STATE OF TENNESSEE
DEPARTMENT OF TRANSPORTATION
DESIGN DIVISION
NASHVILLE, TENNESSEE 37243

INSTRUCTIONAL BULLETIN NO. 12-03

Regarding Crash Cushions Design

Effective Immediately, Section 4-706.00 "END TREATMENTS" is added to the Design Guidelines and subsection 4-705.05 is moved in whole to 4-706.20

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CS:ARH:MWC

4-706.00 END TREATMENTS

4-706.10 ANCHORAGES (RESERVED)

4-706.20 GUARDRAIL END TERMINALS

On the designated state highway system, when using gating type approach end terminals, it is required to specify an end terminal that meets NCHRP 350 crash criteria. Tangential Energy Absorbing Guardrail End Terminals shall be used per Standard Drawing S-GR-43 and S-GR-44, Item No. 705-04.07.

The most desirable approach end terminal continues to be buried in backslope, Guardrail End Terminal (Type 12), Item No. 705-04.02. When it is not applicable to use this type of end terminal, a gating type, tangential energy absorbing guardrail end terminal (type 38) shall be used.

On all other roads not on the designated state highway system, including side roads to state and U.S. highways, when the current design speed exceeds 40 miles per hour, the same type of terminals meeting the NCHRP 350 crash criteria are required as stated above.

On all low speed roads not on the designated state highway system, including side roads to state and U.S. routes, when the current design speed is 40 miles per hour or less, the Slotted Rail Terminal - SRT 75 (Type 21) terminal anchor, or equal shall be used. Payment is to be made under Item No. 705-04.04 Guardrail Terminal (Type 21).

On all low speed, low volume local bridge replacement projects, standard drawing S-GR-23A should be used. The standard details the guardrail attachment at bridge ends and the minimum length of installation for low volume (current ADT ≤ 400) local roads with speeds of 40 mph or less. The use of the earth pad as shown on standard drawing S-GR-39 is not required for this installation.

4-706.30 DESIGN AND SELECTION CRITERIA FOR CRASH CUSHIONS

4-705.31 GENERAL DESIGN PRINCIPLES

Crash cushions (impact attenuators) are used to shield fixed roadside objects located within the clear zone such as bridge piers, overhead sign supports, ends of retaining walls, concrete median barriers, bridge abutments, and bridge railings. Crash cushions operate on the basis of energy absorption or energy transfer by either decelerating a vehicle to a controlled stop after a frontal impact, or by redirecting a vehicle away from a fixed object after a side impact. Where a fixed roadside object is identified, the designer should first consider removing, relocating, making the object breakaway, or shielding the fixed object with a longitudinal barrier. Where this is impractical, the use of an approved crash cushion system should be considered.

All crash cushions specified on TDOT projects must be accepted as crashworthy by the FHWA in accordance with either *NCHRP Report 350* or the *AASHTO Manual for Assessing Safety Hardware (MASH)* for Test Level 3 (TL-3). This requirement shall apply to all temporary work zone and permanent installations.

4-705.32 WORK ENERGY PRINCIPLE (NON-GATING, RE-DIRECTIVE SYSTEMS)

Crash cushion design based on the work energy principle involves the reduction of an impacting vehicle's kinetic energy to zero. Assuming that a vehicle will be stopped after an impact, then the "work" done on a vehicle equals the initial kinetic energy of the vehicle. An impact to a crash cushion will result in some damage to a vehicle; however, under the work energy principle, the potential for serious injury to the vehicle occupants is reduced.

Crash cushions that operate under the work energy principle utilize "crushable" or "deformable" material to convert the kinetic energy of a vehicle into other forms of energy including mechanical, potential, heat, and sound energy. Crash cushions of this type, referred to as compression crash cushions require a rigid support back-up structure or foundation to resist the impact force of the vehicle utilizing the energy-absorbing material. These types of crash cushions are considered non-gating, re-directive systems, in that they are not intended to capture the vehicle upon impact (unless frontal impact occurs); but rather, redirect the vehicle after collision. Various systems are available that offer re-directive capabilities on one or both sides of the system.

