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IN-FIELD INSPECTION METHODOLOGY FOR WEATHERING STEEL W-BEAM GUARDRAIL

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16. Abstract

The objective of this research was to develop an inspection method for evaluating the structural integrity of installed weathering steel W-beam guardrail system, without requiring disassembly.

The researchers conducted a nationwide survey of transportation agencies using weathering steel guardrail. The survey was aimed at determining the extent and location of rail damage due to advanced corrosion, methods or procedures employed to inspect and determine rail damage, and equipment used for inspection. Results of the survey indicated that while some states have experienced significantly compromised performance of the weathering steel guardrail due to advanced corrosion, the level of corrosion in most states is such that the guardrail systems remain functional. The survey also indicated that no non-destructive methods are currently being used for inspecting the weathering steel guardrail.

The researchers reviewed some of the existing NDT technologies for inspecting the integrity of weathering steel guardrail. It was determined that handheld ultrasonic corrosion thickness gauges were most suitable for this application.

The researchers collected various samples of the weathering steel guardrail from different user agencies. These samples were used to evaluate the effectiveness of the ultrasonic thickness gauges in measuring the thickness of the guardrail, and to establish a pass or fail threshold based on the measured thickness. The researchers also evaluated the use of the ultrasonic thickness gauge in lapped splices of the guardrail system, without requiring disassembly. It was determined that these gauges are suitable for use with assembled lapped splices.

The researchers also developed an inspection method for performing in-field evaluation of the rail. The inspection procedure is comprised of a two-level inspection approach. In the first-level, fewer spots are checked along the length of the guardrail system. If however a spot fails in the first-level inspection, a second-level inspection is performed. In the second-level inspection, more thorough inspection is performed at a specified distance upstream and downstream of the failed spot.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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1. INTRODUCTION

1.1 PROBLEM

Many states use weathering steel guardrail (Cor-Ten steel) along their roadways. The Federal Highway Administration (FHWA) recently posted a Frequently Asked Questions (FAQ) list on their roadway departure safety webpage, which states that the use of the weathering steel guardrail should be limited, but may be used if the owner agency adopts a frequent periodic inspection and replacement schedule. Rail deterioration appears to vary from state to state, with severe deterioration reported in some locations and no noticeable deterioration in other locations. An inspection procedure needs to be developed to comply with the direction in the FHWA's FAQ.

1.2 BACKGROUND

Several states across the nation use the weathering steel guardrail for aesthetic purposes. Other types of rail systems such as polyester coating (poly-coat), powder-coat, and acid-etched, are also prescribed by the states for aesthetic purposes. However, this report only addresses weathering steel W-beam guardrail systems. Instead of the zinc galvanization used to prevent corrosion of the standard steel guardrail, the outer surface of the weathering steel guardrail corrodes a certain thickness and maintains a specified core metal thickness. This outer corrosion layer gives a rustic look to the rail, which is considered more aesthetic compared to the metallic look of the galvanized steel guardrail.

It was believed that once the outer surface of weathering steel has corroded a certain thickness, the corrosion process stops and the metallic core thickness is maintained without the need of further surface treatment. However recent observations and in-field evaluations have shown that while weathering steel is resistant to further corrosion of the rail, it does not completely prevent corrosion under certain environmental circumstances *(1)*. More specifically, areas of the rail that overlap, such as in locations of rail splices, or near posts, are prone to increased corrosion due to water retention or other factors. Increased corrosion deteriorates the rail by reducing its tensile capacity and can ultimately result in loss of the rail's cross section.

Due to such observations, FHWA issued a response on their Frequently Asked Questions website limiting the use of weathering steel guardrails unless a frequent and periodic field inspection program was adopted by the user agency *(2)*.

Currently there are no established techniques for conducting field inspection of weathering steel guardrails. Non Destructive Testing (NDT) methods are desired for these inspections, so that they can be conducted without disassembling the rail.

1.2 OBJECTIVE

The objective of this research was to develop an inspection technique for determining the integrity of weathering steel W-beam guardrail systems. A field inspection manual and inspection forms were to be produced in this project.

This project started with an investigation and outreach effort to determine if similar efforts were underway elsewhere. The development of measureable, pass/fail criteria that did not involve disassembling the guardrail was a requirement of this project.

2. SURVEY OF USER AGENCIES

2.1 INTRODUCTION

As part of the ongoing research project for determining a non-destructive field inspection technique for weathering steel W-beam guardrail systems, the researchers conducted a survey of states. The objective of this survey was to determine the experience of pertinent agencies with the use of weathering steel W-beam guardrail. The survey was aimed at determining the extent and location of rail damage due to advanced corrosion, methods or procedures employed to inspect and determine the rail damage, and equipment used for inspection.

2.2 SURVEY PARTICIPATION

The survey was made available on the Internet and invitations to participate were sent through emails to various mailing lists and contacts; including ATSSA Guardrail Committee, AASHTO Technical Committee on Roadside Safety, National Association of County Engineers, and State Highway Safety Engineers.

Overall, 25 participants took the survey from19 states across the United States. The participating state agencies are listed below and also mapped in figure 2.1.

- Florida DOT / Florida Turnpike
- Illinois DOT
- Iowa DOT
- Kansas DOT
- Kentucky Transportation Cabinet
- Louisiana DOT and Development
- Maine DOT
- Mississippi DOT
- Nevada DOT
- New York State DOT
- North Carolina DOT
- Ohio DOT
- Pennsylvania DOT
- South Carolina DOT
- South Dakota DOT
- Tennessee DOT
- Vermont Agency of Transportation
- Washington State DOT
- Wyoming DOT

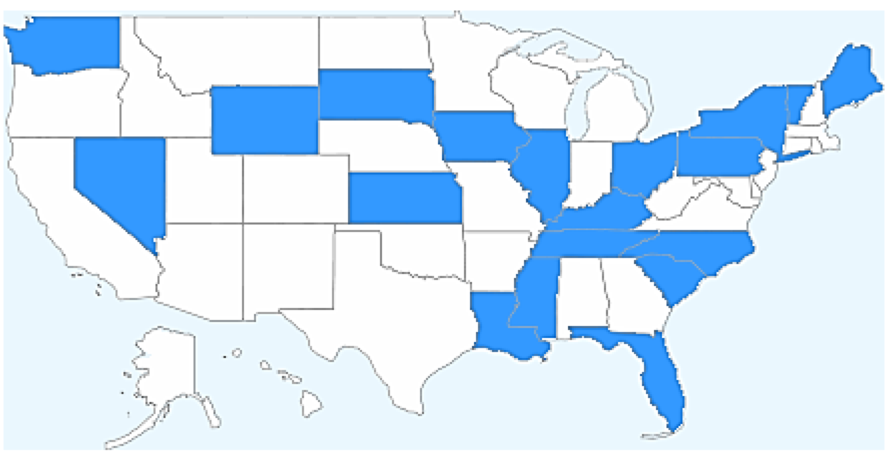


Figure 2.1: Map of the United States indicating the participating states (shown in blue).

2.2 SURVEY RESULTS

Results of the survey questions are presented next.

2.2.1 Current or Past Usage

Six of the 19 states taking the survey indicated their state has not used the weathering steel guardrail systems. Responses from these states were not recorded in compiling survey results. Thus results were compiled from the input of 13 states that indicated having used the weathering steel guardrail.

2.2.2 Type of the Weathering Steel Used

The participants were asked to indicate the ASTM specification of the steel used in their state for the weathering steel guardrail systems. In all, five different ASTM steel specifications are currently being used among the participating states, as shown in table 2.1. Of these, ASTM A588 and ASTM A606 are the most commonly used steel types. Washington State indicated using both ASTM A606 and ASTM A607 steel. Similarly, Wyoming indicated using both ASTM A606 and ASTM A847 steel.

Table 2.1: Type of weathering steel used by states

Steel Type	Number of States (State Abbreviations)
ASTM A588	5 (PA, SD, ME, VT, NY)
ASTM A242	1 (NC)
ASTM A606	5 (FL, KY, WY, WA, OH)
ASTM A607	1 (WA)
ASTM A847	1 (WY)

2.2.3 Miles of the Weathering Steel Guardrail

The participants were asked to indicate the approximate number of miles of the weathering steel guardrail that is (or was) installed in their state. The participants were also asked to indicate if their selections were based on inventory information or best estimate. Approximately 92% of the respondents mentioned using best estimate for indicating the approximate mileage of the guardrail used. The results of the usage are presented in figure 2.2.

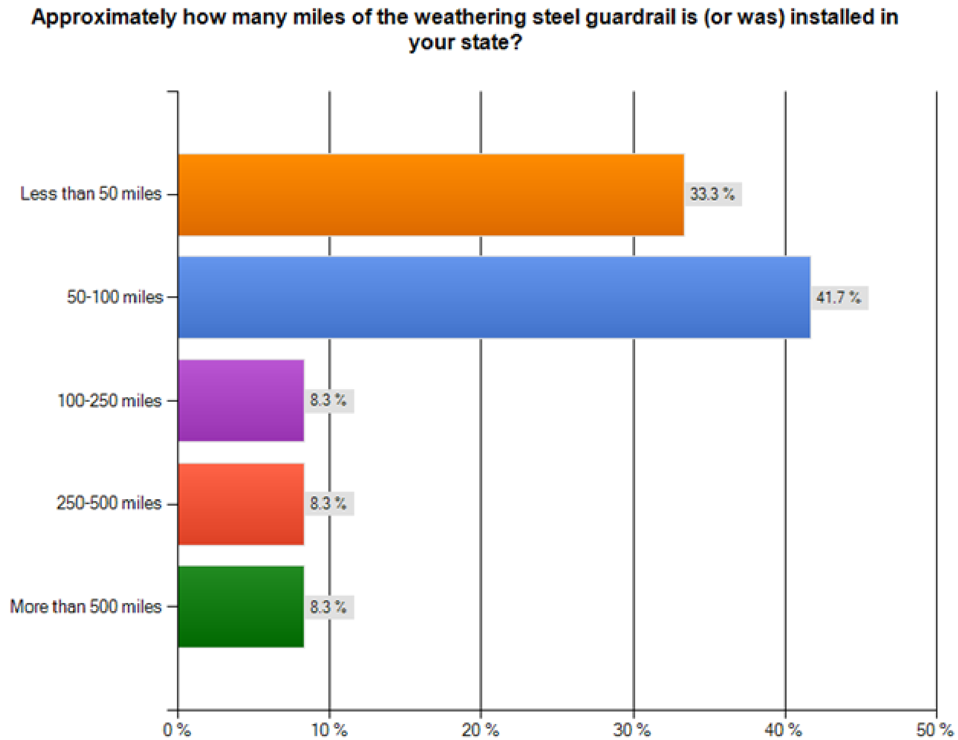


Figure 2.2: Usage in range of miles (estimated).

