H6 Barrier End Treatments and Crash Cushions

H6.1 Introduction

Impacts with the untreated ends of barrier systems or with a fixed object may pose a risk to occupants of the vehicle. This is due to the high deceleration forces, possible cabin penetration, or potential vehicle instability. Energy dissipation hardware is used to reduce the severity of such impacts by gradually decelerating the vehicle to a controlled stop, or by redirecting it around or away from the hazard.

There are three types of energy dissipation hardware:

- Arrestors
- End Treatments
- Crash Cushions.

All three primarily serve to lessen the severity outcome of collisions, rather than to prevent them from occurring.

While some end treatments may help to reduce the frequency of collisions by being highly visible and displaying chevrons or other markers to assist drivers with guidance, other protective devices may actually increase the frequency of collisions, since a larger area of vulnerability may be presented, in comparison to the object being shielded.

An Arrestor is a system installed in advance of the hazard to safely decelerate and stop the vehicle. Typically, the purpose of this system is to slow down and stop out-of-control vehicles, specifically large commercial vehicles, before hitting the hazard, or causing significant damages to a particular feature.

An End Treatment is normally used at the end of a barrier system where traffic passes on one side of the system and protection from a head-on impact is necessary in one direction only.

A Crash Cushion is normally used to shield the end of a median barrier system, a fixed object located in a median, or an object located within a gore area. It may also be used to shield an object on either side of a roadway, if the designer decides that a crash cushion is more suitable and/or cost-effective than a barrier system.

End treatments and crash cushions are classified as gating or non-gating, depending on their behaviour when impacted on the face near the approach end:

- A gating end treatment or crash cushion allows a vehicle impacting the nose, or the side of the unit, to pass through the device. For impacts within the Length of Need, gating end treatments should have acceptable characteristics for redirection that are compatible with the barrier system.
- A non-gating end treatment or crash cushion is capable of redirecting a vehicle impacting the nose or the side of the unit. Non-gating end treatments or crash cushions are designed to ensure that vehicles do not normally pass through the system.

End Treatments and Crash Cushions are generally designed to safely stop or redirect passenger cars and light-duty trucks. Deceleration forces are to be below specified limits for design impact situations, resulting in a relatively lower risk of serious injury to vehicle occupants.

End Treatments and Crash Cushions do not function in isolation from adjacent barrier systems or other features. They are selected and designed as one element of an integrated roadside safety system that includes consideration of the roadway, shoulder,

drainage facilities, and the roadside environment. These elements are designed to function in conjunction with one another, maximizing the safety benefits of the highway as a system.

In this guide, the term "end treatment" refers to both End Treatments and Crash Cushions.

Since gating end treatments allow an errant vehicle to pass through the end treatment when impacted at the nose, or the side of the unit, the area behind gating-type end treatments should be reasonably traversable and free of significant fixed objects or hazards.

In addition, for gating end treatments that do not require additional flare grading to accommodate the end treatments such as the ET-Plus, additional grading, as illustrated on **Figure H6.1**, should be provided if possible. A minimum roadway embankment extension that provides a wider flat area behind and in advance of the end treatment should be provided if the preferred grading requirements cannot be accommodated. **Figure H6.2** illustrates this minimum extension. **Figure H6.3** illustrates the preferred grading requirements for flared end treatments.