Table summarizes the three types of non-gating/re-directive crash cushion systems considered acceptable for use on TDOT projects.

Non-Gating Crash Cushion Classification	Roadway Location Characteristics			
	ADT	Impact Frequency per Year	Distance (D) from Travel Way (feet)	Repair Considerations
Sacrificial	<25,000	N/A[1]	D>10	Requires entire system replacement when hit
Reusable	<25,000	1-2	D>10	Many reusable components, Unlimited repair time
Low Maintenance/Self Restoring	≥25,000	3 or more	D≤10	Time and work space limitations, Multiple hits before repairs needed

[1] Low history or expectation of impacts occurring over lifetime of crash cushion.

Table
Non-Gating Re-directive Crash Cushion Classification

4-705.33 CONSERVATION OF MOMENTUM PRINCIPLE (GATING SYSTEMS)

The conservation of momentum principle for crash cushion design involves the transfer of the vehicle's momentum to an expandable mass of material located in the vehicle's path. The conservation of momentum principle is involved with all crash cushion impacts, since some portion of a vehicle's kinetic energy is transferred to the cushion by accelerating and moving various components of the cushion during an impact. For gating systems, this expandable mass will normally consist of containers filled with sand. Sometimes referred to as inertial crash cushions, these types of systems require no rigid backup or support to resist a vehicle's impact force, and may be used for both temporary and permanent installations.

Gating systems are energy dissipation devices only, and rely on the conservation of momentum principle. They have no capability to re-direct an errant vehicle; but rather, will either capture a vehicle or allow it to pass through the system along the same general path. Use of a gating crash cushion should be limited to locations where the roadside object is not likely to be impacted at an angle on the side with any significant velocity, or when no other safety device product will fit the location (i.e. very wide hazards). Also, gating systems may be appropriate for use on low speed facilities and in temporary work zones with higher speeds where lane widths are constrained and the potential for a high angle impact is limited. Every gating system must be specifically designed for the fixed object that it is intended to shield.

For gating, non-redirective systems (i.e. sand-filled barrel arrays), the designer should verify that adequate clear run-out area is available behind the device. Barrel arrays should not be used where there is high potential for vehicles to impact the device in the reverse direction (e.g. a vehicle would hit the heaviest barrels placed directly adjacent to the fixed object being shielded).

4-705.34 CRASH CUSHION SELECTION GUIDELINES

The location of all crash cushions should be shown on the Proposed Layout Sheets along with the cushion type for each occurrence of a crash cushion on the project. In addition, the designer should provide the available reserve area (length and width after deducting for offsets - See Figure) for each location where a crash cushion is to be installed. Contractors will be required to determine the proper unit when they bid the project, so that it will fit the location shown on the plans. In some instances, it may be necessary to provide special details for a given location. When special details are required, they should be shown on the Detail Sheets within the final construction plans.

The criteria for selecting crash cushions should be based on crash history and ADT. For existing roadways, the crash history and roadway characteristics will provide the designer with important information for selecting the appropriate type of system. Average Daily Traffic should be used as the barometer for impact frequency on new installations and at sites where crash history is not available. Additionally, repair times, proximity to roadway, and gore areas should also be considered when selecting the appropriate crash cushion system.

Once a decision has been made that a roadside object should be shielded by a crash cushion, the designer should consider the following factors when selecting a system for a particular location:

- Site characteristics
- Structural and safety characteristics of the systems

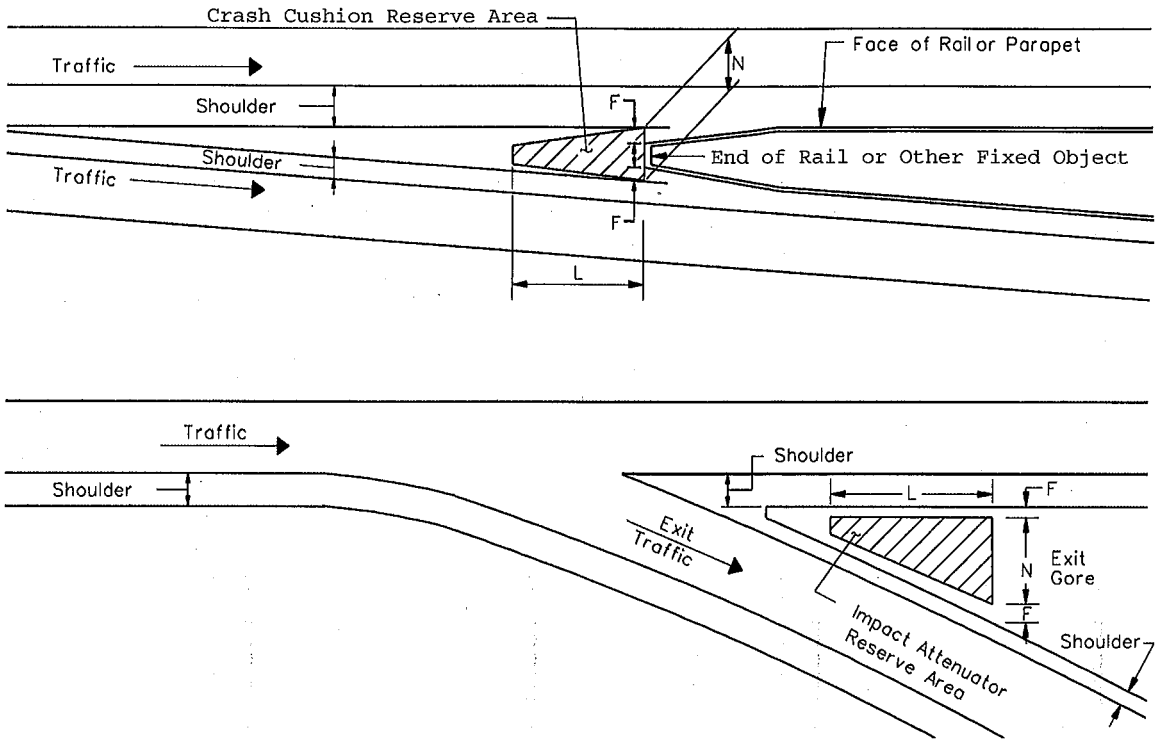
- System costs
- Maintenance characteristics

Each of these factors should be considered in the selection process and are further discussed in the following sections.

4-705.35 SITE CHARACTERISTICS

Provisions for providing adequate space (reserve area) for crash cushions to shield fixed objects should be made during the preliminary plan stage for new roadway construction projects and for the rehabilitation or reconstruction of existing roadways. Figure suggests the minimum and desired reserve area dimensions that should be made available. Although a gore location is depicted in Figure, the recommendations in the table can be applied to other fixed objects that require shielding. The preferred condition represents the optimum and desirable values for any location. The unrestricted conditions represent the minimum dimensions for all locations. The restricted conditions shall be used only where it can be demonstrated that dimensions of the unrestricted condition are unattainable. The information in the table is for preliminary design purposes. Final design should be based on the crash cushion system selected and the manufacturer's specifications. Additionally, the table values are generic and may not apply to some proprietary systems.

For preliminary design purposes, the terms N and L in Figure represent the assumed width (N) and length (L) of space necessary for the placement of a crash cushion. F is the maximum width of the fixed object that requires shielding. For concrete barriers (temporary or permanent), F is considered the widest width above the finished grade of the surface.



Design Speed on Mainline (mph)	Dimensions for Crash Cushion, Reserve Area (feet)								
	Minimum Dimensions						Preferred Conditions		
	Restricted Conditions			Unrestricted Conditions					
	N	L	F	N	L	F	N	L	F
30	6	8	2	8	11	3	12	17	4
50	6	17	2	8	25	3	12	33	4
70	6	28	2	8	45	3	12	55	4

Figure
Area Available for Crash Cushion Installation

The designer should be aware of the site conditions that might dictate the type of crash cushion needed; especially in terms of width. Where a fixed object's width (F) is less than 36 inches, the object can be shielded with a narrow crash cushion. Where F is greater than 16 feet, sand barrel arrays can effectively shield the obstacle. Sand barrel designs are usually more adaptable to wide obstacles and the redirective non-gating systems to narrow obstacles.

In general, the width of any selected system should be as narrow as possible while still providing the appropriate level of attenuation for the fixed object.

To allow crash cushions to compress uniformly during an impact, systems should be installed on a hard, smooth, and generally flat surface of asphalt or concrete (preferred). All non-gating systems will require a foundation of this type. This can easily be accommodated for in new construction; however, at retrofit locations or major roadway rehabilitation sites, the designer should attempt to remove sloped surfaces as part of the project plans. Longitudinal and transverse slopes in excess of 5 percent should be avoided. Additionally, if the cross slope varies by more than 2 percent over the length of the system, the designer may need to make site alterations. For gating systems, the hard flat surface should be provided so as to provide a uniform foundation on which the barrel-array pattern may be installed and the design masses of the sand-filled barrels can be marked. These marked locations will aid in the proper reconstruction of the barrel system to its originally designed capacity and configuration after a vehicle impact.

On new construction projects, no curb, curb and gutter, or raised pavement should be designed in the area surrounding or occupied by the crash cushion. When retrofitting an existing location, existing curbs, curb and gutter, or raised pavement should be removed where possible. If an existing curb is to remain, it shall be no more than 4 inches in height. The designer should also verify that the existing curb has not previously contributed to poor crash performance.

The designer should verify if sight distance will be compromised by installing a crash cushion at some intersection locations (i.e. locations at the end of concrete median barriers located at at-grade intersections). Where this is a concern, the designer should choose a system that provides reduced overall height while still meeting the attenuation need at the location.

4-705.36 STRUCTURAL AND SAFETY CHARACTERISTICS

Often times more than one approved system will fit a specific location. The designer should evaluate the structural and safety characteristics of each crash cushion system to including impact deceleration, re-directive capabilities, anchorage, backup structure needs, and the amount of debris that could be produced when a vehicle impacts the system.

Systems approved for TL-3 criteria have the capability to decelerate an impacting vehicle within tolerable levels or to re-direct or contain (capture) vehicles impacting the sides of the crash cushion system. TL-3 criteria shall be met for all permanent or temporary crash cushion systems specified on TDOT projects.

The necessity or need for redirective capabilities of the system should be evaluated during the plan development process. Non-gating systems provide redirective capabilities to a vehicle impacting downstream of the nose of the unit. Gating systems have no capability to re-direct an errant vehicle in a side impact; and thus, should be limited to locations where the hazard is not likely to be impacted at an angle or where rear corner impacts are not likely to occur.

Non-gating, redirective systems will require rigid backup and anchorage for the system to function properly. This may be specifically designed backup or the obstacle itself may serve as the backup. Transitions between the non-gating crash cushion system and the shielded object should be smoothly shaped to reduce the possibility of vehicular snagging.

Roadway joints, especially bridge expansion joints or deflection joints in deep superstructures within the crash cushion area may require special design accommodations pertaining to ground anchorage.

While gating crash cushion systems can be designed to shield obstructions of practically any width, the potential to generate considerable debris when hit is relatively high. Gating systems should not be used where flying debris (sand, lids, etc.) could pose a danger to pedestrians or other motorists.

4-705.37 SYSTEM COSTS

The cost of the various crash cushion systems should be considered during the selection process. Cost considerations should include site preparation cost, initial material and installation cost, maintenance costs, and repair or replacement costs. Life cycle cost for repairing or replacing a crash cushion system could be a significant factor in the selection process, especially at locations where frequent hits are expected. Consideration for each available system is as follows:

Sacrificial Crash Cushions - In terms of cost, non-gating crash cushions considered sacrificial (replaceable) are generally designed for a single impact. These systems offer low initial costs and may be cost effective if used at locations where the designer expects infrequent crashes to occur, where the existing crash history is low, and the ADT is less than 25,000. Full replacement or substantial field repairs may be required following an impact.

