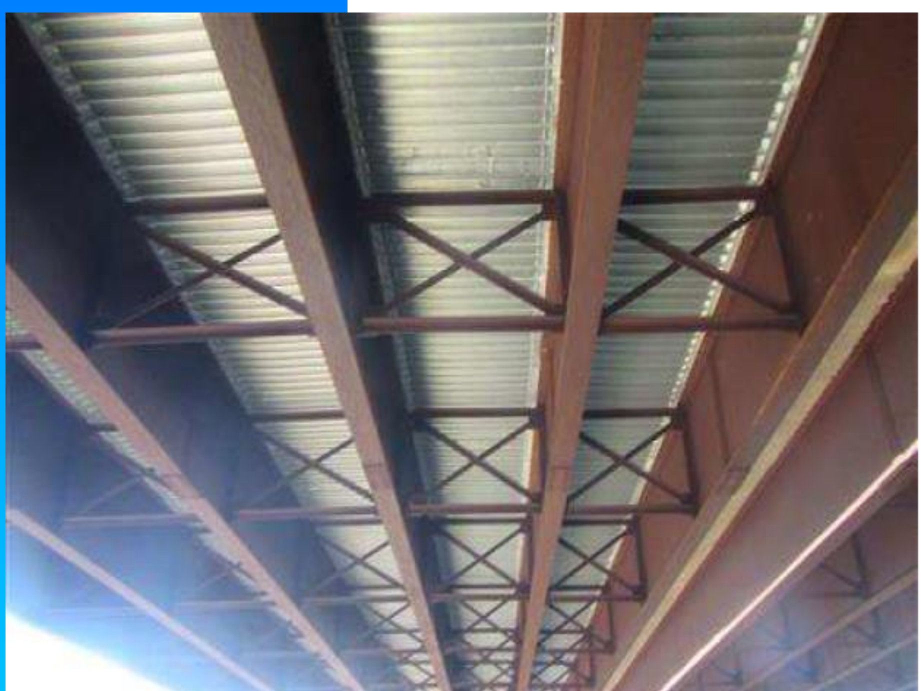
Study of Corrosion Performance of Weathering Steel Bridges

State Project No. 170-3301

CHA Project Number: 064341

Prepared for:

Connecticut Department of Transportation
2800 Berlin Turnpike
Newington, CT 06131



Prepared by:

CHA Companies, Inc.
101 East River Drive, 1st Floor
East Hartford, CT 06108
Phone: (860) 290-4100

May 24, 2021

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

Weathering Steel is a designation of steel that resists corrosion through the formation of a protective patina when exposed to the environment. Uncoated weathering steel has been used in Connecticut for over 50 years. These structures often have both long-term and short-term cost effectiveness as they do not require initial painting, nor is repainting needed throughout the service life. Not utilizing a paint on the structure also provides environmental benefits of not expelling the volatile organic compounds. These structures are not impermeable to section loss caused by corrosion, however. As a result, Federal Highway Administration (FHWA) released a set of guidelines in the late 1980s for the use and implementation of weathering steel in bridge structures to optimize their performance. There are also recent and on-going national studies regarding the performance of unpainted weathering steel.

This report reviews the current state of practice for the implementation of weathering steel bridges in the state of Connecticut followed by a review of a large group of weathering steel bridges in the state. The review focuses on three potential causes of corrosion:

1. Environmental Effects: Proximity to the coast, rivers, and wetlands
2. Vehicle Effects on overpasses: Spray from trucks and trains
3. Detailing: Corrosion brought on by details (i.e. leaking deck joints)

This review looks at the section loss at the beam ends and in-span as well as the details and features crossed to isolate sources of corrosion and section loss, concentrating on leaking, design detail, and feature crossed, including roadways, waterways, and railways. Other aspects of the feature crossed, such as the clearance below the structure, the volume of truck traffic on the roadways below the structure, the electrification of the railways below the structure, and the composition of the water below are also investigated. The report ends with the conclusions reached from the data and a set of recommendations based on the findings for future structures constructed in the state.

2.0 CURRENT STATE OF PRACTICE IN CT

In Connecticut, the use of weathering steel is outlined in the state's Standard Design Practices and Procedures [1]. Currently in the state, weathering steel is the first consideration for steel bridges, as it eliminates the need for painting the structures. Any steel structure crossing a railroad is also to be constructed of weathering steel. The areas currently considered high risk for uncoated weathering steel are "… bridges subject to vehicular salt spray, near a saltwater environment, or a heavy industrial area…".

The guidelines of the Connecticut Department of Transportation (CTDOT) conform with the FHWA Technical Advisory T5140.22 [2], “Uncoated Weathering Steel in Structures.” These guidelines are as follows:

- The use of weathering steel in marine coastal areas, areas of frequent high rainfall, high humidity or persistent fog, within highly industrial areas, in tunnel like graded areas, and with low clearance over water crossings (defined as < 10 ft over stagnant water, and < 8 ft over moving water) are to be considered areas which pose a higher risk for the corrosion of uncoated weathering steel.
- When utilizing uncoated weathering steel, the design should incorporate details that eliminate bridge joints, use expansion joints that control water on the deck and divert it away from the structure, paint the beam ends for a length 1.5 times the depth of the beam, utilize no welded drip bars where fatigue stresses could be critical, minimize the numbers of scuppers in the structure, eliminate details that trap water, seal box members or allow the drainage of water and circulation of air, cover and screen any openings in box structures, protect piers and abutments from staining from the superstructure, and seal overlapping surfaces exposed water.
- Maintenance of weathering steel structures should detect and minimize corrosion, control the drainage on the roadway, diverting it from the structure, maintain the draining system, repaint and clean the beam ends, remove dirt/debris/vegetation which can trap moisture, and maintain covers and screens over access holes.

CTDOT amends the basic FHWA guidelines as follows:

- Structures subject to vehicular salt spray, or those near saltwater or a heavily industrialized area should incorporate a modest increase in flange plate thickness to accommodate minor section loss in the future.
- The interior surfaces of the box girders shall be painted to protect the structure from any water that may stagnate within the structure. The paint system should include a white intermediate coat to facilitate inspection.
- Deck joints should be eliminated whenever possible. When it is not possible, the structure should be protected from leaking. The beam ends in structures featuring a deck over backwall design need not be painted.

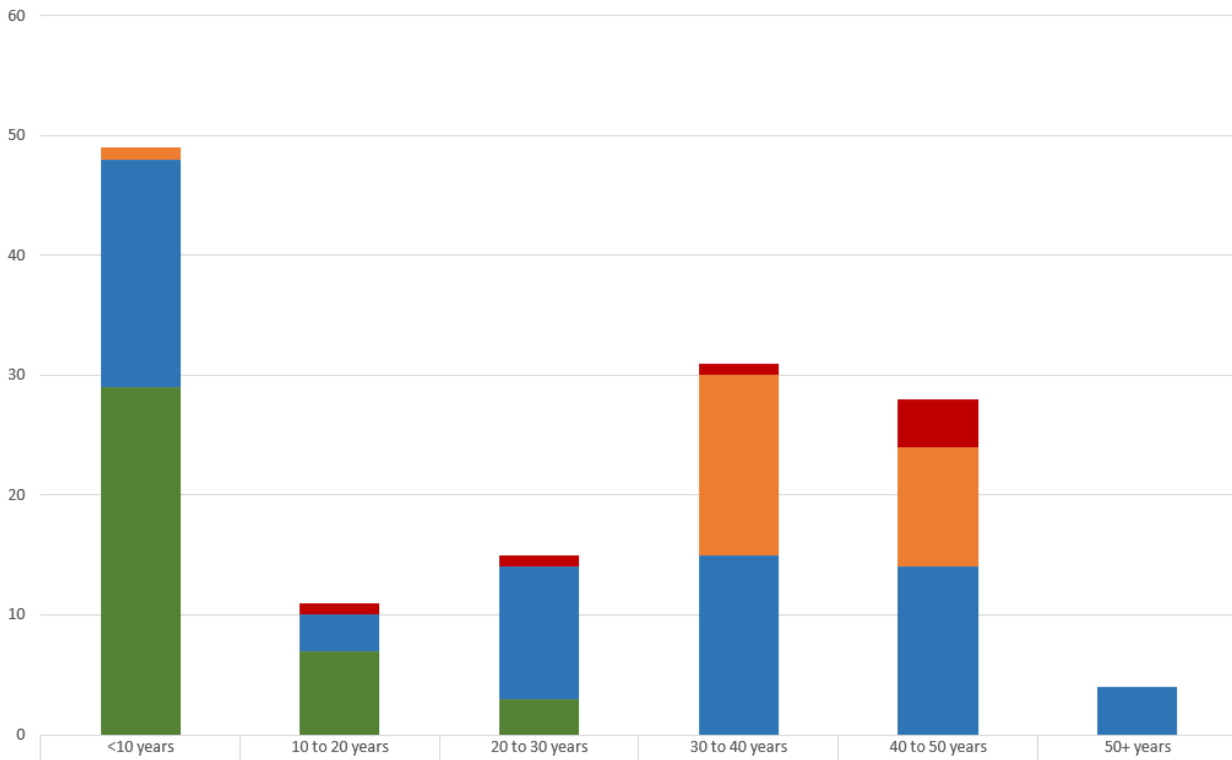
Most of the structures within the state constructed after 1989, when these guidelines were published, follow these recommendations. Some deviations were noted. There were four structures which fell below the minimum suggested clearance to waterways, with these structures falling between a freeboard clearance of 1 ft 9 inch and 7 ft 5 inch. Of these four structures, only one had any section loss noted (1/16 inch in Bridge No. 01077 with freeboard clearance of 7 ft 1 inch) [3].

There were also three structures with slabs terminating in front of the backwall to accommodate finger joints for longer spans.

3.0 OVERVIEW OF WEATHERING STEEL STRUCTURES IN CT

The first implementation of a weathering steel bridge in Connecticut completed construction in 1969 in Manchester and carries the I-384 WB on and off ramps over the Hop River. This report was able to identify a total of 138 structures whose superstructure utilized weathering steel. Of these 138 structures, the average age is 23.4 years. Only 24% of these structures have a superstructure rating of 6 or less. Figure 1 shows a distribution of the superstructure condition rating found in structures based on their age. Throughout the service life, the superstructure rating remains high.

Most of these structures are I-shaped, either rolled or welded plate girders, with only ten of the 138 structures being box girders. The average clearance below the structures is 19.5 ft. 64 of the structures cross a roadway, 48 cross a waterway, and 47 cross a railway. The Average Daily Truck Traffic (ADTT) below the 64 structures crossing roadways has an average of 4,935 vehicles per day. This value assumes an ADTT of 0 for those structures not listing information for the intersected feature. Of the 48 crossing waterways, only four of those cross salt or brackish water. 24 of the 47 structures crossing railways are electrified, and 18 of those 24 electrified rail crossings cross the Metro North Railroad (MNRR), which has a significantly higher volume of train traffic underneath.



	<10 years	10 to 20 years	20 to 30 years	30 to 40 years	40 to 50 years	50+ years
5	0	1	1	1	4	0
6	1	0	0	15	10	0
7	19	3	11	15	14	4
8	29	7	3	0	0	0

Figure 1. Number of Structures with Particular Superstructure Condition Ratings Compared to Age of Structure

The beam end details for each of the bridges were recorded where bridge plans were available. Of the 138 bridges, 41 of the details were not able to be found. Of the 97 structures where beam end details were able to be found, four detail categories were identified: Integral (includes girders with concrete diaphragms), Slab to Back of Backwall, Slab on Backwall (includes stepped backwall to accommodate the approach slab), and Slab in Front of the Backwall. Integral abutments, depicted in Figure 2a, and beam ends with concrete end diaphragms, depicted in Figure 2b, counted as the same type of beam end detail. Deck slabs extending to the back of the backwall, depicted in Figure 2c, and deck slabs terminated over a backwall sloped towards the approach slab, depicted in Figure 2d, were counted as the same beam end detail. The slabs being detailed terminated on a flat or stepped backwall are depicted in Figure 2e. The final beam end detail has deck slabs terminating in front of the backwall, depicted in Figure 2f.