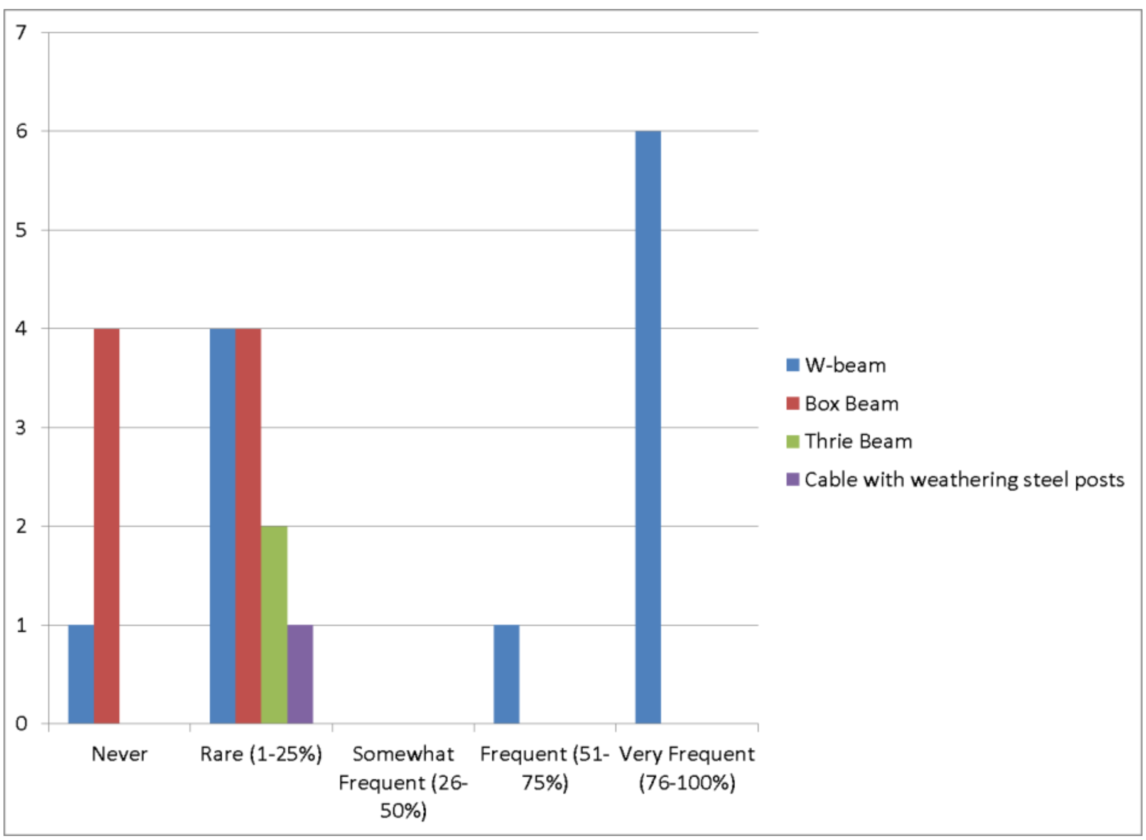


Figure 2.3: Different types of guardrail systems using weathering steel.

2.2.4 Types of Guardrail Systems Using Weathering Steel

The participants were asked to indicate the types of weathering steel guardrail systems used in their state. W-beam guardrail system was indicated to be the most frequently installed weathering steel system. Box-beam guardrail system was the next in usage, followed by the thrie beam guardrail system. One of the states indicated using a hybrid cable barrier system with weathering steel posts. The approximate frequency of these systems, as indicated by the participants, is shown in figure 2.3.

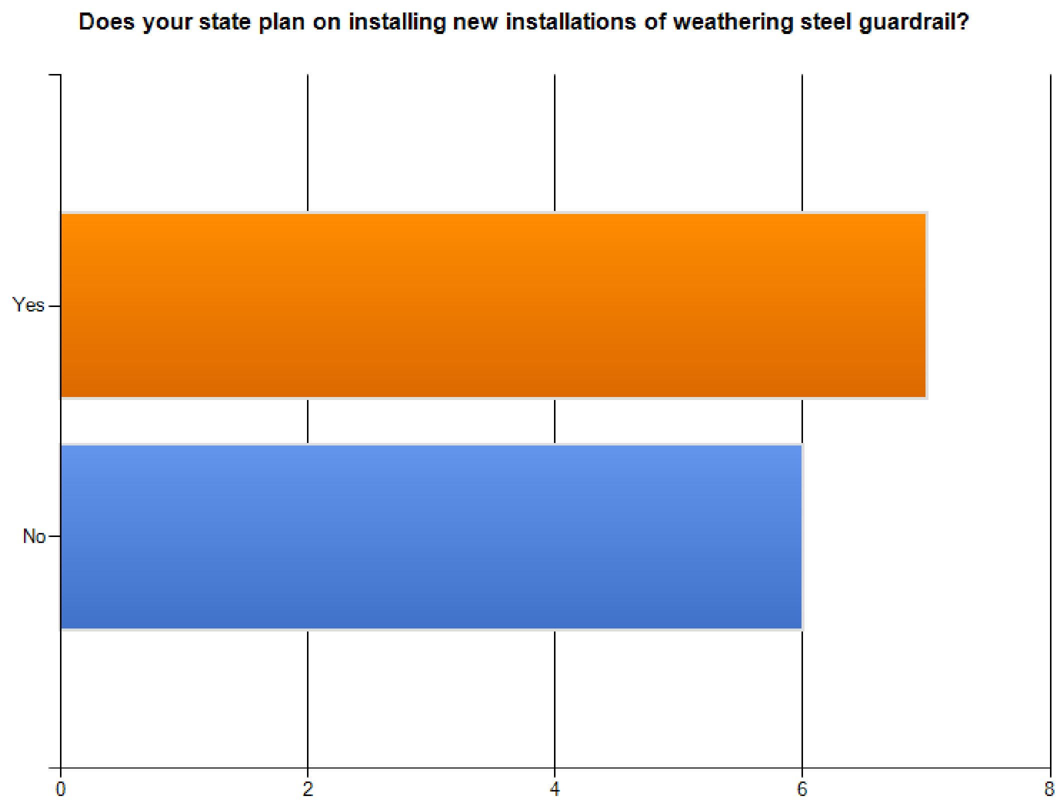


Figure 2.4: Weathering steel guardrail usage continuation plans.

2.2.5 Usage Continuation Plans

The participants were asked to indicate if their state planed on installing new installations of the weathering steel guardrail. Most states plan continued the usage as shown in figure 2.4. It is worthy to note that two of the six states planning to discontinue usage of weathering steel guardrail cited FHWA's recommendation to discontinue usage of weathering steel as the primary reason. These states did not indicate observing significant corrosion of the weathering steel in their installed systems.

2.2.6 Inspection Procedures

The participants were asked to describe any existing procedures or methods used for inspecting installed weathering steel guardrail systems. Most of the states indicated having no existing procedures or methods (figure 2.5). The inspection procedures of the four agencies that indicated having some guidance in place are either not adequate to accurately determine advanced corrosion, or do so in a non-destructive manner.

The procedures mostly involved visual inspection to detect apparent signs of advanced corrosion, or striking the rail with a hammer for some evaluation of the guardrail's integrity. New York Department of Transportation (NYDOT) indicated conducting an evaluation program to prioritize replacement of its weathering steel guardrail systems in 2008. Simple inspection methods were used to prioritize systems that needed to be replaced first. One of these methods was a "thud test" for the box beam guardrails. It involved evaluating the quality of the ringing sound generated by a hammer strike at the middle of a box beam span. The rails were judged to have a rating between one and four (four being least corroded) based on the amount of ringing. The accumulation of rust flakes inside the box beam dampens the ringing effect. Thus higher ringing indicates lesser corrosion. The W-beam guardrail on the other hand was evaluated using a micrometer. The "thud test" does not work for the W-beam rail because a ringing sound cannot be produced in an open section guardrail. The NYDOT evaluation procedure required using sand paper to take off some of the loose surface rust prior to measuring the cross-section thickness with a micrometer. The guardrails were then discerned to have different levels of corrosion based on the measured thickness. This method does not allow for evaluation of lapped splice regions without uninstalling the guardrail.

Ohio Department of Transportation (ODOT) indicated cutting out a sample section from the guardrail and then determining the engineering cross section of the rail.

The participants did not indicate using any other special equipment to detect advanced corrosion of the weathering steel.

2.2.7 Part Replacement Policy

None of the respondents indicated having a policy specifically geared towards replacing corroded parts of a weathering steel guardrail system. Some of the states indicated using their policy for galvanized steel guardrails for replacing the weathering steel guardrail parts. Fifty percent of the participants did indicate having a policy for replacement of parts of a conventional galvanized steel guardrail system.

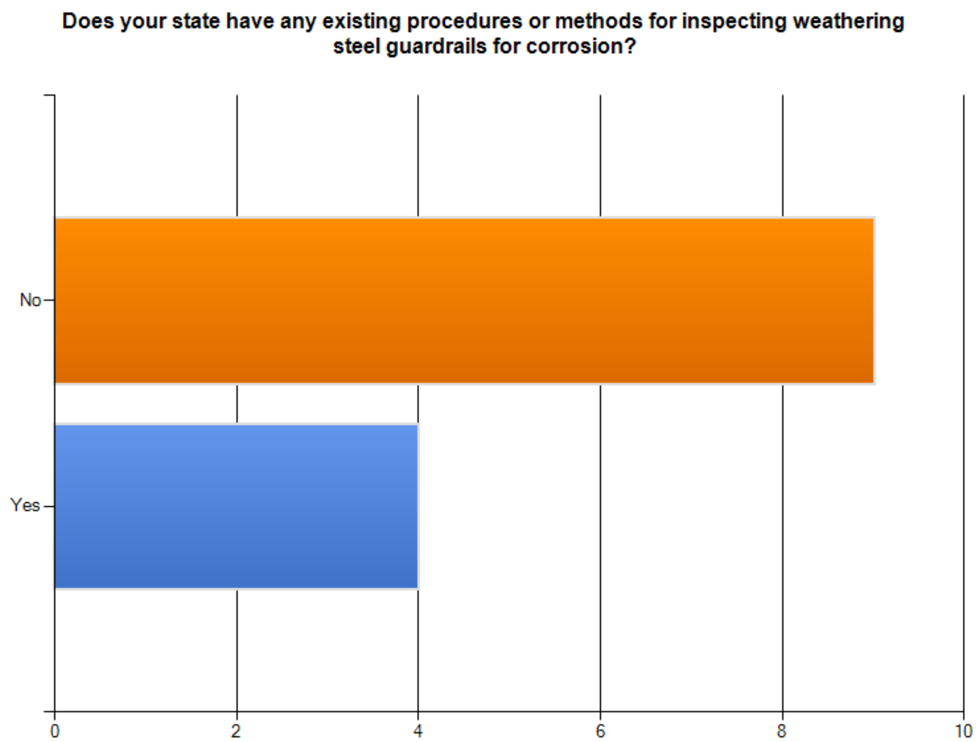


Figure 2.5: Existing inspection guidance.

2.2.8 Extent of Corrosion

Figure 2.6 shows the frequency of advanced corrosion of weathering steel guardrail observed in each participant's state. Six (55%) of the participants indicated rarely observing advanced corrosion in their state. Three (27%) states indicated that advanced corrosion was observed somewhat frequently, but in less than 50% of the installations. Two (18%) of the states indicated observing advanced corrosion very frequently (i.e. in greater than 75% of the installations). The states that rarely observed advanced corrosion were Florida, Kentucky, North Carolina, South Dakota, Washington, and Wyoming. Illinois and New York were the two states indicating very frequent observation of advanced corrosion. Maine, Vermont, and Nevada indicated observing advanced corrosion somewhat frequently (i.e. 26-50% of the installations).

Among the five states who indicated observing advanced corrosion somewhat or very frequently, four (Maine, Vermont, New York, and Nevada) indicated using deicing salts and chemicals in close proximity of the weathering steel guardrail systems.

The participants were also asked to indicate the extent of advanced corrosion observed as a function of the age of the installation (see results in figure 2.7). While it would have been difficult to answer this question as most states do not have related system inventory data, it is interesting to note that most states indicated observing none to moderate corrosion for installations of all ages. Moderate was defined as the extent of corrosion that resulted in some parts needing replacement, but the guardrail system would be fully functional.

