

A Guide for W-Beam Guardrail Damage Assessment (DRAFT)

A Field Manual for
Highway Maintenance Personnel



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Highway Research
Program
Project 22-28

ACKNOWLEDGEMENT

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Introduction

This document provides guidance to aid highway maintenance personnel in assessing damage and repair priority of the most widely used strong-post w-beam guardrails – namely the modified G4(1S) and the G4(2W). These systems are also identified as SGR04 in the *Standardized Highway Barrier Guide*. The evaluation procedures are presented in a graphical format to facilitate the assessment process. For each damage mode, a commentary is also provided to support the evaluation criteria. A worksheet is provided at the end of this Manual to be used in assessing guardrail condition and reporting materials to be repaired.

There are many risk factors, in addition to guardrail condition, that state agencies must consider in deciding which systems most warrant repair, such as traffic exposure, operating speeds, site conditions and crash history to name a few. The guidance presented herein is based solely on the effectiveness of the damaged guardrail to safely contain and redirect errant vehicles.

Three classifications are used to denote the relative priority for repair – High, Medium and Low. These were adopted from NCHRP Report 656 and are defined as follows:

- **High Priority:** Indicates severe damage. The crash performance of the barrier has been compromised to such a degree that a second impact to the damaged barrier would likely result in unacceptable performance.
- **Medium Priority:** Indicates moderate damage. The crash performance of the barrier has likely been compromised to some degree, but the system should perform effectively for a majority of impact conditions.
- **Low Priority:** Indicates that the damaged guardrail is expected to remain fully functional.

Online Version

An on-line version of this guide is available at:
<http://www.roadsafellc.com/GCA/index.php>

Lateral Rail Deflection



Maximum lateral deflection =	> 9 inches	High
	6 – 9 inches	Med
	< 6 inches	Low

Commentary

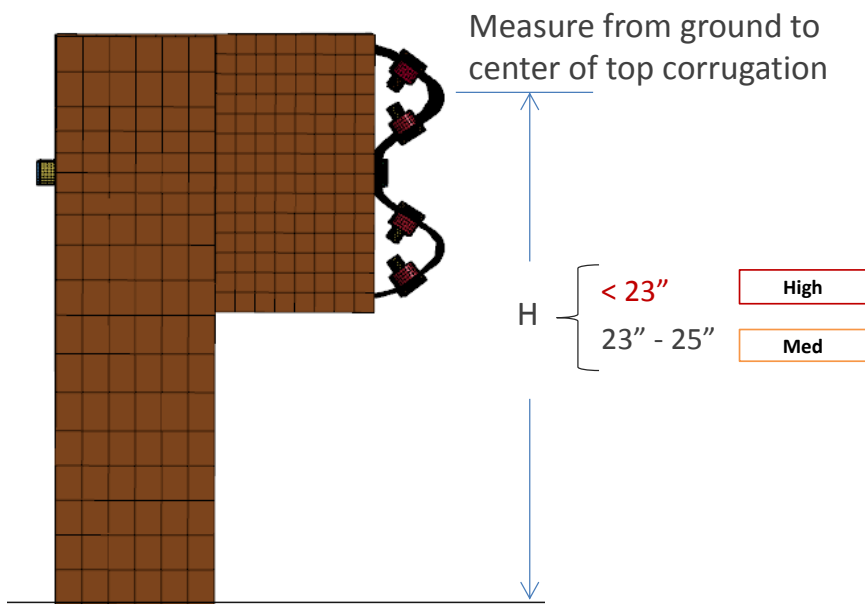
Although the effects of rail damage differ between the G4(1S) steel post guardrail and the G4(2W) wood post guardrail, the threshold of damage that constitutes the need for repair is essentially the same for both systems; thus the relative repair thresholds defined by Gabler *et al.* in NCHRP Report 656 are considered valid for both systems and were adopted here.

Rail deflections exceeding 9 inches may significantly affect the ability of the guardrail system to contain and redirect vehicles. Beyond this critical deflection, the G4(2W) was shown to be susceptible to rail rupture, while the G4(1S) had an increased probability of overriding the barrier.

Rail deflections of 6 to 9 inches were found to compromise system performance, but the guardrail should function adequately under a majority of impacts.

At rail deflections less than 6 inches, the guardrail is expected to remain fully functional.