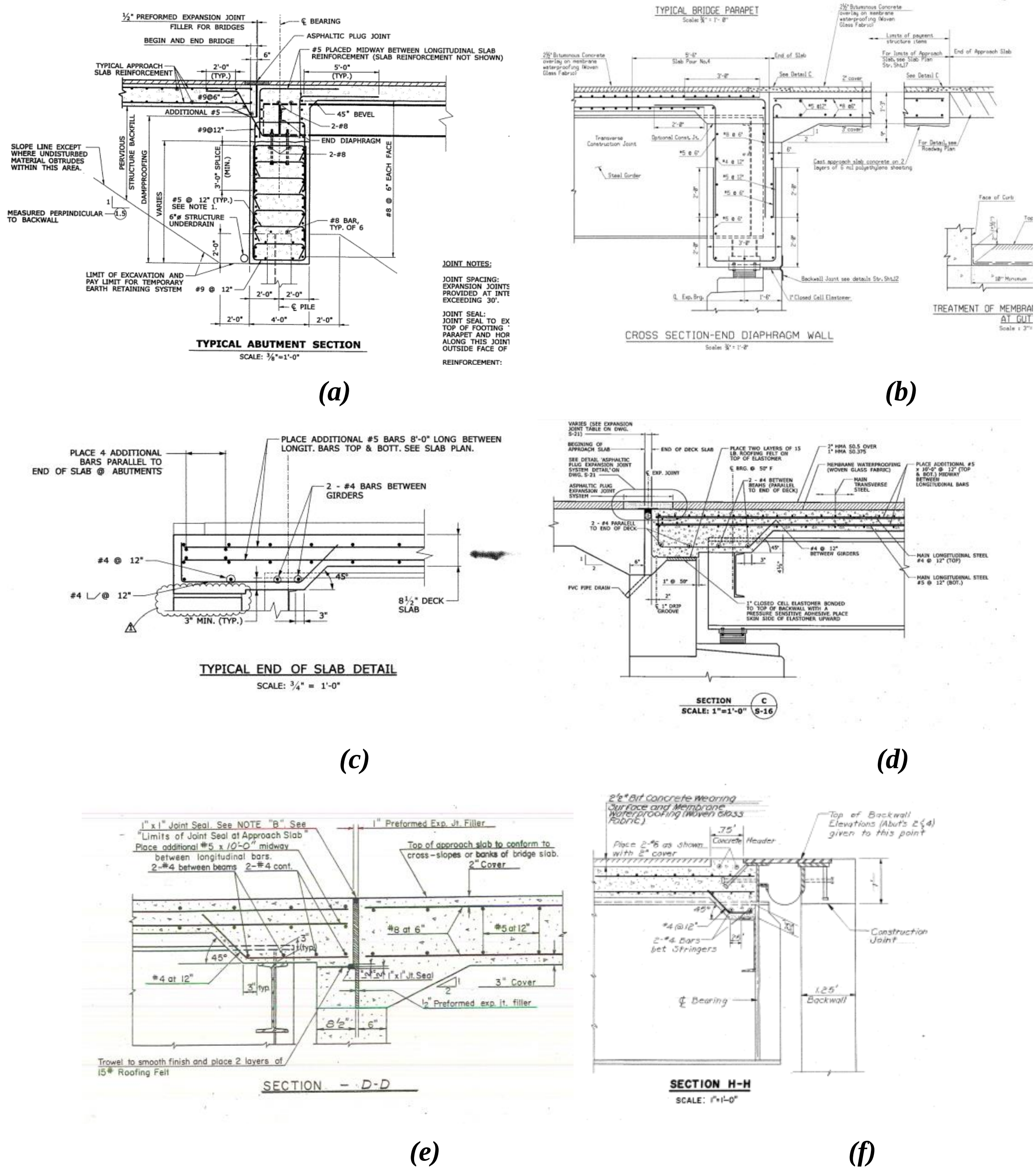
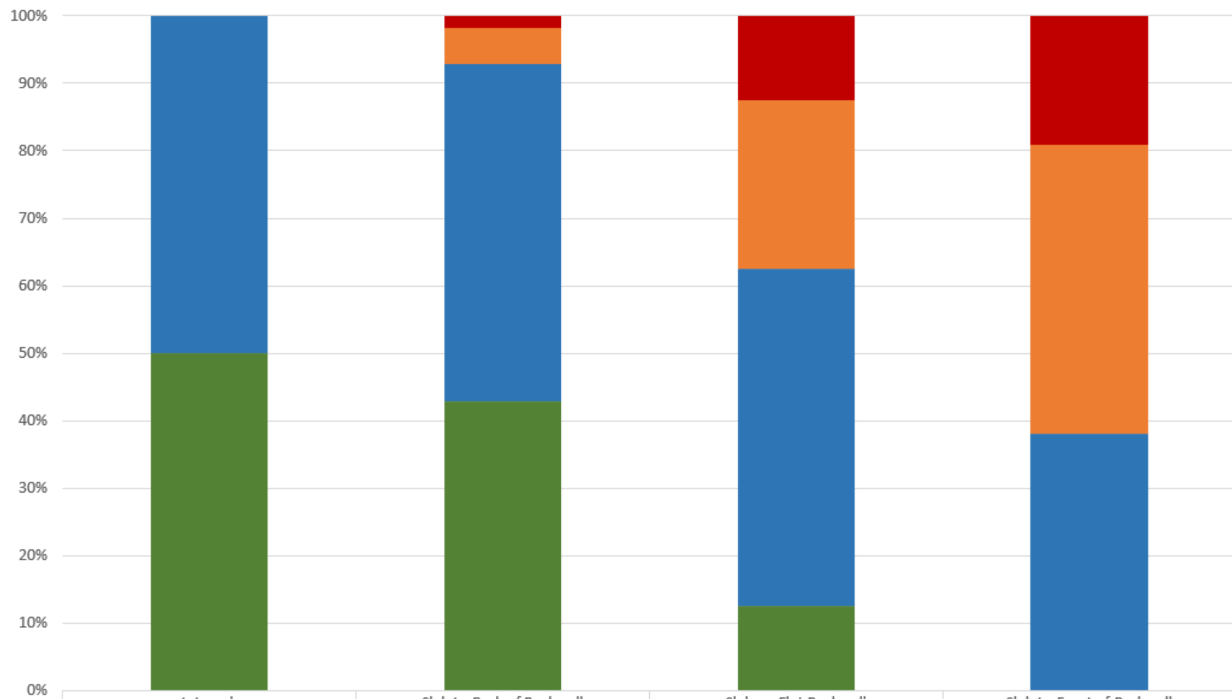


Figure 2. Samples of Details in Structures Observed.

If a single structure included differing details at abutments, the less desirable detail was considered in the analysis. Figure 3 shows proportion of structures with a given superstructure condition rating based on the beam end detail found. Structures with either integral or Slab to Back of Backwall details have higher ratings than those with other end details.



	Integral	Slab to Back of Backwall	Slab on Flat Backwall	Slab to Front of Backwall
5	0%	2%	13%	19%
6	0%	5%	25%	43%
7	50%	50%	50%	38%
8	50%	43%	13%	0%
Number:	12	56	8	21

Figure 3. Superstructure Condition Rating Compared to the Beam End Detail

Another major issue considered is evidence of active or past leaking within the latest inspection report. Leaking in the structure was divided into three distinct locations: the abutments, within the span, and at piers. Leaking through the joints and decks are the major source of section loss and reduction of the superstructure condition rating. As can be seen in Figure 4, any structure with a superstructure rating of 6 or below had leaking that was noted withing the structure, often being the source of the corrosion responsible for the reduced rating.

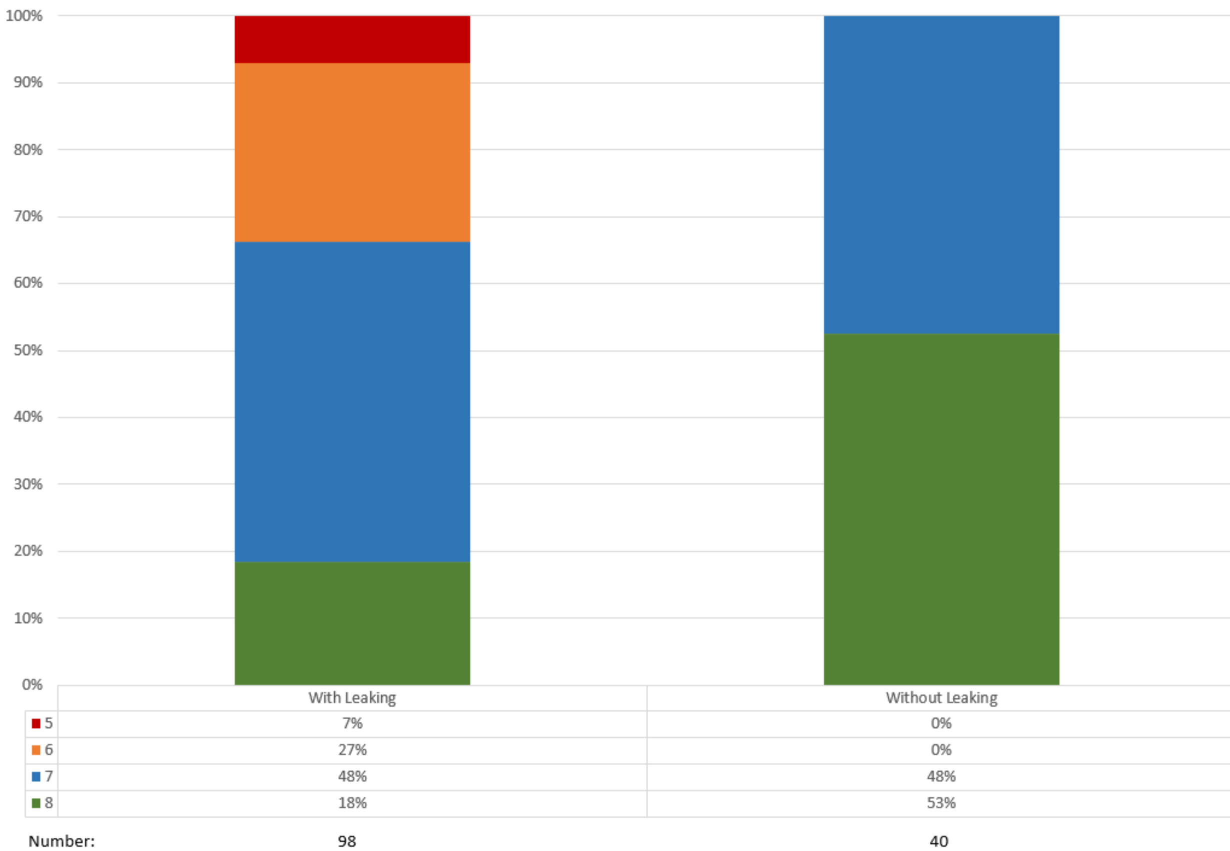
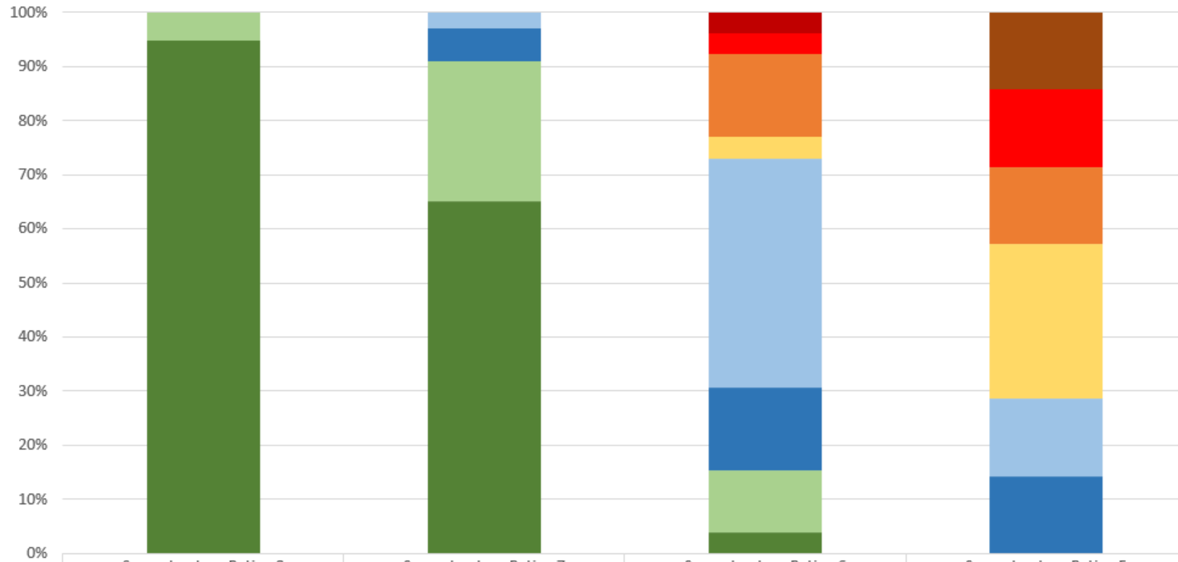


Figure 4. Superstructure Condition Rating Compared to Leaking Noted in the Structure

For the remainder of the report, comparisons are made to the section loss noted in the structure rather than the condition rating of the superstructure itself. This was decided as the goal of the study was to evaluate the performance of weathering steel bridges in the state. The superstructure condition rating is affected not only by section loss, but also other issues such as weld condition, cracking, and bolting (As can be noted in Bridge No. 05241 which has a rating of 6 due to missing welds despite having no section loss due to corrosion noted in the structure) [4]. Section loss was seen to be the critical factor in determining the long-term performance of weathering steel structures, and something that could be easily extracted from inspection reports. The section loss was separated into two categories: section loss at beam ends, and section loss within the span. Figure 5 shows that the maximum section loss (the larger of the two values measured), section loss is a good analogy to the condition rating of a structure.

