RESEARCH SUMMARY

REVIEW OF WEATHERING STEEL GUARDRAIL FOR CALIFORNIA HIGHWAYS

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1. Introduction

1.1. Problem

The Tahoe Regional Planning Agency (TRPA) requested that the guardrail used in the Tahoe area blend into the surrounding landscape more than the standard guardrail used by Caltrans, which is typically galvanized steel. This galvanized guardrail turns a dull gray with age, but is shiny with new construction or when scratched[1]. Another option was to use coated steel, but repairs to this type of product proved to be expensive and difficult to match. TRPA was concerned that using either of these options would detract from the scenic views that many tourists (and locals) expect when traveling through the Tahoe area. They wanted Weathering Steel Guardrail (WSGR) to be used in the Tahoe Basin, but current State policy states that it cannot be used in areas with 8 inches or more of rain annually[2].

Figure 1 - Galvanized Steel Guardrail

Figure 2 - Weathering Steel Guardrail

Figure 3 - Weathering Steel Guardrail

Weathering Steel Guardrail has been considered aesthetically pleasing to local agencies and the public because of a naturally forming patina (brown) layer of oxidation that forms on the exposed surface. This patina layer, which will protect the underlying steel, is developed through a wetting and drying process which happens when left outside. The patina will act to protect the steel so long as the concentration of chemical corrosives is kept low. If the weathering steel has any confined spaces (spaces which do not readily allow for rinsing of the surface), an effect known as "crevice corrosion" can occur. As a crevice dries, the concentration of corrosives goes up, increasing the oxidation of the steel inside the crevice.

Metal beam guardrail has crevices at the lap splice and the blockout connections, making it very susceptible to crevice corrosion when the environment is right. Rain, snow, dirt, mud, pollution, sun, shade, and temperature each have an effect on the rate of the corrosion and the potential life span of a particular installation. However, since it is not feasible to study how each environmental factor might affect the corrosive process, use of weathering steel should be based on past applications in a similar environment.

To meet TRPA's request, locations where weathering steel was used in an environment similar to that of the Tahoe region could be identified. Samples of weathering steel from these locations could be tested to discover the extent of strength lost due to corrosion. At the same time different coating and inserts at the connections could be tested in an environmental chamber to see if failure at the joints can be prevented or the working life prolonged.

1.2. Objective

Determine if weathering steel's working life can be prolonged with the use of an insert or coating at the joints. Once that is known a new policy can be created and it will be known as to what extent TRPA's request can be attained.

1.3. Background

Weathering steel for guardrail is specified as ASTM A606 Type 043. This type of steel is also used in structural elements like bridge girders under the ASTM specification A588. It is commonly referred to as "corten", which is actually a brand name. Weathering steel guardrail is also called "rust rail" since the steel is allowed to rust.

The benefit of using this type of steel is that it can be left bare in the environment with no protective coatings. Under proper environmental conditions and appropriate design details, the surface of the steel will oxidize to a certain extent and form a tightly adherent film that protects the steel from further atmospheric corrosion. Wetting and drying of the surface is required for this protective film or patina to form completely and then stop corroding. If the surface remains wet for significant time periods, the steel will continue to corrode. In salty climates, particularly those close to the ocean, corrosion is continual. If rainfall is too high or the area has a high humidity, a spotty, non-protective oxide film that promotes pitting could be formed. The corrosion rate is increased in these locations and the strength of the material is reduced. This is due to the steel not drying completely preventing the oxide film from developing. In the case of w-beam rails, the lap splice is especially susceptible to moisture retention and incomplete rinsing of corrosives for long periods of time.

1.4. Literature Search

The following includes Federal Highway Administration's policy on weathering steel w-beam guardrail. In addition, the Departments of Transportation (DOT) for both New Hampshire and North Carolina have conducted similar weathering steel guardrail research over the last ten years. These Departments came to different conclusions.