Rail Height Condition



Field Example

Commentary

Rail height has traditionally been measured with respect to the top of the rail; however, for crash damaged guardrail it may be more appropriate to measure height with respect to the top corrugation of the rail. For example, a guardrail with standard top-of-rail height of $27\frac{3}{4}$ inch with a dent on the top of the rail that reduces (locally) the top-of-rail height by 4 inches may not significantly affect guardrail performance as long as the top corrugation is more than 23 inches above grade (also see Rail Crush criterion).

Analyses and full-scale tests have shown that there is a high probability for vaulting over the rail when rail height, as measured from the ground to the center of the top corrugation of the w-beam, is less than 23 inches. Therefore, when rail height, H , is less than 23 inches, the relative priority for repair is high.

In the FHWA memorandum issued on May 17, 2010 it was stated that,

"Transportation agencies should ensure the minimum height of newly-installed G4(1S) W-beam guardrail is at least $27\frac{3}{4}$ inches (minimum) to the top of the rail, including construction tolerance. A nominal installation height of 29 inches, plus or minus one inch, may be specified and is acceptable for use on the NHS."

Note that a top-of-rail height of $27\frac{3}{4}$ inches corresponds to $H=25\frac{1}{4}$ inches. Thus, based on the memorandum, when the rail height, H , is 23 to 25 inches, the relative priority for repair is classified as medium.

Splice Damage



-

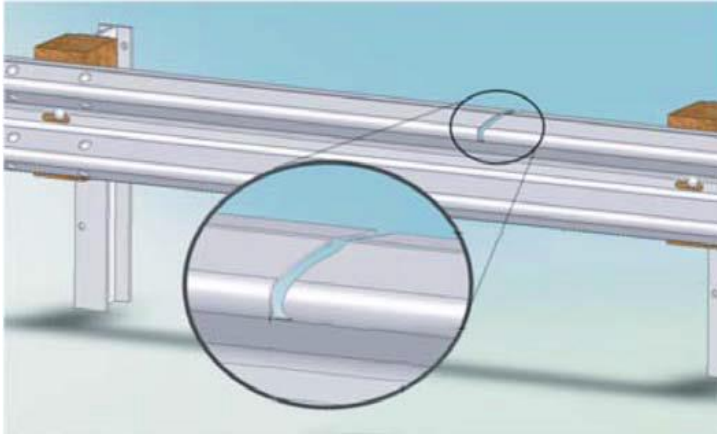
} High

Field Example

Commentary

TBD

Vertical Tears



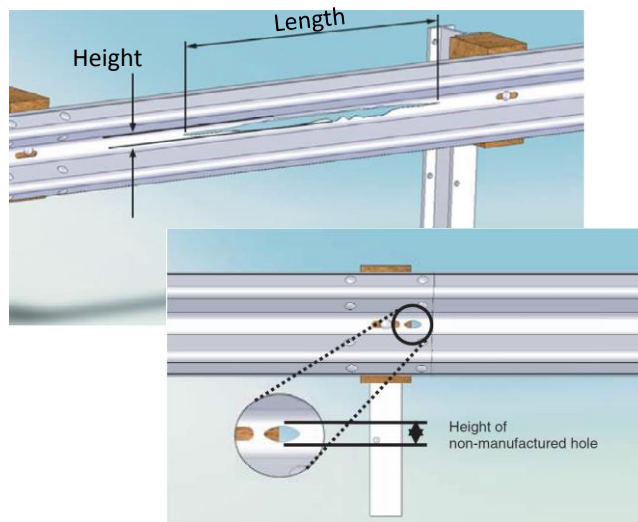
Any size vertical tear → **High**



Commentary

Any vertical tear on a w-beam rail may significantly affect the ability of the guardrail system to contain and redirect vehicles. A vertical tear, particularly on or near the edge of the rail, has a high probability of propagating during impact and resulting in complete rupture of the rail. All vertical rail tears, therefore, indicate high priority for repair.

Rail Holes / Horizontal Tears



- Any size hole or tear at top or bottom edge
 - Hole with height > 1"
 - Three or more holes or tears on a panel
- High**
-
- 1 to 2 holes with height < 1"
 - Horz. Tears with Length > 12"
 - Horz. Tears with height 0.5 – 1"
- Med**



