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# Memorandum

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Subject: INFORMATION: Guidelines for the Selection of W-Beam Barrier Terminals

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In Reply Refer To: HSA-10

To: Resource Center Directors
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Since late 1998, W-beam terminals installed on the NHS have been required to be crashworthy. The NCHRP Report 350 was adopted in 1993 as the standard by which the "crashworthiness" of roadside hardware is judged and its adoption has resulted in many new or re-designed terminals for W-Beam guardrail. However, all crashworthy terminals do not have the same performance characteristics and thus should not be used interchangeably without regard to site-specific conditions. The purpose of this memorandum is to provide specific information on the characteristics of most W-beam guardrail terminals that have been accepted for use on the NHS under the test evaluation criteria contained in NCHRP Report 350, and to provide guidelines for their selection. In addition, it provides specific information on the proper design and use of the generic buried-in-backslope design, an issue that was raised by the NTSB in conjunction with its recent report on a multiple fatality crash.

Designers must assure that all W-beam terminals, especially those that do not dissipate significant impact energy in end-on hits, are situated to provide an adequate recovery area behind the terminal. Adequate advance grading, adjacent grading and runout distance grading are critical for achieving optimal crash performance for all W-beam terminal designs. For a buried-in-backslope terminal, care should be given to assuring a proper length of need is established and that an appropriate recovery area is provided beyond and behind the rail if the backslope is flatter than approximately 1:1. In addition, the guardrail height for a buried-in-backslope terminal design should be measured from the roadway grade and not from the ground directly below the rail on high-speed NHS routes.

The attached guidelines provide general information on a number of W-beam barrier end treatments as well as an expanded discussion of the design criteria noted above. Detailed information on specific terminals is at http://safety.fhwa.dot.gov/report350hardware under Terminals and Crash Cushions, using the keyword “W-beam Terminals” from the dropdown list. If you have further questions, please contact Mr. Richard Powers at (202) 366-1320 or at richard.powers@fhwa.dot.gov.

Attachment

## GUIDELINES FOR THE SELECTION OF W-BEAM BARRIER TERMINALS

### 1. Introduction

These guidelines are intended for use by design, construction and maintenance personnel involved with the selection, design, installation, or repair of terminals used with roadside W-beam guardrail. They do not address terminals for any type of median barrier or for any roadside barrier other than strong-post W-beam or Thrie-beam that is transitioned to W-beam.

As is often stated, barrier itself is a hazard and its use is justified only when impacts with a barrier are likely to be less severe than the consequences of a vehicle continuing off the roadway at the same location. To be effective, the barrier itself must be long enough and high enough to intercept a vehicle prior to its reaching a shielded object or non-traversable terrain. The primary purpose of a W-beam terminal is to provide anchorage for the barrier to allow development of the full tensile strength of the W-beam rail element for all impacts within the barrier length of need (LON) while minimizing injury to vehicle occupants in the event of a crash near or at the end of the terminal. Crashworthy terminals are required on all guardrail installations on the NHS and recommended for use on all public roads.

Terminals are subjected to a series of tests in which the vehicle type, size, orientation, impact speed and angle, and point of contact are all specified. Crashworthiness is assumed if a terminal has met all of the evaluation criteria listed in the NCHRP Report 350 for each of the required crash tests. As many as seven tests are generally required and virtually all terminal tests to date have been conducted over flat approach terrain that extends behind and beyond the test installations. An important fact noted in NCHRP Report 350 is that roadside features that have met the evaluation criteria for a given test level may often have different performance characteristics. A second fact to note is that actual crashes will almost always differ from the specified test conditions – vehicle types, vehicle position at impact, impact angles, impact speeds, points of initial contact, site conditions, and driver reactions all have a significant effect on the end results of a real-world crash. Optimal terminal performance is most likely to occur when both the crash conditions and the site conditions closely replicate the test conditions.

### 2. Terminal Characteristics

Although the terms “gating” and “non-gating” have traditionally been used to categorize terminal designs, these definitions are seriously misleading when applied to W-beam terminals. **All the W-beam terminals discussed below, except some buried-in-backslope treatments, are gating terminals.** That means simply that all of them, when struck at or near the nose at an angle of 15 degrees or greater, will yield readily, allowing a vehicle to continue into the area immediately behind and beyond the terminal. Thus, for angle hits of 15 degrees or higher at or near the first post, all W-beam terminals perform about the same and most impacting vehicles will travel behind and beyond the terminal.

