Guardrail Replacement and Maintenance Guidelines

Minnesota Department of Transportation

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Guardrail maintenance is a key component of protecting the roadside, but there is uncertainty as to how to maintain the various guardrails and end treatments that are currently in use. Local jurisdictions continue to perform guardrail maintenance but there are no current guidelines to ensure that maintenance practices are to standard and are consistent throughout the state. These guidelines summarize current issues, the accepted approved guardrail types and end treatments used in Minnesota, inspection and maintenance practices for guardrails and resources and standards on guardrails and end treatments. Appendices A and B provide quick reference sheets to highlight the guardrails and end treatments currently used in Minnesota and the suggested use of each type.

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GUARDRAIL REPLACEMENT AND MAINTENANCE GUIDELINES

FINAL REPORT

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We would also like to acknowledge the Reference Manual from the USDOT/FHWA NHI Course No. 380034A *Design Construction and Maintenance of Highway Safety Features and Appurtenances* (Publication No. FHWA-NHI-04-014 March 2004) as information from this manual is referenced throughout this report. A hardcopy of this manual can be purchased at: http://www.nhi.fhwa.dot.gov/training/NHIStoreSearchResults.aspx?get=&COURSE_NO=380034A&KEYWORD=&TITLE=

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1. INTRODUCTION

Improving roadside safety is a concern for every city, county and state traffic agency. Motor vehicle crashes inflict a tremendous hardship on American society. Nationally, the number of fatalities each year in the United States has remained relatively constant at nearly 42,000 per year (source: *Traffic Safety Facts 2008 Data*, NHTSA's National Center for Statistics and Analysis). In 2008, 37,261 people died in the United States as the result of traffic related crashes and 2.3 million more were injured (source: *Minnesota Motor Vehicle Crash Facts 2008*, Minnesota Department of Public Safety). In the State of Minnesota in the year 2008, 283 (67%) of all fatal crashes occurred in rural areas (which are defined as having a population of less than 5,000 people) and 129 (31%) of all fatal crashes occurred on county state aid highways, and 98 of those were in rural areas. In Minnesota, approximately 18 percent of the 79,095 crashes that occurred in 2008 were run off the road crashes. Of these run off the road crashes, approximately 36 percent resulted in a fatality or personal injury. The high representation of run off the road crashes on rural roads in Minnesota identifies the need to focus on protecting drivers from the roadside. Guardrails are a key tool that can be used to reduce these crashes.

Unfortunately, crashes will continue to occur due to mechanical problems, weather conditions and/or driver errors. Driver errors include excessive speed, falling asleep, reckless or inattentive driving and driving under the influence of alcohol or other drugs. Traffic engineers must keep informed of new technology and follow the approved practices for safe roadside design in order to protect the driving public. Maintaining guardrails to standards is also important to avoid liability.

Guardrail maintenance is a key component of protecting the roadside, but there is uncertainty as to how to maintain the various guardrails and end treatments that are currently in use. Local jurisdictions continue to perform guardrail maintenance but there are no current guidelines to ensure that maintenance practices are to standard and are consistent throughout the state. These guidelines summarize current issues, the accepted approved guardrail types and end treatments used in Minnesota, inspection and maintenance practices for guardrails and resources and standards on guardrails and end treatments. Appendices A and B provide quick reference sheets to highlight the guardrails and end treatments currently used in Minnesota and the suggested use of each type.

2. DISCUSSION OF CURRENT ISSUES

a. Change in ADT threshold

As of 2005, Minnesota State Aid Rule 8820.9920 states that "Guardrail is required to be installed at all bridges where the design speed exceeds 40 mph, and either the existing ADT exceeds 400 or the bridge clear width is less than the sum of the lane and shoulder widths" A copy of this rule is located at this website:
https://www.revisor.leg.state.mn.us/rules/?id=8820.9920

3. GUARDRAILS

Guardrails are protective devices for redirecting errant vehicles from a dangerous path. The term "guardrail" refers to those longitudinal barriers normally installed along the side of the road to prevent a vehicle from colliding with an obstruction or taking a perilous, off-roadway course where recovery of vehicle control is not reasonably possible.

a. Review of guardrails used in Minnesota

Mn/DOT generally uses one of the four types of guardrail systems listed below. All have passed NCHRP-350 crash standards (see details of the NCHRP 350 in section 5 of this report – *Review of Resources and Standards*). The systems are used for both low and high volume roads.

- Cable Barriers
- Plate Beam Guardrail (W-beam and Thrie-beam)
- Bull Nose Rail System
- Concrete Barriers

Systems must meet the NCHRP-350 criteria to be approved for use on the Minnesota Trunk Highway system. A list on Mn/DOT approved vendors for new construction is currently being developed and will be available in the future at the following website: http://www.dot.state.mn.us/products/index.html

One page summaries have been developed for each guardrail system to give a general overview of each system, including description, use, design, Mn/DOT standard plates, specifications, costs, expected deflection, potential benefits and potential problems. These summaries are available in Appendix A of this report.

b. Guardrails Inspection and Maintenance

Guardrail and end treatments are designed to reduce the severity of crashes. However, a damaged system can be a hazard and requires repair as soon as possible. Agencies should consider how to document a process that can be followed for each system that includes standard practices for installation and repair. The process could include response time requirements for repairs and required spare parts inventory. In addition, the process could identify who makes decisions on reusing parts and who inspects repairs. This documented process can help each agency provide public safety and protection from possible lawsuits.

The information below is directly from the *NHI Course #380034A reference manual – FHWA –NHI-04-014 Design, Construction and Maintenance of Highway Safety Features and Appurtenances.* This information should be used as guidance on inspection and maintenance practices for the various barrier types that are typically used in Minnesota.

> To ensure that roadside safety features are capable of performing their intended functions, periodic review, inspection and maintenance of in-service traffic barriers are necessary. Review, inspection, and maintenance of existing barriers should be included as part of the planning

and design process for highway reconstruction or repair process. Periodic, routine inspection of roadside barriers should be a part of the normal maintenance function. Inspection may also be triggered by a crash report indicating a high severity or incidence of run-off-road crashes.

Barriers perform best when in full compliance with current standards. All barriers must be in good repair to ensure acceptable performance, and must be in reasonable conformity with current standards. However, it is not feasible to immediately upgrade all existing barriers every time a small change is made in a barrier standard. The decision to upgrade existing barriers that are in reasonably good condition and reasonable conformity with current standards must be based on a thorough analysis of the costs and potential improvements in highway safety.

1. W-Beam and Thrie-Beam Barriers

The W-beam is the most commonly used plate-beam guardrail or barrier in Minnesota and the rest of the nation. It derives its name from the shape of the plate-beam. W-beam guardrail is a semi-rigid system that can be mounted on either wood or steel posts. With this type of system, impact is resisted by a combination of bending and tension of the rail acting with the posts to limit lateral deflection. The thrie beam is a stronger and wider version of the W-bean, with one additional corrugation to the plate.

Basic Inspection:

Periodic, routine inspection of roadside barriers should be part of the normal maintenance function. Examination of the following points should be included in all inspections, including routine maintenance inspections:

Barrier Rail

1) Is the barrier generally in shape, with no significant corrosion, accident damage or other misalignment?
2) Are all splice bolts and post attachment bolts in place and tight?
3) Are the rails properly attached to terminals and transitions?
4) Have any fixed objects such as small trees, poles, or other objects intruded within the deflection space?
5) Is the required rail height maintained?
6) Is there anything in front of the barrier that can cause a vehicle to vault? Typical problems include rough ground, erosion, vegetation and debris.
7) Is the barrier face smooth? Irregular curves or joints can cause a vehicle to snag and should be repaired as soon as possible.
8) Is the barrier the correct height? See designs for specific barriers. When the variation of height is greater than 2 in., plans should be made for correction.