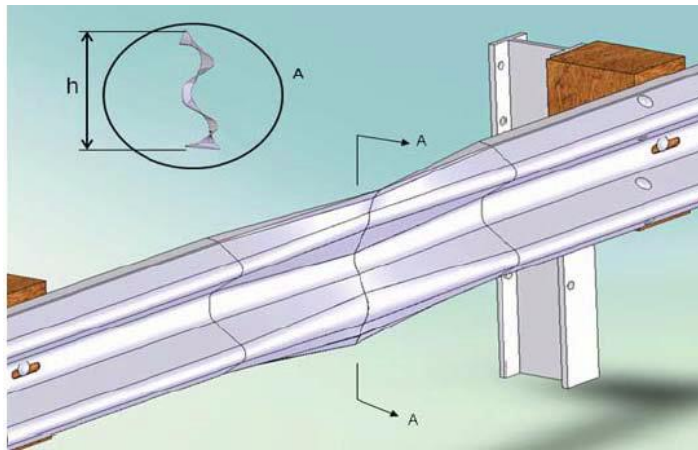
Commentary

Any size hole or horizontal tear located at the top or bottom edge of the rail has the potential for causing a tear to propagate vertically and is therefore consider high priority for repair. Also, for holes with heights greater than 1 inch, or when there are three or more holes or horizontal tears on a w-beam panel, the relative priority for repair is classified as high.

For horizontal tears with lengths greater than 12 inches, or with heights between 0.5 – 1 inch, or when there are 1 to 2 holes with height less than 1 inch on a single panel, the performance of the guardrail may be compromised, but it should function adequately under a majority of impacts. Thus the relative priority for repair is classified as medium for those cases.

Pendulum tests have shown that horizontal tears located between the top and bottom corrugations of a w-beam rail do not notably reduce the tensile capacity of the rail. Such tears, however, can result in a part of the vehicle (e.g., front bumper) passing through the tear, exposing the component to direct impact against the guardrail posts; or further extending the tear as the vehicle progresses forward along the rail, increasing the potential for rail rupture. Engineering judgment should be used on a case by case basis when assessing horizontal tears with lengths greater than 12 inches.

Rail Flattening and Rail Crush



Height of Rail Cross-Section, $h =$	$> 17''$	Med
	$9 - 17''$	Low
	$< 9''$	Med



Field Example of
Rail Flattening



Field Example of
Rail Crush

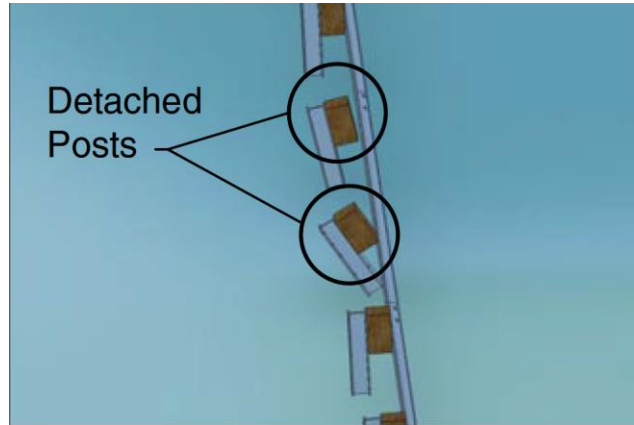
Commentary

Rail flattening and rail crush have not been shown to significantly affect guardrail performance. However, when the cross-section height of the rail, as illustrated in the figure to the left, is less than 9 inches (e.g., crushed) or greater than 17 inches (e.g., flattened), the performance of the guardrail is likely compromised, but it should function adequately under a majority of impacts.

For rail damage resulting in a cross-section height of 9 to 17 inches, the guardrail is expected to remain fully functional.

Note that the cross-section height of an undamaged w-beam rail is 12 inches.

Posts Separated from Rail



- Post/rail separation > 3"
- 2 or more posts separated from rail

Med



Field Example

Note:

1. If the blockout is not firmly attached to the post, count as missing blockout.
2. Lateral deflection guidelines may apply for this damage mode.

Commentary

This damage mode has not been shown to significantly affect guardrail performance; however, engineering judgment should be used on a case by case basis.

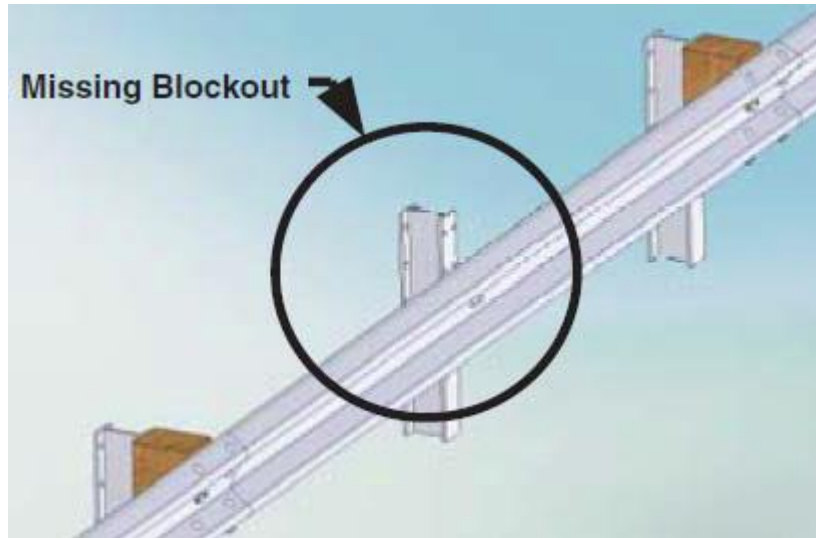
For the case of a single post separated less than 3 inches from the rail, the system should remain fully functional. However, when two or more consecutive posts are separated, or when post/rail separation for a single post exceeds 3 inches, guardrail performance may be compromised. The relative priority for repair in such cases is generally medium; however, such damage often denotes the existence of other damage modes.

Post and rail separation rarely occurs without post and rail deflection or damage to other components. When post/rail separation greatly exceeds 3 inches or if multiple posts are separated from the rail, it is recommended that other aspects of the system be critically evaluated (e.g., lateral deflection, missing or damaged blockouts, etc.).

The photo shown to the right is an example of rail-post separation that warrants high priority for repair. Although the rail deflection is negligible, the extreme deformation and separation of the posts in this case render them nonfunctional.



Blockout Condition



Any blockouts:

- Missing
- Cracked across grain
- Split through post hole
- Rotted

Med



Field Example

Commentary

This damage mode has not been shown to significantly affect guardrail performance; however, when one or more blockouts are missing, cracked across the grain, split vertically through the post-bolt hole or rotted, there is an increased potential for the rail to directly contact the posts during a collision, which may increase the propensity for rail tears (particularly for rail contact with steel wide-flange posts).

For this damage mode, the guardrail is expected to perform adequately for the majority of impact cases. The relative priority for repair is classified as medium.

Wood Post Deterioration

Damage Levels

Damage Level	8-inch Round Posts (nominal)			General
	Capacity		Resi Score	Relative Capacity
	Peak Force (kips)	Strain Energy (kip-in)	S _U or S _{MOR}	
0 (new)	> 14	> 35	> 45	100%
1	12 - 15	26 - 40	35-45	75%
2	7 - 13	20 - 30	25 - 35	55%
3	< 9	< 20	< 25	< 45%

Visual Cues (see Commentary)



DL3



DL2



DL1

Force (k): 3.8 < 9
 Energy (k-in): 5.3 < 20
 Resi: 11.9 < 25

7.6 7-13
 21.3 20-30
 27.7 25-35

14.8 12-15
 32 26-40
 41.1 35-45

Commentary

Four levels of deterioration for wood guardrail posts are defined in terms of load and energy capacity of the post data, as well as in terms of relative capacity. Therefore, if post strength is measured or otherwise determined in the field (e.g., stress wave techniques, force-deflection techniques, resistograph, etc.) then the relative capacity may be used to identify damage level.

If strength and/or deterioration measurement tools are not available, then visual inspection and “sounding” procedures should be utilized by experienced maintenance personnel to assess the soundness of the posts.

Visual and Auditory Cues

DL3: Significant deterioration at top of post is usually evident. Deterioration is often deep (>1”) and covers the full cross-section of the post. Mildew or mold is often present on the side of the post near the ground line; and the post is audibly very soft (punky) when struck with a hammer near the groundline.

DL2: Often marked by shallow deterioration at top of post (<1”), extending over most if not all the cross-section. Post is audibly soft but not punky when struck by a hammer.

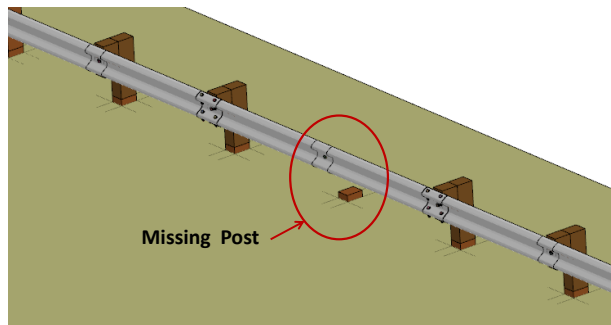
DL1: Generally there is no deterioration evident at the top of the post. In some cases, however, signs of deterioration may exist near the top-center of post, but will not extend to the outer shell. The post is relatively sound when struck with a hammer.