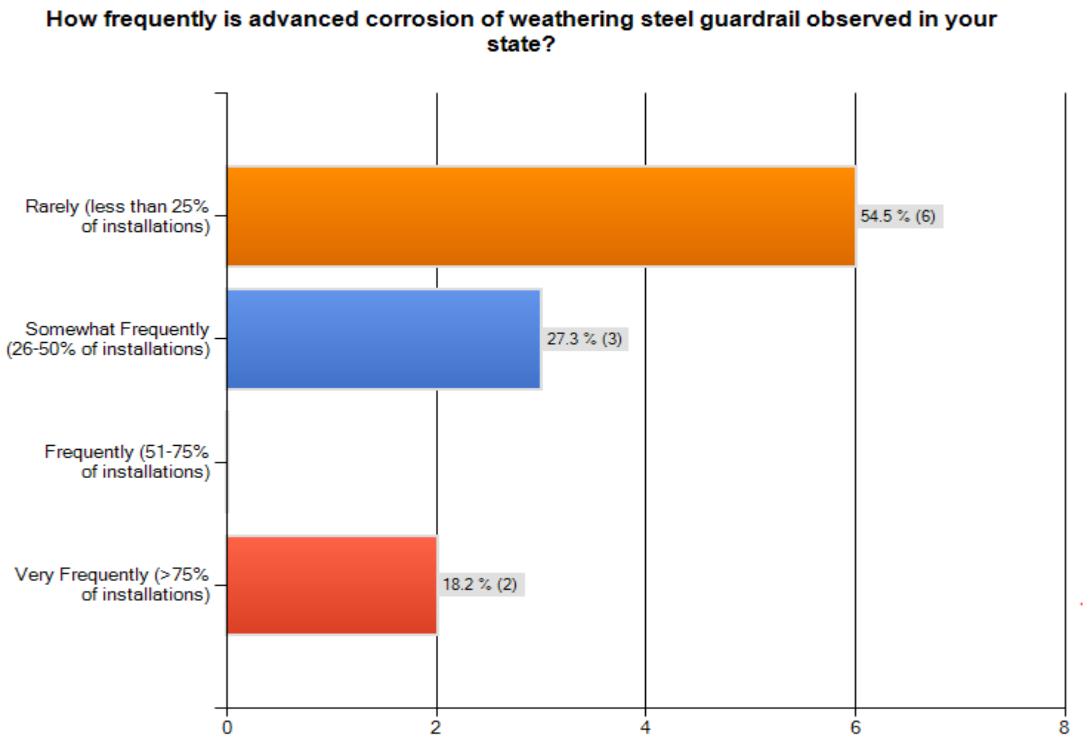


Figure 2.6: Frequency of advanced corrosion observed.

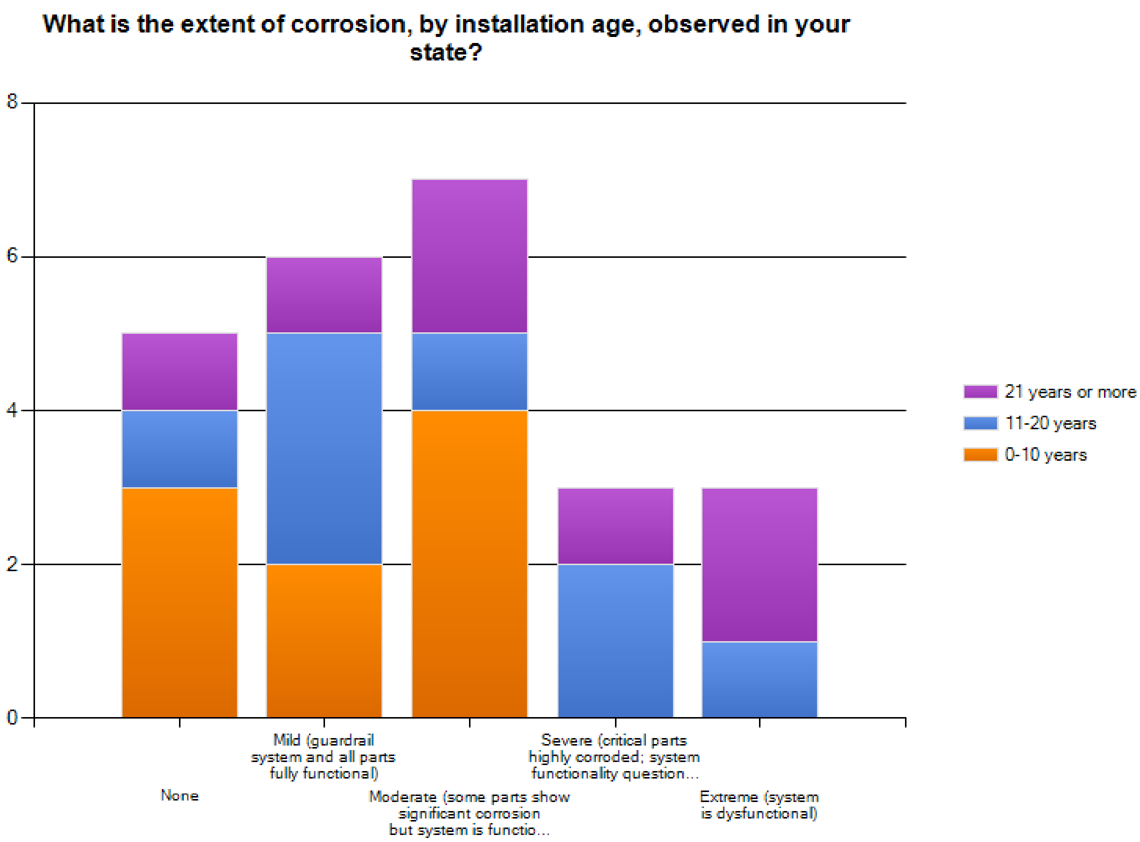


Figure 2.7: Extent of corrosion by installation age.

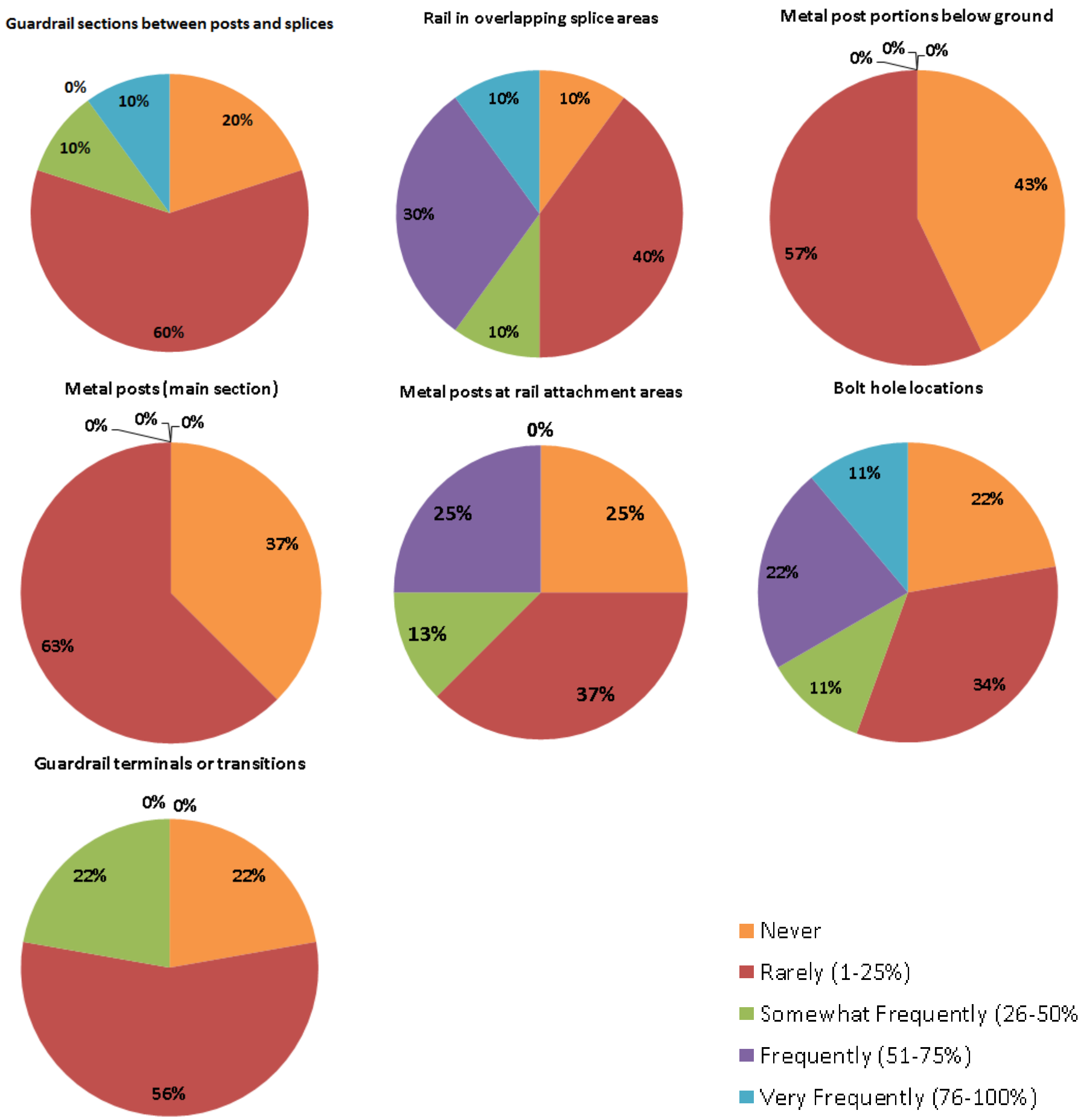


Figure 2.8: Areas and parts with advanced corrosion

The response of the participants to questions related to the level of advanced corrosion observed indicates that most user states do not see the extent of corrosion some states have observed. The level of corrosion in most states is such that the weathering steel guardrail systems remain functional.

2.2.9 Location of Advanced Corrosion

The participants were also asked to identify areas or parts of the weathering steel guardrail system where advanced corrosion is typically observed. Results from the survey are presented in figure 2.8. Results indicate that the greatest amount of advanced corrosion is observed in overlapping splice connection areas, followed by the bolt-hole locations of the guardrail. Advanced corrosion is typically not observed in main guardrail sections between splices. Advanced corrosion is also not common for metal post sections below or above grade; however 25% of the respondents indicated observing advanced corrosion in metal posts at rail attachment areas frequently (i.e. 51-75% of times). Weathering steel guardrail terminals and transitions usually do not exhibit advanced corrosion.

2.2 SUMMARY AND CONCLUSIONS

The objective of this survey was to determine the experience of pertinent agencies with the use of weathering steel W-beam guardrail system. The survey was aimed at determining the extent and location of rail damage due to advanced corrosion, methods or procedures employed to inspect and determine the rail damage, and equipment used for inspection. The survey was taken by 25 participants from 19 different states. Of these, the responses were compiled from the input of 13 states that indicated having used weathering steel guardrail systems.
Results of the survey can be summarized as follows.

- States use several ASTM standards for the weathering steel guardrail systems. ASTM A588 and ASTM A600 are the most commonly used steel types.
- Usage of the weathering steel guardrail systems for most states is less than 100 miles of the installed guardrail, with 50-100 miles being more common.
- W-beam guardrail system is by far the most commonly used weathering steel guardrail system application, followed by some usage for box-beam and thrie beam guardrail systems.
- Seven (7) of the 13 states currently using (or those who have used) weathering steel guardrail systems plan to continue using it. Six (6) of these states have plans to discontinue (or have already discontinued) using weathering steel guardrails.
- Currently, there are no non-destructive evaluation (NDE) methods being employed by the states for adequately inspecting the installed weathering steel W-beam guardrail systems.
- While some states have developed guidance for when to replace galvanized steel parts of a guardrail system, none of the states have such standards specifically for the weathering steel guardrails.
- Fifty five percent (55%) of the states rarely observe advanced corrosion in their state. Twenty seven percent (27%) of the states observe advanced corrosion somewhat frequently, but in less than 50% of the installations. Eighteen percent (18%) of the states indicated observing advanced corrosion very frequently (i.e. in greater than 75% of the installations).
- While some states have experienced significantly compromised performance of the weathering steel guardrail due to advanced corrosion, the level of corrosion in most states is such that the weathering steel guardrail systems remain functional.
- The highest amount of advanced corrosion is observed in the guardrail in overlapping splice connection areas, followed by bolt-hole locations of the guardrail.

3. NON-DESTRUCTIVE TESTING

One of the objectives of this project was to recommend a technique for evaluating weathering steel W-beam guardrail that does not require disassembly of the guardrail components, such as lapped splices and connections to posts. For such applications, non-destructive testing (NDT) methods could potentially be used. The researchers therefore reviewed some of the existing NDT technologies for their use in inspecting the integrity of the weathering steel guardrail.