FIGURE H6.1 Preferred Grading Requirements for Gating End Treatments

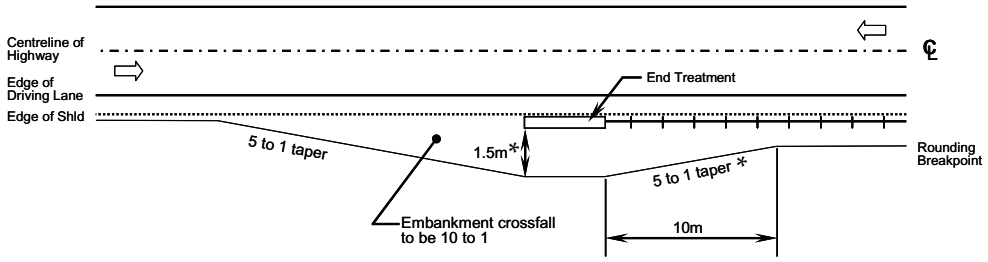


FIGURE H6.2 Minimum Grading Requirements for Gating End Treatments

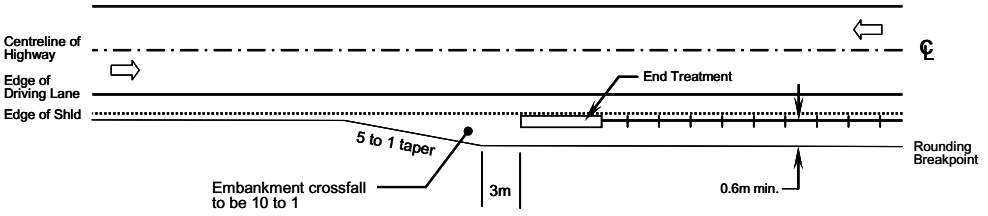
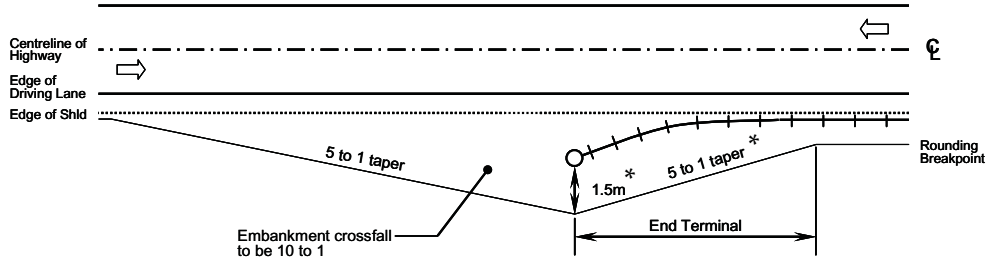


FIGURE H6.3 Preferred Grading Requirements for Flared End Treatments



* The 1.5m and 5:1 taper dimension are "preferred" dimensions. Refer to Standard Drawings for typical minimum dimensions.

Velocity-attenuating designs and devices suitable for attenuating large vehicles do exist, and are collectively referred to as arrestors.

The proper performance of end treatments is heavily dependent on correct installation, maintenance and post-crash restoration. Careful attention should be paid during design to device selection and specifications, integration with other design elements, as well as orientation and positioning. Grading and anchorage requirements, Length of Need and suitability to expected traffic characteristics should also receive proper attention.

Once a device is in-service, maintenance efforts should focus on sustaining its operational integrity within the specified tolerances. Roadway elements upon which the proper performance of the device depends should receive similar attention. This includes, but is not limited to, the following:

- grading to provide for a traversable area in front of, behind and beyond the device, as necessary
- maintenance of the specified mounting height
- fastener torque and cable tension
- removal of ice and snow, as soon as is practicable.

Many of the end treatments available in the marketplace are proprietary in nature. Such products are generally purchased as a complete system, with ongoing logistical support (spare parts and replacements for sacrificial components) available from the manufacturer.

Specifications for a variety of non-proprietary products are also available. These are often generic devices initially developed by road authorities for their own use. The availability of detailed material and design specifications, and the absence of patents, permit fabricators to produce generic copies of these non-proprietary systems.

Alberta has specified the use of *NCHRP Report 350* TL-3 barrier systems and end treatments on some of the highways. The designer should confirm the requirements of the particular highway prior to selecting the end treatment.

