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Evaluation of Current Repair Criteria for Longitudinal Barrier with Crash Damage

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Abstract

To protect motorists and avoid tort liability, highway agencies expend considerable resources to repair damaged longitudinal barriers, such as w-beam guardrails. With limited funding available, though, highway agencies are unable to maintain all field-installed systems in the ideal as-built condition. Instead, these agencies focus on repairing only damage that has a detrimental effect on the safety performance of the barrier. The distinction between minor damage and more severe performance-altering damage, however, is not always clear. This paper presents a critical review of current United States (US) and Canadian criteria on whether to repair damaged longitudinal barrier. Barrier repair policies were obtained via comprehensive literature review and a survey of US and Canadian transportation agencies. In an analysis of the maintenance procedures of 40 US States and 8 Canadian transportation agencies, fewer than one-third of highway agencies were found to have quantitative measures to determine when barrier repair is warranted. In addition, no engineering basis for the current US barrier repair guidelines could be found. These findings underscore the importance of the development of quantitative barrier repair guidelines based on a strong technical foundation.

INTRODUCTION

Longitudinal barriers, such as guardrails, are installed along a roadway or in the roadway median to prevent an errant vehicle from traversing a steep slope, impacting a more dangerous roadside object, or entering opposing vehicle travel lanes. Full scale crash testing is used to ensure that these barriers will function properly prior to their installation along a highway (Ray and McGinnis, 1997; Ross et al, 1993). Based on an evaluation using real-world crash data, these barrier have consistently been shown to be effective (Short and Robertson, 1998; Michie and Bronstad, 1994; Elvik, 1995). Very little is known, however, with respect to how these barriers perform after they have been damaged.

Highway agencies expend considerable resources to repair damaged longitudinal barriers. Limited funds prevent highway agencies from maintaining all field-installed systems in an ideal as-built condition. Instead, these agencies focus on repairing only damage that is perceived to have a detrimental effect on the safety performance of the barrier. The distinction between minor damage and more severe performance-altering damage, however, is not always clear. In the case of a high severity crash involving rail penetration (left image in Figure 1), the need for barrier repair is obvious. Much more common, though, is minor barrier damage, e.g. a shallow dent which occurs in a low speed collision or a sideswipe (right image in Figure 1). Minor damage to barriers may also result from routine highway maintenance operations, including snowplowing, mowing or paving, and exposure to the environment, which may result in corrosion or termite damage.

Regardless of the cause, damage of this type poses a challenge to highway agencies. A failure to repair damage that affects barrier performance may lead to fatal consequences for passing motorists as well as potential exposure of the agency to a tort liability claim. Crash testing of undamaged barriers has consistently demonstrated that seemingly insignificant alterations to a barrier, such as using a rectangular washer on the post-rail connection, may result in catastrophic consequences for an impacting vehicle. This underscores the importance of the ability of agencies to identify seemingly minor damage that has serious implications on crash performance.

OBJECTIVE

The purpose of this research is to determine current US and Canadian criteria for repair of damaged flexible or semi-rigid longitudinal barrier.

METHODOLOGY

The general methodology for this study was to both examine the available literature and conduct a survey of transportation agencies to ascertain current damaged barrier repair thresholds among transportation agencies in the U.S. and Canada. The literature review focused on available national guardrail repair guidance and individual agency guidelines for the repair and maintenance of semi-rigid and flexible longitudinal barriers. These individual agency guidelines generally fell into two categories: (1) maintenance manuals that describe conditions that warrant repairs on a particular barrier and (2) maintenance assessment criteria that are used to assess barrier condition against a reference condition. Maintenance assessment criteria typically evaluate barrier functionality but can also include other factors such as aesthetics. Although maintenance assessment criteria may not be directly linked to barrier repair, they have been included as they are a gauge of barrier condition.

Using the findings from the literature survey, a survey instrument was developed for distribution to the US and Canadian transportation agencies. The 22 question survey was organized into the following 5 sections:

- Inventory of Guardrail and Median Barrier
- Repair Policies
- Non-Crash Related Damage/Deterioration
- Notification and Repair Responsibilities
- Inspection Policies and Procedures

The purpose of the barrier inventory section was to understand the types of barriers most used within a particular agency's jurisdiction. The repair policies section, the crux of the survey, was intended to provide insight into what thresholds are currently used to determine barrier repair need, how damaged sites are prioritized, timelines for repair, documented cases of impacts into damaged barrier, and whether the agency would benefit from more quantitative barrier repair guidelines. This paper will present the survey results on the guardrail inventory and repair policies sections.