In addition to these data, the clearance below the structure was recorded. This was recorded as the value of the 'Log Minimum Vertical Underclearance' (Item 54) for structures crossing roadways or railways, or the freeboard distance for structures crossing waterways. In the event the structures crossed multiple features, the least value was recorded. Values for the ADT and percentage of trucks on the intersected roadway (Items 29 and 109, respectively) were recorded for structures crossing a roadway, or as 0 if no data was given for the roadway intersected. For structures crossing railways, it was recorded weather the railway crossed was electrified or not. Structures crossing waterways were noted if they crossed freshwater or saltwater.



	Superstructure Rating 8	Superstructure Rating 7	Superstructure Rating 6	Superstructure Rating 5
1/2"	0%	0%	4%	0%
3/8"	0%	0%	0%	14%
5/16"	0%	0%	4%	14%
1/4"	0%	0%	15%	14%
3/16"	0%	0%	4%	29%
1/8"	0%	3%	42%	14%
1/16"	0%	6%	15%	14%
Negligable	5%	26%	12%	0%
None	95%	65%	4%	0%
Number:	39	66	26	7

Figure 5. Maximum Section Loss Noted in Structures Based on the Superstructure Condition Rating

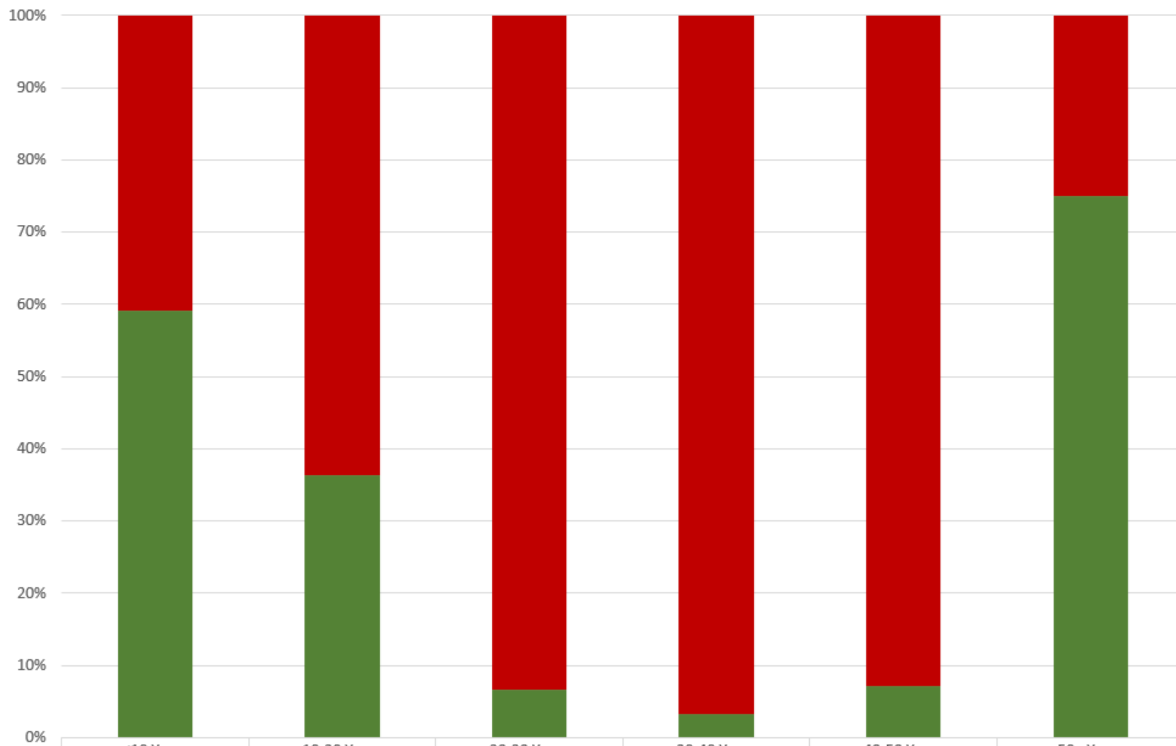
4.0 REVIEW OF FINDINGS

This section presents the findings of the data collection and provides analysis on potential areas of corrosion. The data collected included noted leaking in the beam end and within the span, the detailing of the abutment joints, features being crossed including roadways, waterways, and railways, clearance below the structure, traffic data from below the structure, the electrification of railway below the structure, and whether the body of water crossed is saltwater.

There are three types of section loss measured in this section: the 'maximum section loss at the beam end', the 'maximum in-span section loss', and the 'maximum section loss' which is the maximum of the beam end and in-span section loss. This enables the condition of the beam ends and the mid-span to be investigated independently, and a way to quantify the general condition of the structure.

4.1 LEAKING

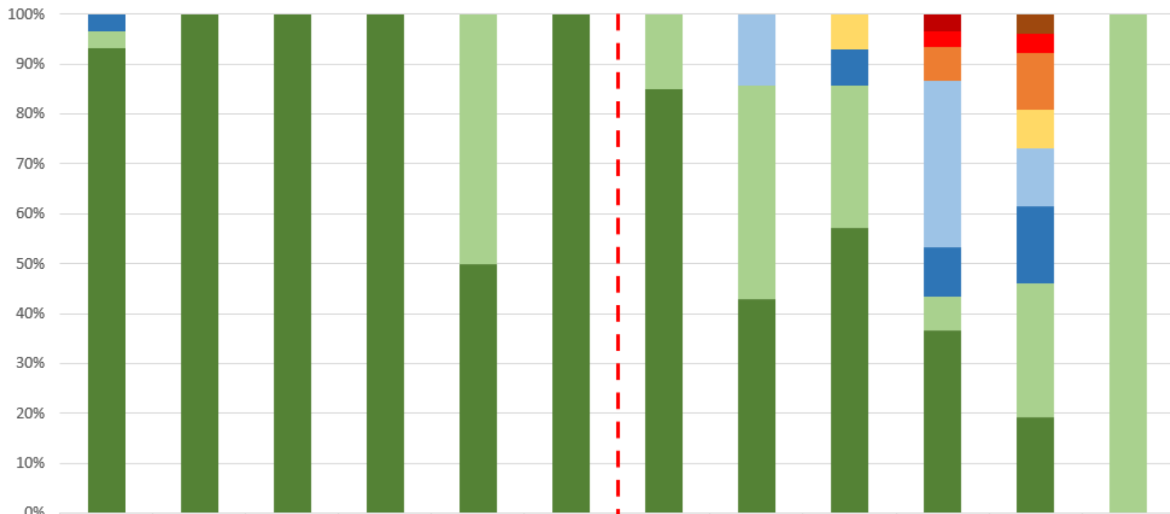
As was observed in Figure 4, all structures with superstructure condition rating below 7 show evidence of leaking. Leaking is an inevitable occurrence in any structure, with over 90% of structures over 20 years old showing evidence of either active or past leakage, as shown in Figure 6.



	<10 Years	10-20 Years	20-30 Years	30-40 Years	40-50 Years	50+ Years
Leaking	41%	64%	93%	97%	93%	25%
No Leaking	59%	36%	7%	3%	7%	75%
Number:	49	11	15	31	28	4

Figure 6. Percentage of Structures with Evidence of Leaking Based on Age of the Structure

Figure 7 shows the proportion of structures with a maximum section loss developed in structures both with and without leaking. Structures without leaking show little to no section loss on the structure, regardless of age. Section loss in structures that do exhibit leaking begin becoming evident in structures over 10 years of age. Structures between 10 and 30 years have an average loss of 0.018 inch for each of the 10-year intervals, those between 30 and 40 years have average loss of 0.092 inch, and structures between 40 and 50 years have an average loss of 0.094 inch. This shows that leaking is a direct cause of much of the section loss noted in inspection reports.

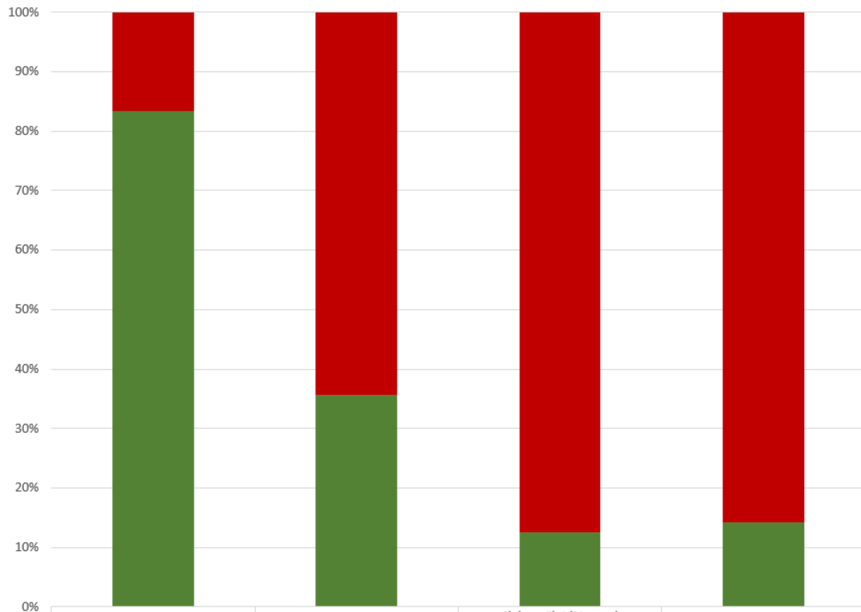


	Age <10 yr Without Leaking	Age 10-20 yr Without Leaking	Age 20-30 yr Without Leaking	Age 30-40 yr Without Leaking	Age 40-50 yr Without Leaking	Age 50+ yr Without Leaking	Age <10 yr With Leaking	Age 10-20 yr With Leaking	Age 20-30 yr With Leaking	Age 30-40 yr With Leaking	Age 40-50 yr With Leaking	Age 50+ yr With Leaking
1/2"	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%
3/8"	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%	0%
5/16"	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	4%	0%
1/4"	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	12%	0%
3/16"	0%	0%	0%	0%	0%	0%	0%	0%	7%	0%	8%	0%
1/8"	0%	0%	0%	0%	0%	0%	0%	14%	0%	33%	12%	0%
1/16"	3%	0%	0%	0%	0%	0%	0%	0%	7%	10%	15%	0%
Negligible	3%	0%	0%	0%	50%	0%	15%	43%	29%	7%	27%	100%
None	93%	100%	100%	100%	50%	100%	85%	43%	57%	37%	19%	0%
Number:	29	4	1	1	2	3	20	7	14	30	26	1

Figure 7. Maximum Section Loss in a Structure Compared to the Age of the Structure for Leaking and Non-Leaking Structures

4.1.1 Beam End Leaking

Figure 8 shows the proportion of each beam end detail that has either active leaking or evidence of past leaking noted in the most recent inspection report. Two types of leaking were able to be identified from inspection reports at the beam ends: leaking through the deck joint and leaking through a weep onto the structure. Figure 9 shows examples of these two types of leaking, with leaking through the joint visible in the left picture, and a weep pipe aimed and the end diaphragm on the right picture. Evidence of corrosion can be seen in both examples, with scaling occurring in the left figure and painting of the structure due to corrosion in the right figure. The data shows that no beam end details are immune from leaking, although integral abutments are significantly less likely to leak, with only 17% of details exhibiting evidence of leaking. Of the other three identified details, all three have over 60% of the details experiencing leaking. Slab to the back of backwall has the best performance of the three remaining details with 36% of the details not showing evidence of leaking, compared to 13% for slab on a flat/stepped backwall, and 14% for a slab in front of backwall detail. Three of the structures with leaking were caused by a weep at the beam end leaking onto the structure, rather than from leaking through the abutment. Two of these occurred in a structure with the slab to back of backwall, and the third was with a slab to front of backwall detail.