Wood Post Condition

Missing / Broken:



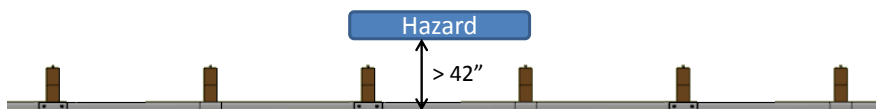
High



High

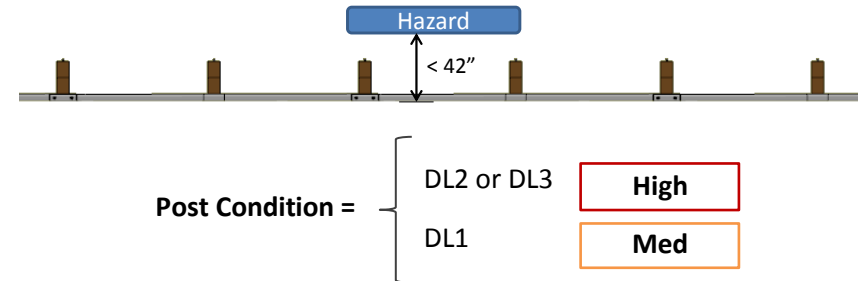
Deteriorated Posts:

If hazard is located more than 42" behind face of rail:



Post Condition =	DL3	High
	DL2	Med
	DL1	Low

If hazard is located less than 42" behind face of rail:



Commentary

If any posts are missing, broken or cracked across the grain the guardrail will not function properly and should be repaired. Also, any posts with deterioration level 3 (DL3) are essentially non-functional and are considered to be of high priority for replacement.

When a fixed/rigid hazard is located within 42 inches behind the guardrail, then posts with damage level DL2 or greater should be replaced with high priority, due to potential for large rail deflection leading to vehicle contact with the hazard.

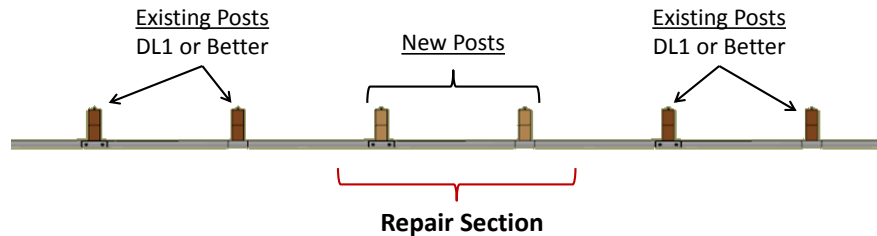
Otherwise, posts with damage level DL2 should function adequately under a majority of impacts and are thus considered to be of medium priority for replacement.

Posts with damage level 1 (DL1) are considered fully functional.

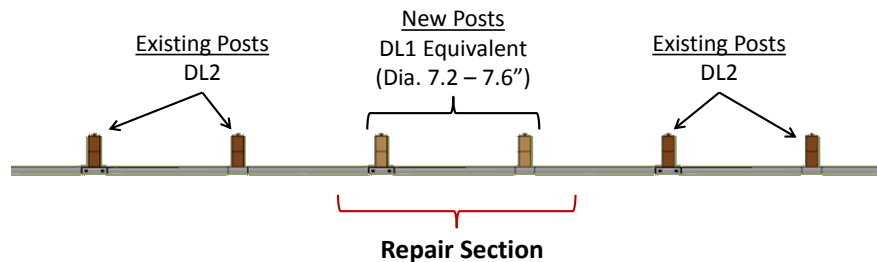
Wood Post Condition

If Repair is Warranted

If posts adjacent to the repair section are DL1 or better:



If posts adjacent to the repair section are DL2:



Commentary

If it is determined that replacement of guardrail post(s) is warranted, (e.g., in a crash damaged section), then the posts immediately upstream and downstream of the repair section should be checked for deterioration to ensure stiffness compatibility between the repair section and the existing guardrail.

If the adjacent posts are DL1 or better then only the posts in the damage region need to be replaced.

If the adjacent posts are DL2, then either: (1) all posts in the system should be replaced with new posts or (2) the damaged posts in the immediate repair section should be replaced with posts of equivalent strength to DL1 (e.g., new posts with reduced cross-section). From available test data, new round posts with a diameter of 7.2 to 7.6 inches meet this condition. Moreover, these reduced post diameters also meet the minimum size criteria for round posts (i.e., 8 ± 1 inches).