W-beam guardrail terminals have also been classified as either tangent designs (installed parallel to the roadway edge) or flared designs (flared away from the roadway). Experience has shown, however, that even “tangent” terminals such as the ET-2000 and the SKT-350, are best installed with a one or two-foot offset from the line of barrier proper (over the entire terminal length) to minimize nuisance hits. Typical flared terminals such as the ELT and the SRT generally require a 4-foot offset from the barrier itself although some designs have been successfully tested with lesser offsets. The actual offset distance of a terminal may have a significant affect on site grading requirements as discussed later in more detail. However, the most significant difference in terminal performance is whether or not a terminal is likely to slow an impacting vehicle appreciably in near end-on crashes.

Tangent terminals have been designed and developed to dissipate significant amounts of the kinetic energy in a head-on crash and are considered to be energy-absorbing designs. In high-speed, head on impacts on the terminal nose, energy-absorbing terminals have demonstrated their ability to stop impacting vehicles safely in relatively short distances (usually 50 feet or less depending on type of terminal). Most flared terminals are classified as non-energy absorbing designs and will allow an unbraked vehicle to travel over 150 feet behind and parallel to the guardrail installation or along the top of the barrier when struck head-on at high speeds.

The decision to use an energy-absorbing terminal versus a non-energy absorbing terminal should be based on the likelihood of a near end-on impact and the nature of the recovery area immediately behind and beyond the terminal. **If the barrier length of need was properly determined, it is unlikely that a vehicle will reach the primary shielded object after an end-on impact regardless of the terminal type selected. However, if the terrain beyond the terminal end and immediately behind the barrier is not safely traversable, an energy-absorbing terminal is recommended.**

## 3. Site Grading Requirements

Grading in the area of the terminal is an important consideration regardless of the specific terminal type used. As previously noted, terminals are tested for crashworthiness on flat and unobstructed terrain which is a feature seldom found in field applications. The grading must be considered from three perspectives:

***advance grading***, ***adjacent grading*** and ***runout distance grading***. Proper grading in **advance** of the terminal is needed to be sure the vehicle is stable at the point of initial contact. Proper grading **adjacent** to the terminal is needed to be sure the vehicle remains stable while in physical contact with the terminal. Finally, proper ***runout distance grading*** immediately downstream and behind the terminal is needed to be sure the vehicle remains stable after it clears the terminal and comes to a stop. This runout distance, not to be confused with the runout length needed to calculate barrier length of need, is especially important for near end-on hits into non-energy absorbing terminals.

***Advance grading*** must be applied to the terrain over which a vehicle may travel before contact with a barrier terminal. For W-beam terminals, this area should be no steeper than 10:1 to ensure that a vehicle is stable at the moment of impact and that its suspension is neither extended nor compressed. Some design standards require construction of a grading platform or "bulge" in the roadside slope to accommodate a terminal installation. In some cases, this bulge creates slope discontinuities in advance of the terminal that may cause motorists to lose control of their vehicles and possibly overturn before reaching the terminal. Some grading platforms create significantly steeper slopes immediately behind the terminal as well. When grading platforms are built, they must be smoothly transitioned to existing sideslopes so that the entire roadside approach to the barrier remains traversable as well as the area immediately behind it. In many instances, it will be more cost-effective to extend the barrier itself so its terminal can be installed without the need for additional earthwork or to use a terminal that requires less flare.

***Adjacent grading*** refers to the area on which the terminal is installed and the area immediately behind it. Ideally, this area should be essentially flat so the terrain itself does not exacerbate vehicle roll, pitch or yaw upon impact with the terminal. For impacts into the side of a terminal where redirection is expected (from the third post back for current W-beam terminals), the terminal posts should have at least 2 feet of soil support behind them. For near head-on impacts, a relatively flat area should extend 5 feet behind the terminal nose in a direction away from the roadway so a motorist striking the terminal with the left front of a vehicle will not have reached a high roll angle prior to impact. These recommended dimensions are shown in Figure 8.2 in the 2002 AASHTO Roadside Design Guide. If a grading platform was constructed, the departure end of this platform must be gradually blended into the (usually) steeper sideslopes behind the barrier. From a practical standpoint, a recoverable slope of 4:1 behind the terminal may be a practical compromise, and in some cases a traversable slope as steep as 3:1 may be acceptable. As a general guideline, if a motorist in a passenger vehicle could drive around a terminal and park directly behind it, it might be reasonable to assume the adjacent grading is at least adequate. If the slope is too steep or too cluttered to permit this at even a crawl speed, it is a good assumption that a high-speed crash into the terminal would produce uncertain results. While such grading should be possible on freeways and many other high-speed arterial highways, it may not be cost-effective on roadways with limited rights-of-way and reduced clear zones. In these locations, the area immediately behind the terminal should be at least similar in nature to the roadside immediately upstream from the terminal.

