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# AN ASSESSMENT OF WEATHERING STEEL BRIDGES IN WEST VIRGINIA

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## ABSTRACT

The use of weathering steel in highway bridges has historically been a source of controversy, despite the potential for significant increases in cost-effectiveness. The first weathering steel bridges in America were constructed in the mid-1960s, with a significant percentage of the early weathering steel bridges constructed in Michigan. Numerous problems with weathering steel bridges in that state, along with problems reported in other states, led many states to question the performance of these structures. In the past two decades, research has attributed the majority of these past problems to: the use of weathering steel bridges in inappropriate environments, excessive salt contamination from deicing salts or marine environments, or problems with design details (such as leaky joints). Therefore, when these problems are controlled or eliminated, weathering steel bridges are an attractive alternative that can provide substantial cost savings to bridge owners.

While the initial material cost of weathering steel is more expensive than that of traditional (non-weathering) steels, considering the cost of painting causes weathering steel to be a cost-effective alternative. In addition to the cost savings offered, implementation of weathering steel provides environmental benefits such as preventing the release of volatile organic compounds into the atmosphere during maintenance painting as well as eliminating concerns with containment and disposal of removed paint.

This paper will provide an overview of a comprehensive assessment of the performance of the weathering steel bridge inventory in West Virginia. It will present findings from an evaluation that was used to categorize locations and site conditions that may lead to less than favourable performance of weathering steel bridges, if applicable. It will also present recommendations regarding detailing procedures to be incorporated with weathering steel bridges.

## 1. OVERVIEW OF WEATHERING STEEL

A588 weathering steel is formed by alloying additional elements (2% or less of various combinations of copper, phosphorus, chromium, silicon, and/or nickel) with traditional steels (A36 or A572), which cause the corrosion resistance of the steel to be significantly increased. The behaviour of weathering steel exposed to appropriate environments is fundamentally different from that of traditional steel in that in contrast to the formation of iron oxide (rust) that occurs when traditional steels are exposed to atmospheric conditions, weathering steel forms a protective oxide coating that reduces the rate of corrosion of the steel. However, this protective oxide coating will form only if the weathering steel is not subjected to extended period of moisture. Additionally, proper detailing of the structure is critical to maintain the integrity of the protective coating.

Additionally, environmental factors may adversely affect the ability of weathering steel to develop a protective oxide coating, particularly the presence of excessive levels of chlorides and sulfur dioxides. Of these, chlorides are typically more of concern in the United States because sulfur dioxide levels from pollution are generally not high enough to have a detrimental effect on weathering steel. Chlorides are of great concern however; chloride contamination may result from runoff of deicing salts applied to roadways or proximity of the structure to marine environments having high atmospheric chloride levels. While concerns associated with the impacts of a marine environment are not an issue with this study, in some cases the WVDOH makes heavy use of deicing salts in winter roadway maintenance operations.

## 2. OVERVIEW OF PREVIOUS STUDIES FOCUSED ON EVALUATING WEATHERING STEEL PERFORMANCE

One of the first studies aimed at the evaluation of weathering steel bridges was conducted by the American Iron and Steel Institute (AISI, 1982). At that time, the Michigan Department of Transportation had placed a moratorium on the use of all non-painted weathering steel. This action was due to the observation that many bridges in the state were developing excessive corrosion. This was especially true of: (1) bridges in urban, industrial locations where it was thought that the heavy application of deicing salts in combination with industrial and automotive pollution were creating an extremely corrosive environment and, (2) overpass bridges with less than 20 ft. under-clearance and retaining walls near the shoulders, often referred to as a depressed roadway. For bridges in depressed roadways, the salt-spray caused by traffic underneath the bridge collects on the girders, resulting in a regular application of a highly corrosive solution directly to the bridge superstructure.

As a result of the Michigan moratorium, AISI organized a formal evaluation of weathering steel bridges including the inspection of 49 bridges in seven states (Illinois, Maryland, Michigan, New York, North Carolina, Wisconsin, and New Jersey) to determine if the problems observed in Michigan were indicative of a general problem or were unique to that state/area (AISI 1982). The bridges were selected for inspection based on two criteria: site characteristics and level of salt use. The site characteristic of a particular bridge was classified as being in one of four categories: (1) urban or industrial grade separation, (2) rural grade separation, (3) stream or railroad crossing, or (4) depressed roadway condition. Bridges were also categorized as having heavy, light, or no salt use. Bridges were then selected with the goal of having several bridges in each combination of categories.