If the adjacent posts are DL3, then according to the aforementioned criteria, those posts should also be included in the repair since they render the guardrail non-functional.

Soil Erosion Condition

Erosion at a Single Post within a Four-Post Span:



Erosion =	$\geq 12''$	High
	9 - 12''	Med

Erosion at Multiple Posts within a Four-Post Span:



Erosion =	$\geq 6''$	High
	4 - 6''	Med

Commentary

Erosion at a Single Post within a Four-Post Span:

Erosion depth of 12 inches or greater around the post indicates high priority for repair due to increased potential for excessive pocketing and rail rupture.

Erosion depths of 9 to 12 inches were found to compromise system performance, but the guardrail should function adequately under a majority of impacts. This damage level is classified as medium.

When erosion is less than 6 inches, the guardrail is expected to remain fully functional.

Erosion at Multiple Posts within a Four-Post Span:

Soil erosion depth of 6 inches or greater at two or more posts within a four-post span indicates high priority for repair, due to increased potential for pocketing and rail rupture.

Erosion depth of 4 to 6 inches at two or more posts was found to compromise system performance, but the guardrail should function adequately under a majority of impacts at those erosion levels. The lower bound value of 4 inches was based on engineering judgment, since the study did not include erosion depths less than 6 inches. The upper bound value of 6-inches erosion was based on high magnitude strains around the splice-bolt holes in the w-beam, which were considered borderline regarding high potential for rail rupture.

When erosion is less than 4 inches, the guardrail is expected to remain fully functional.

End-Terminal Condition

Impact Head

Misaligned or missing screws:



High

(Photo: Courtesy of South Dakota DOT)



Note: Attachment hardware for the impact head will vary depending on manufacturer.

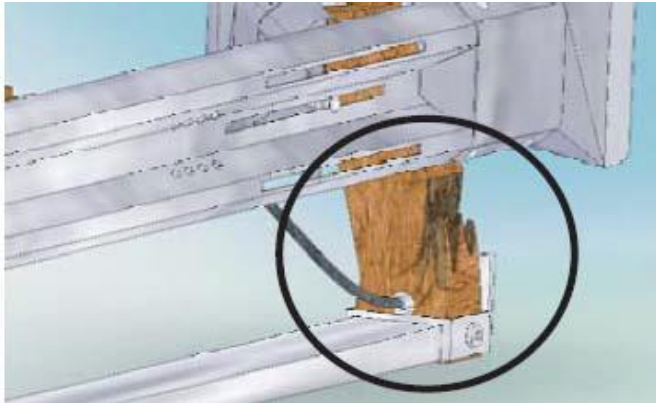
Commentary

The alignment of the impact head on energy absorbing end-terminal is crucial to the functioning of the system in end-on impacts. Thus, if the terminal head is misaligned or not properly attached to the end-post, then the system should be repaired. In most cases the impact head is attached to steel posts using bolts, whereas lag screws are used for attachment to wood posts.

End-Terminal Condition

Damaged End-Post

Damaged, Severely Cracked, Rotted or Missing End-Post:



High



High

Commentary

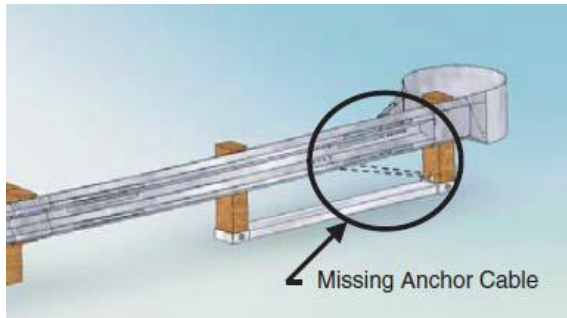
Although the end-terminal of a guardrail serves many purposes, one of its primary functions is to “anchor” the ends of the guardrail so that the resulting tension in the rail can help to limit lateral deflection of the guardrail during downstream impacts.

The anchor mechanism (for most end-terminals) relies on the end-post to hold the anchor cable in place and transfer the loads from the rail to the foundation tubes. Therefore, any end-posts that are damaged, severely cracked, rotted or missing are considered high priority for repair.