***Runout distance grading*** refers to the area into which an impacting vehicle may travel after breaking through a gating terminal. The physical extent of the area needed will vary depending on vehicle size and impact speed, impact angle, driver reaction, terrain character, and terminal type. For impacts at a 15-degree angle at the nose of all W-beam terminals, test vehicles have traveled over 100 feet laterally, away from the roadway. Clearly it is impractical to provide lateral runout distances (or clear zones) so wide. However, the lateral runout distance directly behind a terminal should ideally be at least as wide as the roadside recovery distance immediately upstream of the terminal. It is not likely to be cost effective, nor is it recommended, to provide greater clear zone behind a terminal than exists elsewhere along the road.

Longitudinal runout distance, parallel to and behind the rail is more difficult to address. In the NCHRP Report 350 certification test 3-31, an end-on hit at a nominal speed of 60 mph with a pickup truck, the truck essentially came to rest upright about 50 feet beyond the initial impact point in all tests with energy-absorbing terminals like the ET-series and the SKT. In the same test into non-energy absorbing terminals like the TL-2 MELT, the Eccentric Loader Terminal (ELT), the REGENT-C, and the SRT, the impacting pickup truck either rode up onto and slid along the top of the guardrail for approximately 150 feet or traveled over 150 feet parallel to and directly behind the rail. Under the test conditions, the area behind the rail was flat and unobstructed and all test vehicles remained upright as they came to a stop. If the barrier length of need has been properly calculated, a vehicle traveling 150 feet behind a barrier will not likely reach the feature the barrier was designed to shield. However, in most cases, that area will not be readily traversable, either because of its topography or because of the presence of other features that could cause vehicle instability. **While it is desirable to have a long recovery area available immediately behind the barrier, practical considerations will often dictate a much smaller area. As recommended in Section 8.2 of the 2002 AASHTO Roadside Design Guide, the minimum recovery area behind and beyond all W-beam terminals should be an area approximately 75 feet long and 20 feet wide.** This size area was based on the final resting position of the small car in a 60 mph end-on impact into a non-energy absorbing terminal. A lesser recovery area may be adequate for energy absorbing terminals (or for any type terminal at reduced impact speeds) and a larger area is desirable for non-energy absorbing designs to accommodate near end-on impacts. Note that if the roadside in advance of the terminal does not have a 20-foot wide recovery area, it is not intended that additional clear zone be provided behind the terminal, but the recovery area should at least be consistent with that available elsewhere along the road. As suggested above, if a motorist could drive 75 feet behind and parallel to the guardrail installation, the minimum longitudinal runout distance probably exists. If that is not possible even at a crawl speed, the consequences of striking the terminal head-on at 60 mph are likely to be severe. However, in many cases, particularly on two-lane facilities off the

NHS, it may not be practical to provide even a minimum runout area due to physical constraints such as restricted rights-of-way, environmental concerns, or inadequate resources.

## 4. Buried-in-Backslope Terminal

A W-beam barrier that can be terminated in a backslope is a preferred end treatment because it eliminates any possibility of a true end-on hit. However, an effective installation must satisfy several design criteria. First and foremost of these must be the steepness of the slope into which the W-beam is anchored. The ideal slope is one that is nearly vertical, in which case the slope in effect becomes an extension of the barrier and a motorist cannot physically get behind the terminal. In such a case, the barrier can be brought into the backslope as soon as practical using the maximum flare rate appropriate for the design speed of the highway. If the backslope is significantly flatter than 1H:1V a buried-in-backslope design behaves essentially like a turned-down terminal and can be overridden. In these instances, the full design length of need of the barrier must be provided and there should be a minimum distance behind the rail that is 75 feet long and 20 feet wide that is both free of fixed objects and reasonably traversable, just as with all other W-beam terminals. **For the buried-in-backslope design, the length of need begins at the point where the W-beam remains at full height in relation to the roadway shoulder, usually at the point where the barrier crosses the ditch line. If the backslope continues under and in front of the flared W-beam, the rail height is effectively reduced and the slope forms a ramp that could allow a vehicle to override the rail instead of being redirected.**