1.4.1. Federal Highway Administration's Weathering Steel W-Beam Guardrail Policy

> "The use of weathering steel (sometimes called Cor-Ten, A-588, or rusting steel) in guardrails should be limited. Because roadside barriers are usually close enough to the path of travel that they might be sprayed with water from passing vehicles, chemicals

found in the water spray can affect and degrade the structural integrity of weathering steel barriers. If weathering steel is desired for aesthetic purposes, agencies should adopt a frequent inspection and replacement schedule. It may continue to be used on the backside of steel backed timber rail."[4]

1.4.2. New Hampshire

On October 23, 2009 Mike Hazlett, a Senior Engineer with the New Hampshire Department of Transportation (NHDOT), replied to an inquiry about New Hampshire's decision to stop using weathering steel guardrail. Mr. Hazlett stated that he had been with the NHDOT for approximately 33 years and had been involved in roadside barrier design and its evolution for almost the entire time. In his reply he stated that "this rail deteriorates at such a rapid rate that it does not fulfill its primary role without excessive maintenance/replacement, particularly at a time where fiscal constraints are exceedingly tight. Without this intensive maintenance/replacement commitment, this rail all too quickly moves from being a physical barrier to a visual barrier as far as effect on errant vehicles."

Other key elements of New Hampshire's experience with WSGR are given below:

- They have had the rail deteriorate not only at the joints but also along the length of the beam. Figure **4** - Figure **6** show an installation on NH I-93 that is over ten years old.

Figure 4 - Weathering Steel Guardrail on New Hampshire's I-93

Figure 5 - Weathering Steel Guardrail on New Hampshire's I-93

Figure 6 - Weathering Steel Guardrail on New Hampshire's I-93

- New Hampshire conducted a Salt Fog Chamber test to see if they could prolong the joint life of WSGR. They used Zinc inserts, Procyon Corrosion Inhibitor, Fibered Roof Coasting, Royston Tac Tape, Zinc Hyogel Anode inserts, MC Miozinc, and M45-M46 Epoxy Mastic Coating to protect the inside of the guardrail joints from corrosion. The results of the test showed that the majority of the inserts and coatings provided some protection but the Zinc inserts appeared to provide the greatest protection.
- New Hampshire conducted a weathering steel guardrail condition survey at six different locations. Random thickness measurements were taken, the age of the guardrail was established, and the condition was compared to galvanized rail of the same age. Their results showed that weathering steel guardrail that had been in service for 10 to 15 years had a failure rate of 25% at the mid-span and a 50% failure rate at the lap connections. Also, weathering steel guardrail that had been in service for 15 to 20 years had a failure rate of 25% at the mid-span and a 71% failure rate at the lap connections. With a failure defined as 10% or more section loss. Galvanized steel guardrail exposed to the same environments and equal number of years in service showed no decrease from the original dimensions and that the galvanized rail became less shiny and had a more environmentally blending appearance over time.

New Hampshire is no longer using weathering steel guardrail. (Illinois has also stopped using weathering steel guardrail.)

1.4.3. North Carolina

In the document "Performance of Weathering Steel Guardrail in NC" the North Carolina Department of Transportation (NCDOT) gives their reasons for keeping weathering steel guardrail on their highway system. NCDOT compares themselves to New Hampshire, conducted research at 25 sites testing the minimum thickness of the WSGR, and also compared injury collision percentage of WSGR to GSGR. The researchers also conducted a survey of other transportation agencies throughout the United States.

North Carolina's experience with WSGR is given below:

- Structural analysis conducted by North Carolina on existing WSGR installations found no evidence the thickness of the WSGR had deteriorated below AASHTO's minimum thickness specification. The researchers also found no trends of deterioration thickness as a function of guardrail age, elevation, and the annual average daily traffic (AADT) data.
- Only 36 state transportation agencies responded to NC survey, of the 36 agencies only 21 had installation of weathering steel guardrail in their jurisdictions. The survey findings include:
    - Many states responded that they allow the use of WSGR in specialized areas only, particularly natural areas.
    - Three states responded that they have used WSGR in the past but have discontinued its use because of concerns over its structural integrity, cost, or availability.
    - Use of WSGR in an area requires stockpiling extra guardrail to replace damaged sections. If WSGR isn't available to replace a damaged section of existing WSGR, the replacement with GSGR section can be less than ideal from an aesthetics perspective.