Results of this investigation showed that 30% of the bridges were in good condition in all areas, 58% of the bridges showed moderate corrosion (flaky rust) in some localized areas, but were in generally good condition, and 12% of the bridges exhibited heavy corrosion in some areas, but were in generally good condition. Local areas of corrosion were most often attributed to salt-laden runoff through leaking joints or open expansion dams. It was also found that bridges in depressed roadway conditions generally did not develop the protective oxide coating desired. High sulfate levels (from industrial or automotive pollution) did not appear to have an effect on corrosion rates.

The study concluded that the majority of weathering steel bridges was performing satisfactorily, although exceptions existed in the state of Michigan (AISI 1982). It should, however, be noted that since the study has been published, other researchers have identified weathering steel bridge structures in states other than Michigan in which the protective coating has not performed adequately.

In 1984, Albrecht and Naeemi also conducted an extensive evaluation of weathering steel performance. This study reviewed the bridges inspected and states considered in the AISI (1982) study as well as the experiences of other states that had reported less than optimal performance of weathering steel bridges. Specifically, bridges in both Alaska and California that exhibited excessive corrosion were evaluated; it was concluded that site conditions with heavy rainfall, fog and high humidity were subjecting these structures to prolonged periods of wetness leading to the poor performance of weathering steel.

Albrecht and Naeemi (1984) also reported that two of Louisiana's sixteen weathering steel bridges were not performing as expected. Both of these were located in close proximity to the Gulf of Mexico and it is believed that salt contamination (as a result of salt-laden wind and fog) and high humidity were both factors preventing formation of a protective oxide coating.

They also reported several cases of inadequate weathering steel performance in Ohio. The cause of corrosion in these structures was also attributed to prolonged periods of wetness caused by low clearance over underlying streams. Chemical analysis of rust samples taken from one of these bridges showed only trace amounts of sulfates and chlorides, indicating that neither salt contamination nor pollution was a likely cause of the excessive corrosion observed.

Conclusions of the Albrecht and Naeemi study (1984) were in general agreement with the finding of the AISI First Phase Report (AISI 1982); Albrecht and Naeemi also state that the majority of weathering steel bridges are in good condition, but local areas of pronounced corrosion exist in several structures.

Subsequent to the initial investigation on weathering steel bridges by AISI a second study was conducted and the results are summarized in "Performance of Weathering Steel in Highway Bridges: A Third Phase Report" (AISI 1995). In this study, researchers from AISI revisited the bridges that were initially inspected in the Phase I Report (AISI 1982, referenced above) and also inspected several additional bridges. These were located in West Virginia, Louisiana, Iowa, California, and Puerto Rico.

Findings of this evaluation indicated that weathering steel bridges that are designed and detailed in accordance with the FHWA Technical Advisory on weathering steel bridges (T 5140.22, FHWA 1989) were performing well throughout the United States, including those in marine and industrial environments. However, other researchers have found that the distribution of airborne salts in marine environments may vary greatly from location to location and have noted structures in these environments where the weathering steel has not performed adequately.

AISI also reports that several bridges inspected were located in areas of high rainfall, high humidity, or frequent fog and no problems were observed with any of these bridges. The only weathering steel bridges that were found to be performing unsatisfactorily were those located in the metropolitan Detroit area. It was thought that the negative performance of these bridges was due to the amount and frequency of deicing salts used in the Detroit area, the chemical composition of these salts, or a combination of both of these factors. Additionally, local areas of corrosion were reported for some bridges; the most common causes of these problems were reported to be leaky deck joints and clogged scuppers.

In addition to the above-mentioned studies, several states have independently evaluated weathering steel bridges in their inventory and these include: Louisiana, Idaho, and Texas.

Louisiana has cited corrosion problems in some of its weathering steel bridges, particularly along the gulf coast, due to airborne salts (Raman and Naszrazadani 1989). The primary locations where excessive corrosion was found to develop include areas: (1) near piers, (2) where wildlife (particularly birds) sheltered, (3) where condensed water collected and pooled, and (4) at locations with accumulated debris. In their research, Raman and Naszrazadani cite instances in which the application of a tannic acid solution was found to stabilize the corrosion rate (1989). However, it is not yet known if this would be acceptable as a general practice.

In 1995, the Idaho Transportation Department inspected 12 of its 40 unpainted weathering steel bridges (Jobes 1996). A protective oxide coating was observed on all 12 of these bridges and the continued use of weathering steel bridges in appropriate environments was recommended.