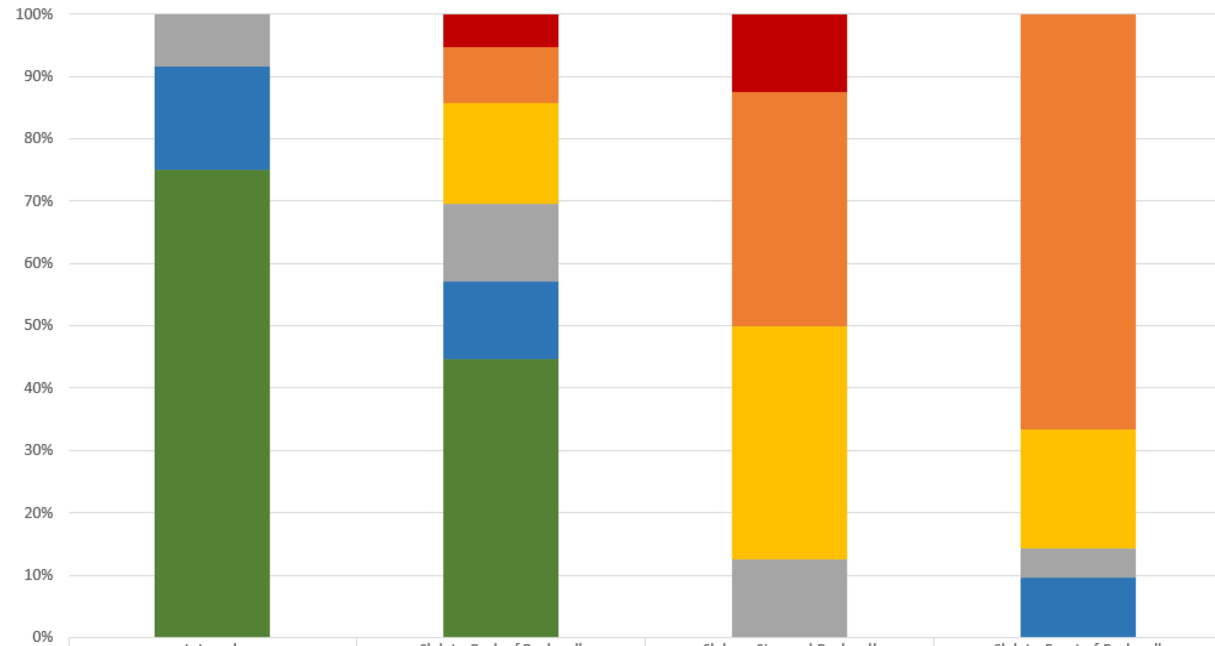


	Integral	Slab to Back of Backwall	Slab on Flat/Stepped Backwall	Slab to Front of Backwall
Beam End Detail with Leaking	17%	64%	88%	86%
Beam End Detail no Leaking	83%	36%	13%	14%
Number:	12	56	8	21

Figure 8. Active Leaking or Evidence of Past Leaking in the Various Beam End Details Identified

Figure 9. Examples of the Two Types of Beam End Leaking

It should be noted that in the last 16 years, only integral and slab to back of backwall details have been used. The distribution of age is given in Figure 10. The average age of the structures with the details is eight years for integral abutments, 18 years for slab to back of backwall, 38 years for slab on flat/stepped backwall, and 39 years for slab in front of backwall. The youngest slab on front of backwall is 16 years old, and the youngest slab on flat/stepped backwall is 24 years old. This could be part of the cause of lower proportion of leaking observed in integral and slab to back of backwall. This also shows that recently the better performing details have been being used exclusively.

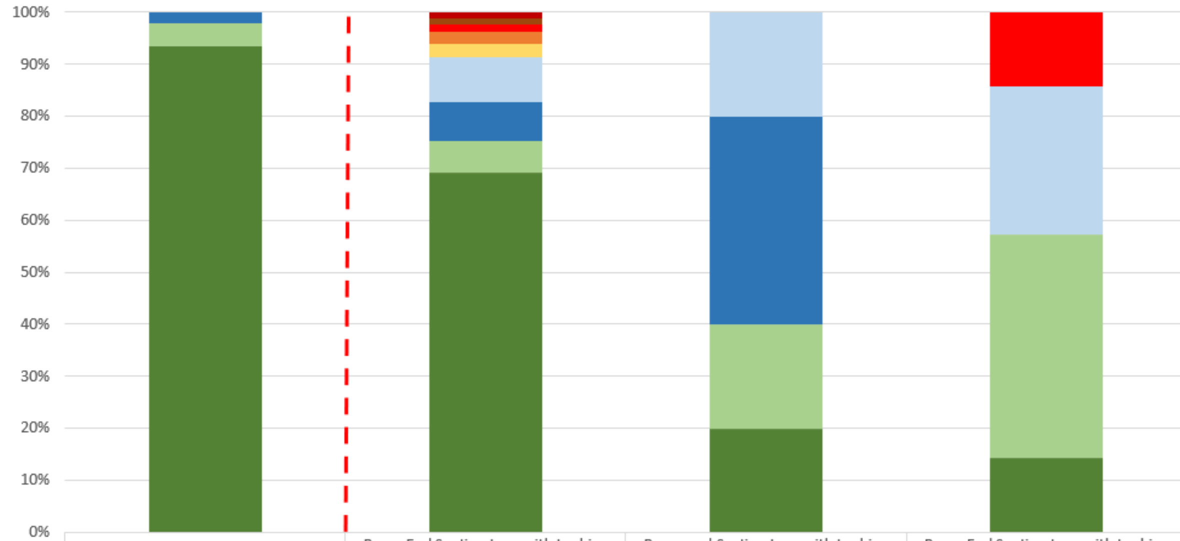


	Integral	Slab to Back of Backwall	Slab on Stepped Backwall	Slab to Front of Backwall
50+	0%	5%	13%	0%
40-50	0%	9%	38%	67%
30-40	0%	16%	38%	19%
20-30	8%	13%	13%	5%
10-20	17%	13%	0%	10%
<10	75%	45%	0%	0%
Number:	12	56	8	21

Figure 10. Age Distribution of Beam End Details

For beam end details prone to leaking, three types of leaking were identified: leaking from the joint, leaking from a weep onto the structure, or both. Figure 11 shows the maximum amount of section loss noted at the beam end based on the type of leaking noted at the beam ends. These results are not unexpected, showing that 98% of structures have no or negligible section loss if no leaking is present. The only structure showing measurable section loss at a beam end (Bridge No. 01077, 1/16”) [3] has the section loss at the bottom of the web extending on a single side from the beam end to midspan. The average section loss at the beam end was 0.041 inch if only joint leaking was noted, it was 0.050 inch when leaking was occurring from a weep onto the structure and was 0.080 inch for evidence of both types of leaking. This is expected as joint leaking does not necessarily deposit water onto the structure as having a weep directed onto a structure would.

Though it does show that leaking has a measurable effect on the amount of section loss measured at beam ends, and therefore any leakage should be addressed as soon as possible. If section loss is to be reduced, using joint details that minimize the potential for leakage should be implemented.

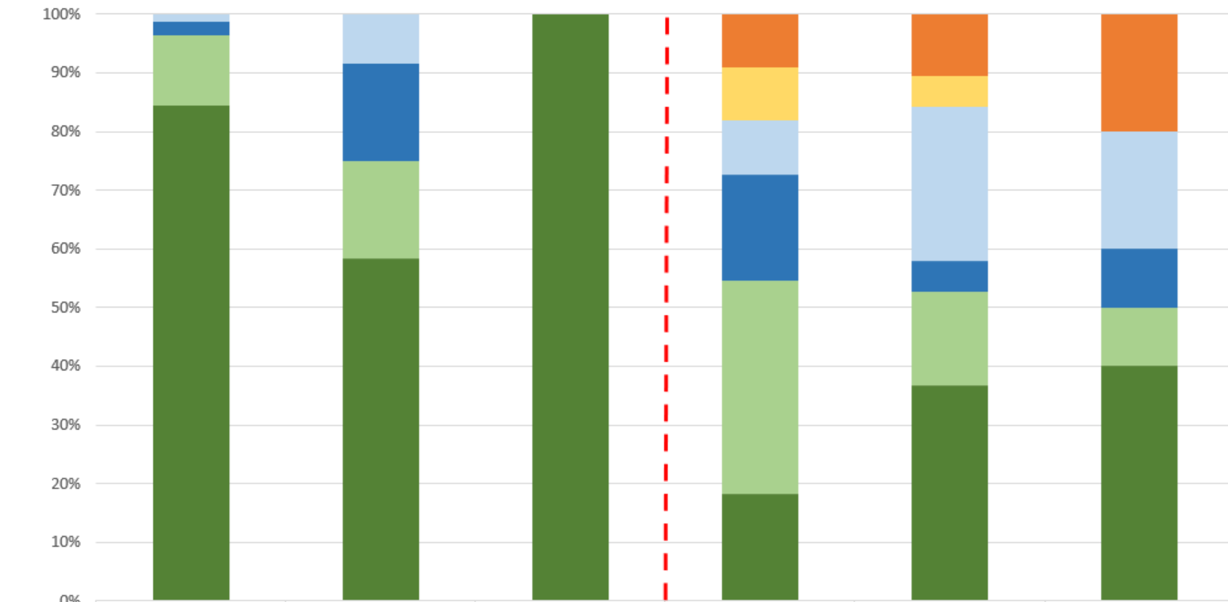


	Beam End Section Loss no Leaking	Beam End Section Loss with Leaking from Joint	Beam end Section Loss with Leaking from Weep/Scupper	Beam End Section Loss with Leaking from Joint and Weep/Scupper
1/2"	0%	1%	0%	0%
3/8"	0%	1%	0%	0%
5/16"	0%	1%	0%	14%
1/4"	0%	2%	0%	0%
3/16"	0%	2%	0%	0%
1/8"	0%	9%	20%	29%
1/16"	2%	7%	40%	0%
Negligable	4%	6%	20%	43%
None	93%	69%	20%	14%
Number:	45	81	5	7

Figure 11. Maximum Beam End Section Loss Based on Type of Leaking Noted

4.1.2 In-span Leaking

As with the beam ends, the observed maximum section loss is often higher when leaking is present. Figure 12 shows the extent of in-span section loss separated into six types of leaking identified from inspection reports. 96% of structures with no in-span leaking do not show any measurable in-span section loss, as do 75% of structures with short weeps, and all structures with leaking from conduits. This compares to 50% to 54% of structures without measurable corrosion with some type of detrimental in-span leaking. These sources of leaking are identified as leaking from scuppers/weeps onto the structure, leaking through the deck or stay-in-place (SIP) forms onto the structure, and leaking through construction joints. 40 structures have one of these forms of leaking. The average section loss in structures with leaking from a scupper/weep onto the structure is 0.063 inches, the average loss for structures with leaking through the deck/SIP forms is 0.072 inch, and the average section loss with leaking through a construction joint is 0.081 inch. This compares to an average section loss of 0.005 inches in structures either with no in-span leaking or leaking that isn't directed onto the structural steel. Similar to beam end details prone to leakage, the evidence shows that any mid-span leakage of water onto the structural steel is a direct cause of section loss. Figure 13 shows some examples of in-span leaking noted within the bridges.



	No In-Span Leaking	Short Weep Noted	Leaking from Conduits	Scupper/Weep Leaking onto Structure	Leaking through Deck/SIP Forms	Leaking through Construction Joint
1/4"	0%	0%	0%	9%	11%	20%
3/16"	0%	0%	0%	9%	5%	0%
1/8"	1%	8%	0%	9%	26%	20%
1/16"	2%	17%	0%	18%	5%	10%
Negligable	12%	17%	0%	36%	16%	10%
None	84%	58%	100%	18%	37%	40%
Number	83	12	3	11	19	10

Figure 12. Maximum In-Span Section Loss Compared to Type of In-Span Leaking Noted

Figure 13. Examples of In-Span Leaking Noted in Bridges

4.2 BEAM ENDS

Based on the data collected, the beam ends experience more severe corrosion when compared to within the span. Of the 138 bridges, the average section loss in span is 0.024 inches, while the average section loss is 0.030 inches, 25% more than in span. The maximum section loss experienced at beam ends is also two times greater than the maximum loss in span, increasing from 1/4 inch in span to 1/2 inch at the beam ends.