3.1 NDT METHOD

Various tools are currently available for evaluation and testing of NDT methods. Among the different NDT methods are electromagnetic testing, ultrasonic testing, radiography, magnetic particle testing, leak testing, etc. Depending on the nature of physics involved in a particular method, a method may only be suitable for specific types of applications. In this project, the researchers focused on finding an NDT method that could be used to detect corrosion in metals. The suitability of various technologies was mostly done by reviewing product manuals.

Among the factors considered for determining an NDT method's suitability were the ability to detect corrosion, accuracy, ease of use, and portability. It was determined that ultrasonic corrosion thickness gauges were the most suitable for this project. These gauges are commonly used in the industry for measuring thicknesses of pipes and tank-walls with internal and/or external corrosion. They work by transmitting sound waves into the metal from one side and determining its thickness by measuring the time it takes for the sound waves to be echoed back to the probe from the other side. Using the ultrasonic thickness gauge eliminates the need to cut or disassemble corroded metal plates, as long as they can be accessed from one of the sides.

Ultrasonic thickness gauges are usually hand held, highly portable electronic devices. Different versions of these gauges are available with varying capabilities and technical complexities. A gauge may be used for continuous monitoring with a data logger to record and recover measurements over time, generate statistical reports, allow thru-coat measurements, produce 2D plots, etc. But at a very basic level, these devices can be trimmed down to a pocket size electronic gauge with a probe. Once calibrated using a calibration block, the probe is placed on the surface of the rusted metal. The gauge then shows the thickness of the metal in preset units.

3.2 NDT DEVICE

There are several manufacturers of ultrasonic corrosion thickness gauges. Based on the initial product literature review, the researchers selected General Electric and Olympus Corporation for a detailed product evaluation and demonstration. General Electric did not respond to several requests from the researchers. Olympus Corporation provided a detailed demonstration of their products and loaned its equipment for use in this project. While the results presented in this report are based on measurements using Olympus MG2 Series Ultrasonic Thickness Gauge, it should be noted that other manufacturers have similar products that are expected to have similar performance and applicability.

3.3 USING ULTRASONIC THICKNESS GAUGE

As mentioned above, the researchers used Olympus MG2 Series Ultasonic Thickness Gauge (shown in figure 3.1) for measuring thicknesses of the weathering steel guardrail samples during this project. Detailed information about various capabilities and instructions on using a specific make and model of an ultrasonic thickness gauge device are best obtained from the user's manual. However, a basic and a general description on the use of handheld ultrasonic thickness gauges, as applicable to this project, is included in this section.

Figure 3.1 Handheld ultrasonic thickness gauge with probe.

The ultrasonic thickness gauge is a rectangular handheld device, and is thus very portable. The front face of the gauge is comprised of a digital screen and a keyboard. The top of the device has a port for attaching an external probe to the gauge. The probe usually comes attached to a cable, which allows greater flexibility in taking measurements of hard to reach areas.

3.3.1 Device Calibration

When the gauge is first turned on, it needs to be calibrated using a certified calibration block such as the one shown in figure 3.2. During the calibration process, the gauge is used to measure two known thickness from the calibration block. Any difference in the measured and the known values is zeroed to achieve calibration.

Figure 3.2 Calibration steel block.

3.3.2 Surface Preparation

Before measuring the thickness, the surface should be cleaned of any dirt, residue, loose rust flakes, etc. In all measurements taken during this project, the researchers cleaned the surface using a cotton rag.

It is important to note the flat circular tip of the probe needs to set properly on the metal surface being measured. Thus measurements should be taken at surfaces that are flat enough to achieve full contact with the probe. If the probe is not set properly against the metal surface, an erroneous reading is likely. Thus readings should be avoided on surfaces that are very irregular, or at locations of sharp changes in surface profile.

Figure 3.3 Advanced rail corrosion with pitting.

Advanced corrosion in weathering steel can lead to irregular surfaces with pitting, such as the one shown in figure 3.3. Taking a reliable thickness reading in these regions can be difficult. Furthermore, thickness of the metal beam can vary significantly in these regions. Therefore, it is recommended that parts showing such clear signs of advanced corrosion be replaced, regardless of the ability to take a thickness measurement.

3.3.3 Couplant Gel

Ultrasonic thickness gauges require application of a small quantity of a couplant gel to the spot where probe will be placed to take a thickness measurement. This gel provides a continuous medium for transmitting ultrasonic waves between the probe and the metal sheet. The couplant gel must be applied after cleaning the surface at every spot thickness is measured, including during the calibration process described above. Couplant gels can be purchased from the device manufacturers, but are also readily available from many vendors.

3.4 PATINA THICKNESS

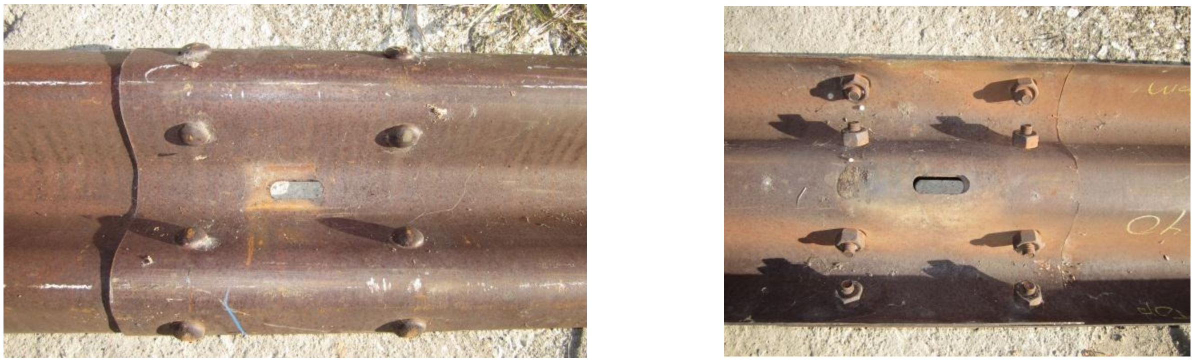
Weathering steel starts to corrode and develops a thin layer of rust at its surface, called the patina layer. If the corrosion advances further, the thickness of the patina layer increases and eventually the rust build up separates from the steel surface in the form of rust particles and flakes. This gradually reduces the overall thickness of the rail. The rust particles or flakes fall off or are cleaned during the surface preparation process. However, the thin patina layer that is closely bonded to the base metal cannot be easily removed during the inspection procedure.

As previously mentioned, the ultrasonic thickness gauge works by measuring the time it takes for a sound wave to be echoed back from a material flaw or void, or the other side of the metal rail. While this technology can measure thickness excluding rust flakes or other relatively loose rust buildup, the thin but tightly bonded oxidation layer (patina) that builds up on the rail without voids is not discerned by the device. Thus the thickness measured from the ultrasonic gauge includes the thickness of the patina layer. Therefore, the true structural thickness of the guardrail is the value measured from the ultrasonic gauge, less the thickness of the patina layer.

To suggest an inspection procedure that allows a fail or pass assessment of the weathering steel guardrail based on the thickness measurement, it was important to make some assessment of the range of the patina layer thickness. While it would have been desirable to collect a large number of weathering steel samples, exposed to a wide range of environmental conditions, and with a broad range of service age, this was not possible within the scope and budgetary constraints of the project. However, the researchers were able to collect a limited number of samples from various agencies using weathering steel guardrail. Thicknesses were measured for these samples before and after taking off the patina layer to determine a range of the patina layer thickness.

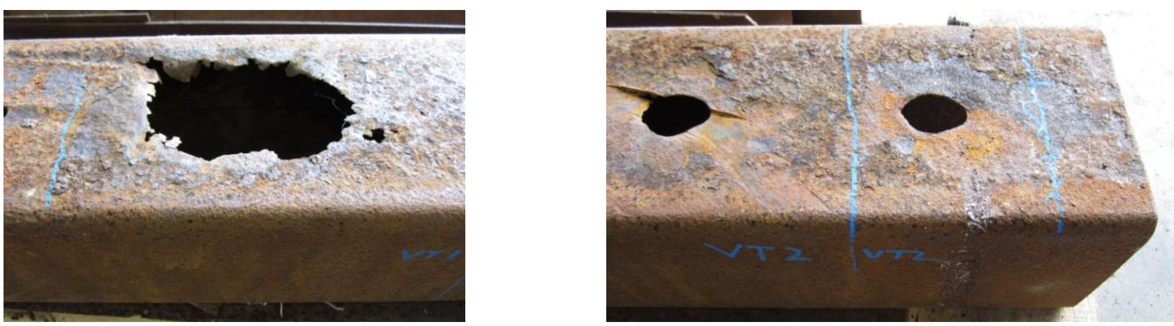
3.4.1 Weathering Steel Guardrail Samples

The researchers collected samples of weathering steel guardrail that had been in service for a considerable amount of time. Samples were collected from California, New York, Vermont, and Washington, and are shown in figure 3.4. A brief description of the samples is presented in table 3.1.



California W-beam rail splice

New York W-beam



Vermont box-beam

Washington W-beam from splice region

Figure 3.4 Photos of the weathering steel guardrail samples.

Table 3.1: Weathering steel guardrail samples.

State	Sample Description
California (Caltrans)	3 intact (still assembled) lap splice sections (5-6 ft. total length). No visual signs of deterioration due to corrosion.
New York (NYDOT)	2 W-beam guardrail samples (1-ft long) with visual signs of significant corrosion
Vermont (VAOT)	1 box beam sample (4-ft long) with extensive corrosion, including loss of section
Washington (WSDOT)	1 W-beam guardrail section (3-ft long). One end of the sample was used in lapped splice. Visual signs of moderate corrosion.

3.4.2 Rust Removal

To determine the thickness of the weathering steel guardrail sample without the rust, the researchers removed the patina layer by immersing the guardrail samples into muriatic acid. Prior to evaluating the thicknesses of different guardrail samples, the researchers ensured that the thickness of the samples was not being reduced by the chemical reaction once the patina layer was removed. To verify this, the researchers measured thickness of a rail sample at three locations, as shown in figure 3.5.

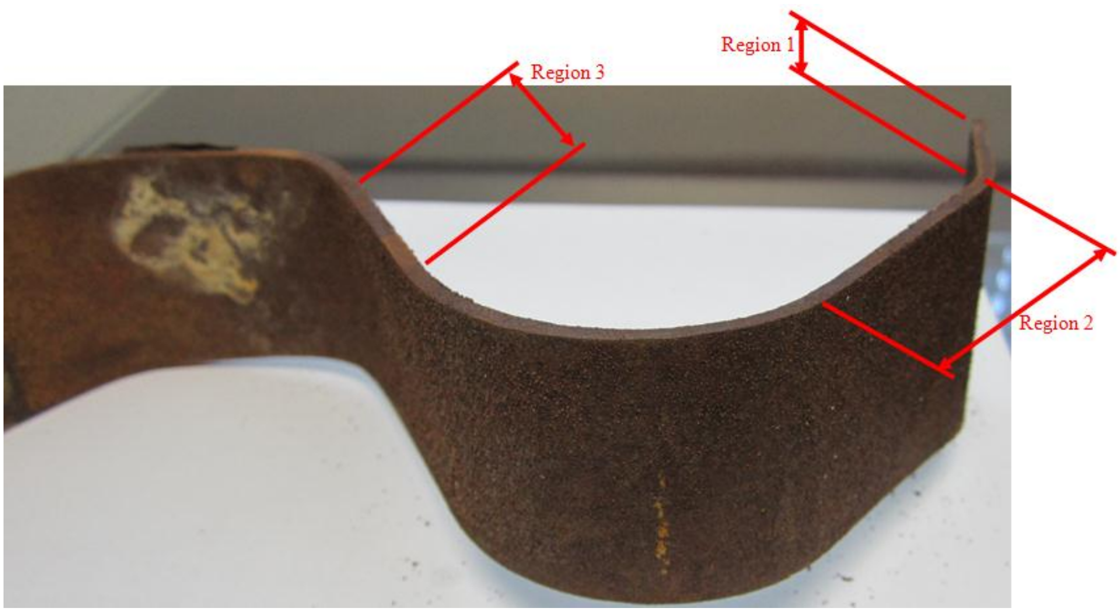


Figure 3.5 Regions where guardrail thickness was measured.