The Texas Department of Transportation (TxDOT) has also recently completed a study focusing on the performance of weathering steel used in bridges in that state (McDad et al. 2000). During this project, 40 weathering steel bridges throughout the state were independently inspected. The bridges were selected to be representative of five different site conditions: coastal, industrial, urban, suburban, and rural. The inspections revealed similar findings for all of the bridges except for those in coastal areas. In particular, the interior surfaces of bridges in coastal areas had larger flakes than the other bridges inspected; the exterior surfaces of the coastal bridges were similar to those of the other bridges evaluated.

McDad et al. (2000) concluded that weathering steel bridges were generally a cost effective alternative for use in Texas. The situations in which they did not recommend its use were: (1) in the presence of corrosive industrial or chemical pollution, (2) in locations of heavy salt-water spray or salt-laden fog, (3) uses in conjunction with timber decking, and (4) in depressed roadway conditions over roadways on which deicing salt is used.

While the above studies confirm that weathering steel bridges perform favorably in most locations in the U. S., they have also revealed that there are some sites where weathering steel may not perform as intended. Specific areas where weathering steel should be used cautiously include: (1) locations with frequent rainfall, fog, or high humidity, (2) sites with topography that may subject the steel to excessive periods of wetness, (3) low-level water crossings, (4) marine environments, (5) locations where concentrated chemical pollution may drift directly onto the structure, and (6) in depressed roadways.

The above studies have also attributed the excessive, local corrosion of some weathering steel bridges to problems with design details. One of the most significant sources of this type of corrosion is due to leaky bridge joints. Similarly, it is of significant importance that consideration is given to controlling drainage on and around a weathering steel bridge.

## 3. SUMMARY OF FINDINGS FROM BRIDGE INSPECTIONS

The corrosion performance of the weathering steel members of the bridges inspected during this study varies considerably from one bridge to another and between different components of a given bridge. The majority of the bridges were observed to be in good condition with few corrosion problems; however, exceptions do exist. Based on a critical review of the corrosion performance of the inspected bridges, the following three factors have been identified as being most influential to the performance of weathering steel bridges: deck type, span type (e.g., stringer, arch, frame, etc.), and crossing (e.g., stream, highway, railroad, etc.). A discussion of the influences of each of the deck, span, and crossing types encountered in weathering steel bridges in West Virginia follows.

Various additional factors relating to the environment of a bridge site have previously been set forth by other researchers as being influential to the performance of weathering steel. Some of these environmental factors include: proximity to industrial locations, surrounding vegetation, clearance over bodies of water, and terrain that shelters the bridge site from sunlight. A broad range of site environments were investigated in this study including bridges that were: near two different power plants, immediately adjacent to a coal field, in urban environments, located in rural areas, and densely sheltered by terrain and vegetation. While it will not be disputed that these factors may affect the corrosion characteristics, for the broad range of site environments investigated in this work, it is believed that these factors alone are not sufficient to create a situation where the performance of the weathering steel is unsatisfactory. Instead, these factors may only intensify a corrosion problem caused by some other source, as discussed below.

### 3.1 Deck Type

The following deck types were found to be used in conjunction with weathering steel bridges: reinforced concrete decks, reinforced concrete with stay-in-place (SIP) metal deck forms, concrete-filled metal grid deck, and timber decks. Comments are made addressing the corrosion issues related to each of these deck types below.

#### <u>3.1.1 Reinforced-Concrete Decks</u>

Bridges with reinforced concrete decks exhibit the fewest corrosion problems. This is attributed to the fact that the concrete decks are generally a continuous surface, thus preventing water from penetrating the deck and reaching the steel elements below. However, when cracks or inadequately sealed construction joints are present in the surface of the deck, corrosion problems beneath these cracks and joints frequently exist. One such situation is shown below in Fig. 1.

It is also observed that concrete decks with relatively wide overhangs exhibit significantly less corrosion on the exterior girders. Corrosion on the bottom flanges and the bottom of webs of exterior girders is common in cases where the depth of the girder is greater than the width of the overhang. This is caused by the lack of shelter to the exterior girder. The horizontal surface of the bottom flange then allows water to accumulate and capillary action draws this moisture up the web. An example of this situation is shown in Fig. 2a. This water also flows along the bottom surface of the bottom flange leading to corrosion as depicted in Fig. 2b.

(a) Deck joint (b) Corrosion beneath joint

Fig. 1. Corrosion caused by open deck joint

(a) Corrosion of bottom flange and web (b) Corrosion of bottom flange

Fig. 2. Corrosion due to narrow overhang

3.1.2 Reinforced-Concrete Decks with Stay-in-Place Metal Deck Forms

Bridges with reinforced-concrete decks with stay-in-place metal deck forms have corrosion characteristics similar to the reinforced-concrete decks discussed above. One difference between the two would be that the SIP forms would provide an additional barrier for water if the deck were to be become cracked in any way. However this would lead to corrosion of the SIP forms and only serve as a delay to future corrosion of the girders.