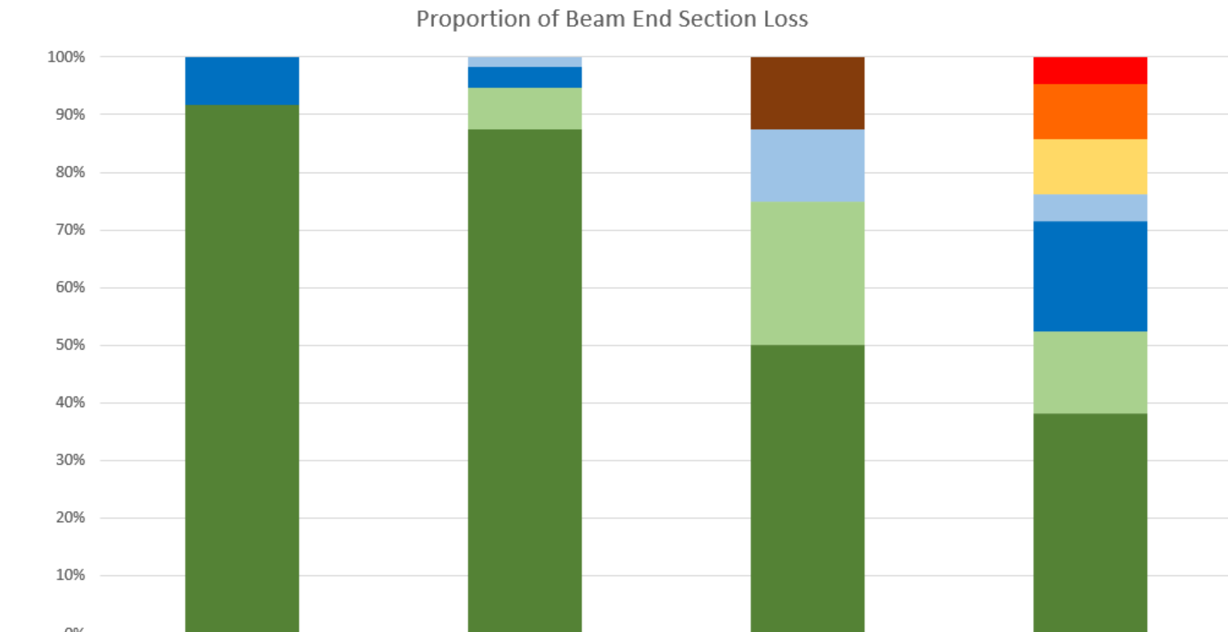
Beam ends are much more susceptible to leaking. Of the 138 structures within the study, 93 of the structures have been indicated to have either active leaking or evidence of past leaking. By comparison, only 40 have noted leaking within the span. Because of this, the details used at the beam ends should be studied to determine if there are any correlation between the details used in beam ends and either the presence of leaking or the overall section loss observed.

4.2.1 Beam End Details

There were four basic types of beam end details that were identified: Integral (includes girders with concrete diaphragms), Slab to Back of Backwall, Slab on Backwall (includes stepped backwall to accommodate the approach slab), and Slab in Front of the Backwall. Of the 138 structures, 97 structures were able to have the beam end detail determined. 12 structures were identified as having integral abutments. 55 structures were identified as having a Slab to Back of Backwall detail. 8 structures have beam ends with the slabs being detailed terminated on a flat or stepped backwall, and 21 structures have end details with the deck slab terminating in front of the backwall. Examples of these end details are available in Figure 2.

Occasionally, some of the beam ends are painted to help to mitigate corrosion when leaking is present. Of the 138 structures, 31 have been painted, although seven of them were painted in response to section loss.

4.2.2 Beam End Section Loss



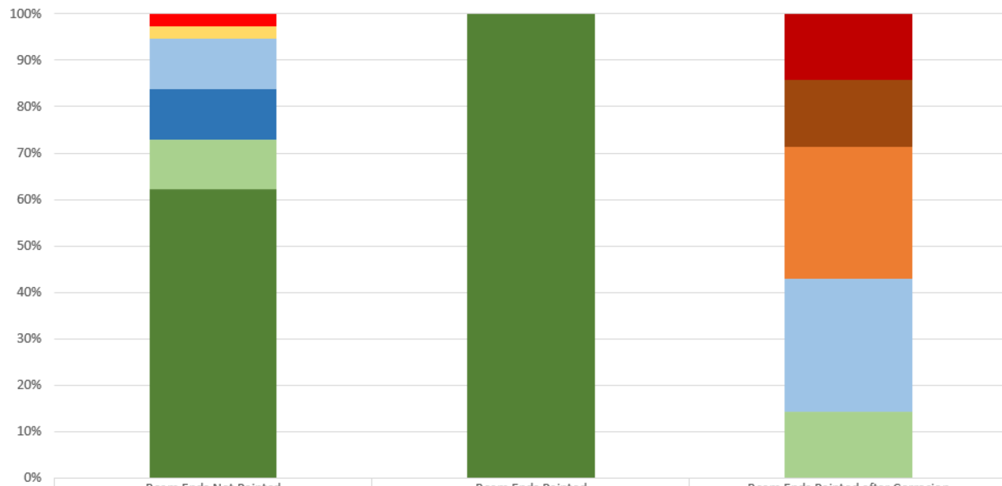
	Integral	Slab to Back of Backwall	Slab on Stepped Backwall	Slab to Front of Backwall
3/8"	0%	0%	13%	0%
5/16"	0%	0%	0%	5%
1/4"	0%	0%	0%	10%
3/16"	0%	0%	0%	10%
1/8"	0%	2%	13%	5%
1/16"	8%	4%	0%	19%
Negligable	0%	7%	25%	14%
None	92%	88%	50%	38%
Number:	12	56	8	21

Figure 14. Maximum Beam End Section Loss Noted in Beam End Details

In the previous section, the beam end leaking was compared to the detail used. Figure 14 shows the maximum beam end section loss noted in the latest inspection report. This shows that the maximum beam end section loss was significantly lower in beam ends with integral and slab to back of backwall details. Over 90% of integral and slab to back of backwall have no noted or negligible section loss, compared to 75% of slab on stepped backwall, and 52% of slab in front of backwall showing no or negligible section loss. The average section loss was 0.005 inch for integral abutments, 0.004 inch for slab to back of backwall, 0.063 inch of slab on flat/stepped backwall, and 0.074 inch for slab in front of backwall. Figure 15 shows sample corrosion at the beam end.

Figure 15. Example Section Loss at the Beam End

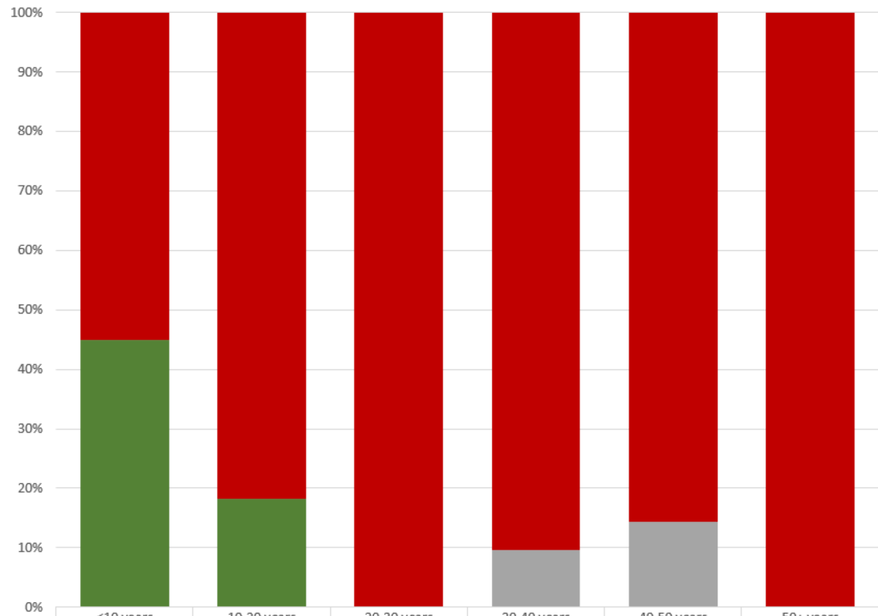
4.2.3 Beam End Painting



	Beam Ends Not Painted	Beam Ends Painted	Beam Ends Painted after Corrosion
1/2"	0%	0%	14%
3/8"	0%	0%	14%
5/16"	3%	0%	0%
1/4"	0%	0%	29%
3/16"	3%	0%	0%
1/8"	11%	0%	29%
1/16"	11%	0%	0%
Negligable	11%	0%	14%
None	62%	100%	0%
Number:	74	12	7

Figure 16. Beam End Section Loss in Structure with Leaking Separated by Painting

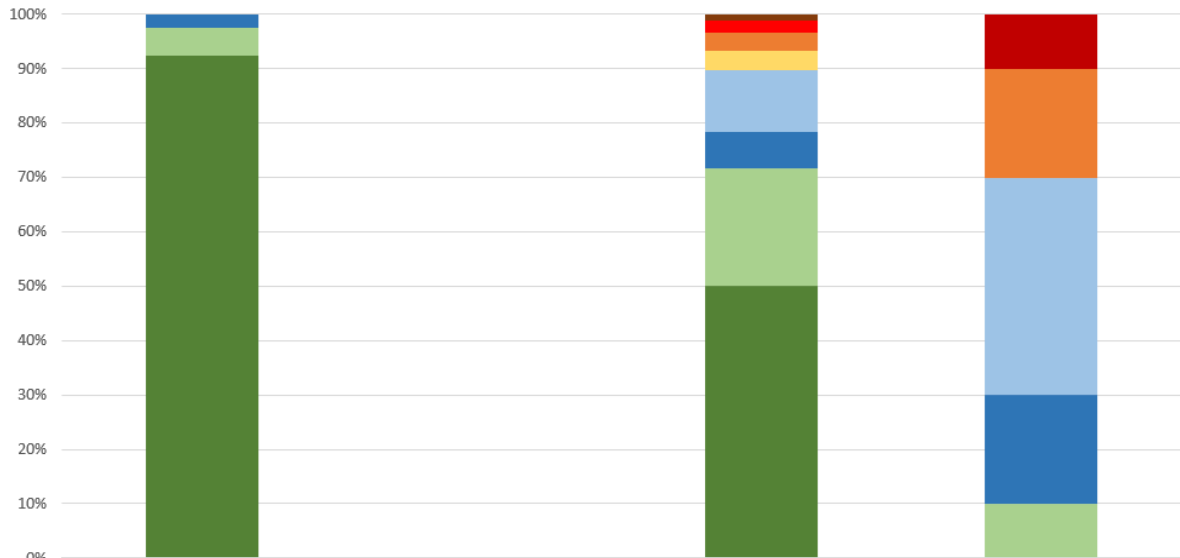
As every type of joint has been shown to have some level of leaking, ways to mitigate section loss at a leaking beam end is then needed. Painting the beam ends is the most common solution that could help to eliminate section loss experienced caused by leaking on beam ends. As 98% of structures without leaking do not have any section loss, those were excluded from this section. Figure 16 shows the amount of maximum beam end section loss based on whether the beam ends are painted. Of the 12 leaking beam ends with evidence of leaking that are painted, none exhibit any rusting. Figure 17 shows that painting of the beam ends, particularly before any corrosion is noted, is a relatively recent practice that began 16 years ago. This may be part of the reason that no meaningful section loss is noted as they have not had the same length of exposure. Only two structures of the 60 that are less than 20 years old have measurable section loss at beam ends.



	<10 years	10-20 years	20-30 years	30-40 years	40-50 years	50+ years
Beam Ends Not Painted	55%	82%	100%	90%	86%	100%
Beam Ends Painted after Corrosion	0%	0%	0%	10%	14%	0%
Beam Ends Painted	45%	18%	0%	0%	0%	0%
Number:	49	11	15	31	28	4

Figure 17. Proportion of Beam Ends Painted Based on Age

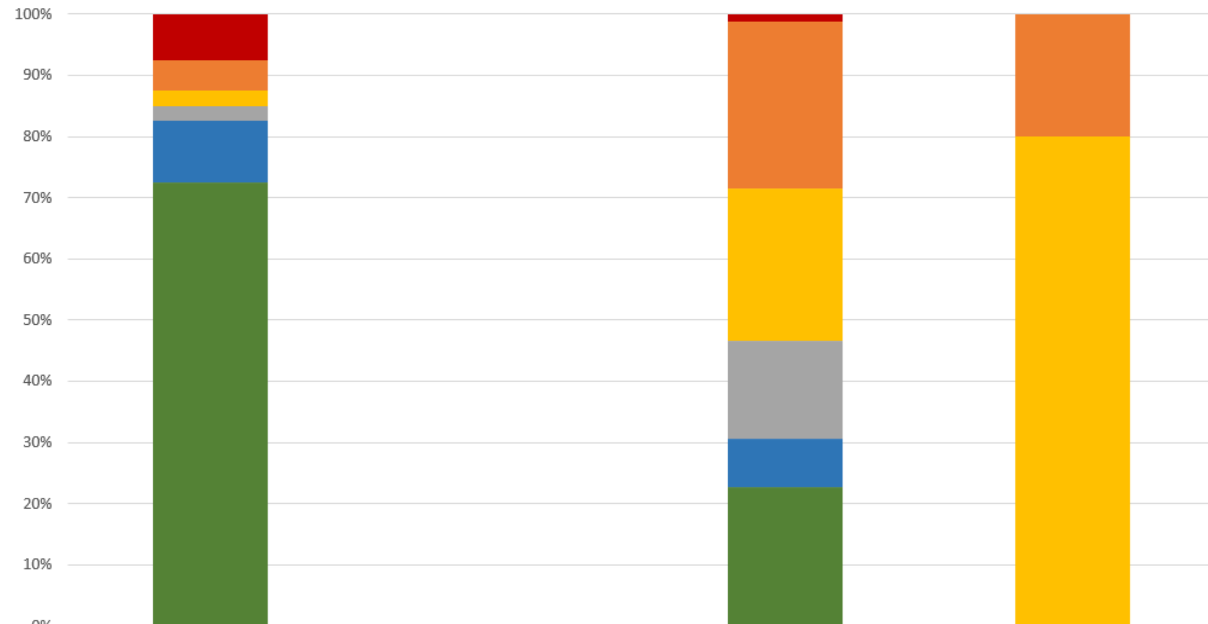
4.3 SUPERSTRUCTURE SHAPE



	I Shape Without Leaking	Box Shape Without Leaking	I Shape With Leaking	Box Shape With Leaking
1/2"	0%	0%	0%	10%
3/8"	0%	0%	1%	0%
5/16"	0%	0%	2%	0%
1/4"	0%	0%	3%	20%
3/16"	0%	0%	3%	0%
1/8"	0%	0%	11%	40%
1/16"	3%	0%	7%	20%
Negligable	5%	0%	22%	10%
None	93%	0%	50%	0%
Number:	40	0	88	10

Figure 18. Maximum Superstructure Section Loss Compared to Superstructure Type and Leaking Noted

There were two major types of superstructures, I-shaped and box girders. Figure 18 shows the proportion of maximum section loss in the structure separated by I- and box-shapes with and without leaking. Only ten of the structures were box-shaped, and all experienced leaking. They also experienced more section loss when compared to I-shaped, 0.163 inch compared to 0.045 inch, when leaking was present. Many of the inspection reports for the box girders note standing water within the structures, particularly in beam ends, which may be the cause of the larger average section loss. However, the use of weathering steel box-shaped superstructures has fallen out of favor for I-shaped ones, with the most recent structure being 33 years old, as can be seen in Figure 19.