The sample was then immersed in muriatic acid for 9 minutes, which was enough to completely remove the rust. The researchers then measured the thickness of the guardrail sample at the same three locations. After that, the sample was immersed again in muriatic acid for another 15 minutes. At the end of the 15-minute exposure of the base metal (with patina removed) to muriatic acid, the thicknesses were measured again. A comparison of thicknesses was made to find out if the chemical reaction significantly reduced the metal thickness due to longer exposure to the acid.

The researchers determined that the total 24-minute exposure to acid reduced the base metal thickness by only 0.001 inches in all three locations. Since most of the samples required significantly less time to remove the patina layer (9 – 12 minutes), the effect of the chemical reaction on the base metal did not significantly influence the thickness measurements.

3.4.3 Patina Thickness

The researchers measured thicknesses of the weathering steel guardrail samples before and after taking off the patina layer. Two test specimens were cut from each of the weathering steel guardrail samples received. For samples with splice regions, test specimens were cut such that they included splice bolt locations. For each test specimen, thickness measurements were made at three spots. If present, bolt hole locations were picked as spots for taking the thickness measurements. Some of the specimens used are shown in figure 3.6. As can be seen from the figure, patina was removed from only half of the rail's section to facilitate proper identification and marking of the specimens before and after the rust was removed. Spots where thickness measurements were made can be seen by the presence of the couplant gel in the photos shown.

The thickness of the patina layer (i.e. the difference in the thickness of the samples before and after taking off the patina layer) varied among the samples measured. The average patina thickness was 0.007 inches, with 0.016 inches being the maximum and 0.002 inches being the minimum.

With rust

Without rust

New York's W-beam Sample

With rust

Without rust

California's W-beam Splice Sample

Figure 3.6 Weathering steel guardrail samples before and after removing patina layer.

3.4.4 Use in Lapped Splice Areas

One of the key objectives of this project was that the inspection device or method selected should be able to evaluate the integrity of the W-beam guardrail without requiring disassembly of the guardrail parts, such as the lapped splices. The researchers therefore evaluated the use of the ultrasonic thickness gauge in the lapped splices without disassembling them. The guardrail samples received from Caltrans contained lapped splices that had not been disassembled. These samples were used in this evaluation.

To determine the integrity of the guardrail in the lapped splice region, a thickness measurement needs to be taken for each of the rail elements separately. Thus a reading for the traffic-side rail element of the splice should be taken by placing the probe from the traffic side. Similarly, the thickness of the field-side rail element should be measured from the field side of the guardrail system.

The researchers first measured the thickness of the rail elements with the lapped splices intact, and without taking off the patina layer. In the second step, the splices were unassembled and thicknesses were measured again (without removing patina). In the final step, the patina layer was removed and the thicknesses were measured again.

By comparing the different thickness values, it was determined that measuring thickness of the rail elements with the splices assembled had no significant effect on the measurement. Thus the use of ultrasonic thickness gauge is suitable for use with assembled lapped splices. Figure 3.7 shows typical debris and rust collected between the splices used in the thickness measurements.

Figure 3.7 Debris and rust collected between lapped splices of the samples used.

3.5 FAIL THICKNESS THRESHOLD

When thickness is measured during an inspection procedure, a determination needs to be made if the rail has passed or failed to meet the minimum thickness threshold required to maintain the structural adequacy of the rail.

Thickness of the weathering steel W-beam guardrail is specified in American Association of State Highway Transportation Officials (AASHTO) standard M 180 as 0.105 inches, with a maximum negative tolerance of 0.009 inches. *(3)* This implies that 0.096 inches is the minimum thickness allowed according to the AASHTO M 180 standard. However, the limited evaluation of patina layer thickness in this research shows that the thickness of the base metal is further reduced by an average of 0.007 inches, and can be reduced by up to 0.016 inches. The reduction in the base metal thickness due the corrosion layer results in the reduction of the overall tensile capacity of the rail. Thus the determination of the thickness at which the guardrail would be considered structurally inadequate is not straightforward.

To determine the fail thickness threshold of the W-beam guardrail, or the thickness below which the guardrail would be considered structurally inadequate, the researchers used the tensile capacity of the guardrail, and the tensile load generated in the rail due to a vehicle impact.

Using the material properties specified in the AASHTO M180 specification, the minimum tensile capacity of the rail is calculated to be 74.01 kips (based on 0.096 inch minimum thickness) in the plane containing the bolt-holes for the lapped splice connection. The actual tensile load generated during a vehicle impact under design impact conditions is considerably less than the tensile capacity of the rail.

In 1999, Texas Transportation Institute (TTI) performed a crash test with a galvanized W-beam guardrail under National Cooperative Highway Research Program (NCHRP) Report 350 Test 3-11 impact conditions (i.e., 4409 lb pickup impacting the rail at 62.2 mi/h and 25 degrees). *(4)(5)* This test was performed to evaluate the performance of the W-beam guardrail system with stronger W6×12 steel blockouts instead of the standard W6×8.5 blockouts. The W-beam guardrail in this test was instrumented using strain gauges to measure the tensile load in the rail immediately upstream and downstream of the impact region. As the vehicle passed by a splice 14.75 ft. downstream of the initial impact point, a tear developed in the rail at the interface of the overlapping splice, which then propagated to cause rail rupture (see figure 3.8). At the time of the rupture, the rail had deflected 3.28 ft. laterally. The pickup truck penetrated the guardrail system and subsequently rolled on its side. Even though the rail ruptured during the test, the tensile force measured just upstream of the impact region had peaked at 33.72 kips prior to the rupture. Thus the force data measured from the test is a good estimation of the tensile load in a rail due to an NCHRP Report 350 Test 3-11 vehicle impact.

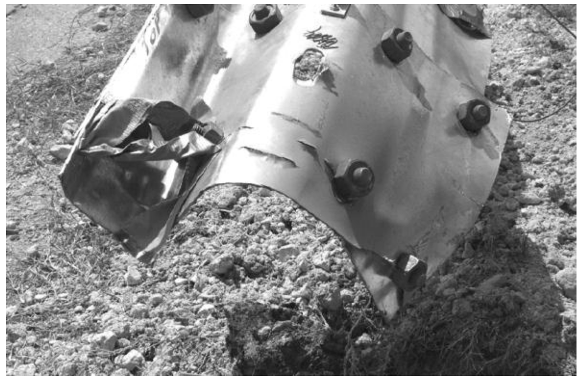


Figure 3.8: Rail rupture in TTI test with instrumented W-beam guardrail

Using the peak tensile load measured in the test and the tensile capacity of the rail, it was determined that a significant reserve tensile capacity (factor of safety of 2.2) is available when using the specified minimum rail thickness of 0.096 inches. However, it should be noted that the test described above was performed using the NCHRP Report 350 criteria, which has now been superseded by AASHTO's Manual for Assessing Safety Hardware (MASH). In the MASH criteria, the impact severity of test 3-11 has increased by 13.5% due to the increase in the mass of the design test vehicle from 4409 lb. to 5000 lb. *(6)* Thus a slightly higher tensile load is expected in a MASH test than what was measured in the NCHRP Report 350 test.

Furthermore, crash testing experience indicates that rail rupture in a W-beam guardrail system usually does not occur due to exceeding the rail's tensile capacity. Instead, rupture is most often associated with the initiation and propagation of a crack or tear in the rail at a post location due to the complex stress state and interactions that exist at post locations. The presence of a post and lapped rail elements results in high local stress concentrations as the vehicle interacts with the rail. This can initiate a small tear at the edge of the rail, which then propagates through the cross-section and results in complete rail rupture. For this reason, some of the newer guardrail systems offset posts away from the lapped splice connections to effectively increase rail strength without changing the cross-sectional area of the W-beam rail. *(7)(8)* Offsetting the posts away from the splices reduces the sudden change in the lateral stiffness of the rail, thus reducing localized stress concentrations that can result in a tear. So even though there is a significant reserve tensile capacity in the W-beam guardrail based on the load measured in TTI's test, due to the complex and localized nature of rail rupture, a conservative approach is needed in deciding the minimum thickness of the W-beam guardrail.

Based on the discussion above, the researchers suggest using a thickness value of 0.096 inches as the fail thickness threshold for inspecting the weathering steel W-beam guardrail. While the actual base metal thickness will be reduced further by the presence of the patina layer, the reserve tensile capacity of the rail (factor of safety > 2) is expected to be sufficient for accommodating the thickness reduction due to the patina layer. Furthermore, this reserve capacity also allows for accommodating a slightly higher load resulting from a MASH impact. The researchers believe a thickness threshold of 0.096 inches provides a conservative estimate of the rail's reserve capacity, keeping in mind the complexity of the rail rupture mode.

Thus if the thickness measurement using the ultrasonic thickness gauge is 0.096 inches or greater, the rail strength would be considered satisfactory. Any rail with a thickness less than this value would be considered structurally inadequate.

The 0.096-inch thickness threshold may be revised in future if further research supports doing so. Such research can include determining patina thicknesses using a larger sample size of weathering steel guardrails, for different ambient conditions and service durations. Future research can also incorporate full-scale crash testing to determine minimum rail thickness needed for acceptable W-beam guardrail performance.

4. INSPECTION PROCEDURE

Inspection of the weathering steel guardrail may be conducted using a two-level approach. In the first-level inspection, fewer spots are checked along the length of the guardrail system. If, however, a spot fails in the first-level inspection, a second-level inspection is performed. In the second-level, more thorough inspection is performed upstream and downstream of the failed spot.

4.1 Visual Inspection

Visual inspection is an integral part of the inspection procedure described herein. If at any time during the inspection (first or second-level), visible signs of advanced corrosion are observed with tears or holes in the rail, or other signs indicating loss, or imminent loss of rail integrity or functionality, the effected parts should be identified as having inadequate structural integrity. (see figure 4.1 for examples) *(1)*.

Figure 4.1: Examples of failed guardrails that can be visually identified.

If significant visual signs of advanced corrosion exist, such as rust build up, pitting, rust flakes, etc., but a visible hole or tear is not present, several thickness measurements should be taken in the suspected region to ensure integrity of the system.

Details of the first and second-level inspections using the ultrasonic thickness gauge are presented next.

4.2 First-Level Inspection

In conjunction with the visual inspection, non-destructive inspection of weathering steel W-beam guardrail should be started using the first-level inspection procedure by default. If a spot fails a thickness check during the first-level inspection, a second-level inspection procedure must be used in the vicinity of the failed spot.

First-level inspection is performed by checking the thickness of the weathering steel W-beam guardrail at a specified inspection interval along the length of the guardrail. The inspection interval can be determined from table 4.1 based on installation age, ambient conditions, and the length of the installation. In less stringent environmental conditions, the inspection interval is 400 ft. for shorter installations (shorter than 1000 ft.) and 1000 ft. for longer installations (longer than 1000 ft.). In a marine or high humidity environment, or where deicing chemicals are used, the inspection interval is 400 ft. or 200 ft., depending on the age of the installation. Shorter inspection intervals have been prescribed in this case because marine and high humidity environments, and/or use of deicing salts and chemicals in the vicinity of the guardrail can cause greater deterioration to the weathering steel.

Table 4.1: Inspection interval selection procedure

For maximum exposure rate (either/all) marine environment, deicing chemicals, high humidity
- For installation age ≤ 5 years, inspection interval = 400 ft.
- For installation age > 5 years, inspection interval = 200 ft.

For minimum exposure rate dry/arid environment, no deicing chemicals, low humidity
- Inspection interval for short run guardrail (i.e. <1000 ft.) = 400 ft.
- Inspection interval for long run guardrail (i.e. > 1000 ft.) = 1000ft. with the following restriction
    - If noted visible damage to rail exists (i.e., deterioration or holes in rail, minor impact damage to post or rail, W-beam deformations, missing components, etc.), use:
        - For installation age ≤ 5 years, inspection interval = 400 ft.
        - For installation age > 5 years, inspection interval = 200 ft.