- Several respondents noted that they have no concerns with WSGR beyond what is expected of any guardrail (environmental conditions and frequency of deicing chemical use affects all types of guardrail). The expected design lifespan of WSGR installations are being exceeded in numerous states.
- The hardware (nuts and bolts) are difficult to remove when replacing damaged sections, which makes repairs more time consuming and expensive.
- Alternative types of guardrail to replace WSGR reported by respondents include: painted guardrail, stained GSGR, polyester coated GSGR, powder coated, acid washed GSGR, steel-backed timber guardrail, stainless steel or galvanized steel tube railing with reinforced concrete base, stained concrete, concrete with encouragement of lichen growth, and stone columns.

Overall their research suggests no structural concerns with regard to using WSGR in North Carolina.[5]

1.5. Scope

This research consists of two parts that would be conducted at the same time. One part would consist of collecting guardrail joints from guardrail installations around the state in different environments. Sample collection would start in the Lake Tahoe area. The guardrail joints would be tensile tested once they had been collected to see if there had been any loss of strength due to its exposure to the environment in the area that it was taken.

Part two would be to insert a number of guardrail joint assemblies into a salt fog chamber for a year. There would be two lengths of guardrail placed in the chamber. One size would be disassembled after its exposure to see how much of the guardrail thickness was lost due to corrosion. The other size would be tensile tested to see how much strength was lost due to corrosion. Along with the different sizes some of the joints will have a zinc foil or galvanized steel guardrail insert inside of the joint. The purpose of these inserts is to see if the joint can be protected from corrosion in the joint due to crevice corrosion and extend the working life of WSGR.

In an effort to make it easier for maintenance crews to disassemble WSGR joints a number of the bolts used in some of the WSGR joints will be coated with Geomet 500B. Geomet 500 is the brand name of a metal coating that protects against corrosion. The B stands for the grade of the coating and means that Geomet 500 is applied in three coats. Typically weathering steel bolts are used to assemble WSGR. When the protective patina develops on the WSGR it also develops on the threads of the nuts of the bolts. This often prevents the bolts from being disassembled without cutting the bolts, requiring them to be replaced with new bolts. It is the hope that the Geomet 500B coating would allow the bolts to be disassembled without having to cut them.

2. Research History

2.1. Tensile Testing Field Samples

It was more difficult to find test samples on California's highways than it was initially thought. This is probably due to Caltrans policy of requiring that WSGR only be used in areas with less than 8 inches of rain per year and that existing installations be repaired with galvanized parts. When samples were found it was difficult to have maintenance crews collect the samples due to limited resources as well as differing priorities. Also, maintenance crews wanted to only collect samples during the wet season because they have to use a cutting torch to cut the bolts that hold the guardrail to the post. After a year and a half only three samples were collected.

Each sample was six feet long and had the joint at the mid-point and came from a similar environmental area. The samples showed no visual signs of thickness loss due to corrosion. Due to the small number of samples and their visual appearance it was deemed that tensile testing the samples would not produce enough statistical data to reach a conclusion. Therefore there was no tensile testing conducted. Ultimately, the samples were sent to the Texas A&M Transportation Institute (TTI) to assist in research on developing Report Number 405160-29 "In-Field Inspection Methodology for Weathering Steel W-Beam Guardrail".

2.2. Salt-Fog Corrosion Chamber Test

The Caltrans Corrosion unit built a salt fog chamber that used a 3.5% by mass salt water solution. Four times a day the solution was sprayed on the samples for a minute. Six times a day fans were turned on for one hour to help the samples dry faster. Twice a day distilled water was sprayed on the samples for two minutes to rinse the samples off and keep the salt concentration levels down. The following table shows the daily schedule of the salt fog cycle. The samples were in the chamber for a year.