The following end treatments (non-*NCHRP Report 350* and *NCHRP Report 350* approved), as provided in **Table H6.1**, are currently used on Alberta highways:

TABLE H6.1 Summary of Barrier End Treatments

Barrier Systems	NCHRP Report 350 Test Level	End Treatments
Alberta Weak Post W-Beam*	N/A	Wing End
	N/A	Turn Down
High Tension Cable System	TL-4	Proprietary Cable Terminal
Weak Post Box Beam	N/A	Turn Down
	TL-3	Bursting Energy Absorbing Terminal (BEAT)
Strong Post W-Beam and Modified Thrie Beam	N/A	Wing End
	N/A	Turn Down
	TL-3	Flared Energy Absorbing Terminal (FLEAT)
	TL-3	ET-Plus
	TL-3	FLEAT-MT (median application)
	TL-3	CAT-350
Concrete Barriers	N/A	Flared and Tapered Turn Down (when posted speed is 60 km/h or less)
	TL-3	TRACC
	TL-3	CAT-350
	TL-3	QuadGuard

*Where a TL-3 end treatment is provided such as the FLEAT, ET-Plus, or CAT-350 end treatment, transition of Alberta Weak Post W-Beam to Strong Post W-Beam system prior to installation of TL-3 end treatment is required.

Guidelines for the selection of the appropriate end treatment are provided in **Section H3.2.3.2**.

Consult the recommended products list to confirm that the selected end treatments may be used in Alberta. The recommended products list may be accessed in INFTRA's website.

Other systems that may also be used are Sand Barrel Systems and Gravel Bed Attenuation Systems.

For a single point hazard, such as a bridge pier, Sand Barrel Systems may be the appropriate system to shield the hazard.

Gravel Bed Attenuation Systems are arrestor systems used to slow down and stop out-of-control vehicles, specifically large commercial vehicles, on a downgrade of the highway before hitting the hazard, or causing significant damages to a particular feature.

The following section provides additional information on proprietary and some non-proprietary end treatments, as well as on Sand Barrel Systems and Gravel Bed Attenuation Systems.

H6.2 Bursting Energy Absorbing Terminal (BEAT)

The Bursting Energy Absorbing Terminal (BEAT) system is a proprietary, energy-absorbing redirective terminal designed to shield the end of the Box Beam Barrier.

The proprietary manufacturer is Road Systems, Inc., USA.

When impacted by an errant vehicle, the head of the BEAT pushes down the box-beam rail causing the rail to expand and burst at the corners at a desired energy absorbing rate.

The system is 4.3 m in length. The BEAT end treatment is approved under *NCHRP Report 350* as a TL-3 end treatment.

For more information on the BEAT system, refer to the Road Systems website.

H6.2.1 Application

The BEAT end treatment is the preferred end treatment when a TL-3 end treatment is required for Box Beam barrier.

H6.2.2 Restrictions

None.

H6.3 CAT-350

The Crash Cushion Attenuating Terminal (CAT-350) is a proprietary, energy-absorbing, gating, redirective terminal designed to shield narrow hazards.

The proprietary manufacturer is Trinity Highway Safety Products Division, USA.

The system is 9.5 m in length and 0.762 m in width.

The CAT-350 is designed to gate when impacted within the third post from the end of the system. This allows the impacting vehicle to travel behind the device. The system redirects vehicles during angle side impacts downstream from the third post.

The CAT-350 end treatment has been approved under *NCHRP Report 350* as a TL-3 end treatment.

H6.3.1 Application

The CAT-350 is designed to shield narrow fixed objects such as the end of a concrete barrier. It may also be used to shield hazards on either side of the roadway.

The CAT-350 end treatment is designed for attachment to a Strong Post W-Beam system. Where this type of end treatment is chosen for any other type of system, for example Alberta Weak Post W-Beam, Modified Thrie Beam or Concrete Barrier, a transition to Strong Post W-Beam is required prior to the beginning of the end treatment.

H6.3.2 Restrictions

CAT-350 should not be used on curves with a radius of less than 250 m.

H6.4 ET-Plus

The Extruder Terminal (ET-Plus) is a proprietary, energy-absorbing, gating, tangent end treatment.

The proprietary manufacturer is Trinity Highway Safety Products Division, USA.

The end treatment is set tangent to the roadway. The overall length of the end treatment is 11.43 m.

Where grading allows, the ET-Plus should be installed with a flare to place the extruder head farther from the edge of the driving lane to reduce the vulnerability to nuisance hits. The suggested flare rate for ET-Plus is 50:1 but can be increased to 25:1 as suggested by the manufacturer.

When impacted along the side of the system, after the third post, the ET-Plus functions as a barrier.

The ET-Plus is designed to break away and gate when impacted at an angle near the nose, or at the side before the third post, allowing the vehicle to travel behind the end treatment.

The ET-Plus end treatment has been approved under *NCHRP Report 350* as a TL-3 end treatment.

H6.4.1 Application

The ET-Plus end treatment is designed for attachment to a Strong Post W-Beam system. Where this type of end treatment is chosen for any other type of system, such as Alberta Weak Post W-Beam, Modified Thrie Beam or Concrete Barrier, a transition to Strong Post W-Beam is required prior to the beginning of the end treatment.

H6.4.2 Restrictions

ET-Plus is not to be used on curves with a radius less than 250 m.

H6.5 FLEAT and FLEAT-MT

The Flared Energy Absorbing Terminal (FLEAT) is a proprietary, energy-absorbing, gating, flared end treatment.

The proprietary manufacturer is Road Systems, Inc., USA.

The end treatment is flared an additional 1.2 m from the edge of shoulder. The total length of the end treatment is 11.43 m.

When impacted along the side of the system, after the third post, the FLEAT functions as a barrier.

The FLEAT is designed to break away and gate when impacted at an angle near the nose, or at the side before the third post, allowing the vehicle to travel behind the end treatment.

The FLEAT system uses a straight flare which has the potential to provide improved redirection performance in impacts downstream of the third post. Another potential advantage of a straight flare is that it allows the anchor cable to come under tension faster, reducing the potential for vehicle snagging.

The FLEAT-MT is similar to the standard system and is used for median applications. It is designed to accommodate hits by errant vehicles in both the direction of traffic and the opposite direction.

The FLEAT end treatments have been approved under *NCHRP Report 350* as TL-3 end treatments.

H6.5.1 Application

The FLEAT is suited to applications where the area behind the end treatment is limited. The energy-absorbing characteristics of the end treatment, when impacted head-on, offer the potential to reduce run out distances, relative to other gating end treatments.

It is critical that a traversable area, free of fixed objects, be provided behind the terminal, as the system is designed to break away when impacted, allowing the vehicle to travel behind the guardrail.

The FLEAT end treatment is the preferred treatment when a TL-3 end treatment is required.