All first-level inspections should be performed at the lapped splice nearest to the point determined from the inspection interval. At each splice, two bolt hole locations should be checked, one from the traffic side of rail, and other from the field side. The spot where the thickness measurement is to be taken should be cleaned with a cloth prior to applying the coupalant gel. The inspector should try to take the thickness reading as close to the bolt hole location as possible. Note that if there are other regions that show visual signs of deterioration, thickness should be measured in those areas in addition to the prescribed two spots per splice. If the thickness of a spot is less than 0.096 inches, it should be marked as failed, and a second-level inspection should be performed in the upstream and downstream vicinity of the rail. If the thickness is 0.096 inches or greater, the next spot should be checked. Note that thickness in the mid span sections of guardrail are not checked during the first-level inspection unless there are visual signs of advanced corrosion.

The inspection interval described in the first-level inspection procedure should be reduced as needed in the transition and end-terminal regions so as not to skip short guardrail lengths. The user agency may specify a reduced inspection interval in consideration of the nature of the hazard being shielded, such as extreme drop-offs, trees, etc.

4.3 Second-Level Inspection

Second-level non-destructive inspection is performed when either a visual inspection determines a region of the rail has failed, or if a spot fails to meet the thickness threshold in the first-level inspection. In both situations, the inspector must perform second-level inspection on a region spanning three splices upstream and downstream of the failed region or spot.

During the second-level inspection, every splice within the inspection region is checked by taking thickness measurements. In checking the thickness of the rail elements in the overlapped splice region, four spots near bolt-hole locations should be measured on the traffic-side rail, and four spots should be measured on the field-side rail element. The measurements should be taken in a zigzag manner covering all bolt locations (i.e. by not using the same bolts-hole locations to measure thickness on the field and traffic sides), as shown in figure 4.2. The red markers in the figure show the bolts where the thicknesses should be measured. The thicknesses may be measured anywhere in the close vicinity of the bolts. In addition to the eight bolt-hole locations of the splice, one additional thickness measurement should be taken around the middle slot provided for attaching the post to the rail. During the second-level inspection, if more than three (3) spots fail in a splice region, the splice should be considered to have inadequate structural integrity.

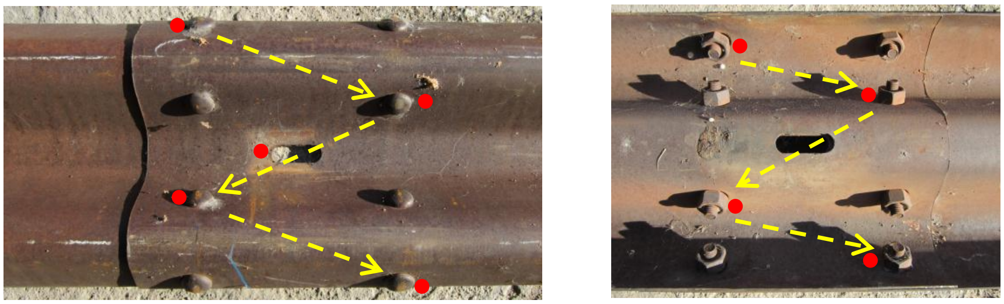


Figure 4.2 Spots and the zigzag pattern for measuring rail thickness during second-level inspection.

In addition to the splices, thickness of the guardrail should also be checked at the midpoint between splices where the rail attaches to a post. The measurement at the midpoint location should be taken from the traffic side of the rail, around the slot provided for bolting the rail to the post.

It should be noted that second-level inspection is to be performed in conjunction with the visual inspection. In addition to the spots described in the inspection procedure, any areas showing signs of significant corrosion should checked by taking thickness measurements at various locations in the affected area.

While most of the installed weathering steel W-beam guardrail systems are expected to have splices at post locations, some of the newer guardrail designs offset splices to mid-span between the posts. For these systems, second level inspection should be performed in a similar manner as described above for systems with splices at post locations. However, with splices offset between posts, there will be two post locations between each splice. Both post locations between splices should be inspected as described above.

The procedures described in this report are expected to enable user agencies to inspect weathering steel W-beam guardrail systems in an effective and efficient manner. Appendix A includes sample inspection forms that can be tailored by user agencies for their use. Inspection procedures described herein may be adjusted in consultation with FHWA as more experience is gained in conducting in-field inspections.

Inspection of the weathering steel guardrail may need to be performed periodically, as a system that passes the inspection once may corrode over several years and result in a failed system. Since the survey of user agencies performed in this research indicates significant variation in the levels of rail deterioration across the country, it is not ideal to suggest one frequency of guardrail inspection for all regions. It is therefore recommended that each user agency adopt a frequency for periodic evaluation of their weathering steel guardrail systems in consultation with their local FHWA office.

Researchers have developed an inspection manual and sample inspection forms based on the procedure described in this report. This manual and the forms are presented in appendix A as a standalone document that can be tailored by user agencies for their use.

5. SUMMARY AND CONCLUSIONS

The objective of this research was to identify an inspection technique for evaluating the structural integrity of weathering steel W-beam guardrail. The inspection technique was required to allow evaluation of the rail without requiring disassembly. Using the technique identified in this research, the researchers were to develop an inspection procedure for conducting an in-field inspection.

The researchers conducted a nationwide survey of transportation agencies using weathering steel guardrail. The survey was aimed at determining the extent and location of rail damage due to advanced corrosion, methods or procedures employed to inspect and determine the rail damage, and equipment used for inspection. Results of the survey indicated that while some states have experienced significantly compromised performance of weathering steel guardrail due to advanced corrosion, the level of corrosion in most states is such that the weathering steel guardrail systems remain functional. Highest amounts of advanced corrosion are observed in the overlapping splice connection areas, followed by bolt-hole locations of the guardrail. There are currently no non-destructive methods being used by the user agencies for inspecting weathering steel guardrail.

The researchers reviewed some of the existing NDT technologies considered for the purpose of inspecting the integrity of the weathering steel guardrail. Among the factors considered for determining an NDT method's suitability were the ability to detect corrosion, accuracy, ease of use, and portability. It was determined that handheld ultrasonic corrosion thickness gauges were most suitable for this application. While detailed information about various capabilities, and instructions on using a specific make and model of an ultrasonic thickness gauge are best obtained from the product user's manual, a basic description, as applicable to this project, was presented in this report.

The researchers collected various samples of the weathering steel guardrail from different user agencies. These samples were used to evaluate the effectiveness of the ultrasonic thickness gauges in measuring the thickness of the guardrail, and to establish a fail thickness threshold for in-field inspection. The researchers also evaluated the use of the ultrasonic thickness gauge in the lapped splices without disassembling them. It was determined that the ultrasonic thickness gauges are suitable for use with assembled lapped splices.

When thickness is measured during an inspection procedure, a determination needs to be made if the rail has passed or failed to meet the minimum thickness threshold required to maintain the structural adequacy of the rail. This fail thickness threshold, or the thickness below which the guardrail would be considered structurally inadequate, was determined using the tensile capacity of the weathering steel W-beam guardrail, and existing crash test data. It was determined that if the thickness measurement using the ultrasonic thickness gauge is 0.096 inches or greater, the rail strength would be considered satisfactory. Any rail with a thickness less than this value would be considered structurally inadequate.

The researchers also developed an inspection method for performing in-field evaluation. This method was developed in consultation with WSDOT and FHWA. The inspection procedure prescribes conducting the inspection using a two-level approach. In the first-level, fewer spots are checked along the length of the guardrail system. If a spot fails in the first-level inspection, a second-level inspection is performed. In the second-level inspection, more thorough inspection is performed within a specified distance upstream and downstream of the failed spot. In both levels, visual inspection is also performed to identify any regions requiring additional evaluation.

Researchers have developed an inspection manual with sample inspection forms based on the procedure described in this report. This manual and the forms are presented in appendix A as a standalone document that can be tailored by user agencies for their use.

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APPENDIX A. WEATHERING STEEL W-BEAM GUARDRAIL INSPECTION MANUAL AND FORMS

Weathering Steel W-beam Guardrail Inspection Instructions

Weathering steel W-beam guardrail should be inspected periodically to ensure that the guardrail has not corroded significantly, and that the rail has the required structural integrity for containing and redirecting errant vehicles. This inspection is to be carried out by measuring the rail thickness without requiring disassembly of the rail. The procedures described herein is recommended for this inspection.

NDT Device

An ultrasonic corrosion thickness gauge, which is a non-destructive testing (NDT) device, can be used for the purposes of weathering steel guardrail inspection. Using an ultrasonic thickness gauge eliminates the need to disassemble the guardrail, especially in overlapping splice areas. Detailed instructions on using a specific make and model of an ultrasonic thickness gauge device are best obtained from the user's manual. These devices have an approximate price range of $1,500 to $3,000.

Olympus MG2 Series

Calibration Block

Device Calibration

An ultrasonic thickness gauge (similar to the one show above left) must be calibrated using a certified calibration block (such as the one shown above right) according to the device manufacturer's instructions. Calibration is usually performed by measuring two or more known thicknesses from the calibration block. Device calibration is a simple, but necessary step to ensure reliable thickness measurements and should never be ignored.

Surface Preparation

Before measuring the thickness of the rail, the surface should be cleaned of any dirt, residue, loose rust flakes, etc. The surface can generally be adequately cleaned by rubbing it with a cotton rag.

Setting the Probe

When taking a thickness measurement, it is important to set the tip of the probe in full contact with the metal surface. If the probe is not set properly on the metal surface, an erroneous reading is likely. Thus readings should be avoided on surfaces that are very irregular, or at locations of sharp changes in surface profile.

Couplant Gel

Ultrasonic thickness gauges require application of a small quantity of a couplant gel to the spot where the probe will be placed to take a thickness measurement. This gel provides a continuous medium for transmitting ultrasonic waves between the probe and the metal sheet. The couplant gel must be applied after cleaning the surface at any spot where thickness is measured.

Fail Thickness Threshold

Fail thickness threshold for the weathering steel W-beam guardrail is 0.096 inches. Thus if the measured thickness at a rail location is less than 0.096 inches, it would be marked as failed.

Inspection Procedure
Inspection of the weathering steel guardrail is to be conducted using a two-level approach. In the first-level inspection, fewer spots are checked along the length of the guardrail system. If, however, a spot fails in the first-level inspection, a second-level inspection is performed. In the second-level, more thorough inspection is performed upstream and downstream of the failed spot. In both levels, visual inspection is also performed. Visual inspection, first-level inspection, and second-level inspection procedures are described below. These inspections should be performed by using the inspection forms provided.

Visual Inspection
Visual inspection should be performed at all stages of the guardrail inspection. If at any time during the inspection (first or second-level), visible signs of advanced corrosion are observed with tears or holes in the rail, or other signs indicating excessive section loss, or imminent loss of the system's functionality, the effected parts should be identified as having inadequate structural integrity (see examples below).



If significant visual signs of advanced corrosion exist, such as rust build up, pitting, rust flakes, etc., but a visible hole or tear is not present, several thickness measurements should be taken in the suspected region to verify integrity of the system.

First-Level Inspection
In conjunction with visual inspection, first-level inspection is to be performed by using the form provided (Form 1). The inspection starts by determining the appropriate inspection interval using the table below.

Table: Inspection interval selection procedure

For maximum exposure rate (either/all) marine environment, deicing chemicals, high humidity

- For installation age ≤ 5 years, inspection interval = 400 ft. (64 posts @ 6 ft.-3 in. spacing)
- For installation age > 5 years, inspection interval = 200 ft. (32 posts @ 6 ft.-3 in. spacing)

For minimum exposure rate dry/arid environment, no deicing chemicals, low humidity

- Inspection interval for short run guardrail (i.e. ≤ 1000 ft.) = 400 ft. (64 posts @ 6 ft.-3 in. spacing)
- Inspection interval for long run guardrail (i.e. > 1000 ft.) = 1000ft. (160 posts @ 6 ft.-3 in. spacing) with the following restriction
  - If noted visible damage to rail exists (i.e., deterioration or holes in rail, minor impact damage to post or rail, W-beam deformations, missing components, etc.), use:
    - For installation age ≤ 5 years, inspection interval = 400 ft.
    - For installation age > 5 years, inspection interval = 200 ft.