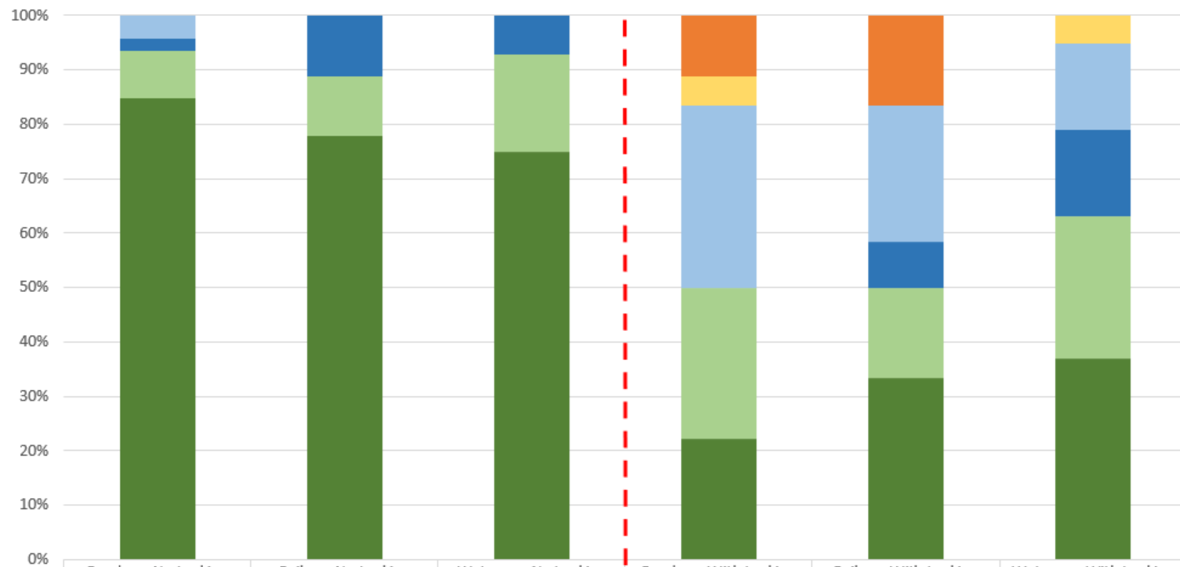


	I Shape Without Leaking	Box Shape Without Leaking	I Shape With Leaking	Box Shape With Leaking
50+	8%	0%	1%	0%
40-50	5%	0%	27%	20%
30-40	3%	0%	25%	80%
20-30	3%	0%	16%	0%
10-20	10%	0%	8%	0%
<10	73%	0%	23%	0%
Number:	40	0	88	10

Figure 19. Age of Structures Separated into Superstructure Type and Leaking Condition

4.4 FEATURE CROSSED

The structures were recorded as what feature they were crossing: roadway, railway, and/or waterway. If a structure were to cross multiple features, then they were recorded as crossing each. Figure 20 presents the maximum in-span section loss in the structure separated into type of feature crossed and whether there is noted in-span leaking within the structure. In the structures not experiencing leaking, 75% or more of structures crossing show no corrosion. The average loss for each of these passages are all less than 0.007 inch. For those structures experiencing leaking, the level of maximum section loss is significantly higher, with the average maximum section loss being 0.080 inch for those crossing roadways, 0.078 inch for those crossing a railway, and 0.039 inch for those crossing a waterway. This suggests that traffic below the structure, whether that is roadway or railway, does seem to accelerate the rate of corrosion in a structure when coupled with leaking from the structure itself. This section investigates each of the three crossing types to see if correlations can be found to help identify accelerants to section loss.



	Roadway No Leaking	Railway No Leaking	Waterway No Leaking	Roadway With Leaking	Railway With Leaking	Waterway With Leaking
1/2"	0%	0%	0%	0%	0%	0%
3/8"	0%	0%	0%	0%	0%	0%
5/16"	0%	0%	0%	0%	0%	0%
1/4"	0%	0%	0%	11%	17%	0%
3/16"	0%	0%	0%	6%	0%	5%
1/8"	4%	0%	0%	33%	25%	16%
1/16"	2%	11%	7%	0%	8%	16%
Negligable	9%	11%	18%	28%	17%	26%
None	85%	78%	75%	22%	33%	37%
Number:	46	36	28	18	12	19

Figure 20. Maximum Section Loss in the Structure Compared to Feature Crossed

4.4.1 Bridges over Roadways

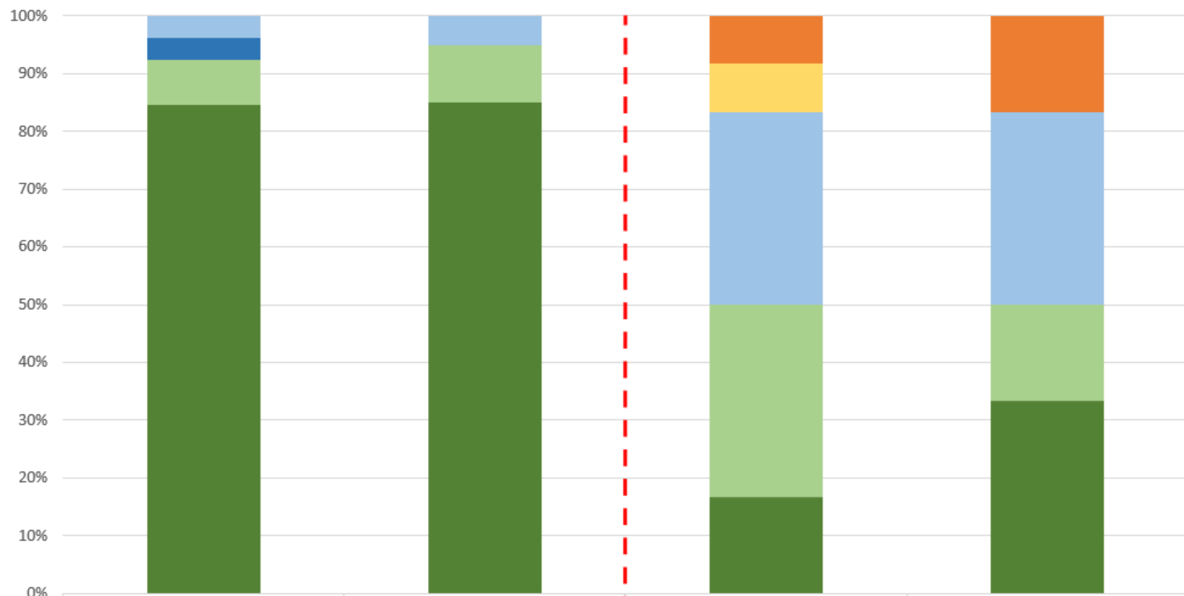
One of the potential causes of section loss in structures crossing roadways is the spray from passing trucks carrying moisture and chlorides from the roadway below. To investigate this, there are two variables that were investigated: Average Daily Truck Traffic (ADTT) and the clearance below the structure. The two variables were divided into structures experiencing leaking and those not experiencing leaking.

4.4.1.1 ADTT

ADTT was calculated based on the Average Daily Traffic (ADT) and the percentage of trucks included. If the inspection report did not include either an ADT, then the ADTT is assumed to be 0. The overall average of ADTT between all the roadways crossed is 4,935 vehicles per day. This section considers 5,000 vehicles per day as a dividing ADTT between low and high ADTT.
Figure 21 shows the proportion of structures experiencing section loss divided by ADTT and whether there is any noted in-span leaking. For structures not experiencing leaking, the average

section loss for structures crossing low ADTT roadways is 0.007 inch, and 0.006 inch for structures crossing high ADTT roadways. In structures experiencing mid-span leaking, the average section loss for structures crossing low ADTT roadways is 0.078 inch, and 0.083 inch for structures crossing high ADTT roadways. The overall average of maximum in-span section loss regardless of leaking status is for structures crossing low ADTT roadways is 0.030 inch, and 0.024 inch for structures crossing high ADTT roadways.

Based on these values, there is no strong evidence of correlation between the ADTT below the structure with the maximum in-span section loss. Those structures without in-span leaking noted are thought to be more indicative, as the lack of leaking within the structure leads to no direct cause of section loss. However, the section loss in structures without section loss in Figure 21 show no clear difference between section loss and the ADTT below the structure.

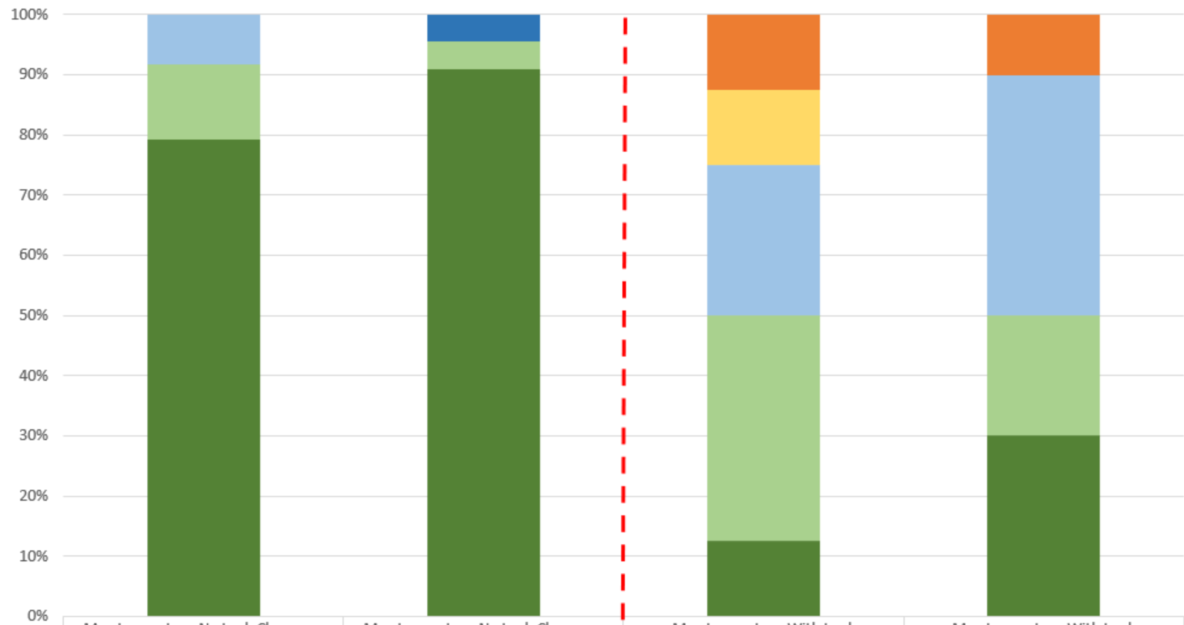


	Max in-span loss no leaking ADTT <=5,000	Max in-span loss no leaking ADTT >5,000	Max in-span loss with leaking ADTT <=5,000	Max in-span loss with leaking ADTT >5,000
1/4"	0%	0%	8%	17%
3/16"	0%	0%	8%	0%
1/8"	4%	5%	33%	33%
1/16"	4%	0%	0%	0%
Negligable	8%	10%	33%	17%
None	85%	85%	17%	33%
Number:	26	20	12	6

Figure 21. Maximum In-Span Section Loss Based on ADTT Below the Structure

4.4.1.2 Clearance

The clearance below the structure is also a potential source of section loss, as it can be closer to the salt spray from vehicles below. Of the structures, clearance to roadways below varied between 14.67 ft and 41 ft, with an average 17.3 ft. Figure 22 divides the bridges into high and low clearance to roadways below around 16.5 ft, and whether there is leaking in the structure. Like with ADTT, there is no real evidence of correlation between clearance over roadways and maximum in span section loss.