Table 1 - Daily Salt Fog Chamber Cycle

Process	Time On	Time Off	Duration
Fan	1:00am	2:00am	One Hour
Salt Water	3:00am	3:01am	One Minute
Fan	5:00am	6:00am	One Hour
Salt Water	7:00am	7:01am	One Minute
Fan	9:00am	10:00am	One Hour
Distilled Water	11:00am	11:02am	Two Minutes
Fan	1:00pm	2:00pm	One Hour
Salt Water	3:00pm	3:01pm	One Minute
Fan	5:00pm	6:00pm	One Hour
Salt Water	7:00pm	7:01pm	One Minute
Fan	9:00pm	10:00pm	One Hour
Distilled Water	11:00pm	11:02pm	Two Minutes

Eight 15-inch samples were placed in the salt fog chamber. There were four control samples, two were galvanized steel guardrail with galvanized bolts and the other two were weathering steel guardrail with weathering steel bolts. The other four samples were as follows:

- Weathering steel guardrail with a galvanized steel guardrail insert and weathering steel bolts,
- Weathering steel guardrail with a galvanized steel guardrail insert and half of the bolts being Geomet 500B coated mild steel and the other half being Geomet 500B coated weathering steel,
- Weathering steel guardrail with a Zinc foil insert and weathering steel bolts, and
- Weathering steel guardrail with a Zinc foil insert and half of the bolts being Geomet 500B coated mild steel and the other half being Geomet 500B coated weathering steel.

The purpose of these samples was to see how much the inserts protected the joint and how much the Geomet 500B coating protected the bolts.

Four 34-inch samples were placed in the salt fog chamber. There were two control samples, one was a galvanized steel guardrail with galvanized bolts and the other was a weathering steel guardrail with weathering steel bolts. The other two samples were weathering steel guardrail with different inserts, one had a galvanized steel guardrail insert and the other had a zinc foil insert. These samples were to be tested for tensile strength.

Due to a high turnover of key personnel in the corrosion unit, a summary of the salt fog chamber results is incomplete. There were, however, a number of preliminary measurements on the 15-inch samples of WSGR but not for the 15-inch samples of GSGR. It was clear from early results that the corrosion rates on the weathering steel were excessive and that many samples were deteriorating too fast to give valuable results.

2.2.1. Results of Thickness Inspection of Salt-Fog Corrosion Chamber Samples

All WSGR samples showed excessive corrosion damage with a flaky, brittle surface. All guardrail needs to meet specifications given in AASHTO M180. The following table gives the specifications for 12 gauge galvanized and weathering steel guardrail:

Table 2 - Guardrail Specifications

Specification	Galvanized Steel Guardrail	Weathering Steel Guardrail
Nominal Thickness	0.108"	0.105"
Minimum Thickness	0.099"	0.096"
Over Thickness	No limit	No limit
Thickness of Zinc Coating	0.003"	N/A
Nominal Thickness Without Coating	0.105"	N/A
Minimum Thickness Without Coating	0.096"	N/A

2.2.1.1. Galvanized Steel Guardrail, Control

All GSGR samples were measured and met the above specifications before being placed in the salt fog chamber. There were two GSGR samples with galvanized bolts and these were control samples. Unfortunately the thicknesses of the samples after exposure were not recorded. Figure 7 - Figure 11 shows one of the GSGR samples still assembled after exposure, after it was disassembled, and after the corrosion was cleaned off.