RESULTS

National Guardrail Repair Guidance

National guidance regarding the repair of w-beam barriers is provided by the Federal Highway Administration's (FHWA) "W-Beam Guardrail Repair and Maintenance" Guide (1990). This document provides highway maintenance personnel with a comprehensive overview of the importance and logistics of w-beam barrier repair.

Guidance is provided on determining whether repair is necessary, which hinges on a site visit and a classification of the damage severity. A damaged barrier is classified into one of three categories, as summarized in Table 1.

According to the FHWA guidelines, the type of damage dictates how quickly it is ideally repaired. For instance, the report recommends that Category 1 damage be repaired as soon as practical as the barrier may be a hazard to motorists. Category 2 and Category 3 represent less of a threat to passing motorists and thus the report suggests that repairs can be scheduled with other repair work or performed when convenient, respectively. Despite the relatively quantitative description of the damage categories shown in Table 1, no documentation has been found which describe an engineering basis for the guidelines. It is suspected, however, that the guidelines were developed based on previous state experience with w-beam barrier and engineering judgment.

The American Association of State Highway and Transportation Officials (AASHTO) also provide guidelines on longitudinal barrier maintenance in their Maintenance Manual (2007). Although comprehensive in terms of what types of damage requires repair, little is provided in terms of quantitative guidelines. For instance, w-beam guardrail repair is recommended when a "deep pocket in the rail line" exists, with no mention of a length or depth threshold. Other examples of guardrail damage requiring repair include "sections torn loose from posts", "rail section flattened", or an "anchor at either end of a run broken loose".

Published State Transportation Agency Guidelines for Damaged Barrier Repair

The literature review included published guidelines from 26 U.S. state transportation agencies relating to the maintenance and/or performance assessment of longitudinal barrier. Of these 26 agencies, only 9 were found to have quantitative longitudinal barrier repair criteria (6 maintenance assessment criteria and 3 maintenance manual criteria). For the purpose of this study, 'quantitative' is defined as both objective and measurable. A guideline indicating that posts out of alignment more than 305 mm (12 in.) horizontally require repair, for instance, would be considered 'quantitative'. However, a guideline indicating that barrier needs to be repaired if 5% of the barrier is not functional would not be classified as 'quantitative' as there is no measurable definition of "not functional". For transportation agencies, quantitative barrier repair criteria are important for consistently and objectively identifying barrier damage that requires repair.

As additional quantitative barrier repair criteria were identified via the survey, all quantitative criteria are combined and discussed further in the survey results section. Table 2 summarizes selected agency barrier repair thresholds that were not classified as quantitative. The prevailing maintenance manual and maintenance assessment damage threshold is stated as “damage that affects the structural integrity of the barrier”. For maintenance assessment criteria, several agencies even rate barrier in terms of a percentage that is “functional” without specifically defining damage that impairs barrier functionality. Without an objective definition of the damage that affects barrier integrity, maintenance personnel tasked with evaluating barrier repair need may have significantly different interpretations of what damage impairs barrier functionality. The fact that the majority of state agencies employ this blanket statement without accompanying quantitative guidelines underscores the importance of developing a better understanding of how quantifiable barrier damage correlates to subsequent impact barrier performance.

Also evident from this literature review is the variation between maintenance manuals and maintenance assessment criteria even within the same jurisdiction. For instance, North Carolina has quantitative barrier repair guidelines in the maintenance manual but no quantitative guidelines for maintenance assessment (see Table 2). It should be noted that these criteria for a given agency are not required to coincide as these manuals are typically developed independently. In addition, maintenance assessment criteria are not necessarily used by maintenance personnel to justify barrier repair and may include factors other than the safety performance of the barrier in their scope. For all the published maintenance assessment manuals found in this study, however, functionality was a main component of barrier condition. Another observation from these published guidelines was that there was little distinction between the repair thresholds based on barrier application, e.g. on the roadside or in the median.

Analysis of Survey Responses

Responding Agencies and Guardrail Inventory

A total of 39 transportation agencies responded to the survey. From the U.S., there were responses from 29 transportation agencies from the continental states as well as Hawaii and Puerto Rico. From Canada, there were responses from a total of 8 Canadian Provinces: Alberta, British Columbia, Manitoba, New Brunswick, Nova Scotia, Ontario, Prince Edward Island, and Quebec. Approximately 38 percent of the respondents (15 agencies: 11 U.S. States, 3 Provinces and Puerto Rico) provided detailed information for guardrail within their respective jurisdictions. In total, these agencies provided an inventory in excess of 37,000 miles of longitudinal barrier (no distinction was made between roadside and median barriers). The strong post w-beam barrier was the most frequent barrier type, accounting for roughly 60 percent of total barrier length by the responding state agencies. Excluding the two agencies that reported no use of strong post w-beam (South Carolina and British Columbia), the average use of strong post w-beam barrier was approximately 75 percent. Concrete, cable barrier, strong post thrie beam, weak post w-beam were ranked second through fifth, respectively, based on the responding agencies providing detailed barrier information. The proportion of barrier identified in this survey appears similar to those reported by Ray and McGinnis (1997). Note, however, that the Ray and McGinnis study did not request agencies to report barrier mileage.

Repair Policies

Approximately 60 percent of responding agencies (23 of 39) indicated the presence of specific guidelines for determining when guardrail needs to be repaired. Of these 23 agencies, however, only 7 were classified as 'quantitative' with 2 of these agencies previously identified through the literature review. In general, the quantitative guidelines resulting from the survey were similar to those found via literature review. For the purpose of this study, the quantitative criteria found via the survey and literature review have been combined and shown in Table 3 through Table 6. Table 3 through Table 5 summarizes the metal beam barrier criteria while Table 6 summarizes the criteria for cable barrier. Each criterion is grouped based on the barrier component to which it refers: the rail element, the posts/blockouts, or the connections. For the rail element and post/blockout categories, the criteria have been further classified into 3 general damage types: (1) deflection, (2) tearing/breaks and/or punctures, or (3) deterioration. The transportation agencies using each of these criteria are listed on the right hand side of the table and grouped into one of two categories: maintenance or maintenance assessment. Again, note that for the same agency, maintenance manual-based criteria and maintenance assessment criteria are not necessarily the same. Ohio Department of Transportation (DOT), for instance, has quantitative criteria for both barrier maintenance and maintenance assessment; however, as indicated in the table, these criteria are not the same. Another example is Indiana DOT that has quantitative maintenance assessment criteria but the maintenance manual uses only a non-quantitative 'functional/non-functional' criterion and thus is not included in the tables. Note that references for each agency's barrier repair criteria appear next to the agency name.

Current FHWA guidelines for metal beam barriers have been provided for reference and are the thresholds to distinguish between the "minor damage" and "damaged but may still work" categories. No FHWA guidelines exist for cable barrier. The majority of the criteria listed in the table are those used to distinguish between minor damage and damage that needs to be repaired (or results in a 'deficient' rating in terms of maintenance assessments). Some agencies also have (or only have) criteria for severely damaged barrier; these criterion are marked with an asterisk.

For metal beam barrier rail elements, the most prevalent 'quantitative' criterion for repair was barrier deflection with a majority of agencies using the FHWA-endorsed 152 mm (6 in.) threshold. Maintenance assessment procedures in Missouri, however, allow only a 76 mm (3 in.) deflection threshold for guardrail. Even with severe metal beam barrier damage there are variations; the California maintenance manual specifies 305 mm (12 in.) of rail deflection while the North Carolina maintenance manual specifies 457 mm (18 in.). With respect to rail flattening, two states (Montana and Washington State) specify guardrail deficient if rail flattening is present even if the barrier was not deflected more than 152 mm (6 in.). The maintenance assessment procedures in Iowa were the only that prescribe specific thresholds for rail flattening: 50 and 30 percent of the cross-section thickness and height, respectively. For damage to posts, a majority of the agencies use a threshold of one or more broken or cracked posts. Two exceptions were Ohio and Indiana maintenance assessment procedures which prescribes two or more broken or cracked posts. For post deflection, a majority of the agencies use horizontal distance out of alignment; a notable exception was Pennsylvania and Nova Scotia which use post angle. For metal beam barrier connections, most maintenance assessment criteria rate a barrier as deficient if one or more bolts are missing while maintenance assessment in Wyoming specifies 4 or more missing bolts. Interestingly, none of the quantitative maintenance criteria use a threshold for missing bolts.