Barrier Posts and Blockouts:

1) Are any posts missing or severely misaligned?
2) Are any blockouts missing or rotated out of the vertical position?
3) Do the posts appear firmly embedded, with no tilting or soil erosion around the posts? A minimum of 2ft of soil on a 1V:10H slope is required.

In-Depth Inspection:

A more in depth inspection should be carried out when the roadway is proposed for reconstruction or extensive repair, including the following points:

1) Rail height should be checked throughout the proposed project to ensure it will be within tolerance after completion of the road work. If necessary, height adjustment should be included in the project.
2) Are all existing barriers needed to meet the existing standards? Can the hazard be removed or modified to eliminate the need for a barrier?
3) Does the existing barrier meet length of need criteria, or are length adjustments required?
4) Do curb or embankment slopes in front of the barrier pose a risk of vehicle vaulting over the barrier?
5) Are flat slopes provided in front of terminals and transitions and traversable and clear areas behind "gating" terminals?
6) Is this type of barrier appropriate considering current highway and traffic parameters, or would another barrier type provide a significant safety upgrade?
7) Is post spacing appropriate for the available deflection distance?
8) Are terminals and transitions consistent with current standards, including proper flares and offsets?

Routine Maintenance:

Routine maintenance requirements are minimal. Occasionally, it may be necessary to replace post attachment bolts or realign posts damaged by snowplowing. Some agencies routinely apply herbicides along roadside barriers to avoid difficulties involved in mowing grass and weeds along and under the barrier.

Modifications to the barrier must not be made unless consistent with more modern standards for that barrier type. Barrier components or features must not be omitted.

Crash Related Maintenance:

The primary maintenance requirement for a W-beam barrier is the repair of crash damage. Since these barriers are inherently stiff, most minor impacts result only in cosmetic damage, which usually requires no maintenance response. For moderate impacts, damage is often limited to one or two sections and minor post misalignment. For more severe accidents, significant damage may occur that requires removing and

replacing rail sections, blockouts, and damaged posts. Whenever maintenance activities are performed on traffic barriers, several general principles should be followed:

1) Standard specifications for the barrier in question should be reviewed to ensure that proper details are followed.
2) All parts used must meet appropriate specifications. If used or salvaged parts are used, they must be in good condition.
3) Modifications to the barrier must not be made unless consistent with more modern standards for that barrier type. Barrier components or features must not be omitted.
4) During repairs, roadside conditions affecting performance should be checked, such as introduction of new fixed objects.
5) If significant damage occurs to a substandard barrier or terminal, it should be upgraded to current standards.
6) Feedback on recurring problems should be provided to design and construction staff so future installations can be improved.

Posts

Posts can be extracted using a tractor bucket or dump truck body. In the event that wood posts are completely fractured by severe impacts, it will be necessary to dig around the stub to a sufficient depth to wrap a chain around the lower section of the post for extraction. A truck mounted post driver is most effective for replacing steel posts, although they may be installed using hand-held impact drivers, especially if the original hole is not disturbed. In some cases, it may also be possible to drive a new wood post in the existing hole.

Rail

One or more sections of W-beam may be damaged to the extent that replacement is necessary. The bolted connections ease the task of replacing more rail sections as needed. Following replacement and realignment of the posts, blockouts, and damaged rail sections, the repair is completed by attaching the rail to the posts.

Unless severely deformed or torn, damaged rail can be straightened for subsequent use. This is accomplished by running the damaged rail through a motorized forming die, which rerolls the rail to its original shape. Some large agencies own this equipment to refurbish rail at a maintenance facility. Smaller agencies can contract for rail straightening through guardrail vendors and fabricators, or sell damaged rail to scrap processors, who subsequently repair and resell rails.

Terminals

For any impact involving the terminals, or on the standard guardrail section near the terminal, it is essential that terminal is checked for damage. Because some terminal designs are complex and include a number of critical components, the entire terminal must be carefully inspected for hidden damage. Even apparently superficial damage such as

bent or misaligned bolts may have an adverse effect on terminal performance in subsequent impact.

2. Cable Barriers

Cable barriers are comprised of a series of cables mounted on weak wood or steel posts. With this type of system, impact is resisted by cable tension and end anchorage. Deflections of 10 feet or more can be expected.

Basic Inspection:

Periodic, routine inspection of roadside barriers should be part of the normal maintenance function. Examination of the following points should be included in all inspections, including routine maintenance inspections:

Post

1) Are any posts missing or severely misaligned?
2) Do the posts appear firmly imbedded, with no tilting or soil erosion around the posts?

Cable

1) Is there evidence of corrosion or damage to the cable?
2) Are all J-bolts in place and oriented with opening upward? Do the cables appear to be under tension, with no visible sag?
3) Have any fixed objects such as small trees, poles or other objects intruded within the deflection space?
4) Is the cable at the required barrier height?
5) If required, are reflective delineators present and in good condition, or is replacement needed?

Anchor

1) Are the cables attached to the anchors, and the anchors flush with the ground surface?

In-depth Inspection:

A more in-depth inspection should be carried out when the highway is proposed for reconstruction or extensive repair including the following points:

1) Cable height should be checked throughout the proposed project to ensure it will be within design tolerance after completion of the highway work.
2) If necessary, height adjustment should be included in the project.
3) Are all existing barriers needed to meet existing warrants? Is additional barrier needed to meet warrants?

4) Do curb or embankment slopes in front of the barrier pose a risk of vehicles vaulting over the barrier?
5) Is this type of barrier appropriate considering current highway and traffic parameters, or would another barrier type provide a significant safety upgrade?
6) Are post spacing's appropriate for the available deflection distance?

Routine Maintenance:

Routine maintenance requirements are minimal. It may be necessary to replace J-bolts or realign posts damaged by snowplowing. Although the spring compensators are designed to maintain cable tension over an extended period, the prolonged effects of cable creep, anchor movement, and snowplow contact may eventually result in cables becoming slack. It is often necessary to readjust tension. The need for this adjustment can be based on the observance of sagging cable during warm weather. Although such sag may appear unsightly, the effect on barrier deflection during vehicle impact is small unless the amount of sag becomes excessive.

Crash Related Maintenance:

The primary maintenance requirement for cable barrier systems is the repair of accident damage. For most accidents, this is limited to removing and replacing damaged posts, attaching the cables, and readjusting cable tension. Posts can be extracted using a tractor bucket or dump truck body. The flanged-channel posts can be driven using hand tools, at least in small numbers. A truck-mounted post driver is most effective for the other posts, although hand tools may be used, especially if the original hole is not disturbed. Cables are rarely damaged, but if this occurs, damaged sections can be removed and new pieces spliced in using standard attachment hardware. For shorter lengths of cable, however, it may be easier to replace the entire damaged cable, and ensure that the splice does not create a weak point in subsequent accidents.

3. Bull Nose Rail Systems

Bull-nose rail systems are essentially a W-beam guardrail with a curved section, commonly used at bridge overpasses and underpasses. Overpasses bull nose systems protect vehicles from running through the median and colliding with vehicles traveling on the underpass. Underpass bull nose systems protect vehicles from running into bridge supports in the median or other supports associated with the bridge.

Inspection and Maintenance:

Inspection and maintenance of the bull nose guardrail is the same as the W-beam guardrail. See guidance in the previous section 1.

4. Concrete Barriers

Concrete barriers are rigid systems that are used on high-speed, high-volume roadways in locations where little or no deflection can be tolerated, such as in medians, on bridge rails or between other fixed objects such as bridge supports.

Basic Inspection:

Rigid traffic barriers have been in use since at least the 1960s. A number of those early installations may still remain in service, with little or no change since their installation, other than repair of major accident damage. Periodic routine inspection of roadside barriers should be part of the normal maintenance function. Examination of the following points should be included in all inspections, including routine maintenance inspections:

1) Is the barrier generally in good repair, with no significant crash damage or other misalignment?
2) Is the concrete in good condition, with no severe cracking, dislodged pieces, or severe surface spading?
3) Have any roadway features such as sign or luminaire supports been improperly added to the top of the barrier that may be contacted by impacting vehicles?
4) Are terminals and transitions in good repair, properly aligned, and displaying no visible damage?
5) Has dirt or debris accumulated along the base of the barrier that may increase the height of vehicle impact?

In-depth Inspection:

A more in-depth inspection should be carried out when the highway is proposed for reconstruction or extensive repair, including the following points:

1) Barrier height should be checked throughout the proposed project to ensure it will be within design tolerance after completion of the highway work. While NJ and F shape CSS barriers can accommodate up to 75 mm (3 in.) pavement overlays, it is essential to maintain a minimum height of 735 mm (29 in.).
2) Does the barrier shape meet one of the currently approved barrier profiles? Because of its increased risk of rollover, GM shape barriers should be considered for replacement.
3) Can the hazard be removed or modified to eliminate the need for barrier? Are all existing barriers needed to meet existing warrants? Are additional barrier needed to meet warrants?
4) Do curbs or pavement slopes in front of the barrier pose a risk of vehicles vaulting over the barrier or experiencing excessive climb leading to rollover?

5) Are all slopes appropriate for the performance of the barrier?
6) Does the existing barrier meet length of need criteria, or are length adjustments necessary?
7) Is this type of barrier appropriate considering current highway and traffic parameters or would another barrier type provide a significant safety upgrade?
8) Are terminals and transitions consistent with current standards, including proper flares and offsets? Freestanding rigid barrier ends are very hazardous and should be programmed for upgrading. Likewise, any gaps in transitions to bridges or other barriers not in conformity with current principles for transition design represent a significant hazard that should be upgraded as soon as possible.

Routine Maintenance:

Concrete barriers are virtually maintenance free and can last up to 50 years. No routine maintenance is required.

Crash Related Maintenance:

Usually does not require repair work after a collision, which reduces the risk of road workers and work-related congestion.

4. END TREATMENTS

Since the 1960's, guardrail end treatment design has changed considerably. In the 1960's, unprotected or unmodified guardrail ends were severe roadside hazards, spearing vehicles when hit head on. The twist down end treatment design was an economical solution to avoid spearing, and until 1970 was accepted standard practice. However, ramping and roll-overs from twist down end treatments caused researchers to look into new alternatives after FHWA banned twist down end treatments on high-speed, high-volume roads. The *Minnesota Road Design Manual* offers the following guidance for replacing twist down end treatments:

> The twisted-end treatment has been used for many years, nationwide, for a terminal on plate-beam guardrail. However, this end treatment does not meet past or present crash worthiness criteria and should be replaced. A number of plate-beam guardrail terminals are currently available which provide greater safety than the twisted-end treatment, although they are more costly. However, this added cost can be justified for use on high speed and/or high volume roadways. Therefore, the following policy applies to all plate-beam guardrail installations:
>
> 1. Twisted-end treatments shall not be used on new plate-beam guardrail installations on any trunk highway.

2. Reconditioning projects on which the in-place guardrail is disturbed require replacement of twisted-end treatments with crash-worthy terminals on all roadways where the design speed limit is 40 mph or greater.

3. Reconditioning projects on which the in-place guardrail is not disturbed require replacement of twisted-end treatments with crash-worthy approved terminals on all freeways and on expressways and other four-lane roadways where the design speed limit is 40 mph or greater. They also require replacement on two-lane roadways where the design speed limit is 40 mph or greater and the current ADT is greater than 1,000. On roadways where the design speed limit is 40 mph or greater and the ADT is less than the values specified above, the twisted-end treatments may remain in place.

4. Twisted-end treatments can remain in place or be installed on any roadway off the Trunk Highway System on which the design speed limit is less than 40 mph.

a. Review of end treatments used in Minnesota

End terminals approved for use in Minnesota by the *Minnesota Road Design Manual (section 10-7.02.06)* include:

1. Eccentric Loader Breakaway Cable Terminal (ELT) (Standard Plate 8329)
2. Slotted Rail Terminal (SRT-350™) (1)
3. ET-2000™ and ET-2000™ Plus (1)
4. Sequential Kinking Terminal (SKT-350™) (1)
5. Flared Energy Absorbing Terminal (FLEAT-350™) (1)
6. Crash Cushion Attenuating Terminal (CAT™) (1)
7. BRAKEMASTER® 350 (1)

(1) No standard plate as this is a proprietary item

These terminals meet the crash-worthiness criteria of NCHRP Report No. 350 (see details of the NCHRP 350 in section 5 of this report – *Review of Resources and Standards*). This list may be modified as additional terminals are approved. NCHRP 350 approved devices may be found on the FHWA Web Site at:

http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/nchrp_350/

Systems must meet the NCHRP-350 criteria to be approved for use on the Minnesota Trunk Highway system. A list on Mn/DOT approved vendors for new construction is currently being developed and will be available in the future at the following website: http://www.dot.state.mn.us/products/index.html

A one page summary has been developed for each end treatment to give a general overview of each, including description, use, design, Mn/DOT standard plates, costs, potential benefits and potential problems. These summaries are available in Appendix B of this report. Most end treatments are proprietary; therefore Mn/DOT does not have a standard plate for them.

AASHTO has developed a report titled *A Guide to Standardized Highway Barrier Hardware* that contains drawings and specifications for the most commonly used roadside safety appurtenances in the United States. This report also includes FHWA product approval letters and contact information for product manufacturers. An electronic version of this report can be found here: http://aashtotf13.tamu.edu/index.htm

b. Obsolete End Treatments

A partial list of end treatments that are known to be obsolete (do not meet NCHRP 350 requirements) and should be replaced are:

1. W-Beam Rail with Steel Posts and Steel Blockouts
2. Thrie-Beam Rail with Steel Poss and Steel Blcokouts
3. Alpha 60 MD TMA
4. Alpha 2001 MD TMA
5. Alpha 1000 TMA
6. Blunt End Terminal
7. BCT (Breakaway Cable Terminal)
8. CIAS (Connecticut Impact Attenuation System)
9. CRT (Controlled Release Terminal)
10. GREAT (Guard Rail Energy Absorbing Terminal)
11. HEXCELL TMA
12. HFSS (Hex Foam Sandwich System)
13. Hi-Dro Sandwich and Hi-Dro Cell Cluster Systems
14. LMA (Low Maintenance Attenuator)
15. MELT (Modified Eccentric Loader Breakaway Cable Terminal)
16. SENTRE
17. Transitions
18. Trend
19. Turndown End Terminal

This by no means is a complete list of known obsolete end treatments. The NCHRP 350 (see details of the NCHRP 350 in Section 5 of this report – *Review of Resources and Standards*) should be referenced to verify if a specific end treatment is approved for use.

c. End Treatments Inspection and Maintenance

Guardrail and end treatments are designed to reduce the severity of crashes. However, a damaged system can be a hazard and requires repair as soon as possible. Agencies should consider how to document a process that can be followed for each system that includes standard practices for installation and repair. The process could include response time requirements for repairs and required spare parts inventory. In addition, the process could identify who makes decisions on reusing parts and who inspects repairs. This documented process can help each agency provide public safety and protection from possible lawsuits.

The information below is directly from the *NHI Course #380034A reference manual – FHWA –NHI-04-014 Design, Construction and Maintenance of Highway Safety Features and Appurtenances.* This information should be used as guidance on inspection and maintenance practices for the various end treatments that are typically used in Minnesota.

1. Maintenance of the ELT

Maintenance of the Eccentric Loader Breakaway Cable Terminal is not covered in the NHI Course reference manual; however it is similar to the SRT-350™ (section 2 below) and the FLEAT-350™ (section 5 on page 15) and should follow similar maintenance.

2. Maintenance of the SRT - 350™

Maintenance of the Slotted Rail Terminal -350™ can be categorized as routine and repair. Routine maintenance consists of periodically checking the system to see that the cable is taut, the nuts have not been removed from the cable, and the blockouts have not rotated. Repair maintenance has to do with the system after it has been hit. Most hits on the SRT-350™ will require the replacement of 3.81 m (12 ft 6 in.) to 11.43 m (37 ft 6 in.) of rail and broken posts, depending on the severity of the impact. The following steps should be taken in making repairs.

1) The system should be checked periodically to see that the cable is taut, the nuts have not been removed from the cable, and the blockouts have not rotated.
2) If the system has been impacted, remove any debris that has encroached onto the traveled way or shoulder at the accident site. Install any delineation necessary for the damaged system. Take inventory of the damaged system and determine what parts are reusable and what parts need to be replaced. Make sure to obtain all those parts that need replacement before returning to the site.
3) With the replacement parts return to the repair site. To expedite the rail installation, it is suggested that any new rail panel(s) brought to the repair site should have the slot guards already bolted to it to minimize work zone repair time. The slot guards on the damaged rail panel(s) can be removed back at the maintenance yard and used on the next repair.
4) Disconnect and remove the damaged rail from the posts.
5) Remove the broken posts in the steel tubes using one of the two post removal tools that can be assembled from "off the shelf hardware" items. Pound the steel pipe or screw the lag screws into the top of the broken post and remove the broken post by pulling on the chain. If necessary, place a steel rock bar in the loop of the chain and use it as a lever arm to remove the post. Remove any damaged HBA posts.
6) Remove any damaged Controlled Release Terminal (CRT) posts.

7) After the site has been cleared of damaged debris, the system can be reconstructed following the installation instructions. The two slotted rail pieces brought to the repair site should have the slot guards already bolted onto it to expedite repair time. The slot guards on the damaged rail can be removed at the maintenance yard.

3. Maintenance of the ET-2000™ and ET-2000 Plus ™

Maintenance of the Extruder Terminal-2000™ and Extruder Terminal-2000 Plus™ can be categorized as routine and repair. Routine maintenance consists of periodically checking the system to see that the cable is taut, the nuts have not been removed from the cable, and the blockouts have not rotated. Repair maintenance deals with the system after it has been hit. Most hits on the ET-2000™ and ET-2000 Plus™ will require the replacement of the first 7.62 m (25 ft) or 3.81 m (12 ft 6 in.) section of rail and any broken posts. The following steps should be taken in making repairs.

1) Check the extruder head for damage. It can be reused if there is no visible damage.
2) Check the anchor cable and bracket for damage. The bearing plate, nuts, and washers, and anchor bracket are rarely damaged.
3) Check the number of broken posts and wood blockouts that need to be replaced, along with any damaged bolts. Inventory and pick up the reusable parts.
4) Burn off the extruded rail near the extruder head. Note that this is the rail that has passed through the extruder. After the rail has been burned off, hook a chain attachment to the extruder head. Pull the extruder off the rail with the chain attached to a truck frame while the other end of the rail is tied to the downstream rail and posts (these provide an anchor).
5) Remove the broken posts in the steel tubes using one of the two post removal tools, recommended by the manufacturer that can be assembled from "off-the-shelf-hardware" items. Pound the steel pipe or screw the lag screw into the top of the broken post and remove the broken post by pulling on the chain. If necessary, place a steel rock bar in the loop of the chain and use it as a lever arm to remove the post.
6) Remove broken posts not installed in steel tubes.
7) If HBA posts are used, remove those that have been damaged and cannot be reused.
8) Follow the construction instructions to finalize the repair.

4. Maintenance of the SKT-350™ System

Maintenance of the Sequential Kinking Terminal 350 ™ should adhere to the following guidelines:

1) The bolts at the top of the foundation tubes should not be overly tightened so as not to deform the walls of the tubes.

2) The guide chute for the impact head should be parallel to the top of the rail and the impact head should not encroach onto a paved shoulder.

3) The two lag screws holding the impact head to post one should be snug.

4) The 205 x 205 mm (8x8 in.) bearing plate at post one should be correctly positioned and the anchor cable taut and correctly installed.

5) Posts one and two should have the 60 mm (2 ½ in.) hole located parallel to the roadway with the bottom of the hole at the top of the foundation tube. This also applies to posts three through eight if foundation tubes are used.

6) If CRT type posts are used, posts three through eight should have the 90 mm (3 ½ in.) holes located parallel to the roadway with the bottom of the holes located at the ground line.

7) The backfill materials around the posts should be properly compacted.

8) No block outs are used for posts one and two. No washers are used on the face of the rail for posts two through eight.

9) If no repair parts are readily available following an accident, temporary protection of the guardrail end is required.

10) The following equipment is needed for repair operation:
    - an acetylene torch to cut off damaged rail
    - a heavy duty chain, along with a chain hook, to remove the impact head is sometimes required (Note: most of the time the impact head can be removed by hand after cutting off the damaged rail.)
    - various standard wrench or channel lock pliers and sledge hammer
    - post remover tool and other normal guardrail tools

11) The first two foundation tubes are provided with a longitudinal slit which can be pried open slightly to allow easier removal of damaged post stubs. This split tube is optional and may not always be used.

12) After an impact occurs with the SKT-350™, the impact head and cable anchorage assembly are normally reusable, but check for damages. Foundation tubes are generally reusable, but sometimes need realignment to obtain a vertical position. Typically, only replacement of damaged rail sections, posts, and fasteners is required.

13) Cut off the damaged rail that passed through the impact head near the exit end of the impact head. Pull the impact head off the rail by hand if possible. If this is not possible, then use a chain attached to a vehicle. Remove the remaining damaged rail section and posts.

14) After debris has been removed from the site and major components have been inspected for damage, the system can be reconstructed following the construction installation instructions.

5. Maintenance of the FLEAT-350™ System

Maintenance of the Flared Energy Attenuating Terminal 350 ™ should adhere to the following guidelines:

1) The bolts at the top of the foundation tubes should not be overly tightened so as not to deform the walls of the tubes.

2) The rail at post one should be placed at a straight flare offset between 762 mm and 1.2 m (2 ft 6 in. to 4 ft) over the 11.4 m (37 ft 6 in.) terminal length.

3) The guide chute for the impact head should be parallel to the top of the rail and the exit slot of the impact head should be facing traffic.

4) The two lag screws holding the impact head to post one should be snug.

5) The 205 mm x 205 mm (8 in. x 8 in.) bearing plate at post one should be correctly positioned and the anchor cable taut and correctly installed.

6) Posts one and two should have the 60 mm (2 ½ in.) hole located parallel to the roadway with the bottom of the hole at the top of the foundation tube.

7) The controlled release terminal type posts at posts locations three through seven should have the 90 mm (3 ½ in.) holes located parallel to the roadway with the bottom of the holes located at ground line.

8) The backfill materials around the posts should be properly compacted.

9) No block outs are used for posts one and two. No washers are used on the face of the rail.

10) If no repair parts are readily available following an accident, temporary protection of the guardrail end is required.

11) The following equipment is needed for repair operation:
    - an acetylene torch to cut off damaged rail
    - various standard wrench or socket sizes
    - a vice grip or channel lock pliers and sledge hammer
    - post remover tool and other normal guardrail tools

12) The first two foundation tubes are provided with a longitudinal slit which can be pried open slightly to allow easier removal of damaged post stubs. This split tube is optional and may not always be used.

13) After an impact occurs with the FLEAT-350™ system, the cable anchorage assembly is normally reusable, but check for damages. Foundation tubes are generally reusable, but sometimes need realignment to obtain a vertical position. The impact head is often damaged, but may be reusable after some impact conditions.

14) Cut off the damaged rail that passed through the impact head near the exit end of the impact head. Pull the impact head off the rail by hand if possible. If this is not possible, the impact head is probably not reusable. Remove the remaining damaged rail section and posts.

15) After debris has been removed from the site and major components have been inspected for damage, the system can be reconstructed following the construction installation instructions.

6. Maintenance of the CAT™ System

Maintenance of the Crash Cushion/Attenuating Terminal™ can be categorized as routine and repair. Routine maintenance consists of periodically checking the system to see that the cable is taut, the nuts have not been removed from the cable, and the blockouts have not rotated. Repair maintenance deals with the system after it has been hit. Most hits on the CAT™ will require the replacement of the nose section, broken posts, and either two or four of the rail sections, depending on the severity of the hit. The following steps should be taken in making repairs.

1) Check the anchor cable and bracket for damage. The bearing plate, nuts, washers, and anchor bracket are rarely damaged.

2) Check the number of broken posts and wood blockouts that need to be replaced, along with any damaged bolts. Inventory and pick up the reusable parts.

3) Disconnect and remove any damaged rail from the posts.

4) Remove the broken posts in the steel tubes using one of the two post removal tools, recommended by the manufacturer, which can be assembled from "off-the-shelf-hardware" items. Pound the steel pipe or screw the lag screw into the top of the broken post and remove the broken post by pulling on the chain. If necessary, place a steel rock bar in the loop of the chain and use it as a lever arm to remove the post.

5) After the site has been cleaned up of damaged debris, the system can be reconstructed using the construction installation instructions.

7. Maintenance of the BRAKEMASTER® 350 System

Maintenance of the BRAKEMASTER® 350 can be categorized as routine and repair. The routine inspections can frequently be performed by drive-by inspection. Proper maintenance of the BRAKEMASTER® 350 System is essential to assure maximum performance. Take the time to review the maintenance instructions and product limitations thoroughly before performing the necessary work. Do not attempt to install any crash cushion without the installation manual and proper plans. Design and installation manuals are available by calling the Energy Absorption Systems Customer Service Department.

Visual Drive-By Inspection

1) Check to see if there is any evidence of an impact (deformed nose or side panels). If so, a walk-up inspection will be necessary.
2) Check to see that the surface under the unit is clear of debris to ensure proper performance.
3) Note the location, condition of the BRAKEMASTER® 350 System and the date of the visual drive-by inspection. Drive-by inspections are recommended on an as needed basis based upon traffic volume, site accident history, etc.

Physical Inspection

1) Be sure all bolts are tight and rust-free.
2) Be sure the retaining cable is snug and rust free.
3) Check to see that the threaded rods on the front of the break away assembly are intact and that the nuts on the rods are snug.
4) Check to see that the brake assembly has not moved on the cable. Both brakes must be on the cable sleeve and they must be positioned in the channel at the rear of the Brake/Tension Support.
5) Check to see that the laminated straps, the solid straps and the transition straps at the fender panel connection points are installed correctly with bolts in all available holes.
6) Check to make sure that the diaphragm legs are on grade level and clear of debris.
7) Clear any and all debris from the BRAKEMASTER® 350 System site area.
8) Note the location and condition of the BRAKEMASTER® 350 System for entry in the impact attenuator inspection logbook under the date of this inspection. Walk-up inspections are recommended on an as needed basis based upon traffic volume, site accident history, etc.

9) Refer to Post-Impact Repositioning Instructions and installation manual for more information.

Post-impact Repositioning Instructions

1) Deploy the appropriate traffic control devices to protect your crew.
2) Clear and dispose of any debris on the site.
3) Check all components of the BRAKEMASTER® 350 System and transition; any components that are bent or damaged must be replaced.
4) After a design speed impact on the nose, it is possible that the only parts that will be damaged are the brake/tension support and the front anchor.
5) To refurbish the BRAKEMASTER® 350 System, disassemble the unit and replace the damaged parts with new parts.
6) If the front anchor has moved more than 76 mm (3 in.) move it back to position and backfill with loose sand or concrete.
7) The cable/brake assembly must be replaced if the cable sleeve is exposed.
8) During the process of refurbishment, follow the Installation Instructions.
9) Check to be certain that the site is free from any debris. The BRAKEMASTER® 350 System is now ready to be used again.

5. REVIEW OF RESOURCES AND STANDARDS

a. Review of Resources

The following resources are used in Minnesota for deciding when a roadside protection device is needed and what type should be used. The edition of each publication noted is current as of March 2010. Subsequent editions of these publications may be available.

- ***Minnesota Road Design Manual*** **(Chapters 4 and 10**)
  http://www.dot.state.mn.us/design/rdm/index.html
  This design manual is specific to Minnesota. It is assumed that designers using this manual are familiar with the AASHTO *Roadside Design Guide*.

- ***Minnesota State Aid Manual*** **(2007)**
  http://www.dot.state.mn.us/stateaid/manual/sam07/index.html
  This manual indicates clear zone minimum requirements. These standards only apply when using State Aid funding.

- **Mn/DOT Standard Plates and Plans**
  Up-to-date standard plates and plans for guardrails and end treatments are located here on Mn/DOT's website:
  http://www.dot.state.mn.us/design/standard-plates/8000.html
  Note: This report contains information current as of July 2009. Agencies should contact Mn/DOT to insure that the standards and requirements have not changed. If you would like to receive email notifications when standard plates are updated, you can subscribe by contacting designstandards@dot.state.mn.us

- ***Roadside Design Guide*** **(AASHTO 3rd Edition 2006 – update scheduled in 2009)**
  This manual is not available in electronic form online, but can be purchased at:
  https://bookstore.transportation.org/item_details.aspx?ID=148
  This design guide has general background information on where to put roadside safety devices. More specific guidance specific to Minnesota can be found in the Minnesota *Road Design Manual*

- ***Design, Construction and Maintenance of Highway Safety Features and Appurtenances*** **(NHI Course #380034A reference manual: FHWA-NHI-04-014, March 2004)** http://www.nhi.fhwa.dot.gov/Home.aspx
  This NHI course reference manual covers the design, construction, and maintenance of highway safety appurtenances and features. The course book is a great reference for highway safety features. A hardcopy of this manual can be purchased at:
  http://www.nhi.fhwa.dot.gov/training/NHIStoreSearchResults.aspx?get=&COURSE_NO=380034A&KEYWORD=&TITLE=

- **Federal Highway Administration (FHWA) Federal Regulations**
  http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/
  This website includes a federal approved list of vendors.

- ***Recommended Procedures for the Safety Performance Evaluation of Highway Features*** **(National Highway Cooperative Highway Research Program (NCHRP) Report Number 350)**
  http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/nchrp_350/
  The NCHRP-350 Report contains the standards for testing each type of guardrail, end treatment and transition along with the minimum acceptable criteria for each type of installation. Systems must meet the NCHRP-350 criteria to be approved for use on the Minnesota Trunk Highway system. A list on Mn/DOT approved vendors for new construction is currently being developed and will be available in the future at the following website: http://www.dot.state.mn.us/products/index.html

- ***A Guide to Standardized Highway Barrier Hardware*** **(AASHTO-AGC-ARTBA Joint Committee October 2005)**
  http://aashtotf13.tamu.edu/index.htm
  This report contains drawings and specifications for the most commonly used roadside safety appurtenances in the United States. This report also includes FHWA product approval letters and contact information for product manufacturers.

- ***Barrier Guide For Low Volume and Low Speed Roads*** **(FHWA-CFL/TD-05-009 November 2005)**
  http://www.cflhd.gov/techDevelopment/completed%5Fprojects/safety/barrier/
  This report provides assistance in the warranting, selection and design of roadside barriers.

b. Review of Minnesota State Aid Standards

Minnesota State Aid Standards for installation of guardrail is determined by the clear zone (or recovery area) minimum dimensions indicated in a design chart from the Minnesota State Aid Rule 8820.9920. If the minimum dimensions cannot be met, guardrail installation must be approved by the District State Aid Engineer. A copy of this rule is located at the following website: https://www.revisor.leg.state.mn.us/rules/?id=8820.9920

APPENDIX A

GUARDRAIL SUMMARIES

LOW-TENSION THREE-STRAND CABLE GUARDRAIL

Description: Three strands of cable are mounted on breakaway posts. Penetration of a vehicle is prevented by the tensile strength of the cable. Cable guardrails contain errant vehicle through the development of lateral forces, which gradually redirect the vehicle through the roadway.

Use: Roads where plate beam guardrails are not required but a guardrail is needed on curves, high embankments, or to protect a public area. Used where high deflections (up to 11 feet) are not a concern. Should not be used for ditch slopes greater than 2:1.

Design: A flexible barrier, with round weak posts, resists impact using cables tied to PCC anchors. Post spacing is typically 12 feet-6 inch but can be reduced to limit deflections. High deflections of 10 feet can be expected with a 4500 pound vehicle at 60 mph and at a 25 degree hit, with a 12 feet-6 inch post spacing. The posts are designed to break off instead of leaning on impact, reducing roll-overs. Three-Cable guardrail systems have passed NCHRP-350 standard for a weak post design.

Mn/DOT Standard Plate: 8330 (wood) 8331 (steel)

http://www.dot.state.mn.us/design/standard-plates/index.html

Table 1 - Three-strand Cable Guardrail Specifications

Cost Range ($ / ft)[1]		**Minimum Barrier – Hazard Offset (ft)**			
Low	High	Speed:	20 – 30 mph	35 – 45 mph	50 (+) mph
$8.00	$9.00	Deflection	3.5 *	7.5 *	11.5
		System Depth	0.5	0.5	0.5
		Total	4.0 *	8.0 *	12.0
Beam Description: ¾ inch diameter steel cables.					
Post Description: S3 x 5.7 steel, 5 ft-3 inch long at 16 ft spacing 4 lb/ft steel u-channel, 5 ft long at 16 ft spacing 5 ½ inch diameter wood, 6 ft long at 11 ft-6 inch spacing					
Compatibility: A terminal is available. Although transitions are difficult, one is available.					

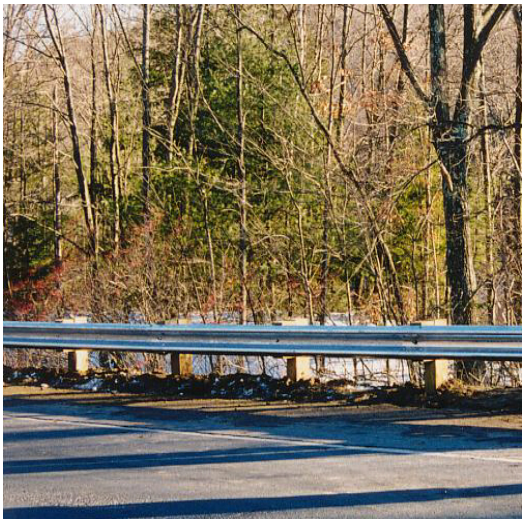
Source: FHWA-CFL/TD-05-009 *Barrier Guide for Low Volume and Low Speed Roads*
* Estimated values
[1] Cost values obtained from Mn/DOT's Average bid prices for awarded projects 2004-2008

Notes: Weathering steel posts are available. Reduced post spacing is recommended for tight curves (12ft spacing for radii up to 440 ft and 16 ft for radii up to 720 ft). Closer post spacing can reduce lateral deflection to some extent.

Potential Benefits: Simple low cost design which will redirect vehicles away from danger, very little rebound of impacting vehicles, no drifting of snow, no view obstruction.

Potential Problems: Even minor impacts can cause maintenance problems, the high deflections limit application, spare parts must be available and crews trained in repair and maintenance.

W-BEAM GUARDRAIL



Description: This system consists of a w-beam mounted on wood posts with blockouts. Upon impact the posts break away and the tensile strength of the beam contain the vehicle.

Use: Interstates and roads where a guardrail is warranted on curves, high embankments, or other hazards where limited deflections are required. This is the most common type of guardrail used in Mn/DOT at the present time.

Design: This semi-rigid barrier strength comes from a combination of the W-beam rail and the 6"x8"x6' strong wood posts to absorb vehicle impact when hit. The W-beam is installed 27 inches high (top of the W-beam) with wood blocks between the posts and the W-beam. Lateral deflection is normally less than 3 feet. The blocked out design minimizes the chance of a vehicle snagging itself in the rail and also reduces the likelihood of vehicle vaulting by maintaining a consistent rail height during impact.

Mn/DOT Standard Plates: 8307 (Wood posts) and 8338 (Steel posts)
http://www.dot.state.mn.us/design/standard-plates/index.html

Table 1 - W-beam Guardrail Specifications

Cost Range ($ / ft)[1]		**Minimum Barrier – Hazard Offset (ft)**			
Low	High	Speed:	20 – 30 mph	35 – 45 mph	50 (+) mph
$13.00	$20.00	Deflection	1.0*	2.0	3.0
		System Depth	1.0	1.0	1.0
		Total	2.0	3.0	4.0
Beam Description: 12 gauge galvanized steel w-beam.					
Post Description: Wood 6"x8"x6' posts. Increased strength can be obtained by decreasing the post spacing. Mn/DOT uses two designs: Design A is for posted speeds of 50 mph or greater and has 6 feet 3 inch post spacing. Design B is for posted speeds less than 50 mph and has 12 feet 6 inch post spacing.					
Compatibility: Several terminals and transitions are available					

Source: FHWA-CFL/TD-05-009 *Barrier Guide for Low Volume and Low Speed Roads*
* Estimated values
[1] Cost values obtained from Mn/DOT's Average bid prices for awarded projects 2004-2008

Notes: There are several options available to reduce the deflection characteristics including reducing the post spacing by fifty percent, nesting w-beams, using a rub rail mounted on the posts below the block-outs, and increasing the embedment of the posts by up to 1 foot. The system can be constructed with weathering steel.