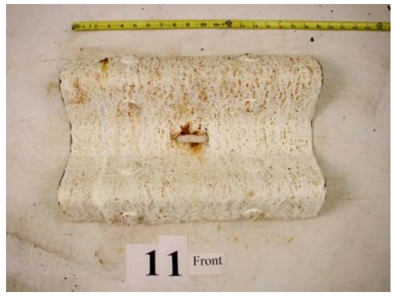

Figure 7 - GSGR Assembled Joint after Exposure

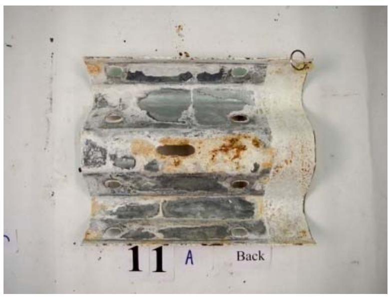

Figure 8 - Part A GSGR Disassembled Joint

Figure 10 - Part A GSGR Disassembled Joint Cleaned

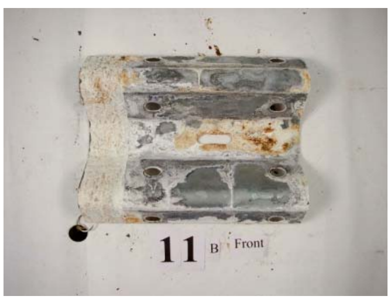

Figure 9 - Part B GSGR Disassembled Joint

Figure 11 - Part B GSGR Disassembled Joint Cleaned

2.2.1.2. Weathering Steel Guardrail, Control

All WSGR samples were measured and met the above specifications before being placed in the salt fog chamber. There were two WSGR samples with weathering steel bolts and these were control samples. The average starting thickness of the WSGR samples was 0.100 inches. At the area where the guardrail overlapped there was an average loss of 29.6% with an average final thickness of 0.070 inches. At the outside edge where there was no overlap there was an average loss of 45.0% with an average final thickness of 0.055 inches. Figure 12 - Figure 16 shows one of the WSGR samples still assembled after exposure, after it was disassembled, and after the corrosion was cleaned off.

Figure 12 - WSGR Assembled Joint after Exposure

Figure 13 - Part A WSGR Disassembled Joint

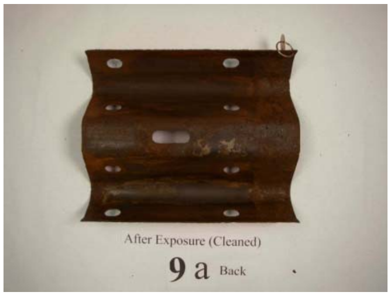

Figure 15 - Part A WSGR Disassembled Joint Cleaned

Figure 14 - Part B WSGR Disassembled Joint

Figure 16 - Part B WSGR Disassembled Joint Cleaned

2.2.1.3. Weathering Steel Guardrail with Galvanized Steel Guardrail Insert

All samples that were WSGR with a GSGR insert were measured and met the above specifications before being placed in the salt fog chamber. There were two WSGR with GSGR inserts samples one with weathering steel bolts and the other with half of the bolts being Geomet 500B coated mild steel and the other half being Geomet 500B coated weathering steel. The average starting thickness of the WSGR samples was 0.099 inches. At the area where the guardrail overlapped there was an average loss of 23.9% with an average final thickness of 0.076 inches. At the outside edge where there was no overlap there was an average loss of 35.2% with an average final thickness of 0.064 inches. Figure 17 - Figure 23 shows one of the samples still assembled after exposure, after it was disassembled, and after the corrosion was cleaned off.