Similar variations can be found with respect to cable barrier repair/assessment criteria. The overall number of criteria pertaining to cable barrier, however, was substantially less than that of metal beam barriers. Notable differences include criteria for cable sag which varies from 38 mm (Iowa maintenance assessment) to 51 mms (Ontario maintenance manual) to up to 152 mm (Pennsylvania maintenance assessment). For broken posts, a majority of agencies use a threshold of one or more (Ohio, Quebec, and Montana) while Ontario uses 3 or more consecutive posts. In general, maintenance assessment criteria employed by Iowa were found to be the most quantitative and comprehensive with respect to both flexible and semi-rigid longitudinal barrier assessment.

Repair Priorities

For 27 different minor barrier damage types, respondents were asked to indicate whether the damage type would be repaired and the corresponding repair priority. A total of 33 respondents filled in this information in whole or in part; the remaining 6 agencies did not provide any information. Table 7 summarizes the responses by indicating the percentage of agencies that would repair the particular guardrail damage. For each damage type, the number of respondents for which it is based has also been listed. Note that not every agency provided a repair indication for each damage type; in most cases, the agency did not provide a response or, in fewer instances, provided alternate responses (other than the yes/no specified by the survey instructions). There appears to be consensus among respondents that post/rail deflection in excess of 152 mm (6 in.) and vertical rail tears need to be repaired. Splice damage, cable tension loss, damage to cables, soil erosion around posts, and bent or missing cable hooks had repair percentages in excess of 90 percent. There appears to be no particular consensus on what damage type does not need to be repaired. Rail deflection only and post/rail defection less than 6 inches appear to be the least likely to be repaired with 50 and 27 percent repair percentages, respectively.

A total of 34 agencies provided repair priority information for each damage type. Respondents were asked to categorize repair priority into one of 4 categories: (1) repair immediately, (2) repair as part of scheduled maintenance, (3) do not repair, and (4) at the discretion of maintenance personnel. Again, not all 34 agencies indicated repair priority for all damage types. On average, however, there were 27 respondents for each damage type. Figure 2 is a summary of the top 10 damage categories based on the percentage of respondents indicating the damage should be repaired as soon as possible. Not surprisingly, post and rail deflections in excess of 152 mm (6 in.), rail tears, and damage to cable ranked as high priority repairs. With the exception of erosion of soil around posts, there is very good agreement between these top 10 and the top 10 presented in Table 7.

With respect to known cases of a vehicle impacting a previously damaged barrier, 32 of 39 respondents indicated no documented cases. Three other responding agencies did not provide an answer to the question while two agencies answered “unknown”. Only two agencies (Oklahoma and New Hampshire) indicated documented cases of a vehicle impacting a damaged barrier. In Oklahoma, the single case identified a vehicle impacting a TMA that was in place (presumably in front of the damage section). In New Hampshire, the only details provided were that second impacts do not happen often.

Two-thirds of responding agencies (26 of 39) indicated that more quantitative guidelines for the repair of guardrail would be beneficial. Eleven agencies (28 percent) indicated that more quantitative guidelines would not be beneficial to their organization; however, only two (California DOT and Florida DOT) of these agencies reported quantitative barrier repair guidelines. Of the remaining two agencies, one indicated that more quantitative guidelines may be beneficial while the other indicated only if sufficient resources were available to comply with the more quantitative guidelines. In the latter case, the agency expressed concern about the increased liability associated with quantitative guidelines that the agency was unable to comply with completely.