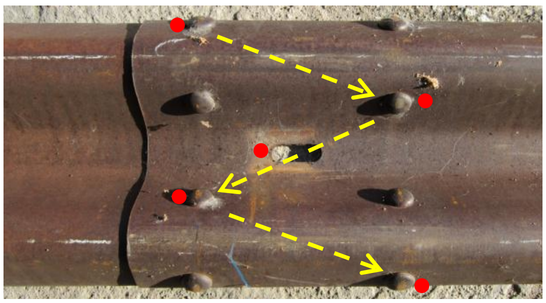
Note:
200 ft. is 32 posts @ 6 ft.-3 in. spacing
400 ft. is 64 posts @ 6 ft.-3 in. spacing
1000 ft. is 160 posts @ 6 ft.-3 in. spacing

First-level inspections should be performed at the lapped splice nearest to the point determined from the inspection interval. At each splice, two bolt hole locations should be checked, one from the traffic side of rail, and other from the field side. The inspector should try to take the reading close to the bolt hole locations and mark them on the photos provided in the form. If there are other spots that show visual signs of deterioration, thickness should be measured in those areas in addition to the prescribed two spots per splice. Thickness in the mid span sections of guardrail are not checked during the first-level inspection, unless there are visual signs of advanced corrosion. The interval prescribed in the first-level inspection procedure should be reduced as needed in the transition and end-terminal regions so as not to skip a short-length guardrail section. It is estimated that first-level inspection should take approximately 5 minutes for each splice location checked.

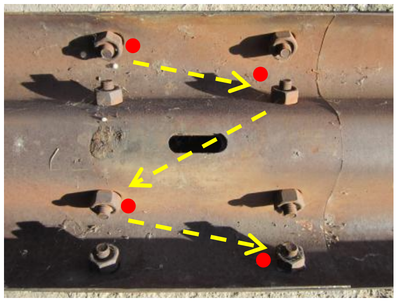
Second-Level Inspection

In conjunction with visual inspection, second-level inspection is to be performed by using the forms provided. The inspection starts by determining the zone of inspection using the figure provided in the form.

In the lapped splices, thickness should be checked at four spots near bolt-hole locations from the traffic side of the rail, and four spots near bolt hole locations from the field-side of the rail. The measurements should be taken in a zigzag manner covering all splice bolts (i.e., by not using the same bolt-hole locations on the traffic and field sides), as shown in the following figure. The red markers in the figure show the bolt where the thickness should be measured. The thickness may be measured anywhere in close vicinity of the bolt. In addition to the eight bolt-hole locations of the splice, one additional thickness measurement should be taken around the middle post bolt slot provided for attaching the post to the rail.



Traffic side rail in splice area



Field side rail in splice area

During the second-level inspection, if more than three (3) spots fail in a splice region, the splice should be considered to have inadequate structural integrity.

In addition to the splices, thickness of the guardrail should also be checked at the midpoint between splices where the rail attaches to a post. The measurement at the midpoint location should be taken from the traffic side of the rail, around the post bolt slot provided for bolting the rail to the post.

Some of the newer guardrail designs offset splices to mid-span between the posts. For these systems, second level inspection should be performed in a similar manner as described above for systems with splices at post locations. However, with splices offset between posts, there will be two post locations between each splice. Both post locations between splices should be inspected as described above.

Second level inspection can be performed using form 2A for systems with splices at post locations, and form 2B for systems with splices between posts. It is estimated that the second level inspection should take approximately 1 hour and 45 minutes to complete.

First-Level Inspection - Form 1
Weathering Steel W-beam Guardrail Inspection

Date: ____________ Inspection Number: ____________________ Inspected by: __________________

Guardrail Location/Identifier: ____

- **STEP 1: Visual Inspection**

Always perform visual checks to identify signs of significant corrosion (see instructions under Visual Inspection for examples). If significant corrosion is visible, check rail thickness at several spots in the corroded region.

- **STEP 2: Determine Inspection Interval**

Determine the appropriate inspection interval using the table in the instructions section.

Inspection Interval: _________________________

Fail Thickness:
Less than 0.096 inch

- **STEP 3: Measure thickness at nearest splice**

☐ Mark splice bolt locations at which rail thickness was measured in the figures below. Do not select same bolt for traffic and field sides)

Mark spot 1: Traffic side splice blot

Mark spot 2: Field side splice bolt (post not shown)

Thickness spot 1 = ________ inches; ☐ Pass ☐ Fail Thickness spot 2 = _________ inches; ☐ Pass ☐ Fail

Thickness at additional spots if measured (optional):

Spot 3: Location Description: ___________________________ Thickness = _______ inches ☐ Pass ☐ Fail
Spot 4: Location Description: ___________________________ Thickness = _______ inches ☐ Pass ☐ Fail
Spot 5: Location Description: ___________________________ Thickness = _______ inches ☐ Pass ☐ Fail
Spot 6: Location Description: ___________________________ Thickness = _______ inches ☐ Pass ☐ Fail

FINAL DETERMINATION

☐ PASS ☐ FAIL

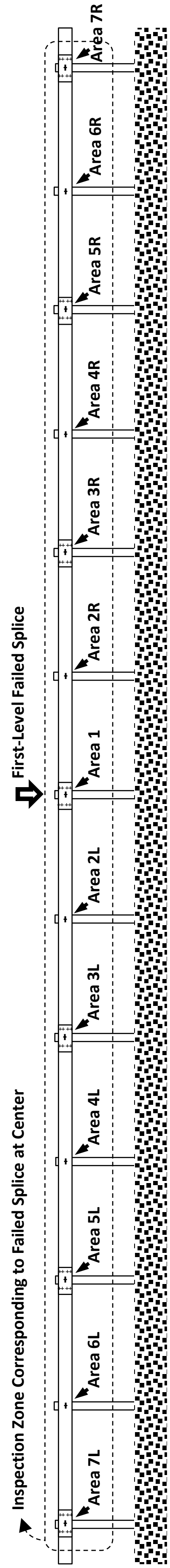
If first-level inspection failed, note following:
Failed spot location: _________________________
Second-Level Inspection No: ________________
Second-Level Inspection Date: ________________

Second-Level Inspection - Form 2A (Splices at Posts)
Weathering Steel W-beam Guardrail Inspection

Date: __________ Inspection No: __________________ Inspected by: ______________

Location/Identifier: ____

First-level inspection number triggering this inspection: ___________________________



- **STEP 1: Identify Zone of Inspection**
  Inspection zone comprises three splices left and right of the splice or spot that failed in first-level inspection. Thickness readings are taken in regions marked as Area 1, Area 2L through Area 7L, and Area 2R through Area 7R in the figure on right.

- **STEP 2: Visual Inspection**
  Always perform visual checks to identify signs of significant corrosion (see instructions under Visual Inspection for examples). If significant corrosion is visible, check rail thickness at several spots in the corroded region.

- **STEP 3: Measure Thicknesses**
  Measure and note thickness of rail in all regions marked in the figure (Area 1, Area 2L through Area 7L, and Area 2R through Area 7R). Nine (9) thickness measurements are taken at each splice location, and one (1) measurement is taken at each post attachment location. See Instructions section for pattern to follow in measuring thickness around splice bolts.

Fail Thickness:
Less than 0.096 inch

Area 1 thicknesses:

Around bolt-holes on traffic-side

Spot 1: _____________ ☐ Pass ☐ Fail   Spot 2: _____________ ☐ Pass ☐ Fail
Spot 3: _____________ ☐ Pass ☐ Fail   Spot 4: _____________ ☐ Pass ☐ Fail

Around bolt-holes on field-side

Spot 5: _____________ ☐ Pass ☐ Fail   Spot 6: _____________ ☐ Pass ☐ Fail
Spot 7: _____________ ☐ Pass ☐ Fail   Spot 8: _____________ ☐ Pass ☐ Fail

Around post attachment holes on traffic-side

Spot 9: _____________ ☐ Pass ☐ Fail

Area 2R thicknesses:

Around bolt-holes on traffic-side   Spot 1: _____________ ☐ Pass ☐ Fail

Area 3R thicknesses:

Around bolt-holes on traffic-side

Spot 1: _____________ ☐ Pass ☐ Fail   Spot 2: _____________ ☐ Pass ☐ Fail
Spot 3: _____________ ☐ Pass ☐ Fail   Spot 4: _____________ ☐ Pass ☐ Fail

Around bolt-holes on field-side

Spot 5: _____________ ☐ Pass ☐ Fail   Spot 6: _____________ ☐ Pass ☐ Fail
Spot 7: _____________ ☐ Pass ☐ Fail   Spot 8: _____________ ☐ Pass ☐ Fail

Around post attachment holes on traffic-side

Spot 9: _____________ ☐ Pass ☐ Fail

Fail Thickness:
Less than 0.096 inch

Area 4R thicknesses:

Around bolt-holes on traffic-side — Spot 1: ____________ ☐ Pass ☐ Fail

Area 5R thicknesses:

Around bolt-holes on traffic-side

Spot 1: ____________ ☐ Pass ☐ Fail — Spot 2: ____________ ☐ Pass ☐ Fail

Spot 3: ____________ ☐ Pass ☐ Fail — Spot 4: ____________ ☐ Pass ☐ Fail

Around bolt-holes on field-side

Spot 5: ____________ ☐ Pass ☐ Fail — Spot 6: ____________ ☐ Pass ☐ Fail

Spot 7: ____________ ☐ Pass ☐ Fail — Spot 8: ____________ ☐ Pass ☐ Fail

Around post attachment holes on traffic-side

Spot 9: ____________ ☐ Pass ☐ Fail

Area 6R thicknesses:

Around bolt-holes on traffic-side — Spot 1: ____________ ☐ Pass ☐ Fail

Area 7R thicknesses:

Around bolt-holes on traffic-side

Spot 1: ____________ ☐ Pass ☐ Fail — Spot 2: ____________ ☐ Pass ☐ Fail

Spot 3: ____________ ☐ Pass ☐ Fail — Spot 4: ____________ ☐ Pass ☐ Fail

Around bolt-holes on field-side

Spot 5: ____________ ☐ Pass ☐ Fail — Spot 6: ____________ ☐ Pass ☐ Fail

Spot 7: ____________ ☐ Pass ☐ Fail — Spot 8: ____________ ☐ Pass ☐ Fail

Around post attachment holes on traffic-side

Spot 9: ____________ ☐ Pass ☐ Fail

Area 2L thicknesses:

Around bolt-holes on traffic-side — Spot 1: ____________ ☐ Pass ☐ Fail

Area 3L thicknesses:

Around bolt-holes on traffic-side

Spot 1: ____________ ☐ Pass ☐ Fail — Spot 2: ____________ ☐ Pass ☐ Fail

Spot 3: ____________ ☐ Pass ☐ Fail — Spot 4: ____________ ☐ Pass ☐ Fail

Around bolt-holes on field-side

Spot 5: ____________ ☐ Pass ☐ Fail — Spot 6: ____________ ☐ Pass ☐ Fail

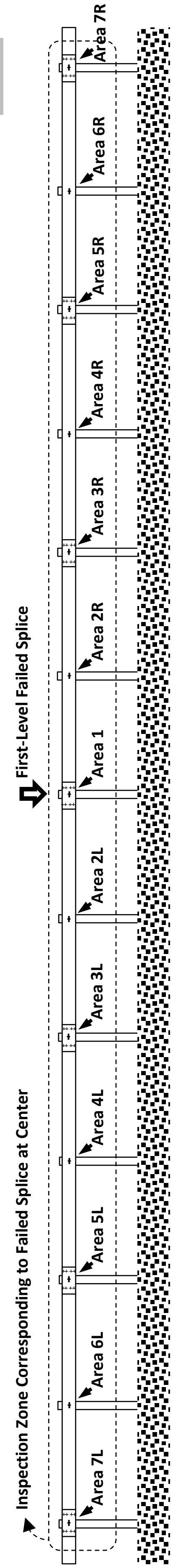
Spot 7: ____________ ☐ Pass ☐ Fail — Spot 8: ____________ ☐ Pass ☐ Fail