Potential Benefits: This system is commonly used. Will redirect errant vehicles away from danger and limit the vehicle deflection. Low vehicle deflection enables a hazard to be closer to the road and keep vehicles safe. Damage as a result of crashes is usually limited. Although severe hits can destroy the system, it is not uncommon for the system to remain serviceable after several crashes.

Potential Problems: Semi-rigid design may cause damage to the vehicle and occupants; however, less damage may result than had the vehicle hit the hazard. May obstruct views somewhat and drift snow.

BULL NOSE GUARDRAIL SYSTEM

Description: A bullnose guardrail system is a crash barrier that is used to prevent out-of-control vehicles from crashing into the bridge supports in the median or falling into the opening between side-by-side bridges. It is known as the "bullnose" guardrail system because of its distinctive U-shaped design.

Use: Commonly used at bridge underpasses and overpasses. Underpass bull nose systems protect bridge supports in the median or other supports associated with the bridge. Overpass bull nose systems protect vehicles from running through the median and colliding with vehicles traveling on the underpass. Both systems consist of a thrie-beam guardrail system, similar to the W-beam system as explained on the previous page. The W-beam bullnose system does not meet criteria for NCHRP-350 and should not be used.

Design: Surrounds the hazard from every direction. Designed to act as a strong post thrie-beam guardrail without any hard ends that need to be treated.

Mn/DOT Standard Plates: None.

Table 1 - Bull Nose Guardrail Specifications

Cost Range ($ / ft)[1]		**Minimum Barrier – Hazard Offset (ft)**			
Low	High	Speed:	20 – 30 mph	35 – 45 mph	50 (+) mph
$43.00	$54.00	Deflection	1.0*	2.0	3.0
		System Depth	1.0	1.0	1.0
		Total	2.0	3.0	4.0
Beam Description: 12 gauge galvanized steel thrie-beam.					
Post Description: Wood 6"x8"x6' posts. Increased strength can be obtained by decreasing the post spacing. Mn/DOT uses two designs: Design A is for posted speeds of 50 mph or greater and has 6 feet 3 inch post spacing. Design B is for posted speeds less than 50 mph and has 12 feet 6 inch post spacing.					
Compatibility: Several terminals and transitions are available					

Source: FHWA-CFL/TD-05-009 Barrier Guide for Low Volume and Low Speed Roads
* Estimated values
[1] Cost values obtained from Mn/DOT's Average bid prices for awarded projects 2004-2008

Potential Benefits: Low cost which protects the hazard from all directions.

Potential Problems: Semi-rigid design may cause damage to the vehicle and occupants; however, less damage may result than had the vehicle hit the hazard. Snow drifting may be a problem in some situations

CONCRETE BARRIER

Description: Rigid concrete barrier. Impacting vehicles tend to ride up on the lower slope, dissipating some of the energy of the crash and thus reducing the rebound that might occur. This system is normally used as a median barrier but can be used in a single-face configuration on the roadside.

Use: High-speed, high-volume highways where little or no deflection can be tolerated, such as median barriers, bridge railings, or between other fixed objects such as bridge supports.

Design: Rigid barriers are constructed 32 inches high and will not deflect when hit. Construction consists of slip-formed, pre-cast, or cast-in-place. Concrete barriers can be placed directly on the pavement or a footing. Additional height may be added if busses or trucks are expected to require this type of guardrail protection. Commonly referred to as Jersey barrier.

Mn/DOT Standard Plates: 8308(reinforced concrete, no glare screen), 8309(reinforced concrete with glare screen), http://www.dot.state.mn.us/design/standard-plates/index.html

Table 1 - Concrete Barrier Specifications

Cost Range ($ / ft)[1]		**Minimum Barrier – Hazard Offset (ft)**			
Low	High	Speed:	20 – 30 mph	35 – 45 mph	50 (+) mph
$34.00	$54.00	Deflection	0.0	0.0	0.0
		System Depth	2.0	2.0	2.0
		Total	2.0	2.0	2.0
Beam Description: The New Jersey shape has a lower slope of 55degrees, breaking to 84degrees, 10 inches above the vertical reveal. The "F" shape is similar, breaking at 7 inches.					
Post Description: N/A					
Compatibility: Crash cushions or transitions to a strong post W-beam with a crashworthy end treatment are commonly used as terminals. Transitions to other systems are available.					

Source: FHWA-CFL/TD-05-009 Barrier Guide for Low Volume and Low Speed Roads
* Estimated values
[1] Cost values obtained from Mn/DOT's Average bid prices for awarded projects 2004-2008

Notes: The "F" shape is preferred because vehicle lift and roll is less pronounced than with the New Jersey shape. The concrete barrier should not be used with a curb, since placing this system on a curb prevents an impacting vehicle from riding up the lower slope as designed.

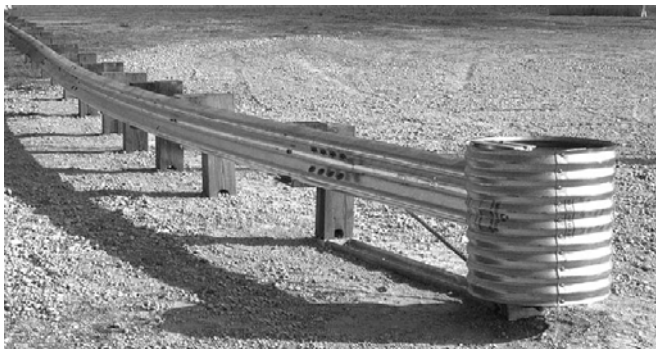
Potential Benefits: Relatively low cost. Generally effective performance for passenger-sized vehicles. Low maintenance is required after installation. No repair necessary on most impacts

Potential Problems: Initial cost, obstruction of views, drifting and storage of snow and pavement drainage. In some cases passenger size vehicles may become airborne during high-speed, high-angle impacts and may reach the top of the barrier. Buses and trucks may lean enough on the standard 32-inch design to strike an object even though the barrier does not deflect.

APPENDIX B

END TREATMENT SUMMARIES

ECCENTRIC LOADER BREAKAWAY CABLE TERMINAL (ELT)



Use: High volume roads with speeds 50 mph or greater. The following are necessary for proper usage: 4-foot flare, 10:1 cross slope or flatter, and 37.5 foot length before the guardrail hard end.

Design: Attempt to change the BCT design (breakaway cable terminal) to correct its marginal performance. Design has a vertical culvert tube covering the end of the end treatment to distribute force on the vehicle as posts break away.

MnDOT Standard Plate: 8329
http://www.dot.state.mn.us/design/standard-plates/8000.html

Cost: N/A

Potential Benefits: Lowest cost alternative to the BCT and twisted down W-beam end treatment. Breakaway posts cause higher deflections on side impacts compared to standard W-beam guardrail. Meets end treatment NCHRP-350 Report crash standards.

Potential Problems: Modifications to the design (less than a 4-foot flare and use on a greater than 10:1 slopes) will adversely affect the performance of this end treatment and should not be made. Most of the system cannot be reused after a collision.

SLOTTED RAIL TERMINAL (SRT-350™)

Use: SRT-350™ systems are gating systems and allow the vehicle to penetrate behind the rail on an end hit. It is an efficient retrofit and upgrade opportunity when replacement or maintenance becomes necessary on obsolete BCT and MELT installations.

Design: The Slotted Rail Terminal (SRT-350™) is a gating, flared end terminal and is available in a 8-Post and 9-Post System. The SRT-350™ is designed with weakened zones in the guardrail panels that provides reliable and predictable impact performance.

MnDOT Standard Plate: None – Proprietary
Contact Vendor - Trinity Highway Products http://www.highwayguardrail.com/default.html

Cost: $2,200-$2,500/ Each (Source: Mn/DOT 2009)

Potential Benefits: The parabolic flare has a "footprint" similar to the previously used BCTs and MELTs, making replacement easier. Fewer posts and a straight layout provide cost savings in construction, making replacement easier.

ET-2000™ AND ET-2000 PLUS™

Use: Any high speed, high volume road where the ELT or MELT cannot be used because of insufficient room for the 4-foot flare or the 10:1 slope ratio. The ET-2000™ and ET-2000 PLUS™ are the same system except for the extruder. The ET-2000™ and ET-2000 PLUS™ do not require a flare and can be positioned next to the road. The ET-2000™ and ET-2000 PLUS™ should not be used if pedestrians or other traffic could be present since head-on hits will extrude the guardrail out the back side.

Design: Designed to protect a hard guardrail end by a feeder chute capacity to extrude, flatten and bend the W-beam guardrail away from the colliding vehicle as travel is brought to a controlled stop. The posts are designed to break away upon impact. This system will also redirect vehicles when hit from the side according to NCHRP-350 standards.

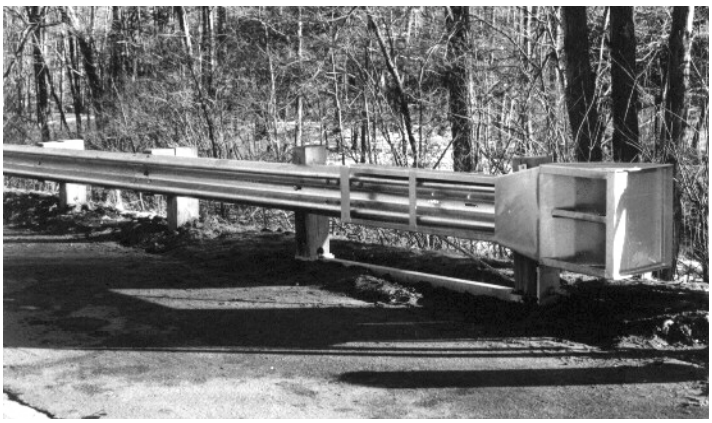
MnDOT Standard Plate: None - Proprietary
Contact Vendor - Trinity Highway Products http://www.highwayguardrail.com/default.html

Cost: $2,200-$2,500/ Each (Source: Mn/DOT 2009)

Potential Benefits: No additional right-of-way is required and the system absorbs energy in order to bring a vehicle to a safe stop. The system is affordable and may partially be reused after a hit.

Potential Problems: System cannot be used near pedestrians or other vehicles because the flattened W-beam rapidly protrudes out the back side as it collapses.

SEQUENTIAL KINKING TERMINAL (SKT-350™)



Use: The SKT 350™ can be used on shoulders or medians where the opposing travel way is at least 25 feet away or outside the clear zone, whichever is greater.

Design: The SKT 350™ is an energy absorbing tangent terminal. The SKT-350™ is 50'-0" long and has 8 breakaway posts. During head-on impacts, the SKT-350™ head slides over the W-beam guardrail. The rail is sequentially kinked or bent as it moves through the head. The kinked guardrail exits the head safely and the vehicle is brought to a controlled stop. When impacted along the side within the length-of-need, the SKT-350™ functions like guardrail. The errant vehicle is safely redirected back toward its original travel path.

MnDOT Standard Plate: None – Proprietary
Contact Road Systems Inc. http://www.roadsystems.com/

Cost: $2,200-$2,500/ Each (Source: Mn/DOT 2009)

Potential Benefits: Made by the same manufacturer as the FLEAT-350™, the only component different from the FLEAT-350™ is the impact head. This greatly reduces inventory requirements. The longer impact head and improved cable anchor bracket results in a better terminal.

Potential Problems: System cannot be used near pedestrians or other vehicles because the flattened W-beam rapidly protrudes out the back side as it collapses.

FLARED ENERGY ABSORBING TERMINAL (FLEAT-350™)

Use: The FLEAT-350™ is intended for use in wide medians

Design: The FLEAT-350™ (Flared Energy Absorbing Terminal) is an energy absorbing flared terminal. The flare is straight and the offset is variable anywhere between 2'-6" and 4'-0". The FLEAT-350™ is 37'-6" long and has 7 breakaway posts. The FLEAT-350™ combines the superior performance of the energy absorbing tangent terminals with the advantage of flared terminals in reducing nuisance impacts. During head-on impacts, the FLEAT-350™ head slides over the W-beam guardrail. The rail is sequentially kinked or bent as it moves through the head. The kinked guardrail exits the head safely and the vehicle is brought to a controlled stop. When impacted along the side within the length-of-need, the FLEAT-350™ functions like guardrail. The errant vehicle is safely redirected back toward its original travel path.

MnDOT Standard Plate: None - Proprietary
Contact Road Systems Inc. http://www.roadsystems.com/

Cost: $2,200-$2,500/ Each (Source: Mn/DOT 2009)

Potential Benefits: Made by the same manufacturer as the SKT-350™, the only component different from the SKT-350™ is the impact head. The FLEAT-350™ has significantly fewer small components than any other flared terminal. This substantially reduces the installation and maintenance time. The flare is straight, not a parabolic curve. This greatly simplifies the installation and improves the performance for traffic face redirection impacts.

Potential Problems: System cannot be used near pedestrians or other vehicles because the flattened W-beam rapidly protrudes out the back side as it collapses.

CRASH CUSHION ATTENUATING TERMINAL (CAT™)

Use: High-volume roads with posted speeds greater than 50 mph. Can be used where traffic or pedestrians are present. Does not require a restraining cable. Use in situations with limited area. The CAT ™ is an energy-absorbing attenuator available for use where blunt ends of rigid barriers and fixed objects are in the median or on the shoulder.

Design: Designed to absorb energy by shearing slotted holes in the W-beam rails. Posts are designed to break away on a direct hit and redirect a vehicle if hit from the side.

MnDOT Standard Plate: None - Proprietary
Contact Vendor Trinity Highway Products http://www.highwayguardrail.com/default.html

Cost: N/A

Potential Benefits: Can be used in tight situations, medians or high impact areas which may be hit from either side. Best economical system for both end and side collisions meeting NCHRP-350 crash standards. Many of the parts can be reused after a typical collision. Requires no concrete pad for installation.

Potential Problems: High initial cost.

BRAKEMASTER ® 350

Use: High volume roads with posted speeds greater than 50 mph. Can be used where traffic or pedestrians are present. Does not require a restraining cable. Use in situations with limited area.

Design: The BRAKEMASTER ® 350 shields dangerous guardrail ends at wide median and roadside sites with adequate clear zones. A special breaking mechanism provides functional resistance through a fixed cable When a vehicle hits, the breakaway assembly, the W-beam telescopes, the posts break and the cable acts to help absorb the energy and bring the vehicle to a safer stop. Redirects when hit from the side.

MnDOT Standard Plate: None – Proprietary
Contact vendor - Energy Absorption System http://www.energyabsorption.com/

Cost: N/A

Potential Benefits: Can be used in tight situations such as medians or high impact areas which may be hit from either side, NCHRP-350 crash tested approved. One of the best systems for both end and side collisions. Many parts can be reused after a collision. It provides bi-directional protection and does not require a concrete anchor or pad, making it fast and easy to install (less than three hours).

Potential Problems: High initial cost