DISCUSSION

A review of the available literature and a survey of U.S. and Canadian transportation agencies support several important notions regarding the current longitudinal barrier repair practices and priorities amongst transportation agencies. First is the general lack of quantitative guidelines to assess the longitudinal barrier damage level and the subsequent need for repair. Combining the literature review and survey results, data was obtained from a total of 40 of 50 U.S. states and 8 of 10 Canadian Provinces (approximately 80 percent of the U.S. and Canadian transportation agencies). Only 13 States and 2 Canadian Provinces, less than one-third of the 48 transportation agencies, had either quantitative barrier repair criteria or quantitative maintenance assessment guidelines for longitudinal barrier. For the remaining two-thirds of agencies, barrier repair and barrier assessment criteria usually required a determination of whether the barrier was "functional", with no specific guidelines for making that assessment. The current FHWA guidelines, published in 1990, do provide some loosely quantitative guidelines for barrier repair; however, the guidelines appear to be founded on engineering judgment instead of a strong analytic foundation. In addition, the survey responses suggest that transportation agencies would see benefit in more quantitative barrier repair guidance.

Second is the apparent variation between barrier assessment criteria, as present in maintenance assessment procedures, and those criteria used to determine the need for barrier repair, as prescribed in the maintenance manual. For thirteen agencies, information from both maintenance assessment procedures and corresponding agency maintenance manuals was available. Six agencies (Indiana, Iowa, Montana, Pennsylvania, Florida, and Washington State) had quantitative maintenance assessment criteria but lacked quantitative barrier repair criteria in the maintenance manual. Two agencies (California and North Carolina) had quantitative barrier repair criteria in the maintenance manual but lacked quantitative barrier assessment criteria. Ohio was the only agency that had both quantitative barrier repair criteria and quantitative maintenance assessment criteria while the remaining four agencies (Texas, Tennessee, Virginia, and Kansas) had no quantitative barrier repair or maintenance assessment criteria. Although these criteria are not required to coincide, all of the maintenance assessment criteria found in this study were either largely or solely based on barrier functionality. At a minimum, the variations noted in maintenance criteria and maintenance assessment criteria warrant further investigation.

Third, failure to promptly repair damaged barrier may increase a transportation agencies legal liability. Crashes involving vehicles impacting previously damaged barriers are found to occur in the field. A review of the available tort liability cases in the U.S. revealed that impacts into previously damaged barriers are not an unknown occurrence (Keller v. State of Illinois, 1982; Leonard Paxton v. Department of Highways, 1999; McDonald v. State of New York, 2002; Rosemary F. Woody v. Department of Highways, 1989). Thus, it would seem advantageous, at least from a legal perspective, to have more quantitative guidelines for when to repair damaged barrier and prioritize damaged barrier sections. Interestingly, the survey results suggest almost no documented cases of vehicles impacting previously damaged barrier.

All of these notions seem to point to the need for a better understanding of the effects of barrier damage on barrier performance. To better understand these effects, the authors recommend an approach that consists of full-scale crash testing of damaged barrier, pendulum testing of damaged barrier sections, and finite element modeling of vehicles impacting damaged barrier. The results of these three approaches can then be combined to develop more rigorous barrier repair guidance.

CONCLUSIONS

Based on the findings of the literature review and analysis of the survey responses, the following conclusions are drawn:

1. A majority of the current U.S. and Canadian transportation agency guidelines for longitudinal barrier repair lack quantitative measures to evaluate the need for barrier repair. In most of these cases, the practice is to repair barrier if it is “non-functional” with no specific guidance on making that assessment.
2. There is a need for the development of more quantitative guidelines for longitudinal barrier repair that are based on a strong analytical foundation. This analytical foundation should include full-scale crash testing of damaged barrier, pendulum testing of damaged barrier sections, and finite element modeling of damaged barrier impacts.
3. Several state transportation agencies, including California, Iowa, Montana, Ohio, Washington State, North Carolina, Pennsylvania, Missouri and Wisconsin, were found to have quantitative measures to rate or provide guidance on the repair of flexible and semi-rigid barriers. Even in these cases, however, there appears to be little connection between the criteria used to evaluate the condition of longitudinal barrier for the purpose of maintenance assessment and the criteria used by maintenance personnel to determine the need for barrier repair. As both criteria are based heavily on barrier functionality, these variations warrant further investigation.

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Figure 1. Does the damage to these w-beam barriers hinder their performance?