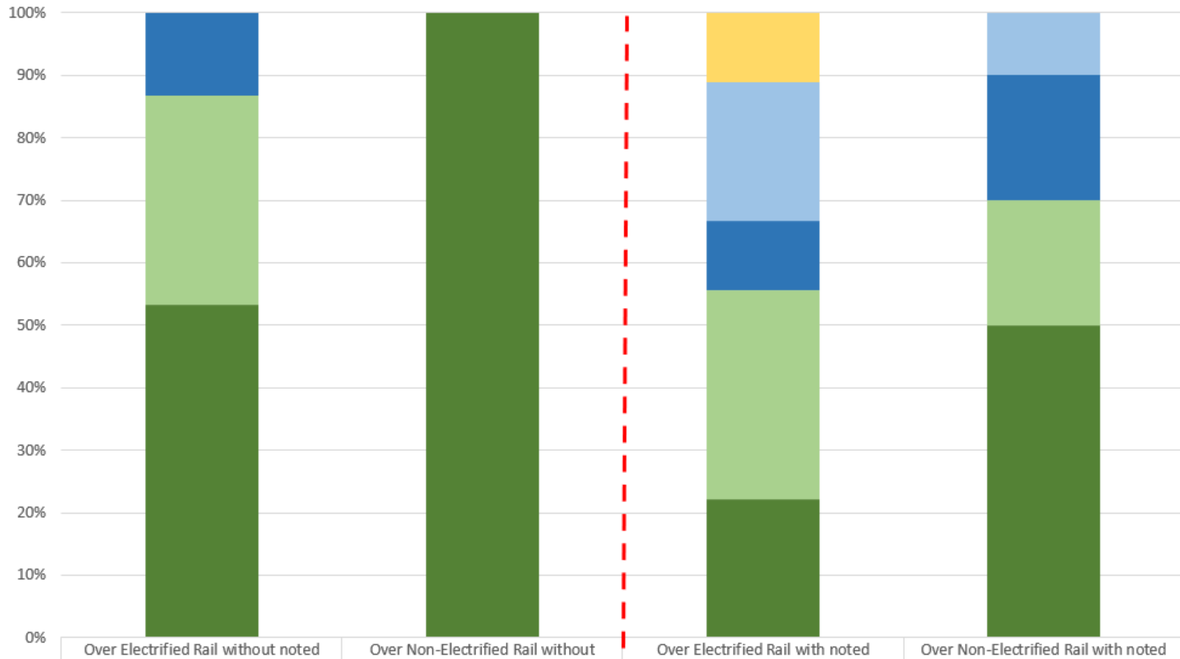
	Max Inspan Loss No Leak Clearance <= 16.5 ft	Max Inspan Loss No Leak Clearance > 16.5 ft	Max Inspan Loss With Leak Clearance <= 16.5 ft	Max Inspan Loss With Leak Clearance > 16.5 ft
1/4"	0%	0%	13%	10%
3/16"	0%	0%	13%	0%
1/8"	8%	0%	25%	40%
1/16"	0%	5%	0%	0%
Negligable	13%	5%	38%	20%
None	79%	91%	13%	30%
Number:	24	22	8	10

Figure 22. Maximum In-Span Section Loss Compared to Clearance Below the Structure

4.4.2 Bridges over Rail

A potential source of section loss in structures crossing railways occurs when the railway below the structure is electrified. To investigate this, structures crossing electrified and non-electrified rail were separated to determine if there are any differences in the level of section loss. Structures crossing Metro North Railroad (MNRR) were also be separated due to the higher volume of rail traffic carried. They were be divided into structures experiencing leaking and those not experiencing leaking. As with structures over roadways, clearance below the structure were also be investigated.

4.4.2.1 Electrification



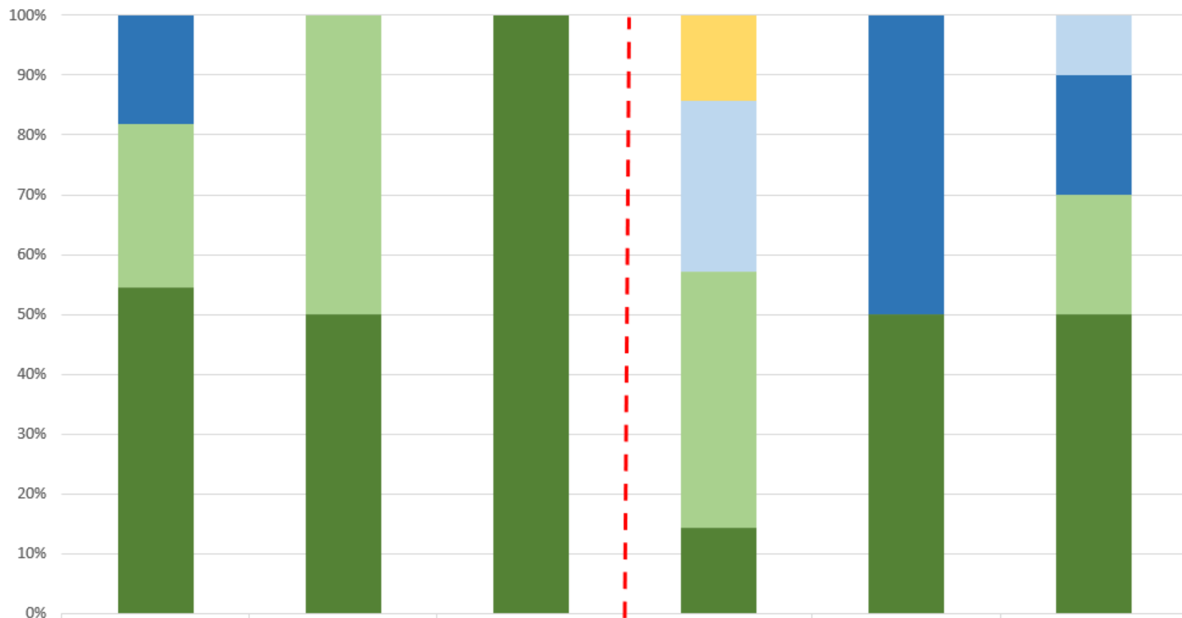
	Over Electrified Rail without noted leaking	Over Non-Electrified Rail without noted leaking	Over Electrified Rail with noted leaking	Over Non-Electrified Rail with noted leaking
3/16"	0%	0%	11%	0%
1/8"	0%	0%	22%	10%
1/16"	13%	0%	11%	20%
Negligable	33%	0%	33%	20%
None	53%	100%	22%	50%
Number:	15	13	9	10

Figure 23. Maximum In-Span Section Loss Compared to Electrification of the Railway Below

Figure 23 shows the maximum in-span section loss for structures crossing a railway divided by whether the railway was electrified or not. In both structures with and without leaking, there is a marked difference between structures both with and without leaking. In structures without leaking, there was no corrosion experienced in any structure over a non-electrified rail, while those over electrified rails have an average of 0.008 inch. When considering those structures with in-span leaking, structures crossing non-electrified rail experiences an average of 0.025 inches, while those over electrified rail experience an average of 0.056 inch of section loss.

While the 0.008 inch of section loss experienced in non-leaking electrified rails is not extremely high, the fact that the observed section loss over electrified rail is greater than that over non-electrified rail for both structures with and without leaking strongly suggest that there is a correlation to section loss caused by electrification of the rail below the structure. In fact, some inspection reports even note potential signs of arcing (Bridge No. 05923) [5] and corrosion around grounding wires (Bridge No. 03836) [6].

4.4.2.2 Metro North Railroad



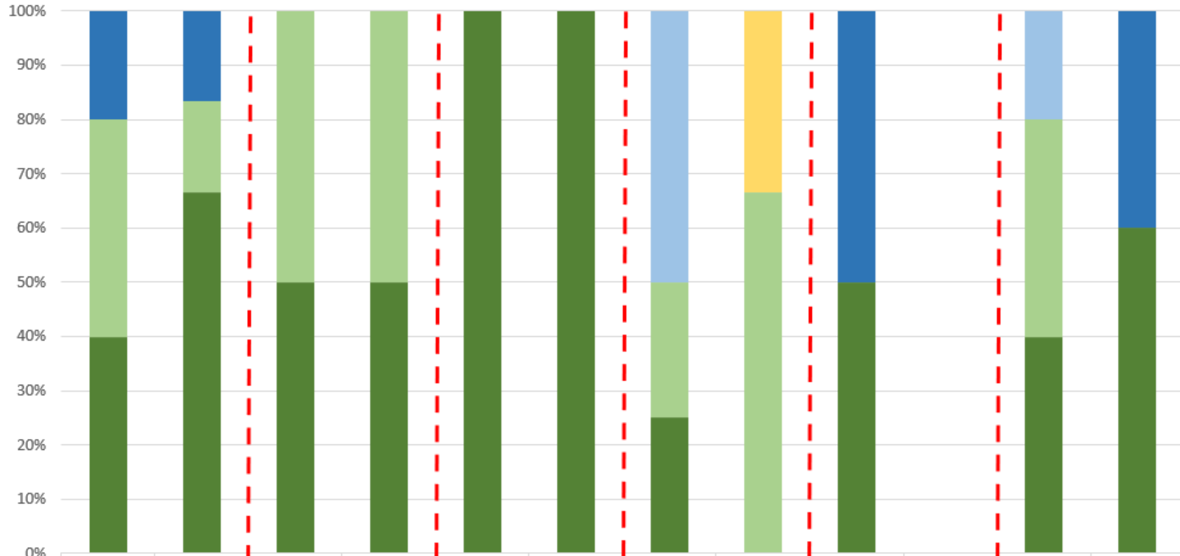
	MNRR without Leaking	Electrified Rail without Leaking	Non-Electrified without Leaking	MNRR with Leaking	Electrified Rail with Leaking	Non-Electrified with Leaking
1/4"	0%	0%	0%	0%	0%	0%
3/16"	0%	0%	0%	14%	0%	0%
1/8"	0%	0%	0%	29%	0%	10%
1/16"	18%	0%	0%	0%	50%	20%
Negligable	27%	50%	0%	43%	0%	20%
None	55%	50%	100%	14%	50%	50%
Number:	11	4	13	7	2	10

Figure 24. Maximum In-Span Section Loss Compared to Electrification of the Railway Below with Crossings over MNRR Extracted

When structures crossing the MNRR is extracted from the other electrified rail lines, all of those experiencing in-span section loss without leaking are over MNRR, as seen in Figure 24. In structures not experiencing leaking, structures crossing MNRR are the only ones with measurable mid-span section loss, while those crossing non MNRR electrified rail only show evidence of corrosion beginning in 50% of structures. This suggests that in addition to electrification affecting the corrosion of the structure, the frequency of trains below the structure also increases observed corrosion.

4.4.2.3 Clearance

When comparing the clearance below structures crossing railways, the average clearance below the structure is 20.7 ft. A division is made at 21 ft in Figure 25 when comparing structures with low and high clearance. When comparing these structures, there is some evidence that lower clearance does tend to have slightly more section loss. Between all three types of rail types crossed, those with clearances less than 21 ft had an average of 0.005 inch without leaking, and 0.040 inch for those with leaking. This compares to an average of 0.004 inch without leaking, and 0.039 inch for those with leaking with clearances over 21 ft.