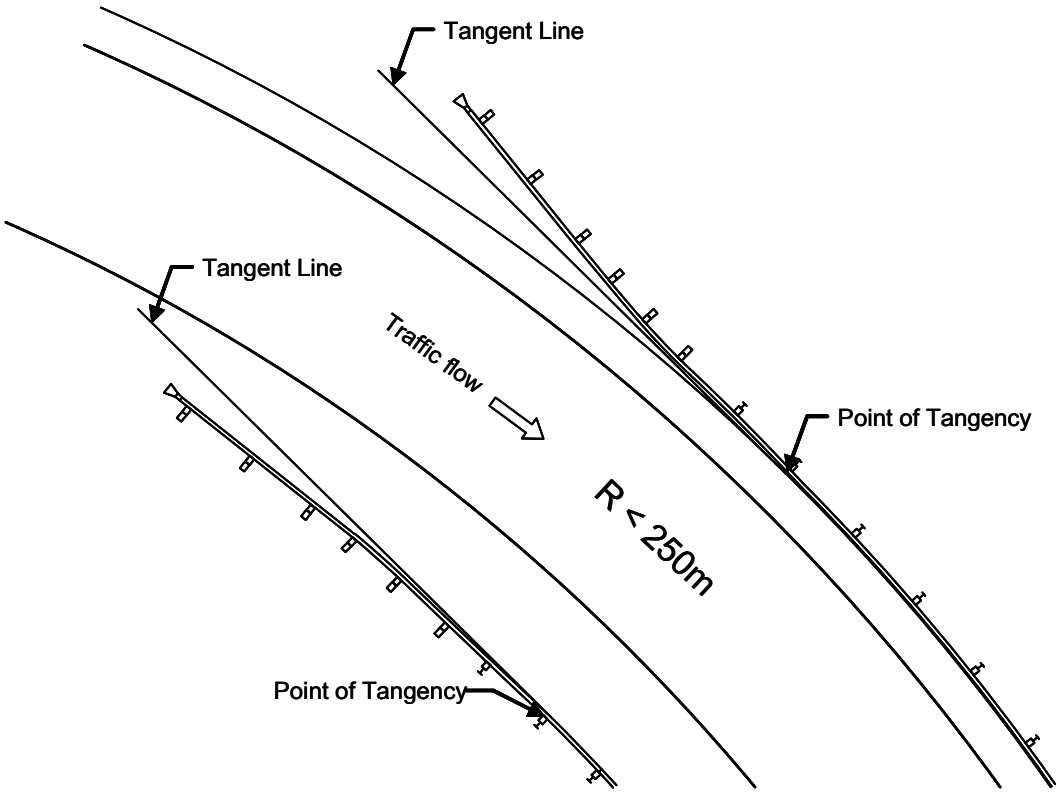
When FLEAT is installed on curves with a radius of less than 250 m, the system should be flared relative to a tangential line that intersects the curve at the downstream end of the flare. **Figure H6.4** illustrates this treatment.

The FLEAT end treatment is designed for attachment to a Strong Post W-Beam system. Where this type of end treatment is chosen for any other type of system, for example an Alberta Weak Post W-Beam, Modified Thrie Beam or Concrete Barrier, a transition to Strong Post W-Beam is required prior to the beginning of the end treatment.

H6.5.2 Restrictions

None.

FIGURE H6.4 System Treatment on Curve



H6.6 QuadGuard

QuadGuard refers to a family of proprietary, energy-absorbing, non-gating, redirective end treatments.

The proprietary manufacturer is Energy Absorption Systems, Inc., USA.

The QuadGuard protects hazards ranging in widths from 0.61 to 2.3 m.

Five width designs are available (0.61 m, 0.762 m, 0.915 m, 1.753 m, and 2.286 m). The length of the crash cushion is 6.74 m long (6 or 12 cartridges, depending on width).

The design consists of several types of energy-absorbing cartridges supported by a framework of steel diaphragms and Quad Beam corrugated steel fender panels. All members of the system function by dissipating the kinetic energy of a crash by telescoping rearward and crushing the cartridges.

In head-on impacts, a framework of steel Quad-Beam rail elements telescope rearward. Impact energy is dissipated either by crushing energy-absorbing cartridges or by squeezing the self-restoring cylinders.

After head-on impacts, the self-restoring crash cushions (QuadGuard Elite or QuadGuard LMC) generally return to their initial position and shape, and are capable of attenuating additional impacts.

In side impacts, QuadGuard will redirect errant vehicles along the side in the direction of travel.

Permanent QuadGuard should ideally be installed on a concrete base.

The concrete pads should be a minimum 200 mm thick, with a slope not exceeding 8% and not varying more than 2% over the length of the system.

The QuadGuard end treatment is a bi-directional device and has been approved under *NCHRP Report 350* as a TL-3 end treatment.

These systems are relatively complex, and their performance is highly dependent on correct specification and assembly. Manufacturer's guidelines should be followed closely.

H6.6.1 Application

The system is designed to shield the end of a concrete barrier system and fixed objects located in the gore area, median, or roadside application.

QuadGuard is the preferred end treatment on higher volume highways where the AADT is more than 50,000 vpd to protect the end of concrete barriers when a TL-3 end treatment is required.

H6.6.2 Restrictions

None.

H6.6.3 Maintenance

Routine maintenance is generally not required for the QuadGuard system. However, it would be advisable to remove any ice and snow that accumulates in front of and behind the system as early as practically possible to ensure proper performance of the system during the winter period.

The QuadGuard system is a restorable device that may be reused after the system is struck by an errant vehicle. Reuse will depend on the severity and location of the impact. The system may be operational after the replacement of the sacrificial cartridges after a low impact hit or may need extensive repairs after a high impact hit.

For QuadGuard Elite or QuadGuard LMC, the systems are designed to eliminate any repair needs when struck head-on by an errant vehicle.

A walk-up inspection is required following an impact of the system to confirm whether it has sustained any damage. If damage to the system is suspected, a detailed physical inspection should be performed to ensure the system is functioning properly. The detailed physical inspection should ensure that:

- the site is free and clear of all debris
- all bolts are correctly tightened
- all anchor bolts remain securely fastened
- fender panels, diaphragms, and cartridges, or cylinders are undamaged and are positioned properly
- the system is properly anchored to the monorail.

H6.7 TRACC

The Trinity Attenuating Crash Cushion (TRACC) is a proprietary, energy-absorbing, restorable, non-gating, redirective end treatment designed to shield narrow hazards.

It includes four major components:

- a pair of guidance tracks
- an impact sled
- a series of intermediate steel frames
- steel beam fender panels.

The proprietary manufacturer is Trinity Highway Safety Products Division, USA.

The TRACC system is 6.4 m long and 0.61 m wide.

Transitional hardware is available allowing the TRACC to be installed at the end of barrier systems or at single-point hazards, as required.

TRACC is installed on a 175 mm thick, reinforced concrete base. It is anchored to the base with steel anchor studs.

In head-on impacts, the impact sled, positioned over the upstream end of the guidance tracks, moves backwards and absorbs energy by cutting the metal plates on the sides of the guidance tracks as it is forced rearward.

During side impacts, the intermediate frames lock onto the guidance tracks, stabilizing the W-Beam to redirect the impacting vehicle.

The TRACC end treatment has been approved under *NCHRP Report 350* as a TL-3 end treatment.

H6.7.1 Application

The TRACC system is designed to shield the ends of concrete barrier and similar, narrow fixed objects located in the gore area, median, or roadside application.

The TRACC system is the preferred end treatment for lower volume highways when the AADT is 50,000 vpd or less where system hits are less likely to occur.

The TRACC system may be used when a TL-3 end treatment is required.

H6.7.2 Restrictions

None.

H6.7.3 Maintenance

Routine maintenance is generally not required for the TRACC system. However, it would be advisable to remove any ice and snow that accumulates in front of and behind the system as early as practically possible to ensure proper performance of the system during the winter period.

The TRACC system is a restorable device that may be reused after the system is struck by an errant vehicle. Reuse will depend on the severity and location of the impact. The system may require removal from site for repair before it can be used again. Consequently, a standby or replacement unit would be required to protect the hazard when the damaged system is removed for repair.

H6.8 Sand Barrel Systems

Sand Barrel Systems refer to a family of proprietary, non-redirective, and gating, end treatments.

There are three types of devices currently approved for use in Alberta:

- Fitch Sand Barrier System by Road Systems, Inc., USA (preferred)
- Energite Inertia Barrier System by Road Systems, Inc. (permitted)
- TrafFix Impact Attenuator Sand Barrels by TrafFix Devices Inc., USA. (permitted)

The Fitch system uses modules of 90, 180, 320, 640 and 960 kg. Each module consists of:

- a cylinder made up of two identical polypropylene structural foam cylinder halves with four integrally molded legs to support the sand support structure and the sand weight
- polyethylene sand support structure (a molded spherical shell with radial ribs on the lower surface)
- a lid
- four "zip strip" connectors fastening two cylinder halves together.