Table 1. Guardrail Damage Classification Details (summarized from FHWA, 1990)

Damage Category	Damage Attributes
(1) Non-Functional	• Rail element is no longer continuous • 3 or more posts broken off or no longer attached to rail • Deflection of rail element more than 457 mm (18 in.)
(2) Damaged but may still work	• Rail element is continuous (can be bent or crushed significantly) • 2 or fewer posts are broken or separated from the rail element • Deflection of the rail element is less than 305 mm (12 in.)
(3) Minor Damage	• Rail element is continuous (can be crushed or flattened) • No posts are broken off or separated from the rail element • Deflection of the rail element is less than 152 mm (6 in.)

Table 2. Summary of Selected Non-Quantitative State Transportation Agency Guardrail Repair Guidelines

Agency	Type*	Criteria Description/Excerpt (Reference)
Alabama Department of Transportation (DOT)	MM	Repair or replacement of guardrail sections, posts and hardware due to crash damage or normal deterioration. (AL DOT, 2005)
Idaho Transportation Department	MM	Any guardrail that is damaged. Most guidance is with respect to upgrading non-standard guardrail to standard hardware if it is damaged. (ID TD, 2008)
Indiana DOT	MM	Maintain guardrail to assure that it will function as designed. Repairs of non-functional barrier should be performed within 5 working days. (IN DOT, 2001)
Kentucky Transportation Cabinet (TC)	MA	Measure and record the total linear feet of guardrail that is damaged to the extent that structural integrity or functionality is lost. (KY TC, 2000)
Michigan DOT	MM	Only a description of how repair work should be completed. No criteria for when guardrail is considered deficient or should be repaired. (MI DOT, 2004)
Montana DOT	MM	“Guardrails are repaired and replaced in order to maintain its structural integrity” (MT DOT, 2002a)
North Carolina DOT	MA	Threshold condition is “Guardrail damaged or not functioning as designed.” (NC DOT, 1998; NC DOT, 2004)
Oregon DOT	MM	Description only of the work involved. Maintain, repair, realign, or replace guardrail to preserve or restore the installation to its designed condition. (OR DOT, 2004)
South Carolina DOT	MA	Threshold condition: "Guardrail damaged or not functioning as designed." (SC DOT, 2004)
Utah DOT	MA	Each guardrail run should function as intended - all posts, blockouts, panels, and connection hardware shall be in place. (UT DOT, 2004)

* MM denotes criteria present in a maintenance manual; MA denotes maintenance assessment criteria.

Table 3. Summary of Quantitative Damaged Barrier Criteria: Metal Beam Barrier Rail Elements

Category	Type	Criteria Description		Maintenance				Maintenance Assessment										
			FHWA (1990)	California (2006)	Ohio (2005)	North Carolina (2000)	Quebec (2004)	Iowa (2004)	Montana (2002b)	Ohio (2004)	Washington State (2006)	Wisconsin (2004)	Pennsylvania (2006)	Missouri (2003)	Indiana (2006)	Wyoming (2006)	Nova Scotia (2006)	Florida (2007)
Rail Element	Deflection	Deflection > 76 mm (3 in.)												X				
		Deflection > 152 mm (6 in.)	X	X				X									X	
		Deflection > 152 mm at any point in 3.6 m section							X		X	X				X		
		* Deflection > 305 mm (12 in.)		X														
		* Deflection > 457 mm (18 in.)				X												
		Rail flattening > 50% thickness					X	X										
		Rail flattening > 30% height						X										
		> 50% crushed								X					X			
		> 50% torn								X					X			
		Rail distortion > 25% of rail section length					X											
		Any rail flattening (even if <152 mm deflection)							X		X					X	X	
		Rail height varies > +/- 51 mm (2 in.) from 706 mm (27 in.) standard height						X										
		Rail height varies > +/- 76 mm (3 in.) from 706 mm (27 in.) standard height												X				
		Rail height < 610 mm (ground to top of rail)											X			X		
		Rail height > 762 mm (ground to top of rail)														X		
	Tearing/Breaks & Punctures	Horizontal tear > 25 mm wide and 305 mm long						X										
		Any length vertical tear						X										
		* Any splits or tearing	X	X														
		> 50% torn													X			
		Non-manufacturer hole in rail > 25 mm diameter						X										
		> 3 Non-manufacturer holes in rail						X										
	Deterioration	Any structural corrosion						X					X				X	