The buried-in-backslope design has been successfully tested over 10:1, 6:1, and 4:1 foreslopes. In each case, the height of the W-beam rail was held constant in relation to the roadway shoulder elevation until the rail crossed the ditch bottom. When the distance from the ground to the bottom of the w-beam exceeds approximately 18 inches, a W-beam rubrail must be added to minimize wheel snagging on the support posts. Earlier tests with a 4500-lb sedan into a terminal flared over a 10:1 slope but with a constant height above the ground failed when the impact angle was 25 degrees, but did contain and redirect the car at a reduced angle of 15 degrees. Because the Report 350 pickup truck has a higher center of gravity than the Report 230 test vehicle, the W-beam height, even across a 10:1 slope, should match the roadway grade on high-speed NHS routes.

## 5. Other non-proprietary Designs

As of mid-2004, there were only three non-proprietary W-beam terminals that had been successfully tested under the NCHRP Report 350 guidelines. The Vermont

Gd-1 and the Modified Eccentric Loader Terminal (MELT) were tested at 70 km/h and accepted as test level 2 (TL-2) terminals. The Eccentric Loader Terminal (ELT) was acceptable as a TL-3 design. None of these terminals are energy absorbing, so each of them should be installed where a reasonable runout distance exists behind them.

## 6. Proprietary Terminals

The three non-energy absorbing proprietary terminals in use in 2004 are the Slotted Rail Terminal (SRT), the REGENT (not often used), and the REGENT-C. These designs are best suited for use in locations where a vehicle can travel at least 75 feet behind and parallel to the rail without reaching the shielded object or any obstacle or terrain feature likely to cause sudden deceleration or rollover. Note that under high-speed test conditions and zero degree impacts, the unbraked test vehicles traveled over 150 feet behind and parallel to the rail. For lower speed impacts and where braking is possible, this distance would naturally be reduced.

The energy-absorbing terminals in use in 2004 are the ET-2000 series, the BEST (not often used), the Sequential Kinking Terminal (SKT), and the Flared Energy Absorbing Terminal (FLEAT). These designs are best suited for use in locations where even the minimum recommended recovery area of 75 feet x 20 feet immediately behind and parallel to the traffic barrier is not attainable.

## 7. Need for Continuing Surveillance

An important facet of terminal selection often overlooked is the understanding that even though a terminal has met the specific crash test evaluation criteria recommended in the NCHRP Report 350 (or its successor), it will not always perform acceptably in the field. Some impacts will still result in injuries and some of these injuries are likely to be severe. Designs are accepted based on no more than seven specific tests at one speed and at designated locations with a small car or a pickup truck. In reality, actual impact conditions are almost infinite when one considers the variables involved in a crash: site conditions, vehicle types, impact speeds and angles, vehicle position at impact, and driver input to name the most obvious. Several reported fatalities have resulted from side impacts into “crashworthy” terminals, an impact scenario which is not part of the crash test matrix. From this two facts become evident. The first is that a crash into any terminal can result in serious injuries so the best choice a designer can make is to eliminate the need for barrier. The second is that each terminal must be selected and installed in such a manner that a motorist striking it at any speed or angle has the best chance for survival. All crashworthy terminals are not automatically suitable for use at all locations. Thus, terminal selection must be a deliberate design decision based on site conditions and on the known performance characteristics of candidate terminals. A barrier installation can often be extended a moderate distance to provide a better location for its terminal.

When a barrier or terminal is hit, every effort should be made to determine if it performed as expected, i.e., did the impacting vehicle remain upright and did vehicle occupants escape serious injuries. A coordinated in-service review of all crash sites, however informal, provides invaluable information on system performance and helps identify common problems that can then be addressed systematically.

## 8. **References**

Specific information on the terminals noted above can be found in the 2002 Edition of the AASHTO Roadside Design Guide and on FHWA's safety hardware website at: [http://safety.fhwa.dot.gov/report350hardware](http://safety.fhwa.dot.gov/report350hardware) .