3.1.3 Concrete-Filled Metal Grid Decks

Several bridges were inspected where the bridge deck was comprised of concrete-filled metal grid decks. All of these decks had been in service for several years and all were leading to corrosion problems on the weathering steel members. Typical photographs of this type of bridge deck are shown in Fig. 3, where it can be seen that this deck type consists of three components: a geometric steel grid, a stiffened bottom plate, and the concrete in-fill. It is evident that water is able to pass through the filled grid deck, which eventually deteriorates the underlying stiffened plate, and allows run-off to flow over the weathering steel members. Thus the weathering steel is frequently exposed to moist conditions and excessive corrosion results.

(a) Grid deck from above

(b) Grid deck from below

Fig. 3. Concrete-filled metal grid deck

3.1.4 Timber Decks

The inspected bridges with timber decks had serious corrosion issues. Similar to the problem cited above with concrete-filled metal grid decks, water easily penetrates between each joint between timbers, providing little shelter to the weathering steel. Furthermore, the timber deck also retains moisture, which worsens the already severe corrosion of the top flange. Figure 4 shows corrosion typical of a weathering steel bridge with a timber deck. It should be noted that many of these bridges have been painted and the paint systems are also failing on these bridges.

(a) General view

(b) Pack rust on top flange

Fig. 4. Typical corrosion on bridges with timber decks

**3.2 Span Type**

For the purposes of the present discussion, the weathering steel bridges in the WVDOH inventory are classified into the following three span types: stringer, box girder, and arch or frame bridges. Comments are made on the influences of each of these span types on corrosion performance below.

3.2.1 Stringer

Stringer bridges are classified as bridges where the main superstructure elements are I-girders or rolled beams supported by concrete abutments. In general, the weathering steel stringer bridges exhibited the most favorable performance. This is directly related to the fact that in this type of bridge, all of the members are sheltered to some degree from the elements.

3.2.2 Box Beam

There is only one box beam weathering steel bridge in the state. While concern has been expressed regarding the suitability of weathering steel box beam bridges due to the potential for water to collect inside the box beams, inspection of this bridge revealed no aspect of the design that was detrimental to corrosion performance. The inside surfaces of this bridge are painted and adequate drainage is provided for water that may accumulate inside the box girder.

3.2.3 Arch and Frame Bridges

The negative aspect of these bridges is that they contain numerous members that are completely exposed to the elements. Especially problematic are: horizontal members where ponding of water may occur; inclined members, particularly at bearings, where members are oriented in such a way as to allows water to collect in places where there is no mechanism for drainage; and open cross-sections particularly in combination with connections that allow for moisture to enter the section. Examples of each of these three conditions are shown in Figs. 5-6, respectively. Fig. 5 shows a heavily pitted horizontal member of a steel deck truss. The excessive corrosion in the interior of an open truss member is shown in Fig. 6; here the substantial corrosion of the bottom bolts should also be noted.

Fig. 5. Horizontal member of deck truss

Fig. 6. Corrosion inside open truss member

### 3.3 Crossing

The inspected bridges serve to cross bodies of water, highways, railroads, or some combination of these three. Figure 7 describes the weathering steel population with respect to crossing type, where it is shown that 89% of the bridges cross water, 26% cross highways, and 15% cross railroads. The influence of crossing type on corrosion performance is discussed below.

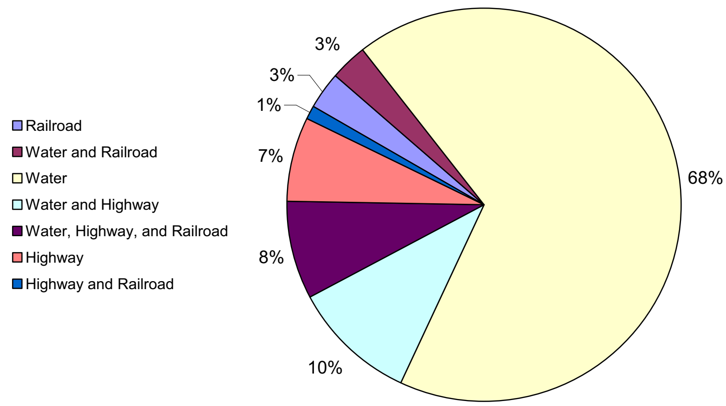


Fig. 7. Categorization of WV weathering steel bridges

#### 3.3.1 Water Crossings

Water crossings do not adversely affect corrosion performance. While previous studies have cited that low clearance over bodies of water (particularly stagnant bodies of water) may cause poor corrosion performance, there was no evidence to support that this factor alone caused excessive corrosion of any of the bridges inspected during this work.