End-Terminal Condition

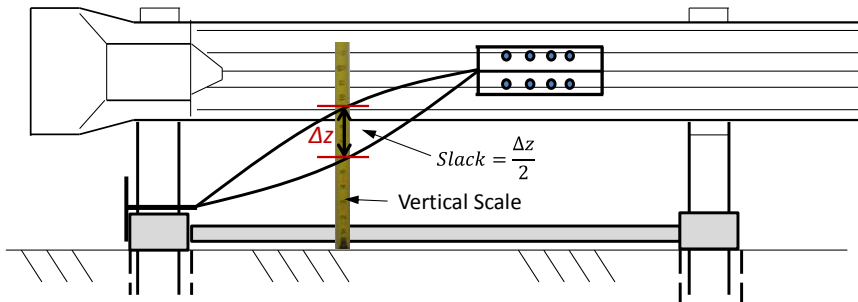
Anchor Cable:

Missing Cable:



High

Loose Cable:



$$Slack = \frac{\Delta z}{2} = \begin{cases} >3 & \text{High} \\ 2-3 & \text{Med} \end{cases}$$



Loose cable is often evidenced by separation between bearing plate and post.

Bearing Plate:



High



Med

Commentary

A missing or unattached anchor cable or a missing bearing plate would result in complete loss of anchorage for the guardrail and render the guardrail non-functional for downstream impacts. Such damages are therefore considered high priority for repair.

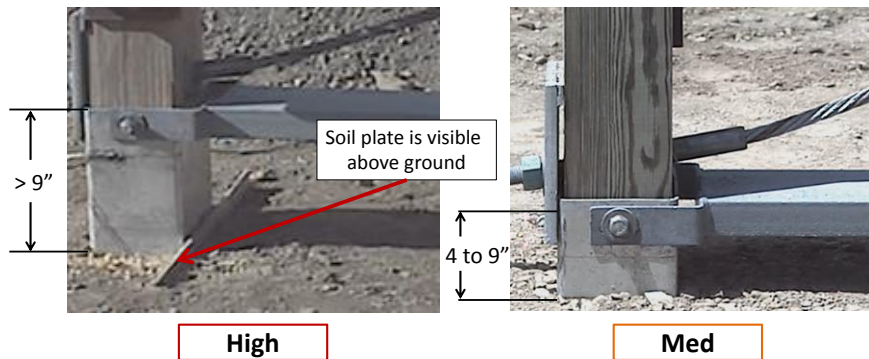
Also, when the anchor cable has more than 3 inches of slack, the performance of the guardrail is significantly compromised and is considered to be high priority for repair. For downstream impacts on the guardrail, a slack anchor cable results in increased lateral rail deflection and increases the potential for pocketing and rail rupture.

A loose cable could also lead to misalignment or loss of the cable bearing plate, as shown above. According to the repair guidelines specified by most end-terminal manufacturers, more than 2 inches of slack in the anchor cable is warrant for repair.

End-Terminal Condition

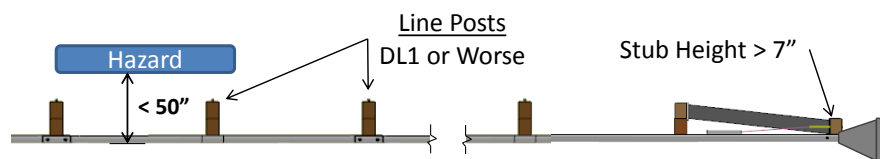
Foundation Tube:

Stub Height:



$$\text{Stub Height} = \begin{cases} > 9" & \text{High} \\ 4-9" & \text{Med} \end{cases}$$

Combination Mode:



$$\text{Combination Mode} = \begin{cases} \text{Hazard within 50" behind rail, and} \\ \text{Stub height > 7" and} \\ \text{Line posts DL1 or worse} \end{cases} \quad \text{High}$$

Commentary

A properly installed foundation tube normally protrudes approximately 2-3 inches above ground to facilitate connection of the groundline strut and for proper positioning of the bearing plate against tube. Stub heights have been observed to exceed this limit due to incorrect installation and, in some areas, due to frost heave.

A stub height exceeding 9 inches corresponds to excessive reduction in anchor strength and is therefore considered high priority for repair. This condition is evident when the soil plate on the foundation tube protrudes more than 1 inch above grade.

Stub heights extending from 4-9 inches above ground are considered to be medium priority for repair. When stub heights extend more than 4 inches above ground there is an increased potential for small vehicles to snag on the foundation tube. Also, further increases in stub height may prevent proper activation of the breakaway mechanism of the end-terminal during end-on crashes.

Additionally, for wood post guardrail systems such as the G4(2W), when a fixed/rigid hazard is located within 50 inches behind the face of the guardrail, then a stub height greater than 7 inches is considered high priority for repair if the guardrail line posts have deterioration level of DL1 or greater. This is due to potential for large rail deflection leading to vehicle contact with the hazard.