* Maintenance criteria is used to indicate a threshold for severe barrier damage (e.g. immediate repair)
X → Agency uses the criteria to determine barrier repair need (maintenance column only) or barrier deficiency (maintenance assessment column only)

Table 4. Summary of Quantitative Damaged Barrier Criteria: Metal Beam Barrier Post and Blockouts

				Maintenance				Maintenance Assessment										
Category	**Type**	**Criteria Description**	**FHWA (1990)**	**California (2006)**	**Ohio (2005)**	**North Carolina (2000)**	**Quebec (2004)**	**Iowa (2004)**	**Montana (2002b)**	**Ohio (2004)**	**Washington State (2006)**	**Wisconsin (2004)**	**Pennsylvania (2006)**	**Missouri (2003)**	**Indiana (2006)**	**Wyoming (2006)**	**Nova Scotia (2006)**	**Florida (2007)**
Posts & Blockouts	Deflection	Deflection > 76 mm (3 in.)												X				
		Deflection > 152 mm (6 in.)	X	X				X									X	
		Post angle > 15° angle from vertical											X					
		Post angle > 20° angle from vertical															X	
		* Deflection > 305 mm (12 in.)		X														
		* Deflection > 457 mm (18 in.)				X												
		1 or more twisted/misaligned blockouts						X			X							
		3 or more continuous twisted/misaligned blockouts								X					X			
		> 10% of blockouts twisted																X
	Tearing/Breaks	1 or more broken/cracked posts	X		X		X	X	X		X	X				X	X	
		2 or more broken/cracked posts								X					X			
		*3 or more broken posts				X												
		1 or more missing blockouts						X						X		X		X
		3 or more continuous missing blockouts			X					X					X			
	Deterioration	1 or more rotten posts			X													
		2 or more continuous rotten posts			X					X					X			
		Rotten post (> 50% cross section)													X			
		> 10% of posts/blockouts deteriorated or rotten																X
		Any structural corrosion						X					X					

* Maintenance criteria is used to indicate a threshold for severe barrier damage (e.g. immediate repair)
X → Agency uses the criteria to determine barrier repair need (maintenance column only) or barrier deficiency (maintenance assessment column only)

Table 5. Summary of Quantitative Damaged Barrier Criteria: Metal Beam Barrier Connections

				Maintenance				Maintenance Assessment										
Category	**Type**	**Criteria Description**	**FHWA (1990)**	**California (2006)**	**Ohio (2005)**	**North Carolina (2000)**	**Quebec (2004)**	**Iowa (2004)**	**Montana (2002b)**	**Ohio (2004)**	**Washington State (2006)**	**Wisconsin (2004)**	**Pennsylvania (2006)**	**Missouri (2003)**	**Indiana (2006)**	**Wyoming (2006)**	**Nova Scotia (2006)**	**Florida (2007)**
Connections	Integrity Loss	Splice damage (< 32 mm of rail material left at any point around the bolt)						X										
		1 or more missing/loose/damaged splice bolts						X										
		Loose/missing or damaged hardware											X					
		1 or more missing bolts							X		X	X		X			X	X
		1 or more posts separated from rail	X					X										
		4 or more missing/loose bolts in single section														X		
		*Bolts are missing or torn through rail element		X														

* Maintenance criteria is used to indicate a threshold for severe barrier damage (e.g. immediate repair)

X → Agency uses the criteria to determine barrier repair need (maintenance column only) or barrier deficiency (maintenance assessment column only)

