. The majority of these fatalities (184) occurred on urban freeways, expressways, and streets. Fifty-seven of the 249 fatalities occurred in work zones. Unfortunately, the total number of hits is not known, but an average of less than 25 deaths per year on crash cushions is an extremely small percentage of the approximately 40,000 deaths from all motor vehicle crashes.

Typically used to shield hazards on high-speed roadways that cannot be removed or effectively shielded by a longitudinal barrier, the number and type of crash cushions available for use have proliferated in recent years. Although each performs essentially the same function, there are differences in the various units currently available that design engineers need to consider when selecting an appropriate crash cushion for a specific site. These guidelines are intended to aid in that selection process.

2. Redirective vs. Nonredirective Crash Cushions

A redirective crash cushion may be defined as one which is designed to function like a longitudinal barrier when struck along its sides, i.e., an impacting vehicle will normally be directed back towards the roadway after a crash. Most crash cushions meeting NCHRP Report 350 evaluation criteria fall in this category. In contrast, a nonredirective crash cushion has little capability to redirect a vehicle upon impact. Instead, the vehicle is "captured" and comes to rest in the immediate vicinity of the crash cushion. The commonly-used sand barrel array is the only crash cushion that is considered to be fully nonredirective. The Connecticut Impact Attenuation System (CIAS) is a nonredirective attenuator for most hits but is designed to redirect a vehicle striking the side close to the rear of the array.

Once again from FARS data for the years 1988 through 1998, of the 188 single vehicle crashes in which striking an impact attenuator was the first harmful event, in only 83 cases was this initial impact the most harmful event. In 36 instances, the impacting vehicle overturned. In 29 instances, the most harmful event was a collision with a bridge pier, bridge rail, guardrail or concrete barrier. Forty-three persons were killed when a vehicle that first hit a crash cushion subsequently collided with one or more other vehicles on the roadway. Since the FARS data are not detailed enough to identify the specific type (or pre-crash condition) of the crash cushion that was struck, it is not possible to draw firm conclusions from this information. However, one can conclude that neither a capability to "capture" a vehicle nor a capability to redirect a vehicle will assure successful field performance. Other factors play a more important role in the selection of the "best" device for any particular application and these will be discussed below.

3. Crash Cushion Selection Guidelines - General

There are five primary characteristics of crash cushions to consider in selecting a specific type for use at any given location. These are its performance capabilities, its physical size, its compatibility with any existing features to which it may be attached, its initial cost, and its life-cycle maintenance and repair costs.

a. Performance Characteristics

For new installations, current FHWA policy requires the use of crash cushions on the National Highway System (NHS) that meet the evaluation criteria of NCHRP Report 350. Three test levels are defined in that report. Impact speeds of 50, 70, and 100 km/h correspond to test levels 1, 2, and 3. As with all barrier terminals and crash cushions, the FHWA considers a test level 3 (TL-3) device to be appropriate for use along roadways that have operating speeds up to and in excess of 100 km/h. Although it is possible to design crash cushions for end-on hits at higher impact speeds (and for vehicles larger than the 2000-kg pickup truck), the total length of a unit would have to be increased significantly to accommodate the higher speeds and heavier vehicles. Additionally, all of the tests recommended in Report 350 for a crash cushion would need to be run at the higher speed to ensure that the unit would meet the appropriate evaluation criteria for both the 820-kg car and the pickup truck for both head-on and angle hits at the nose and along the sides of the unit and that any changes made in the design would not compromise its performance for lower-speed impacts.

Some of the units described below have been modified and tested to test level 2 (70 km/h impact speed). Their use should be restricted to locations where expected impacts will be at or below the tested speed.

b. Physical size

Crash cushions generally fall into two size-related categories - narrow and wide. The narrow units are intended primarily to shield the ends of median barriers, but are sometimes used to shield the ends of roadside barriers. This latter application is seldom cost-effective since there are several barrier terminals available that are generally less expensive than a crash cushion and also have energy-absorbing capabilities.

When a wider object must be shielded, a crash cushion that is at least as wide as the hazard must be used. If sand barrels are selected, the area available for the sand barrels must be wider than the shielded object so the leading corner of the hazard can be partially shielded.

c. Compatibility

Some crash cushions have been developed for use in specific situations and can be attached directly to a median barrier whereas others need to have a rear anchorage system and oftentimes a transition section between the back of the unit and the barrier. Units that are vulnerable to wrong-direction hits must also show satisfactory performance under those impact conditions.

d. Initial Cost

The price of a crash cushion may vary considerably, but can be categorized as low, moderate, and high. Low cost units include the Crash-Cushion Attenuating Terminal (CAT), the ADIEM, and most Sand Barrel arrays. High cost units include the QuadGuard 69-90, the QuadGuard LMC, and the QuadGuard Elite.

e. Maintenance and Repair Costs

Crash cushion maintenance and repair costs can also be categorized as low, medium, and high. As would be expected, devices with the highest initial costs usually have correspondingly lower maintenance and repair costs. This is primarily due to the fact that little or no routine maintenance is required and the units are significantly "self-restoring" after many impacts. In contrast, units having high maintenance and repair costs are usually destroyed when hit and must be replaced. Units with medium repair costs typically are at least partially reusable following a crash. Regardless of the effort required to return a damaged unit to a serviceable condition, it is important that this be done as quickly as possible. The location of crash cushions, particularly those located in gore areas on high-speed, high volume freeways and expressways, makes them extremely vulnerable to frequent impacts. In these instances, a crash cushion requiring no routine maintenance and which can be replaced or repaired quickly when damaged would usually be the most appropriate choice.

4. Recommended Usage by Specific Attenuator Type

This section provides some general information on the specific types of crash cushions that currently meet NCHRP Report 350 evaluation criteria for a test level 3 (TL-3) device.

a. Crash Cushion Attenuating Terminal (CAT)

The CAT is best suited to terminate a double-faced strong-post median w-beam barrier. It can be attached directly to a w-beam median barrier and to a Thrie beam median barrier using the standard w-beam to Thrie beam transition piece. If the CAT is attached to a rigid barrier such as the concrete safety shape, a transition similar to a guardrail-to-bridge rail transition is needed. After an end-on impact, the CAT must be replaced because the w-beam rail elements are destroyed and the weakened timber posts (CRT posts) are snapped off.

b. Brakemaster

The Brakmaster is similar to the CAT in application and may be attached directly to a w-beam or Thrie beam double-faced median barrier, or to a rigid barrier with an appropriate transition. It differs from the CAT in that its support posts rest on the ground and slide backwards in an end-on crash, thus making most of the parts reuseable. However, the spring-loaded braking mechanism which is the energy absorbing device must be replaced or refurbished by the manufacturer after a crash.

c. ADIEM

The ADIEM was developed to terminate and attach directly to a concrete safety shape median barrier. It consists of a precast concrete base onto which low-strength concrete modules are placed. These modules are coated to prevent moisture from deteriorating the low-strength concrete from which they are made. Several State transportation agencies noted that the covering was easily torn during installation or as the result of minor hits and that the modules became ineffective when water penetrates the concrete. As a result, some agencies have limited the use of the ADIEM to temporary (i.e., work zone) applications. In response to this concern, the manufacturer developed and tested a plastic cover as an interim measure and has since adopted a new coating for the modules to protect the concrete from moisture.

d. Trinity Attenuating Crash Cushion (TRACC)

The TRACC is a medium- priced attenuator designed to attach to a concrete median barrier. Consisting of an impact "sled," energy absorbing tracks and w-beam side panels, it can be repaired in place for minor impacts. To repair moderate to heavy damage, the unit can be removed, replaced with a new unit, and repaired off-site.

e. Narrow Connecticut Impact Attenuation System (NCIAS)

The NCIAS is a non-proprietary design developed for the Connecticut Department of Transportation. Consisting of steel cylinders, re-directive side cables, and both front and back anchorages, this attenuator was designed to shield concrete barrier. It can be repaired on-site for minor impacts (barrels can be jacked back to "round"), but must be removed and replaced following major hits.

f. REACT-350

The REACT-350 looks similar to the NCIAS, but its cylinders are made of high-density polyethylene, a material that retains its original shape when its loading is removed. Thus, for many impacts, the REACT-350 is essentially self-restoring and requires little maintenance. It is intended primarily to shield concrete median barrier and is best used in locations where frequent hits are expected.

g. QuadGuard

The QuadGuard is the Report 350 version of the GREAT impact attenuator. While similar in function, the QuadGuard slides back on a single track when struck head-on and uses specially fabricated side panels having four corrugations in contrast to the Thrie-beam fender panels used in the GREAT. Much of the QuadGuard hardware is reusable following a crash, but the energy-absorbing cartridges in each bay need to be replaced. The QuadGuard can be attached directly to a w-beam or Thrie-beam median barrier as well as to a concrete safety shape.

h. Sand Barrels

There are currently three types of sand barrels on the market: Fitch, Energite, and TrafFix Devices. Although the individual barrel designs vary in shape by manufacturer, they all function the same and are, for the same weights, interchangeable within a given array. Sand barrels are unique in that individual arrays may be designed to shield any shape hazard using the transfer of momentum principal. Perhaps their biggest drawback is their susceptibility to damage from nuisance hits. For this reason, they are best used in areas where hits are infrequent so they do not become a continuing maintenance problem.

Since the sand barrels have no appreciable redirective capability, care must be used in the design to ensure the corner of the hazard is reasonably shielded. To accomplish this, the rear corner barrel should overlap the shielded object by at least 30 inches. The FHWA has also allowed a modified single row design for temporary use in work zones where traffic passes on one side only of the array.

i. Connecticut Impact Attenuation System (CIAS)

Like the NCIAS, the CIAS is a non-proprietary crash cushion made from steel cylinders. However, it is intended to shield wide hazards. Vehicles impacting near the front of the CIAS are "captured" by the cylinders as they collapse under load, but vehicles striking the side of the unit near the back are directed past the shielded object. The CIAS can be refurbished in place following minor hits, but must be removed and replaced if it is significantly collapsed.

j. QuadGuard 69-90

This unit is similar to the basic QuadGuard discussed above, but has outwardly tapered sides so it can be used to shield wider hazards.

k. QuadGuard LMC and QuadGuard Elite

These two units use the same general framework as the QuadGuard, but use different energy absorbing elements. The QuadGuard LMC uses elastomeric cylinders and the QuadGuard Elite uses the same type of high density polyethylene cylinders that are used in the REACT-350. Both units are essentially self-restoring after most impacts and are best suited for use in locations where a high number of hits are anticipated.

l. Wide-REACT

This unit is similar to the original REACT-350, but uses a double column of polyethylene cylinders that are separated from each other so an area up to approximately 10 feet wide can be shielded. Four steel cables are anchored front and back on each side of the unit to provide redirection in side impacts. The manufacturer, Energy Absorption, Inc., has placed a moratorium on the sale of this unit based on unsatisfactory test results on a variation of the Wide-REACT design.

5. Need for Continuing Surveillance

One of the major drawbacks in selecting the most appropriate crash cushion to use at a specific location is the lack of usable field performance data. Although some conclusions can be drawn from available FARS data, critical information such as the type of crash cushion struck or its condition prior to impact is not readily available. There have been some detailed studies on impact attenuator performance in the past by individual State transportation agencies, but more current information is needed to assess the performance of the many new types of devices that are currently being installed. Since the annual number of fatal crashes into impact attenuators is relatively small, it should not be particularly difficult to obtain detailed information on each fatal accident to determine whether or not the performance of the device itself was a factor in the crash severity.

There are numerous types of crash cushions currently in place nationwide. Many of the designs popular in the 1970's were not tested to the standards we use today and many are maintenance-intensive (such as the water-filled units). Such crash cushions should be systematically replaced with crashworthy designs. Although FHWA policy allows existing crash cushions that at least meet NCHRP Report 230 guidelines to remain in place when 3R-type projects are undertaken, State transportation agencies should be encouraged to upgrade these installations when the opportunity arises.

6. References

There have been several publications which discussed crash cushion design, testing and selection. While the information in some of them is outdated, these documents provide historical information as well as basic background information on the evolution of crash cushion usage in the United States. These documents include:

"CRASH CUSHIONS: Selection Criteria and Design", FHWA Report, September 1975.

AASHTO "Guide for Selecting, Locating, and Designing Traffic Barriers," 1977.

NCHRP Report 230, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," March 1981.

AASHTO "Roadside Design Guide," 1989.

NCHRP Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features," 1993.

NCHRP Synthesis 205, "Performance and Operational Experience of Crash Cushions - A Synthesis of Highway Practice," 1994.

AASHTO "Roadside Design Guide," 1996.

U.S. Department of Transportation
Federal Highway Administration

Memorandum

SENT VIA ELECTRONIC MAIL

Subject: ACTION: Supplementary Guidance for the Selection of W-Beam Barrier Terminals

Date: ... 17

From: George E. Rice Jr. for John R. Baxter, P.E.
Director, Office of Safety Design

Reply to Attn of: HSA-10

To: Safety Field

My October 26, 2004, memorandum, "Guidance for the Selection of W-beam Terminals", transmitted detailed information intended for use by roadway designers as an aid in selecting the most appropriate W-beam terminal for a specific site. The guidelines presented therein are currently being reviewed by members of the AASHTO Technical Committee for Roadside Safety for inclusion in the next edition of the AASHTO Roadside Design Guide (RDG). In the meantime, some have expressed a concern that the federal guidelines are misleading in regard to the runout areas needed behind and beyond gating terminals. This memorandum provides additional information to assist designers in making appropriate barrier terminal selections.

Current terminal selection recommendations, both in the FHWA Guidelines and in the 2002 RDG, call for a minimum distance of 75' x 20' adjacent to the backside of the W-beam immediately downstream from the terminal end. This distance is clearly noted as being a minimum distance based on the final resting position of the 1800-lb small car in several W-beam terminal end-on tests (NCHRP Report 350 test 3-30). Given the greater weight and resultant impact severity of the 4400-lb pickup truck, it is obvious that a greater runout area would be needed for the truck impact at the same speed and angle (test 3-31). Several individual acceptance letters have specifically noted the distance traveled by the pickup truck in the certification tests and have recommended a minimum length of barrier to accommodate the observed post-crash trajectory.

To assist the designer in selecting an appropriate terminal at a specific site, I am attaching both a tabular and a graphic summary showing the distances traveled and the reported resting positions of both types of test vehicles in selected certification tests. These test data show the reported resting positions of both the small car and the pickup truck after impacts into energy-absorbing designs (BEST, ET-series, SKT, and FLEAT) and non-energy absorbing designs (REGENT, SRT). As would be expected, in the end-on tests (3-30 and 3-31) the impacting vehicles traveled

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a greater distance behind the barrier after striking non-energy absorbing terminals. Also as expected, terminal type has little affect on a vehicle's post-crash travel distance when impacted at an angle (tests 3-32 and 3-33) because energy-absorbing terminals are most effective in limiting penetration behind the barrier in head-on crashes. Finally, as noted above, higher weight vehicles traveled further distances after impact.

The selection of an appropriate W-beam terminal must be a deliberate choice based on specific site conditions. At locations where:

- flat angle impacts are possible and the terrain behind and adjacent to the barrier could allow a vehicle to reach the shielded hazard, or
- where the terrain behind and adjacent to the barrier in advance of the primary (shielded) area of concern is itself likely to cause serious occupant injuries in a crash,

either the barrier itself should be lengthened to lessen the likelihood that a vehicle behind the rail will reach the primary (or any secondary) fixed object or non-traversable terrain, or ***an energy-absorbing terminal should be considered.*** Even in the latter instance, the recommended minimum runout area should be provided wherever practical.

Please discuss barrier terminal selection procedures with those in the State DOT responsible for this activity to ensure they are aware of current guidelines and are taking them into consideration in their terminal selection and installation decisions. States not already doing so should also be asked to investigate all fatal crashes involving barrier terminals to determine if the barrier length or terminal type/location may have contributed to the crash severity. In-service performance evaluation of all safety appurtenances is the only means available to verify the assumed crashworthiness of safety hardware based on limited certification tests and to identify unforeseen problems with hardware that need to be addressed.

Attachment

Full Scale Crash Test Results for W-Beam Terminals

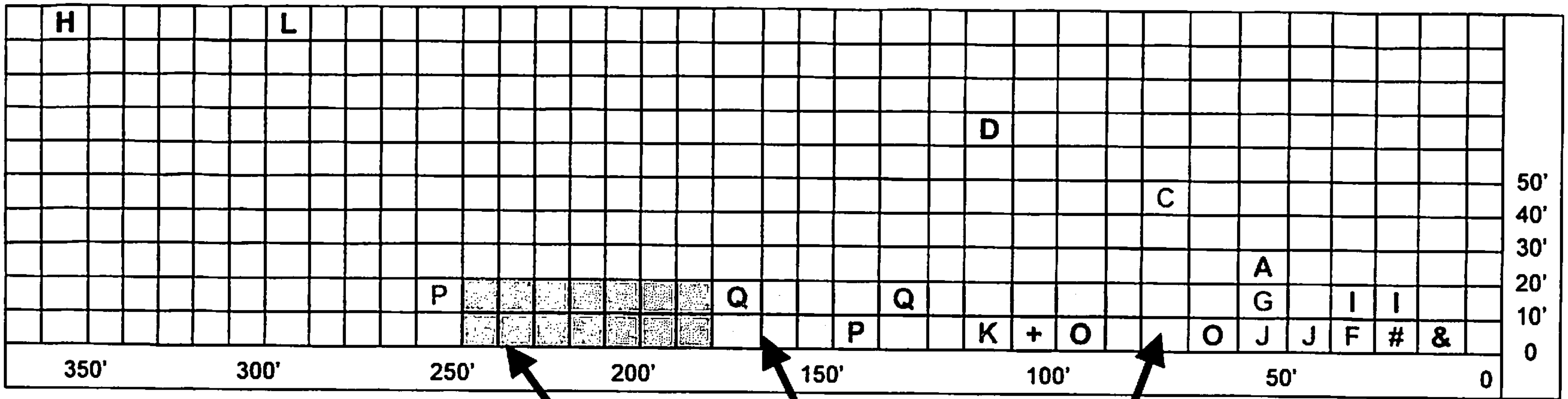
(Final Resting Position of Vehicle Shown for TL-3 Impact Condition)

System Type / Name	Test 3-30 820kg / 0 deg / offset W/4	Test 3-31 2000kg / 0 deg / centered	Test 3-32 820kg / 15 deg / centered	Test 3-33 2000kg / 15 deg / centered
Tangent **BEST** Energy Absorbing	Lat. 8.8 m (28.9 ft) Long. 17.1 m (56.1 ft)	Lat. 0.9 m (3.0 ft) Long. 8.9 m (29.2 ft)	Lat. 13.2 m (43.3 ft) Long. 21.7 m (71.2 ft)	Lat. 21.3 m (69.9 ft) Long. 36.6m (120 ft)
Tangent **ET 2000** Energy Absorbing	Lat. 1.7 m (5.6 ft) Long. 6.3 m (20.7 ft)	Lat. 2.0 m (6.6 ft) Long. 7.62 m (25.0 ft) Lat. 0.0 m (0.0 ft) Long. 12.0 m (39.4 ft)	Lat. 4.6 m (15.1 ft) Long. 17.1 m (56.1 ft)	Lat. 36.6 m (120 ft) Long. 107.9 m (354 ft)
Tangent **SKT** Energy Absorbing	Lat. 5.0 m (16.4 ft) Long. 10 m (32.8 ft) Lat. 5.7 m (18.7 ft) Long. 8.5 m (27.9 ft)	Lat. 0.0 m (0.0 ft) Long. 15.2 m (49.9 ft) Lat. 0.0 m (0.0 ft) Long. 17.5 m (57.4 ft)	Lat. 2.0 m (6.6 ft) Long. 37.0 m (121 ft)	Lat. 35 m (115 ft) Long. 90 m (295 ft)
Flared **FLEAT** Energy Absorbing	Lat. 0.0 m (0.0 ft) Long. 5.5 m (18.0 ft)	Lat. 1.7 m (5.6 ft) **Long. 32.0 m (105 ft) Lat. 1.6 m (5.3 ft) Long. 9.7 m (31.8 ft)	Did Not Conduct	Did Not Conduct
Flared **REGENT** Non-Energy Absorbing	Lat. 3.0 m (9.8 ft) Long. 19.0 m (62.3 ft) Lat. 1.5 m (4.9 ft) Long. 29.5 m (96.8 ft)	Lat. 1.0 m (3.3 ft) Long. 44.0 m (144 ft) Lat. 4.6 m (15.1 ft) Long. 77.2 m (253 ft)	Did Not Conduct	Did Not Conduct
Flared **SRT** Non-Energy Absorbing	Numbers Were Not Reported	Lat. 5.2 m (17.1 ft) Long. 41.8 m (137 ft) Lat. Not Reported Long. Past the 53.3 m (175 ft) test installation	Did Not Conduct	Did Not Conduct

** The FLEAT 3-31 Long. 32.0 m (105 ft) value is from a test involving the impact head deforming sufficiently to block the rail outlet. The rail kinking stopped after only about 1.5 m (5 ft). When the impact head was further reinforced to prevent this behavior the vehicle stopped about 1/3 the distance.

Post Impact Vehicle Trajectories

(Shown are Final Resting Positions for Various NCHRP 350 Roadside Terminals)



A – BEST Terminal Test 3-30
B – BEST Terminal Test 3-31
C – BEST Terminal Test 3-32
D – BEST Terminal Test 3-33

E – ET Terminal Test 3-30
F – ET Terminal Test 3-31
G – ET Terminal Test 3-32
H – ET Terminal Test 3-33

I – SKT Terminal Test 3-30
J – SKT Terminal Test 3-31
K – SKT Terminal Test 3-32
L – SKT Terminal Test 3-33

M – FLEAT Terminal Test 3-30
N – FLEAT Terminal Test 3-31

O – REGENT Terminal Test 3-30
P – REGENT Terminal Test 3-31

Q – SRT Terminal Test 3-31

Vehicles May Travel Over 75 m (250 ft) With Non-Energy Absorbing Terminals

B + F+ N
& E + M
+ N (early design, see note)

23 m (75 ft) x 6 m (20 ft) Area as Described in the AASHTO RDG Section 8.2

Non-Energy Absorbing Terminals:

Recommended Minimum 175 ft. Clear Area Where the Vehicle Can Travel. Refer to FHWA Acceptance Letters:

- **CC-56A – MNDOT – Eccentric Loader Terminal**
- **CC-72 – Trinity Industries – Slotted Rail Terminal**
- **CC-80 – Energy Absorption Systems – REGENT**
- **CC-84 – CTDOT – TL-2 MELT Terminal**