Worksheet for Guardrail Damage Assessment

This guardrail condition questionnaire was developed to aid highway maintenance personnel in assessing damage to guardrails and identifying materials needed for repair. The guidance presented herein applies to two of the most widely used strong-post w-beam guardrails – namely the modified G4(1S) and the G4(2W). If the answer to any of the questions in the questionnaire below is “yes” then it is highly unlikely that the barrier will perform acceptably in subsequent impacts, and the relative priority for repair is considered “high”.

Name	
Date	
State	
Route number	
Side of road	
Mile post at start of damage	

Notes:

Document Damaged Components.

If the answer to any of the questions in the questionnaire is “yes” then document necessary materials using the table below.

Panel Type	# of damaged straight panels	# of damaged curved panels
galvanized steel		
painted		
powder coated steel		
weathering steel		

Bolts	# of bolts needed
Post Bolts	
Splice Bolts	
Other	

Post Type	Size	# of posts to be replaced	# of posts to be reset
galvanized steel			
powder coated steel			
weathering steel			
wood			

Block out Type	# of damaged block outs
composite	
steel	
wood	

End Terminal Type	Missing Components

Level 1: System Damage

If the answer is YES to any of the Level 1 questions, replace all visibly damaged components of the system within the limits of the end anchors and reset the undamaged components to a minimum height of 27 $\frac{5}{8}$ inches.

- ___ Q1. Are there more than 9 inches of lateral deflection to the posts and/or rails?
- ___ Q2. Is the height measured from the ground to the center of the top corrugation of the w-beam less than 23 inches?

Level 2: Splice Damage

If the answer is YES to the Level 2 question, replace the missing or damaged bolts.

- ___ Q3. Are there any rail splices with two or more splice-bolt deficiencies? Do not count more than one deficiency per splice bolt.
- Missing splice-bolt
 - Visibly missing rail material under splice-bolt
 - Splice-bolt torn through rail

Level 3: Rail Panel Damage

If the answer is YES to any of the Level 3 questions, replace the damaged rails.

- ___ Q4. Are there any non-manufactured holes or horizontal tears that meet one or more of the following conditions?
- Intersect either the top or bottom edge of the rail
 - Height > 1"
 - Three or more non-manufactured holes or horizontal tears on a single panel
- ___ Q5. Does the rail have any vertical tears?

Level 4: Post Damage

If the answer is YES to any of the Level 4 questions, the missing and damaged posts should be replaced. The displaced and eroded posts should be reset. Any missing or damaged blockouts and/or post bolts should also be replaced.

- ___ Q6. Are one or more wooden posts missing, broken, rotted, or cracked across the grain?
- ___ Q7. Are one or more metal posts bent, deformed, or have metal tears?
- ___ Q8. Are the posts in good condition, but displaced?
- ___ Q9. Do two or more posts within a four post span length have soil eroded from them at a depth of 6 inches or more, as measured at the back of the post, or does one post have 12 or more inches of erosion?

Note: If there are any rectangular washers under the post-rail bolt heads anywhere in the system, they should be removed.

Level 5: Anchor Damage

If the answer is YES to any of the Level 5 questions, the damaged or missing components should be replaced. Remember to check both upstream and downstream anchors.

- ___ Q10. Is the end post sheared, rotted, cracked across the grain, bent, deformed, or has metal tears?
- ___ Q11. Is the anchor cable missing?
- ___ Q12. Is there more than 3 inches of vertical slack in the anchor cable?
- ___ Q13. Is the terminal bearing plate missing?
- ___ Q14. For energy absorbing terminal, are there any missing or failed lag screws?
- ___ Q15. Does the foundation tube stub height exceed 9 inches?
- ___ Q16. Is the groundline strut missing or otherwise non-functional?
- ___ Q17. Is there any other end-terminal damage that would result in more than 50% reduction in anchor capacity?
- ___ Q18. (*If system has wood posts*) Is there a combination of:
 - Hazard located within 50 inches behind w-beam rail
 - Stub height exceeds 7 inches
 - Line posts have deterioration level of DL1 or greater

Level 6: Steel blockouts

If the answer is YES to the Level 6 question, you should consider upgrading all the blockouts to composite or wood. FHWA encourages agencies to upgrade existing highway safety hardware that has not been accepted under NCHRP Report 350 or MASH when the system is damaged beyond repair.

- ___ Q19. Does your system have steel blockouts AND have you answered yes to any question above?