Reusable Crash Cushions - Reusable (resettable) crash cushions generally have some parts that will need to be replaced after a hit to make the unit crashworthy again; however, major components of the non-gating system may survive an impact. Reusable products are generally more expensive than the sacrificial systems; however, these systems are appropriate in locations where the ADT<25,000, frequent crashes (1 to 2 per year) may occur, or where the crash history is unknown (e.g. a new design location). Generally, these systems are field repairable within moderate parts cost and time constraints.

Low Maintenance/Self Restoring Crash Cushions - Crash cushions categorized as low maintenance/self-restoring systems are premium non-gating systems designed for high traffic areas and locations where vehicular impacts can be expected frequently. The long term maintenance and repair cost savings obtained by using a self-restoring system may offset the initial higher cost. These systems are generally installed on high-speed, high volume roadways (ADT>25,000), ramps, or medians where a high frequency (3 or more per year) of impacts may be expected or is occurring. Many available systems can sustain multiple hits before repairs are needed.

Gating Crash Cushions – Gating systems such as sand barrel arrays are systems that generally have a lower initial cost compared to non-gating systems, but have relatively high maintenance costs, and should be considered for locations well off the roadway where frequent hits are not expected or locations where no other safety device product will fit the location (i.e. very wide obstructions). See additional requirements for allowable use.

4-705.38 MAINTENANCE CHARACTERISTICS

Future inspection and maintenance should be considered by the designer when selecting the appropriate crash cushion system. The designer should be aware that periodic maintenance and inspection will be necessary to confirm that the installed system remains fully functional as intended. The frequency and expected difficulty (or ease) to perform inspection and/or maintenance on the system should be factored into the final selection of the crash cushion. Maintenance characteristics can be classified as either:

- Regular/Routine Maintenance - systems requiring minimal routine maintenance
- Crash Maintenance - required on system as a result of a vehicular impact
- Material Inventory Needs

The use of a low maintenance/self-restoring system should be considered at locations with a history of frequent hits (3 or more per year) or where lateral clearance restrictions make maintenance activities difficult, problematic, or will cause significant traffic delays and traffic exposure risk to maintenance personnel. Where nuisance hits are relatively common, a crash cushion with re-directive capabilities should be considered to reduce the effort required for minor repairs or partial replacement of a system. Crash cushions that utilize a hex-foam cartridge may require periodic inspection to verify that the cartridges have not deteriorated.

For sand-barrel array systems, the plastic barrels may degrade over time due to exposure to ultraviolet light, and therefore requires periodic inspection and possible replacement of barrels due to cracking; especially at locations that have been in service for 10 or more years. Additionally, the barrel lids should be inspected periodically to insure they are securely fastened to the barrels.

Ideally, permanent repairs should be made quickly; therefore, the type and amount of spare parts kept on hand, or that are quickly attainable should be considered. The availability of parts required to restore any system to its original design capacity is closely associated with repair time and cost. The ability of the Maintenance Division to place a damaged system back into service quickly should be a major consideration in the design and selection process.

4-705.39 TEMPORARY WORK ZONES

For temporary work or construction zones, the designer should select a crash cushion system consistent with the expected time and site conditions that may be present at the given location. All crash cushions installed in temporary work zones shall meet Test Level 3 criteria, and each system must be accepted by FHWA as listed on the Qualified Products List. Temporary systems shall be selected, designed, and installed based on the same guidance provided for permanent applications.

Both non-gating and gating systems are approved for use in temporary work zones on TDOT project. Non-gating, redirective systems are available in narrow widths; and thus, have the ability to satisfy attenuation requirements where working conditions are constrained; provided that a paved surface is available for proper anchorage. Where lane widths are constrained, gating systems designed to protect the ends of temporary concrete barrier or other fixed object are acceptable due to the reduced potential for angled impacts. Additionally, some

gating systems do not require a paved surface for short-term temporary installation. Water filled gating systems should be used for temporary work zones only as approved by FHWA.

With all temporary applications, the selected system should provide adequate separation distance between the installed system and the actual area where work is being performed due to the possibility of flying debris during an impact. Additionally, sight distance at intersecting roadways or points of ingress/egress to the work zone should be considered and checked during the selection process.