The Energite system uses modules of 90, 180, 320, 640 and 960 kg. The 90, 180 and 320 kg modules consist of three basic components:

- a model 640 kg outer container, molded in one piece with a minimum capacity of 0.4 m^3
- cone-shaped supporting inserts designed to support 90, 180 or 320 kg sand masses. The height and diameter of the cones are designed to ensure proper elevation of the center of gravity of each module
- a lid.

The 640 kg module consists of two components:

- a model 640 kg outer container as used in 90, 180 and 320 kg modules
- a lid.

The 960 kg module consists of two components:

- a model 960 kg outer container molded in one piece with a minimum capacity of 0.6 m^3
- a lid.

The TrafFix system uses 90, 180, 320, 640 and 950 kg sand barrels made from rotomolded, high-density polyethylene plastic. The 950 and 640 kg modules differ in capacity (the barrels are 1.22 m and 0.915 m tall respectively, with the same diameter at the top). The 320 kg module is assembled on site by locking two different sizes of half barrels together. The 180 and 90 kg modules are the same 320 kg modules, but are installed in an inverted orientation.

H6.8.1 Application

Sand Barrel Systems are designed to shield isolated, low-risk, single-point fixed object hazards such as bridge piers.

Sand Barrel Systems may be used for both temporary and permanent installations.

For permanent installation on Alberta highways, the Fitch Sand Barrier System is currently the preferred system.

A standard drawing for typical array layouts ranging from a speed of 40 km/h to 110 km/h is provided in standard drawing TEB 3.19 in **Appendix B7**.

Consult the manufacturer of the Sand Barrel System and follow their specifications closely to ensure that the Sand Barrel System will function appropriately.

H6.8.2 Restrictions

For restrictions of the specific systems, refer to the manufacturer's information brochure or contact the manufacturer.

H6.9 Gravel Bed Attenuation Systems

Photo provided by Mike Pearsall, Ontario Ministry of Transportation

Gravel Bed Attenuation Systems are arrestor systems intended to slow down and stop out-of-control vehicles, especially large commercial vehicles on long or steep downgrades.

These systems are generally located adjacent to the roadway. The contained bed of loose material absorbs the kinetic energy of the out-of-control vehicle.

H6.9.1 Application

Currently, there are no specific warrants to determine when a Gravel Bed Attenuation System will be required. The need for this system is at the discretion of the designer. However, some general guidance regarding when the system will likely be needed is provided.

The system may be required if:

- there are regular reports from maintenance staff, law enforcement officials, truck drivers, and the general public expressing concerns of vehicles out-of-control at a specific downgrade location of the highway
- a field review indicates that there are damaged guardrail system, gouged pavement surfaces, or spilled oil indicating heavy vehicles have had some difficulty negotiating a downgrade.

For additional information on the design of Gravel Bed Attenuation Systems, refer to the current version of *AASHTO's Geometric Design of Highways and Streets*, under the section for Emergency Escape Ramp.

H6.9.2 Restrictions

For information on the requirements of Gravel Bed Attenuation Systems, refer to the current version of the *AASHTO's Geometric Design of Highways and Streets*, under the section for Emergency Escape Ramp.

H6.10 References

The following documents were used during the development of this section:

Alberta Infrastructure and Transportation,
Traffic Control Standards Manual,
Edmonton, AB, 1995

American Association of State Highway and Transportation Officials,
Geometric Design of Highways and Streets 2004,
Washington, DC, 2004.

American Association of State Highway and Transportation Officials,
Roadside Design Guide 2002,
Washington, DC, 2002.

Joint Cooperative Committee of the American Association of State Highway and Transportation Officials, American Road and Transportation Builders Association, and Associated General Contractors of America,
A Guide to Standardized Highway Barrier Hardware 1995

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