Figure 17 - WSGR with GSGR Insert Assembled Joint after Exposure

Figure 18 - Part A WSGR with GSGR Insert Disassembled Joint

Figure 20 - Part B WSGR with GSGR Insert Disassembled Joint

Figure 22 - Part C WSGR with GSGR Insert Disassembled Insert

Figure 19 - Part A WSGR with GSGR Insert Disassembled Joint Cleaned

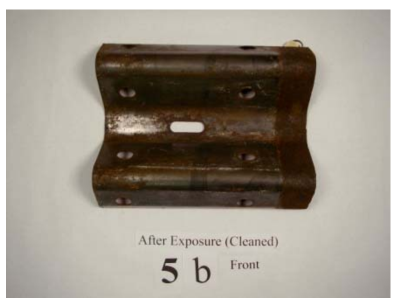

Figure 21 - Part B WSGR with GSGR Insert Disassembled Joint Cleaned

Figure 23 - Part C WSGR with GSGR Insert Disassembled Insert Cleaned

2.2.1.4. Weathering Steel Guardrail with Zinc Foil Insert

All samples that are WSGR with a zinc foil insert were measured and met the above specifications before being placed in the salt fog chamber. There were two WSGR with zinc foil inserts samples one with weathering steel bolts and the other with half of the bolts being Geomet 500B coated mild steel and the other half being Geomet 500B coated weathering steel. The average starting thickness of the WSGR samples was 0.100 inches. At the area where the guardrail overlapped there was an average loss of 25.1% with an average final thickness of 0.075 inches. At the outside edge (no overlap) there was an average loss of 35.5% with an average final thickness of 0.065 inches. Figure 24 - Figure 30 show one of the samples still assembled after exposure, after it was disassembled, and after the corrosion was cleaned off.

Figure 24 - WSGR with Zinc Foil Insert Assembled Joint after Exposure

Figure 25 - Part A WSGR with Zinc Foil Insert Disassembled Joint

Figure 27 - Part B WSGR with Zinc Foil Insert Disassembled Joint

Figure 29 - Part C WSGR with Zinc Foil Insert Disassembled Insert

Figure 26 - Part A WSGR with Zinc Foil Insert Disassembled Joint Cleaned

Figure 28 - Part B WSGR with Zinc Foil Insert Disassembled Joint Cleaned

Figure 30 - Part C WSGR with Zinc Foil Insert Disassembled Insert Cleaned

2.2.2. Results of Tensile Testing Salt-Fog Corrosion Chamber Samples

It was deemed that there was no reason to tensile test the 34-inch samples because of the high degree of deterioration after a year in the salt fog chamber. Figure **31** and Figure **32** shows damage done by corrosion after being in the salt fog chamber.

Figure 31 - WSGR with Flakey, Brittle Oxidized Surface

Figure 32 - Close-Up of WSGR Oxidized Debris

2.2.3. Results of Using Geomet 500B Bolts

As stated above the salt fog chambers results are incomplete and there is no record of the effect of using the Geomet 500B bolts.

3. Conclusions

Based on the preliminary measurements of the weathering steel guardrail exposed to the salt fog chamber it is very apparent that given the right environment WSGR will undergo excessive corrosion. Inserts provided some protection to the inside surface of the joint but there was so much corrosion on the exposed surface of the joint that the insert made little difference. There was also a question as to the affect the thickness of the galvanized steel guardrail insert would have on the crashworthiness of the guardrail system. Unfortunately, there is no way to use the salt fog chamber results to compare to and quantify environmental conditions. In addition, there were not enough field samples collected to reach any statistical conclusion with tensile testing.

This research effort was concluded after three things occurred. First, the publications from several (not all) transportations entities indicate a problem with weathering steel in the field as well as issues with proper inspection. Second, though incomplete, results from the salt-fog chamber tests indicated a problem with lapped guardrail no matter how it was protected. And third, a viable alternative to weathering steel was developed in the form of chemical stains, which can be applied in both controlled and field environments (Figure **33** and Figure **34** show an example of galvanized steel guardrail stained with a staining product.)

Figure 33 - Staining Product of Galvanized Steel Guardrail

Figure 34 - Comparison of Staining Product and Galvanized Steel Guardrail

4. Recommendation

Based on this research, it is our recommendation that there is no need to change current Caltrans guidelines on the use of weathering steel guardrail by limiting its use to areas where the annual rain fall is 8 inches or less. For areas where weathering steel is requested and there is an annual rain fall greater than 8 inches an accepted rust colored staining product should be used instead of weathering steel.

5. References

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