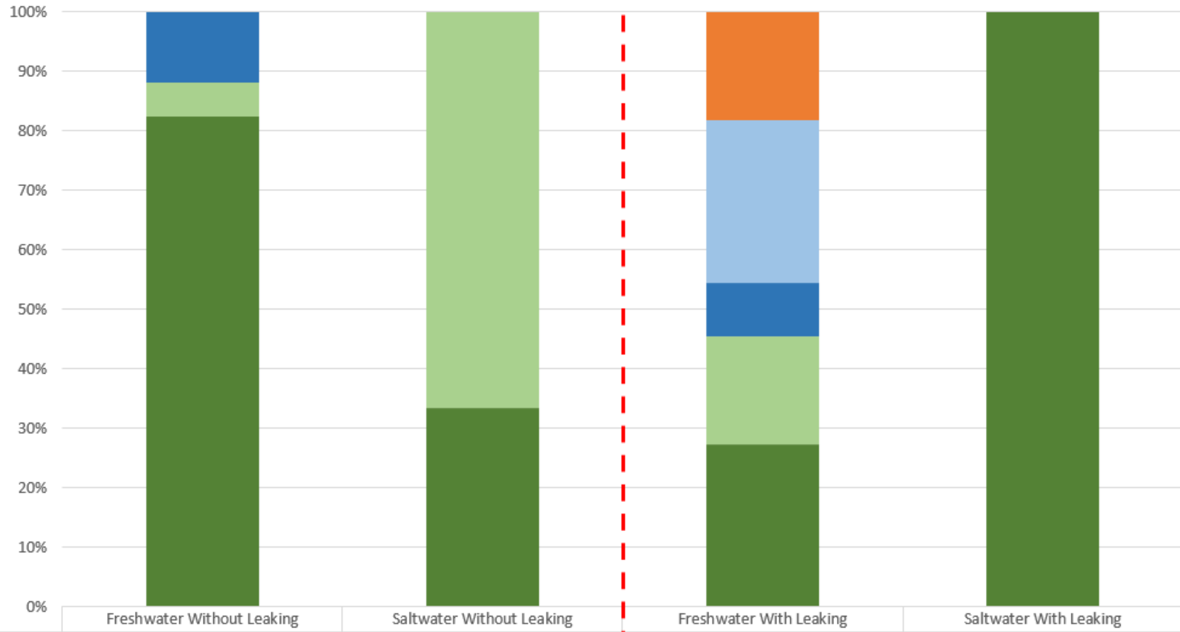


	MNRR without Leaking <=21 ft	MNRR without Leaking >21 ft	Electrified Rail without Leaking <=21 ft	Electrified Rail without Leaking >21 ft	Non-Electrified without Leaking <=21 ft	Non-Electrified without Leaking >21 ft	MNRR with Leaking <=21 ft	MNRR with Leaking >21 ft	Electrified Rail with Leaking <=21 ft	Electrified Rail with Leaking >21 ft	Non-Electrified with Leaking <=21 ft	Non-Electrified with Leaking >21 ft
1/4"	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
3/16"	0%	0%	0%	0%	0%	0%	0%	33%	0%	0%	0%	0%
1/8"	0%	0%	0%	0%	0%	0%	50%	0%	0%	0%	20%	0%
1/16"	20%	17%	0%	0%	0%	0%	0%	0%	50%	0%	0%	40%
Negligable	40%	17%	50%	50%	0%	0%	25%	67%	0%	0%	40%	0%
None	40%	67%	50%	50%	100%	100%	25%	0%	50%	0%	40%	60%
Number:	5	6	2	2	5	8	4	3	2	0	5	5

Figure 25. Maximum In-Span Section Loss Compared to Clearance over Types of Rail Crossing with and without In-Span Leaking

4.4.3 Bridges over Water

For those structures crossing bodies of water, the following two variables were considered in the evaluation of section loss: whether the body of water that is crossed is salt or fresh water, and the clearance below the structure. Unfortunately, of the 49 structures crossing bodies of water, only four of these are over salt or brackish water. Therefore, there is not sufficient evidence to determine whether crossing salt water has an appreciable effect on section loss. Figure 26 shows the section loss in structures crossing freshwater and saltwater.

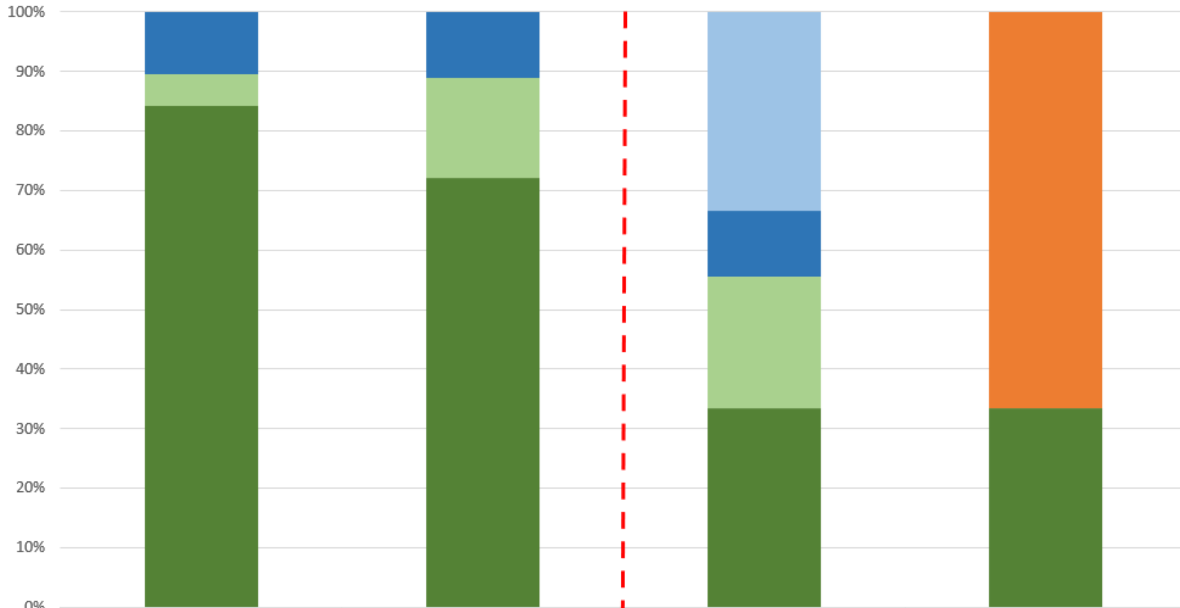


	Freshwater Without Leaking	Saltwater Without Leaking	Freshwater With Leaking	Saltwater With Leaking
5/16"	0%	0%	0%	0%
1/4"	0%	0%	18%	0%
3/16"	0%	0%	0%	0%
1/8"	0%	0%	27%	0%
1/16"	12%	0%	9%	0%
Negligable	6%	67%	18%	0%
None	82%	33%	27%	100%
Number:	34	3	11	1

Figure 26. Section Loss in Structures Crossing Saltwater and Freshwater Bodies

4.4.3.1 Clearance

For structures crossing bodies of water, the average clearance below the structure is 19.6 ft. Figure 27 uses 20 ft in dividing structures with low and high clearance over bodies of water. Based on the data shown, there does not seem to be a significant link between the clearance below structures to the bodies of water being crossed and section loss.



	Without Leaking <= 20 ft	Without Leaking > 20 ft	With Leaking <= 20 ft	With Leaking >20 ft
5/16"	0%	0%	0%	0%
1/4"	0%	0%	0%	67%
3/16"	0%	0%	0%	0%
1/8"	0%	0%	33%	0%
1/16"	11%	11%	11%	0%
Negligable	5%	17%	22%	0%
None	84%	72%	33%	33%
Number:	19	18	9	3

Figure 27. Maximum In-Span Section Loss in Structures Crossing Bodies of Water Divided by Clearance Below Structure

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Based on the data, the following can be said to benefit structural performance of unpainted weathering steel beams:

- Leaking occurs in over 90% of structures over 20 years old. Those structures over 30 years old with leaking have an average section loss of 0.093 inch or greater. There are two noted sources of leaking:
    - Leaking deck expansion joints
    - Deck weepholes
- Beam end detailing utilizing either an integral abutment, a concrete end diaphragm, or extending the deck to the back of the backwall have been shown to have less evidence of leaking and a significantly lower level of section loss when compared to beam end details

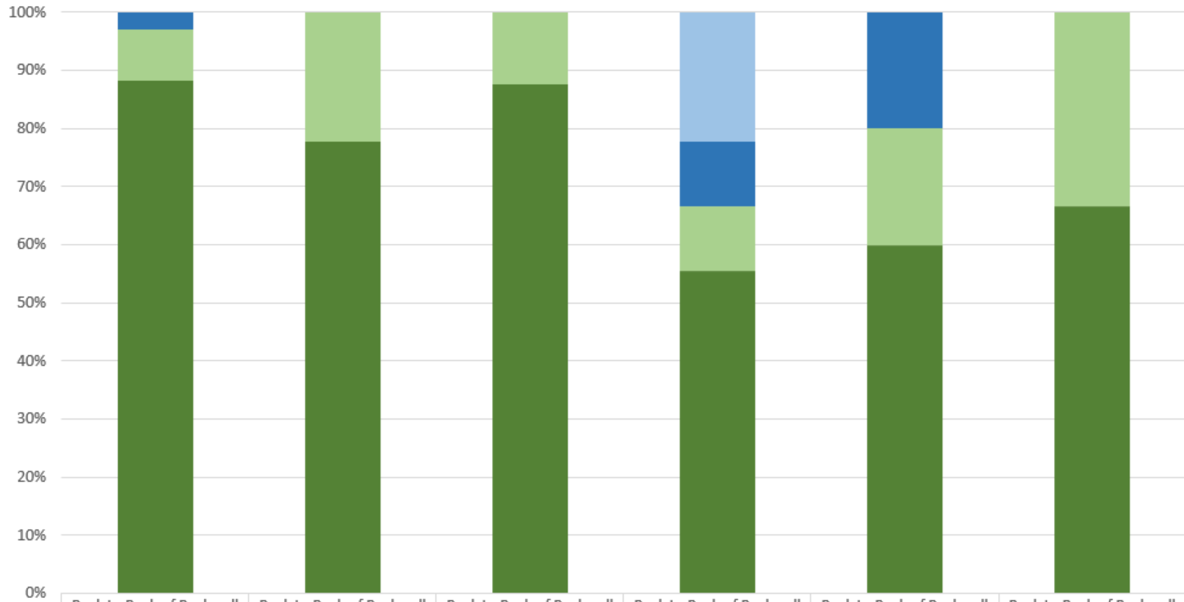
terminating on a flat backwall or in front of the backwall.

- There is no evidence of corrosion when beam ends are paint initially painted.
- In-span leaking onto a structure shows a marked increase in section loss.
- Box beam structures tend to pond water compared to I shapes and show a higher level of section loss.
- There is some evidence that structures with traffic below the structure, either road or rail, have slightly higher level of section loss when compared with those crossing waterways.
- There was no clear link between either ADTT or clearance below structures in structures crossing roadways.
- Concerning structures crossing railroads, there is evidence that electrification, traffic volume, and low structural clearance increase the section loss experienced in the structure
- There were not enough structures crossing saltwater bodies to draw any conclusions on water composition on superstructure section loss

5.2 RECOMMENDATIONS

Some recommendations based on these findings are as follows:

- The current practices being used for weathering steel structures seem to support the findings of this report. As virtually all the structures showing significant end corrosion are over 30 years old and have end of deck details that are not recommended by the current set of guidelines. We see no need to curtail the use of weathering steel, provided that the current practices are followed. There does not appear to be a basis for changing the current practice for bridge overpasses.
- The FHWA guidelines came out in 1989, prior to this there were 17 structures that met the detailing requirements. Figure 28 shows the section loss in these structures by age. The maximum section loss utilizing the details in these guidelines was found to be 1/8 inch. Additional thickness may be provided to account for this and may need to be increased for structures crossing electrified rail. Increased thickness should only apply to critical sections at critical locations. For instance, increasing flange thickness at the bearing does nothing to increase capacity.
- If the beam ends are not painted initially, then they should be painted when leaking is noted in abutment joints.
- The beam ends of structures utilizing the slab to back of backwall should be painted, as 64% of structures with the detail exhibit leaking, and no structures with their beam ends initially painted exhibit section loss.



	Back to Back of Backwall and Integral Details <10 yr	Back to Back of Backwall and Integral Details 10-20 yr	Back to Back of Backwall and Integral Details 20-30 yr	Back to Back of Backwall and Integral Details 30-40 yr	Back to Back of Backwall and Integral Details 40-50 yr	Back to Back of Backwall and Integral Details 50+ yr
1/4"	0%	0%	0%	0%	0%	0%
3/16"	0%	0%	0%	0%	0%	0%
1/8"	0%	0%	0%	22%	0%	0%
1/16"	3%	0%	0%	11%	20%	0%
Negligable	9%	22%	13%	11%	20%	33%
None	88%	78%	88%	56%	60%	67%
Number:	34	9	8	9	5	3

Figure 28. Section Loss in Structures with Detailing Consistent with Current CTDOT Guidelines

6.0 REFERENCES

[1] Connecticut Department of Transportation, "Bridge Design Manual Division 1 - Standard Design Practices and Procedures," CTDOT, Hartford, 2019.

[2] Federal Highway Administration, "Technical Advisory T5140.22 - "Uncoated Weathering Steel in Structures"," FHWA, Washington DC, 1989.

[3] Team 5, "Routine Inspection Report for Bridge No. 01077 - Route 70 over Broad Brook in Cheshire, CT," CTDOT, Hartford, 2/24/2020.

[4] Garg Engineering, "Routine Inspection for Bridge No. 05241 - SR 847 (Thomaston Ave) over Naugatuck Railroad in Waterbury, CT," CTDOT, Hartford, 8/28/2020.

[5] Prime AE, "Routine Inspection for Bridge No. 05923 Ingham Hill Rd over Amtrak Railroad," CTDOT, Routine, 2/24/2020.

[6] Prime AE, "Routine Inspection for Bridge No. 03836 - US Route 1 over Amtrak Railroad," CTDOT, Routine, 2/19/2020.

CHA