Table 6. Summary of Quantitative Damaged Barrier Criteria: Cable Barrier

			Maintenance					Maintenance Assessment							
Category	**Type**	**Criteria Description**	**California (2006)**	**Ohio (2005)**	**North Carolina (2000)**	**Quebec (2004)**	**Ontario (2003)**	**Iowa (2004)**	**Montana (2002b)**	**Ohio (2004)**	**Washington (2006)**	**Wisconsin (2004)**	**Pennsylvania (2006)**	**Missouri (2003)**	**Indiana (2006)**
Rail Element	Deflection	*Cable is on the ground	X							X					X
		Top cable height varies > +/- 51 mm (2 in.) from 762 mm (30 in.) standard height				X		X							
		Spacing between cables > 76 mm (3 in.)						X							
		Horizontal deflection > 76 mm (roadside cable barrier)												X	
		Horizontal deflection > 25 mm (median cable barrier)												X	
		Horizontal deflection > 152 mm (6 in.)							X						
	Tearing/Breaks	Any broken cable strands						X							
		Frayed cable					X								
		* Broken cable			X	X					X				
	Deterioration	Any structural rust						X							
		Cable sag > 38 mm (1.5 in.) between posts						X							
		Cable sag > 51 mm (2 in.)					X								
		Cable sag > 152 mm (6 in.)											X		
Posts	Deflection	Post angle > 15° angle from vertical											X		
	Tearing/Breaks	1 or more broken posts		X		X			X						
		3 or more consecutive posts missing/broken					X								
		Missing first 2 posts adjacent to anchor(s)					X								
		* 4 or more posts knocked down			X										
	Deterioration	Any structural rust						X							
Connections	Integrity Loss	Missing cable hooks (unsecured cables)					X	X							
		Damaged cable hooks										X			
		Corroded cable hooks (unsecured cables)				X									

* Maintenance criteria is used to indicate a threshold for severe barrier damage (e.g. immediate repair)
X → Agency uses the criteria to determine barrier repair need (maintenance column only) or barrier deficiency (maintenance assessment column only)

Table 7. Agency Guardrail Repair Priorities by Damage Type

Damage Type / Description	% Agencies that would Repair	# of Respondents
Post/rail deflection > 152 mm	100	30
Rail Tear (vertical)	100	28
Loss of tension (cable barrier)	96	25
Damage to Cable	96	24
Erosion of soil around posts	96	23
Bent or missing hooks (cable)	95	22
Snowplow damage	95	19
Splice Damage	92	26
Missing bolts/hardware	92	25
Cable Sag	91	22
Rail Tear (horizontal)	89	28
Missing Blockout	89	28
Loose bolts/hardware	87	23
Mowing damage	83	18
Rail flattening	81	27
Post wood rot	81	21
Slope-Related Barrier Lean	79	24
Tear in Steel Post	78	27
Bolt pulled-through rail	77	26
Twisted Blockout	77	26
Insect damage	68	19
Rail/post corrosion or rust	67	18
Cracked Wood Post	64	22
Holes > 25 mm in rail	58	24
Rail Deflection only	50	22
Post/rail deflection < 152 mm	27	22

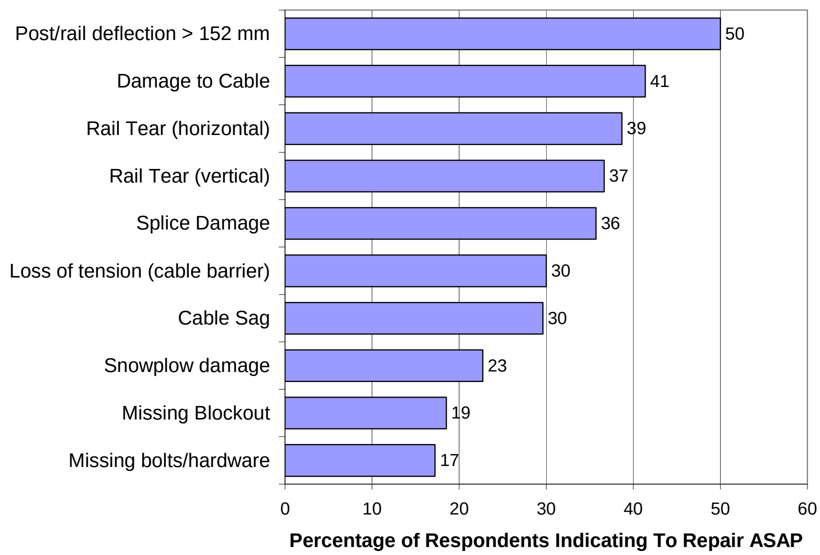

Figure 2. Damage Type Ranked by ASAP Repair Priority

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