#### 3.3.2 Highway Crossings

Highway crossings generally have acceptable corrosion performance. The exception to this rule lies in bridges with relatively low clearance over roadways that are heavily treated with deicing salts and also experience heavy truck traffic (e.g., bridges over interstates). In this case the influence on corrosion seems to be directly related to the amount of salt applied to the roadway and the proximity of the members to the roadway and few cases exist where this situation is leading to excessive corrosion.

#### 3.3.3 Railroad Crossings

No negative effects on corrosion performance were observed in this study that may be attributed to railroad crossings.

## 4. SUMMARY AND RECOMMENDATIONS

This paper presented an overview of a project that visually inspected approximately 100 weathering steel bridge in West Virginia. This population of bridges covered a wide range of applications of weathering steel including site location characteristics, span length, superstructure form, and others.

Literature on weathering steel frequently makes reference to the concept of wet-dry cycles. However, utmost emphasis should be placed on the dry phase of this cycle; there is little merit or benefit to weathering steel being exposed to the wet phase of this cycle. Rather, the most desirable situation is one in which the steel is perpetually dry as no corrosion will occur in the absence of water. Because this is an unrealistic expectation for material exposed to the elements and the presence of moisture is inevitable, it is realized that wet-dry cycles will occur. However, the most general recommendation that can be offered is that every reasonable effort should be made to keep water from reaching weathering steel members such that the wet cycle is minimized to the fullest extent possible. With this general goal of minimizing the amount and duration of moisture in contact with weathering steel members the following recommendations are provided for design and maintenance of weathering steel bridges.

## 4.1 Design

### 4.1.1 Deck Design

A deck consisting of a continuous, solid surface should be provided. Reinforced concrete decks with or without stay-in-place metal deck forms are recommended. Conversely, the use of timber decks and metal grid decks (filled with concrete or unfilled) is highly discouraged as these decks do not prevent water from reaching the girders and in many cases act to trap water on the top flange of the girders, exacerbating the situation.

Construction joints in concrete decks should be grouted. These joints should be carefully inspected during biennial inspections to monitor water penetrability. In many newer bridges, a construction joint located approximately 10 ft from the abutments was observed; consideration should be given to revising design practices to eliminate this joint.

The overhang width should be extended as wide as feasible to provide additional shelter to exterior girders.

### 4.1.2 Drainage

Careful consideration should be given to the drainage system for the bridge. Joints should be eliminated wherever possible and the use of integral or semi-integral abutments is highly recommended where appropriate.

### 4.1.3 Painting

It was observed during the inspections that the ends of girders are typically painted in newer weathering steel bridges. Comparing these bridges to older bridges without paint suggests that this practice is warranted. The length of the girder that is painted varied considerably and ranged between a few inches to several feet. Based on the field observations, it is suggested that the ends of the girders be painted over a length equal to the depth of the girder.

### 4.1.4 Connections

The continued use of bolt spacings that provide water tight connections is recommended.

### 4.1.5 Drip Bars

The use of drip bars is discouraged. These features tend to trap water and debris and are thus counter-productive to their intended purpose.

## 4.2 Maintenance

### 4.2.1 Decks

Decks should be periodically inspected for cracks and open joints as well as signs of moisture penetrating through the deck. Any of these occurrences should be repaired. Caulked joints encountered during the bridge inspections appear to be adequate in preventing future corrosion.

### 4.2.2 Drainage

The drainage system of the bridge should be inspected and assessed as to its functionality. Drains should be cleaned and any other components of the drainage system not functioning as intended should be cleaned or repaired otherwise.

4.2.3 Flooding

When flood waters reach the superstructure, it is inevitable that various sediments and debris will be deposited onto the weathering steel members. Debris ranging from fine silt to large trees was observed lodged on girders and in cross-frames. This debris should be removed due to the tendency for this debris to trap moisture onto the surfaces of the steel.

4.2.4 Deicing Salts

In tunnel situations with high truck traffic it is recommended that alternatives to deicing salt having less severe effects on corrosion be considered.

4.2.5 Acid Solutions

In cases of severe, progressive corrosion, consideration may be given to treating the affected members with an acid solution wash. Limited results suggest such methods may be successful in arresting this corrosion.

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