Around post attachment holes on traffic-side

Spot 9: ____________ ☐ Pass ☐ Fail

Area 4L thicknesses:

Around bolt-holes on traffic-side — Spot 1: ____________ ☐ Pass ☐ Fail



Fail Thickness:
Less than 0.096 inch

Area 5L thicknesses:

Around bolt-holes on traffic-side

Spot 1: ____________ ☐ Pass ☐ Fail   Spot 2: ____________ ☐ Pass ☐ Fail
Spot 3: ____________ ☐ Pass ☐ Fail   Spot 4: ____________ ☐ Pass ☐ Fail

Around bolt-holes on field-side

Spot 5: ____________ ☐ Pass ☐ Fail   Spot 6: ____________ ☐ Pass ☐ Fail
Spot 7: ____________ ☐ Pass ☐ Fail   Spot 8: ____________ ☐ Pass ☐ Fail

Around post attachment holes on traffic-side

Spot 9: ____________ ☐ Pass ☐ Fail

Area 6L thicknesses:

Around bolt-holes on traffic-side   Spot 1: ____________ ☐ Pass ☐ Fail

Area 7L thicknesses:

Around bolt-holes on traffic-side

Spot 1: ____________ ☐ Pass ☐ Fail   Spot 2: ____________ ☐ Pass ☐ Fail
Spot 3: ____________ ☐ Pass ☐ Fail   Spot 4: ____________ ☐ Pass ☐ Fail

Around bolt-holes on field-side

Spot 5: ____________ ☐ Pass ☐ Fail   Spot 6: ____________ ☐ Pass ☐ Fail
Spot 7: ____________ ☐ Pass ☐ Fail   Spot 8: ____________ ☐ Pass ☐ Fail

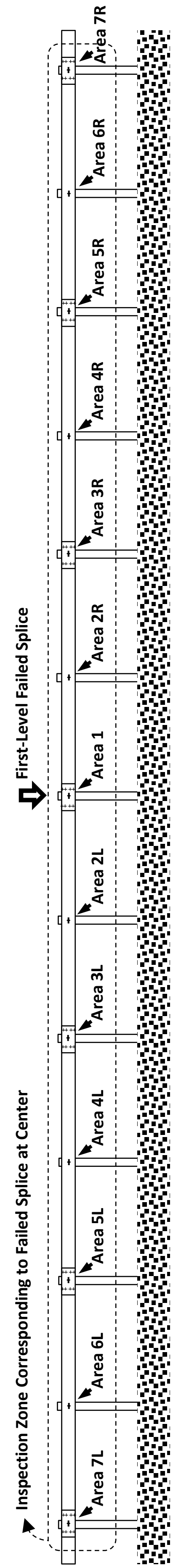
Around post attachment holes on traffic-side

Spot 9: ____________ ☐ Pass ☐ Fail

FINAL DETERMINATION

☐ PASS **☐ FAIL**

Comments:



Second-Level Inspection - Form 2B (Splices Between Posts)
Weathering Steel W-beam Guardrail Inspection

Date: __________ Inspection No: __________________ Inspected by: ______________

Location/Identifier: ____

First-level inspection number triggering this inspection: ___________________________

- **STEP 1: Identify Zone of Inspection**

  Inspection zone comprises three splices left and right of the splice or spot that failed in first-level inspection. Thickness readings are taken in regions marked as Area 1, Area 2L through Area 10L, and Area 2R through Area 10R in the figure on right.

- **STEP 2: Visual Inspection**

  Always perform visual checks to identify signs of significant corrosion (see instructions under Visual Inspection for examples). If significant corrosion is visible, check rail thickness at several spots in the corroded region.

- **STEP 3: Measure Thicknesses**

  Measure and note thickness of rail in all regions marked in the figure (Area 1, Area 2L through Area 10L, and Area 2R through Area 10R). Eight (8) thickness measurements are taken at each splice location, and one (1) measurement is taken at each post attachment location. See Instructions section for pattern to follow in measuring thickness around splice bolts.

Fail Thickness:
Less than 0.096 inch

Area 1 thicknesses:

Around bolt-holes on traffic-side

Spot 1: _____________ ☐ Pass ☐ Fail Spot 2: _____________ ☐ Pass ☐ Fail
Spot 3: _____________ ☐ Pass ☐ Fail Spot 4: _____________ ☐ Pass ☐ Fail

Around bolt-holes on field-side

Spot 5: _____________ ☐ Pass ☐ Fail Spot 6: _____________ ☐ Pass ☐ Fail
Spot 7: _____________ ☐ Pass ☐ Fail Spot 8: _____________ ☐ Pass ☐ Fail

Area 2R thicknesses:
Around bolt-holes on traffic-side Spot 1: _____________ ☐ Pass ☐ Fail

Area 3R thicknesses:
Around bolt-holes on traffic-side Spot 1: _____________ ☐ Pass ☐ Fail

Area 4R thicknesses:

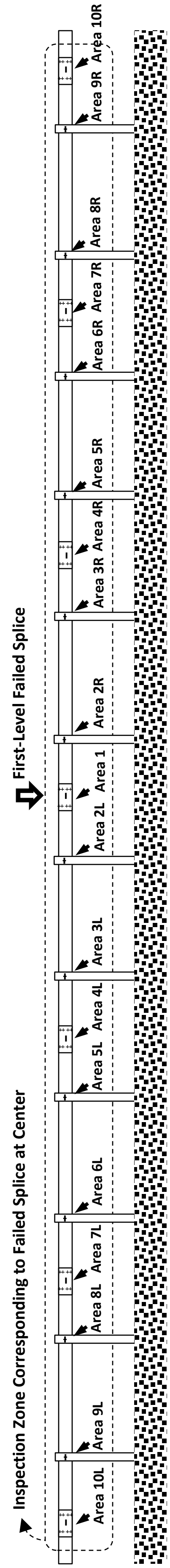
Around bolt-holes on traffic-side

Spot 1: _____________ ☐ Pass ☐ Fail Spot 2: _____________ ☐ Pass ☐ Fail
Spot 3: _____________ ☐ Pass ☐ Fail Spot 4: _____________ ☐ Pass ☐ Fail

Around bolt-holes on field-side

Spot 5: _____________ ☐ Pass ☐ Fail Spot 6: _____________ ☐ Pass ☐ Fail
Spot 7: _____________ ☐ Pass ☐ Fail Spot 8: _____________ ☐ Pass ☐ Fail

Area 5R thicknesses:
Around bolt-holes on traffic-side Spot 1: _____________ ☐ Pass ☐ Fail



Fail Thickness:
Less than 0.096 inch

Area 6R thicknesses:

Around bolt-holes on traffic-side Spot 1: ____________ ☐ Pass ☐ Fail

Area 7R thicknesses:

Around bolt-holes on traffic-side

Spot 1: ____________ ☐ Pass ☐ Fail Spot 2: ____________ ☐ Pass ☐ Fail

Spot 3: ____________ ☐ Pass ☐ Fail Spot 4: ____________ ☐ Pass ☐ Fail

Around bolt-holes on field-side

Spot 5: ____________ ☐ Pass ☐ Fail Spot 6: ____________ ☐ Pass ☐ Fail

Spot 7: ____________ ☐ Pass ☐ Fail Spot 8: ____________ ☐ Pass ☐ Fail

Area 8R thicknesses:

Around bolt-holes on traffic-side Spot 1: ____________ ☐ Pass ☐ Fail

Area 9R thicknesses:

Around bolt-holes on traffic-side Spot 1: ____________ ☐ Pass ☐ Fail

Area 10R thicknesses:

Around bolt-holes on traffic-side

Spot 1: ____________ ☐ Pass ☐ Fail Spot 2: ____________ ☐ Pass ☐ Fail

Spot 3: ____________ ☐ Pass ☐ Fail Spot 4: ____________ ☐ Pass ☐ Fail

Around bolt-holes on field-side

Spot 5: ____________ ☐ Pass ☐ Fail Spot 6: ____________ ☐ Pass ☐ Fail

Spot 7: ____________ ☐ Pass ☐ Fail Spot 8: ____________ ☐ Pass ☐ Fail

Area 2L thicknesses:

Around bolt-holes on traffic-side Spot 1: ____________ ☐ Pass ☐ Fail

Area 3L thicknesses:

Around bolt-holes on traffic-side Spot 1: ____________ ☐ Pass ☐ Fail

Area 4L thicknesses:

Around bolt-holes on traffic-side

Spot 1: ____________ ☐ Pass ☐ Fail Spot 2: ____________ ☐ Pass ☐ Fail

Spot 3: ____________ ☐ Pass ☐ Fail Spot 4: ____________ ☐ Pass ☐ Fail

Around bolt-holes on field-side

Spot 5: ____________ ☐ Pass ☐ Fail Spot 6: ____________ ☐ Pass ☐ Fail

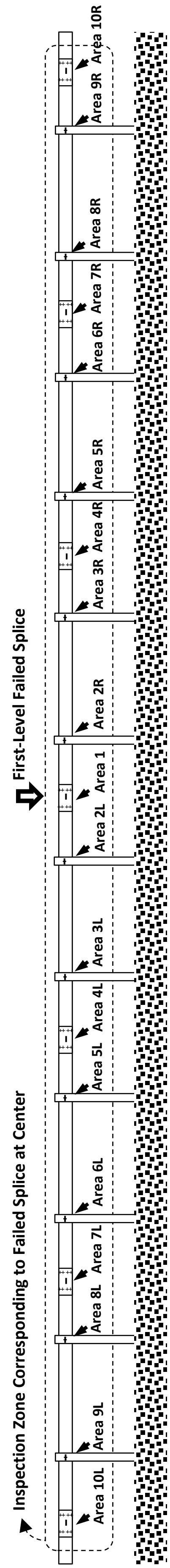
Spot 7: ____________ ☐ Pass ☐ Fail Spot 8: ____________ ☐ Pass ☐ Fail

Area 5L thicknesses:

Around bolt-holes on traffic-side Spot 1: ____________ ☐ Pass ☐ Fail

Area 6L thicknesses:

Around bolt-holes on traffic-side Spot 1: ____________ ☐ Pass ☐ Fail



Fail Thickness:
Less than 0.096 inch

Area 7L thicknesses:

Around bolt-holes on traffic-side

Spot 1: ____________ ☐ Pass ☐ Fail Spot 2: ____________ ☐ Pass ☐ Fail

Spot 3: ____________ ☐ Pass ☐ Fail Spot 4: ____________ ☐ Pass ☐ Fail

Around bolt-holes on field-side

Spot 5: ____________ ☐ Pass ☐ Fail Spot 6: ____________ ☐ Pass ☐ Fail

Spot 7: ____________ ☐ Pass ☐ Fail Spot 8: ____________ ☐ Pass ☐ Fail

Area 8L thicknesses:

Around bolt-holes on traffic-side Spot 1: ____________ ☐ Pass ☐ Fail

Area 9L thicknesses:

Around bolt-holes on traffic-side Spot 1: ____________ ☐ Pass ☐ Fail

Area 10L thicknesses:

Around bolt-holes on traffic-side

Spot 1: ____________ ☐ Pass ☐ Fail Spot 2: ____________ ☐ Pass ☐ Fail

Spot 3: ____________ ☐ Pass ☐ Fail Spot 4: ____________ ☐ Pass ☐ Fail

Around bolt-holes on field-side

Spot 5: ____________ ☐ Pass ☐ Fail Spot 6: ____________ ☐ Pass ☐ Fail

Spot 7: ____________ ☐ Pass ☐ Fail Spot 8: ____________ ☐ Pass ☐ Fail

FINAL DETERMINATION

☐ **PASS** ☐ **FAIL**

Comments: