Performance of Weathering Steel in TxDOT Bridges

A Research Project Conducted for the

Texas Department of Transportation

Project 0-1818
Use of Weathering Steel in TxDOT Structures

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June 2, 2000

Disclaimer

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Serial Number 80620

Acknowledgments

The authors extend their appreciation to the Project Director, Jon Holt, P.E., Houston District; the Texas Steel Quality Council; TxDOT's Design Division's Bridge Inspection and Appraisal (BRINSAP) and Bridge Design sections; all TxDOT districts; and the TxDOT Construction Division's Construction/Maintenance Section and the Materials Section.

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Chapter 1 — Introduction

RESEARCH PROBLEM STATEMENT

Weathering steel is a material that provides a great potential advantage to TxDOT for use in bridges in terms of improved durability and lower construction and maintenance costs. However, there are disparate opinions within TxDOT about how well the material performs. Some contend that it does well in most environments, and others contend that it does not perform at all, but there is little scientific basis for either opinion. The purpose of this research is to determine in what environments, if any, weathering steel performs well, based on field evaluations of the TxDOT's weathering steel bridges, and to provide recommendations for achieving good performance in these bridges.

THE PROTECTIVE OXIDE FORMATION (WEATHERING) PROCESS

In the presence of moisture steel and oxygen generally combine to form rust. On most carbon steels, the rust forms a loose crystalline structure, allowing more water and air through to attack deeper into the steel, forming even more rust and weakening the base metal.

Weathering steel, however, in its bare, mature state, has a unique, coating occasionally referred to as a "patina." The coating is more properly referred to as a 'protective oxide film,' which is about the same thickness as a heavy coat of paint. This protective oxide film adheres tightly to weathering steel in fine, dense grains that are relatively impervious to further atmospheric corrosion, thereby sealing the base metal from the air and further corrosion. The protective oxide film has different colors than the rust on other carbon steels, ranging from a dark reddish-brown to purple gray, depending on the age of the structure, the pollutants in the air, local weather conditions, or the location of the steel within the structure. [4].

The appearance, texture, maturity, and anticipated utility of a protective oxide film depends on several factors. The primary factors are age, degree of exposure, and environment [4]:

- It takes time for the oxide film to change from a rusty red-orange to a dark, rich, purple-brown color. The moderately rough texture becomes more distinct as the coating matures. This weathering process continues over an extended time, depending upon other factors.

- The degree of exposure has a strong influence on the weathering process. Steel exposed to rain, sun, and wind weathers more quickly than steel in a sheltered location. On sheltered surfaces, the oxide tends to be rougher, less dense and less uniform.

- Frequent wet-dry cycles caused by rainfall and/or dew, followed by wind and sun, are important factors affecting protective oxide film formation [4,6]. In moderate industrial environments, weathering steel usually matures most rapidly and achieves the darkest tone.

In rural locations, the protective oxide film develops more slowly and generally has a lighter tone [4].

History of Weathering Steel

The first documented use of the weathering steel process occurred during the revolutionary war, when gunsmiths protected the surface of rifle and pistol barrels with a thin coat of iron oxide. This process, known as “browning,” involved treating the exposed steel surfaces with chemicals to form a corrosion-resistant layer.

Work on the development of weathering steels was evolutionary in nature and stemmed in part from the pioneering work on copper-bearing steels by D. M. Buck, who reported in 1910 that carbon steel containing 0.2 percent or more of copper (Cu) had from 1.5 to 4 times the atmospheric corrosion resistance of carbon steel with a residual copper content [1]. The most significant differences were found in severe industrial atmospheres. The least improvement occurred in rural atmospheres.

Subsequent studies by various investigators pointed to the beneficial effects from the inclusion of 2 percent, or less, of certain common alloying elements. Phosphorous (P), silicon (Si), nickel (Ni), and chromium (Cr) appeared to provide atmospheric corrosion resistance to carbon steel [1].

Early Applications

The first major commercial application of weathering steel came in 1933, when it was used to build coal hopper cars. The exterior of these cars were painted. The weathering steel gave superior performance, and cars with service of up to 25 years showed little corrosive deterioration.

The first use of sheets in a building occurred in 1939, in highway bridges in 1935, and in a river tow boat in 1937.

Beginning in the early 1940s, extensive atmospheric corrosion studies were conducted under the auspices of the American Society for Testing and Materials (ASTM). These confirmed the beneficial effect of elements Cu, Cr, Si, P, and Ni, singularly or in combination, in an aggregate amount of 2 to 3 percent, on the corrosion behavior of low-alloy steels exposed to various atmospheres, including arid, rural, industrial and marine environments. Thus the original “weathering steel,” ASTM A242, was established [1].

Architectural Applications

The first major step in obtaining public acceptance of the weathered steel appearance occurred in 1956, when the architect Eero Saarinen selected this steel as construction material for the John

Deere and Company administration building in Moline, Illinois. However, it was not until the late 1950s that high-strength/low-alloy weathering steels were developed and became of interest to the construction industry. Since that time, weathering steel has been used in other prominent buildings, including the Chicago Civic Center and the 64-story USX Tower in Pittsburgh, Pennsylvania. Subsequently, hundreds of unpainted buildings have been built [1].

Electrical Transmission Towers

The first test applications of weathering steel in electrical transmission towers occurred at the Gary, Indiana, plant of U.S. Steel and the Burns Harbor, Indiana, plant of Bethlehem Steel in the early 1960s. Painting electrical transmission towers is expensive and inconvenient since they must be de-energized for safe painting. Therefore, a large market developed from these early weathering steel applications. Virginia Power and Light company has over 8,000 weathering steel towers that have performed satisfactorily for as long as 25 years [1].

Guard Rail

In the early 1960s, Michigan began using unpainted weathering steel for guardrail (WSG). A cursory examination of this application in 1978 revealed lapped joints bulging from the internal pressure of corrosion products. Ultrasonic thickness gauge measurements indicated that some areas in the joint had lost up to 40 percent of their original thickness. The WSG at a rural/urban site showed a 20 percent reduction in strength after 15-1/2 years. The more corrosive environment of a "tunneled" freeway site resulted in an 11 percent reduction in strength after only 4-1/4 years [8]. See **Appendix A** for details of this study. With a strength reduction almost four times greater for weathering steel guardrail in highly corrosive environments, the material was considered unsuitable for 'tunneled' freeway and other highly corrosive environments.

EXPERIENCE HISTORY OF WEATHERING STEEL IN BRIDGE STRUCTURES

Successful use of weathering steel for building construction and transmission towers led to consideration of its use for bridges to eliminate painting and the consequent interference with traffic flow associated with re-painting. For these reasons, in the mid-1960's, bridges became the largest market for uncoated weathering steel [1].

United States

The first bridge using weathering steel was built over the New Jersey Turnpike in 1964. Weathering steel bridges were soon built in Iowa and Ohio, and other states followed suit [1]. New Jersey was satisfied with the performance of its bridges [2].

In early 1965, the Michigan Highway Department (now Michigan Department of Transportation [MiDOT]) began the erection of four uncoated weathering steel bridges at the crossing of the

Eight-Mile road over U.S. Route 10 in Detroit [5]. A major commitment by MiDOT to the use of unpainted steel in bridges began in 1970. However, Michigan found the material did not perform well, specifically in the Detroit metropolitan area. Poor material performance in Detroit led the state, a leader in the use of weathering steel during this period, to issue a moratorium on its use for highway bridges of all types in 1979. In 1980, MiDOT, following an extensive evaluation of their bridges, banned all uses of nonpainted weathering steel on the state highway system. They had found that traffic-sprayed run-off water contaminated with salt was severely corroding the bridges in rural and urban areas. MiDOT recommended maintenance-painting of all weathering steel bridge structures [6].

No other state banned it outright, but many began to question the suitability of weathering steel in highway bridge construction. Concerns regarding the long range performance of uncoated steel bridges led to an investigative task force organized by the American Iron and Steel Institute (AISI) in 1982 [15]. This task force inspected 49 weathering steel bridges in Illinois, Maryland, Michigan, New York, North Carolina, Wisconsin, and New Jersey, and presented the findings in the three-phase report. They found that 30 percent of the subject bridges showed good performance in all areas; 58 percent exhibited moderate corrosion in some areas; and 12 percent showed heavy corrosion in some areas. Most of these bridges, the report concluded, did not need immediate attention or overall painting. Notable exceptions were most of the structures inspected in the Detroit, Michigan, area [15].

A separate survey, in 1982, by the National Cooperative Highway Research Program (NCHRP) on the performance of unpainted steel in bridges also concluded that problems with weathering steel were not limited to Michigan [10]. Bridges with corrosion problems were found in Alaska, California, Iowa, Louisiana, Ohio, and Texas [15] — structures that were not included in the AISI survey. It was concluded that protective oxide film was not developing on uncoated steel bridges.

In 1983, several states began remedially painting some bridges (Iowa, Louisiana, Michigan, and Ohio) because of poor performance. At the same time, other states were planning such work (Alaska, Indiana, and Washington). In states where weathering steel bridges were excessively corroding in limited areas, the steel near joints was remedially painted (Kentucky, Maryland, and Missouri), or such work was planned (Massachusetts and New Jersey Turnpike) [16]. Texas, after a long period of monitoring two weathering steel bridges near the Gulf of Mexico, decided not to paint any of its weathering steel bridges.

Thereafter, the use of weathering steel in bridges declined, from 12% of the total steel market in 1980 to a low of about 10 percent in 1987. Yet, according to a 1987 telephone survey, over 2,300 weathering steel bridges were in use in the nation’s highway systems alone [16], including the world’s largest arch bridge, the 3030 foot long New River Gorge Bridge in West Virginia [1]. This figure did not include county, city, toll road, or mass transit bridges.

However, as painting costs continued to rise and a better understanding of the nature of the corrosion problems developed, usage of weathering steel in bridges again began to climb. By the end of 1989, this use of weathering steel had risen to a new high of about 15 percent [1].

In 1990, MiDOT, after assessing the recommendations for proper use of weathering steel and the cost of repainting carbon steel bridges, rescinded its moratorium and began to consider weathering steel's use for new bridges if the locations were within the guidelines of the Federal Highway Administration (FHWA) Technical Advisory TS 140.22, "Uncoated Weathering Steel in Structures" [1].

As of 1989, there were four nonusers of weathering steel, 13 former users, and 33 remaining users among the 50 state DOTs [16]. The four states that do not have weathering steel bridges are Arizona, Hawaii, Nevada, and South Dakota. Hawaii does not use it because concrete is more economical than steel. In the other three states the climate is so dry that paint systems on their ordinary steel bridges last indefinitely [16].

The 13 former users no longer specify weathering steel for new bridges. See **Table 1-1** for their reasons.

Table 1- 1

State DOTs no Longer Using Weathering Steel
(As reported in 1989)

DOTs	Reason
Indiana, Iowa, Michigan, Washington, and West Virginia	Excessive corrosion of bridges in their own state
Alabama, Florida, Georgia, and Oklahoma	Concern about experience in other states
New Mexico and South Carolina	Aesthetics
California and North Dakota	Economics

Some state DOTs have more than one reason for no longer using weathering steel. For example, New Mexico and North Dakota also have a semiarid climate in which paint systems on ordinary steel lasts indefinitely [16].

Among the 33 remaining users there is a great variety in degree of usage for new bridges, from almost exclusively (Vermont) to practically none (Pennsylvania and Tennessee). Recognizing the limitations of the material, most remaining users now follow their own design, construction, and site location criteria for enhancing corrosion performance [16], as detailed in **Table 1-2.**

Table 1- 2

Methods to Improve Performance of Weathering Steel [16]

Methods to Improve Performance of Weathering Steel	# of States
Using Weathering Steel:	
Mainly in rural areas, remote areas, or where the bridge is not	8
visible to the public	5
Over streams	3
Over railroad tracks	
Not using Weathering Steel:	
For grade separation structures	4
In cities and where average daily traffic exceeds 10,000	1
Along the coast	6
On heavily salted highways	4
High humidity areas	3
Design Detailing and Maintenance	
Painting steel 5 to 10 feet on each side of joints	10
Blast cleaning all steel before erection	2
Keeping drainage water from running over the substructure and protecting concrete against rust staining	5
Galvanizing scuppers, bearings, and expansion devices	1
Galvanizing finger plates	1
Not using hinges or sliding plates	1
Making decks jointless and building bridges integrally with abutments where conditions permit	1

Idaho

In 1995, the Idaho Transportation Department (ITD) selected a representative group of weathering steel bridges to determine their condition. Twelve of Idaho's 40 unpainted weathering steel bridges were inspected. Field observations indicated that a uniform, protective oxide film had developed on all the bridges inspected. The coating in the higher precipitation areas was generally heavier and darker in color. On most bridges, there was a distinct difference between sheltered interior and exposed exterior surfaces. The sheltered surfaces on most bridges had not been blast-cleaned and had considerable mill scale, resulting in a mottled appearance. Generally, the oxide film in the sheltered areas was light to medium in thickness, less dense, and varied in color from yellow orange to dark brown.

Contrary to expectations, the Idaho data and tests results indicated that deicing salt usage on bridge sites is inversely proportional to the increasing chloride content (ppm) in the oxide films. It appeared that chloride had not significantly contaminated steel structures to cause corrosion. However, because salt contamination from spray was occurring, monitoring through routine inspections was continued.

The results of Idaho's most recent inspection of 12 weathering steel bridges indicated that the material was "performing very well," and its continued use in the proper environments, rural and urban areas, was recommended [10].

Louisiana

Pitting and crevice packing are significant corrosion problems encountered on bridges in Louisiana. Corrosion problems are common and more severe in near-coastal bridges. Bridges located inland, but within the industrial belt have less, and less severe, corrosion. Rust in both coastal area and interior bridges show chloride and sulfur compounds. Bridges located far from coastal zone in rural areas do not show serious corrosion problems.

Louisiana encountered pitting in coastal area bridges at locations where excessive rusting occurred: 1) at the entrance to piers, 2) where wildlife sheltered and birds nested 3) where condensate water collected and stagnated without draining, and 4) at locations that had not been cleaned well. In such places, rust formed as sheets, and serious pitting was found beneath this rust layer.

Pits, though not serious, were also found underneath coarse rust flakes, both on the skyward and downside faces of horizontal beams, but vertical surfaces showed very thin and shallow pits.

Subsequent to the first time analysis, the study was continued one year from the first analysis at such pitted locations, in those areas that had been previously cleaned, analyzed, and subsequently treated with 10% tannic acid aqueous solution, as well as in adjoining areas, where the treatment had been applied directly on the rust present. The intent was to evaluate the effect of application of 10% tannic acid solution on the pitting rate. Tannic acid solution was chosen for treatment since clean samples treated with 10% tannic acid showed lowest corrosion losses under immersion-type situations in laboratory tests. Further, tannic acid formulations are commonly used as rust converter type chemicals in commercial products.

Analysis of measured pit depths, their maximum values, and distribution indicated that the data were about similar to the first derived ones, one year earlier. Maximum pit depths of 60 mils were recorded. No rusting was observed in previously cleaned areas that were subsequently treated with 10% tannic acid solution. In cleaned and treated areas, where subsequently rust debris from other locations or bird nest debris collects, the coating can still be expected to protect. However, bird nesting was not found in such treated areas, though some rust debris was found in some places. Removal of the rust debris collected at this point indicated that the coating was still intact, and, as such, no firm conclusions could be drawn, other than that visual indications show that the treatment was generally useful. In view of the fact that the wildlife does not prefer such cleaned and treated areas, periodic cleaning of such boxed locations and removal of debris and subsequent application of chemicals, either 10% tannic acid solution or 10% tannic acid/phosphoric acid formulation, can be recommended [9].

Test areas of the steel were blast-cleaned to remove rust and expose pits, and pit-depth measurements were made. Maximum pit depths of 60 mils were recorded. The cleaned areas, and the adjacent rusted areas, where additional pits were anticipated, were treated with a 10% aqueous solution of tannic acid or 10% tannic acid/25% phosphoric acid formulation (commonly used as a rust-converter chemicals) by spraying and smearing.

Pitted locations were studied in those areas that had been previously cleaned, analyzed, and subsequently treated with a 10% tannic acid solution. Adjoining areas, where the treatment had been applied directly on the rust, were also studied. No rusting was observed in previously cleaned areas that had been treated with 10% tannic acid solution. In cleaned and treated areas, where debris collected, the coating still protected. However, bird nesting and other signs of wildlife habitation were not found in such treated areas. Louisiana concluded this absence suggested that the two solutions may be a repellent to wildlife [9].

No firm conclusions regarding the continued use of weathering steel were stated in the literature. Visual indications showed the tannic acid treatment was generally useful. Since wildlife does not seem to frequent such cleaned and treated areas, Louisiana recommends periodic cleaning of such boxed locations, removal of debris, and an application of chemicals, either 10% tannic acid solution or 10% tannic acid/phosphoric acid formulation [9].

Michigan

In 1979, field investigations by MiDOT of unpainted weathering steel highway bridges revealed that the steel was not exhibiting the resistance to corrosion initially anticipated. Much of the MiDOT study was directed at two bridges built in 1965 and 1967 and several built in 1972-73.

Visual inspections on about 50 unpainted weathering steel bridges, including urban, suburban, and rural freeway environments, revealed severe corrosion problems in the high-chloride environment created by heavy salting. These included pack rust; accumulation of debris, particularly on the top surfaces of the bottom flanges on bridge beams; and pitting of beams, cover plates, and weldments [6].

As a result of that investigation, MiDOT began to maintenance-coat all of their unpainted weathering steel bridges [6]. At that time, there were approximately 500 weathering steel bridges in service in Michigan. Priorities were assigned based on age, location (urban, suburban, or rural), and traffic volumes under and over the structure. Traffic volume was considered to be very important because it affected the amount of salt applied to the highway, the intensity of salt spray contamination, and the fatigue cycle life of the bridge [6].

MiDOT issued a recommendation to maintenance-paint all weathering steel bridge structures in 1980 [6]. This recommendation was supported by a later Michigan research investigation that concluded that weathering steel should be considered experimental, and that if it were used in northern climates where salt is used, the material should be painted [15]. Further, pitting and its selective corrosion were serious enough that MiDOT recommended the complete removal of mill scale from unpainted weathering steel, even in the absence of a salt-contaminated environment.

Other Countries

The experience with weathering steel construction in Europe is reflected in the specifications issued by France, Germany, and Czechoslovakia. All specifications caution against the deleterious effect that air pollution, prolonged time of wetness, and salt contamination have on corrosion performance.

In 1979, the Department of Transportation in West Germany virtually banned the use of weathering steel for bridges on the federal system. Only two exceptions were granted. Both were for composite girder bridges over electrified railways to eliminate the need to restrict railway traffic to maintenance paint carbon steel.

The higher latitude and the generally higher levels of atmospheric pollutants cause weathering steel to corrode more in the central and northern European countries than in the United States. The lower angle of the sun reduces the intensity of the drying cycle and prolongs the time of wetness.

In Canada, uncoated weathering steel is used for approximately 90 percent of all new bridges. Weathering steel bridges exist in Finland, Holland, Canada, Germany, Italy, Switzerland, and Spain. There are now about 100 weathering steel highway bridges in Great Britain. Other countries using uncoated weathering steel for bridges include Brazil and Japan [1].

According to a survey conducted by the Japanese Society of Civil Engineers, 115 weathering steel bridges had been built in that country by March of 1979. Of those, only five were nonpainted. The primary motivation for using weathering steel prior to that date was to prolong the life expectancy of the paint in industrial environments and coastal areas with relatively high humidity. Japan is now shifting to bare steel construction, with some bridges receiving a sacrificial paint-like "weather coat" that helps the steel form a protective oxide and prevents run-off water from staining the concrete substructure. The Japanese use weathering steel despite having extensive marine exposures with high relative humidity and much rain. They work with these factors by careful design and selective use of a porous protective coating [15].

To evaluate the performance of weathering steel, Japanese steel companies built and operated, within their plants, weathering steel bridges with painted, weather-coated, and nonpainted sections. This experiment allowed them to closely monitor and compare the performance of the three systems. Based on this experience, structural details for new bridges were modified to enhance drainage and inhibit accumulation of debris. These details are being implemented in new construction [15].

Chapter 2 — Research Tasks

Objective

The purpose of this research is to examine and assess the performance of weathering steel as used in TxDOT bridges and make recommendations for its use based on these findings.

Activities

The project consists of the following tasks:

1. Conduct a survey to learn why some TxDOT personnel like weathering steel and others do not

2. Collect data from other states regarding their experience with weathering steel, particularly those with a documented history of the material's performance, such as Idaho, Louisiana, and Michigan

3. Contact mills to get their opinions and participation

4. Contact TxDOT's Design Division, Construction Division, and Districts to learn if they have any helpful data available

5. Collect weather data about various locations in Texas, from weather services and agencies, to see if it can be used to associate performance with climate

6. Collect available data about corrosion of weathering steel

7. Categorize locations of weathering steel bridges in Texas by the type of corrosion occurring, if possible

8. Acquire a database of TxDOT weathering steel bridges from BRINSAP, including location and date built

9. Conduct site visits to inspect weathering steel bridges, including visual inspection, thickness measurements, and sampling for further evaluation

10. Analyze the effect of blast cleaning weathering steel by comparing the performance of blasted versus nonblasted structures

11. Analyze the effect that painting has on weathering steel structures

12. Perform laboratory analysis on samples from various bridge locations in Texas

13. Analyze how well weathering steel structures perform to prevent corrosion, including the influence of these factors:

    - type of design
    - performance of drip bars
    - performance of drip pans

Document and analyze a comparison of costs, savings, and other decision-making factors to determine whether to choose weathering steel versus nonweathering steel

IMPLEMENTATION

The findings of this study are compiled in this report, including recommendations about how to best incorporate weathering steel into bridge design.

As further implementation, research findings will be used to:

Promote the use of weathering steel as an economical means of construction in locations where data suggests that the material performs well

Prohibit the use of weathering steel in those Texas environments where its performance is poor.

Provide the engineer with current and definitive performance information to make appropriate decisions when working in environments where the use of weathering steel is questionable.

Chapter 3 — Tasks Results and Analysis

TXDOT SURVEY

A telephone survey was conducted to determine the level of confidence with the use of weathering steel by TxDOT personnel. The sample included respondents from each of TxDOT's 25 Districts, plus the Design Division and Construction Division, which included discussions with Maintenance and Materials Section personnel. A copy of the survey form is included as **Appendix B**. The breakdown of 28 responses from 25 Districts was: fifteen design engineers; six area engineers, two transportation planning and development engineers; three deputy district engineers; and two district engineers. A breakdown of the personnel who responded is also included **(Table 3 - 1).**

Who Makes the Decision to Use Weathering Steel

At TxDOT, the final decision about the use of weathering steel is made at the District level by either: 1) the district bridge design engineer, 2) the area engineer, 3) the transportation planning and development engineer, 4) a deputy district engineer, 5) the district engineer, or 6) by the consensus of a group meeting. The Bridge Design Section of the Design Division and the Materials and Construction/Maintenance Sections of the Construction Division only make recommendations.

Other Findings

Twenty-two of the districts stated that they approve of the use of weathering steel in steel bridges. Eight districts had previous experience with the material, and 14 had never used weathering steel 1) for design considerations, 2) because concrete is less expensive, or 3) because the design engineer was not aware of the unique features of weathering steel.

Two districts did not approve of the use of weathering steel because they had been told about potential staining problems. Only one district had discontinued the use of weathering steel and decided not to use it again because of staining observed in other districts. This district also commented that it would be difficult to control aesthetics on weathering steel not free of mill scale.

Both the Design and Construction Divisions approved and encouraged the material's use for steel bridges where appropriate **(Table 3 - 2).**

Table 3 - 1

TxDOT Districts Weathering Steel Approval Data

Respondents	Approve	Disapprove
Design Engineers	11	2
Area Engineers	5	1
Deputy District Engineers	2	
District Engineers	2	
Transportation Planning & Development	2	

Table 3 - 2

TxDOT Weathering Steel Usage Data

Entity	Approve And Encourage	Will Not Use
Districts (25 total)	22	3
Design Division	Yes	
Construction Division	Yes	

TXDOT STEEL BRIDGE INVENTORY DATA

The TxDOT Bridge Inspection and Appraisal (BRINSAP) section of the Design Division maintains a database of all in-service bridges in the Texas DOT system, including a code that indicates the materials used in their construction. This database was sorted to isolate weathering steel bridges. In February 1999, the number of weathering steel bridges inspected, listed, and rated by BRINSAP was 99. However, there are several weathering steel bridges that have not received their first condition-rating inspection (generally every two years for non-fracture-critical bridges) and thus are not on the list. This compilation of weathering steel bridges (**Appendix C)** includes a Superstructure Condition Rating that indicates how well each bridge is performing.

The BRINSAP Superstructure Condition Rating Scale allows rankings from 9 (Excellent) to 0 (Failed - Out of Service) on a scale established by the Federal Highway Administration [18]. More details regarding the Superstructure Condition Rating system are listed in **Table 3 - 3**, which follows.

Table 3 - 3

BRINSAP Bridge Superstructure Condition Rating Codes

Code	Description
9	Excellent condition
8	Very Good Condition - no problems noted
7	Good Condition - some minor problems
6	Satisfactory Condition - structural elements show some minor deterioration
5	Fair Condition - primary structural elements sound, but may have minor section loss, cracking, spalling, or scour
4	Poor Condition - advanced section loss, deterioration, spalling or scour
3	Serious Condition - loss of section, deterioration, spalling or scour have seriously affected primary structural components
2	Critical Condition - Advanced deterioration of primary structural elements. Fatigue cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored, t may be necessary to close the bridge until corrective action may be taken
1	Imminent Failure - major deterioration of section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put it back in light service
0	Failed - Out of Service - beyond corrective action.

As can be seen in **Tables 3 - 4 and 3 - 5**, which follow, the BRINSAP data indicates that TxDOT's weathering steel bridges are performing very well. The lowest rating received by any weathering steel structure received was a 5, and that is only one bridge – a bridge built in 1970 that has been painted. Five bridges received a 6, fourteen a 7, 77 an 8, and two bridge structures were rated as 9. Thus, 94% of TxDOT weathering steel bridge superstructures, ranging in age from three years to 29 years, are in at least "Good Condition."

Table 3 - 4

Condition Rating of TxDOT Weathering Steel Bridges

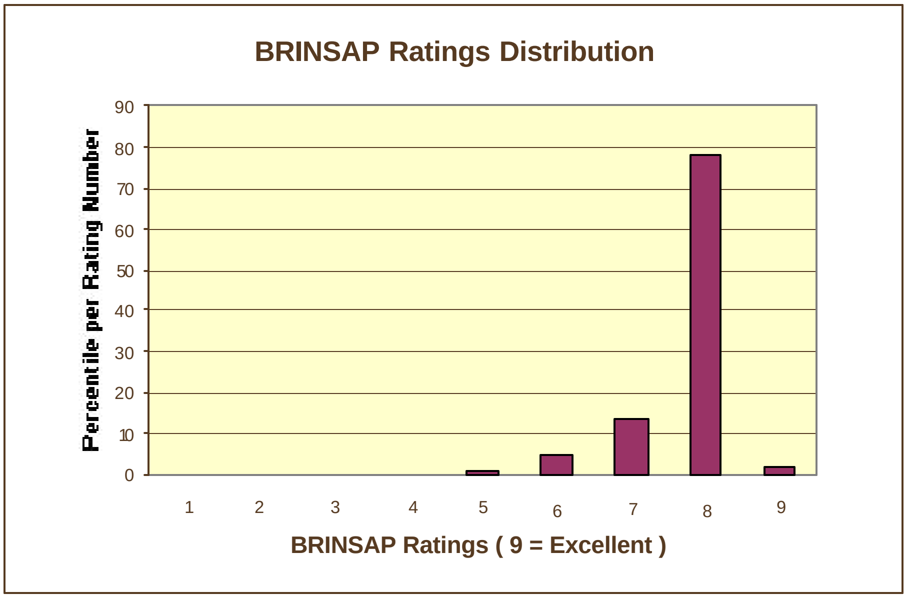

Table 3 - 5

Rating Distribution of TxDOT Weathering Steel Bridges

District	Excellent (9)	Very good (8)	Good (7)	Satisfactory (6)	Fair (5)	Lower half (4,3,2,1,0)
Austin	0	10	3	0	0	0
Dallas	0	0	2	0	1	0
Fort Worth	0	1	1	0	0	0
Houston	2	62	6	5	0	0
San Antonio	0	0	2	0	0	0
Tyler	0	3	0	0	0	0
Wichita Falls	0	1	1	0	0	0
Totals	2	77	14	5	1	0
Percentages	2.02	77.78	14.14	5.05	1.01	0

Weather Conditions

Tables covering weather data in Texas, provided by the National Weather Service, are included in **Appendix D, 1-6**. They detail normal temperature, mean number of days with minimum temperature at 32 degrees or less, relative humidity, rainfall in inches by month, snowfall, and days of rain over 30 years or more. A comparison of climatic conditions to bridge structure performance data from **Appendix C** provides the bridge designer with additional information to factor climate into the decision as to whether or not to use weathering steel.

Field Inspections of TxDOT Bridges

As part of this study, 40 weathering steel bridges in Texas were inspected. The bridges were in areas representative of different Texas climatic conditions: 1) severe coastal with a high salt atmosphere, 2) industrial 3) urban, over highways and rivers, 4) suburban, and 5) rural. At least one structure in each setting spanned a river.

The findings were similar for all structures, except those in severe coastal areas with a high salt atmosphere, where flakes were larger on interior surfaces. Also, in these coastal areas, secondary members, such as diaphragms and floor beams, were corroding faster than main girders, and had much larger flakes. The exposed exterior surfaces were very like the exterior surfaces of bridges in the other four climatic conditions. More details on site visits to the 40 selected structures can be found in **Appendix E.**

Protective Oxide Film

The color of the 40 bridges studied varied from light brown for new structures to a much darker brown for older structures, and all were at least partially covered with small loose flakes of rust. Mill scale was present on the bottom flanges, tops of exposed top flanges of bent caps, and the webs of most structures. Typically, the bottom flanges were more corroded due to more exposure to dampness from condensation, run-off, and moisture held there by debris.

The expected protective oxide film has not formed on most of these 40 bridges but only partially developed on exposed exterior surfaces of some structures. On some structures, exposed areas (shoes, bottom flanges, and steel bent caps) showed little or no flaking, but the surfaces had a more porous look than the examples above.

Detailing

Drip plates were observed on many of the bridges, but only on the outside of the fascia beams. Where properly installed, they reduced or eliminated staining on concrete surfaces. Drip pans were found on ten structures, but were only installed properly on five. These five installations effectively eliminated staining on concrete members below the weathering steel, especially when they were in combination with drip plates. Those drip pans that performed poorly were improperly placed, poorly welded, or damaged during the retrofit process. Drip pans, drip plates, and staining will be covered in detail in Chapter Four.

Stiffener clips on some bridges were of inadequate size and did not provide enough ventilation and drainage. They closed due to an accumulation of debris and corrosion. The clips shown in **Figure 1** were detailed as 1" by 1", which is not adequate for proper drainage.

Figure 1 - Gap closure due to inadequately-sized clips

Thickness Measurements of Weathering Steel

Ultrasonic Testing (UT) was used to ascertain possible section loss due to corrosion by measuring actual material thickness and comparing the result with the original nominal material thicknesses.

Measurements were taken on three structures. The first was the High Island Bridge spanning the Intercoastal Waterway, and the second was the Spur 55 Bridge over Cedar Bayou, both in the area of Beaumont, Texas, near the Gulf of Mexico. The third was the Lake Austin Bridge in Austin, Texas, over the Lower Colorado River.

The High Island and the Spur 55 bridges are situated in the worst environment in Texas, near the Gulf of Mexico. The Lake Austin Bridge in Travis County is in a suburban location, away from coastal areas, and represents an ideal environment for weathering steel bridges.
Although the use of thickness measurements to determine section makes sense intuitively, it is actually not an effective way to evaluate weathering steel performance unless very significant corrosion has resulted, for two reasons. First, there is no data available showing the initial material thicknesses. Original nominal dimensions are available, but actual steel dimensions are normally not close enough to nominal thickness for the nominal thickness to be useful. Second, when steel corrodes, it expands, so it is not possible to differentiate between the amount of expansion and the amount of material loss.

The original plan-specified thickness and the as-measured thicknesses are shown in **Table 3 - 6.**

Table 3 - 6

Bridge Steel Plate Thickness Measurements with Ultrasonic Testing (UT)

Structure	Location of measurement	Plan specified thickness (in)	Average of three field measurements (in)	Difference between field and plan (in)	Steel plate thickness change (%)	Year Built
High Island	Interior girder web	1/2	0.500	0.000	0.00	1978 (21 years)
	Interior girder BF	2 1/4	2.300	+ 0.050	+ 2.22	
	Exterior girder web surface from inside	1/2	0.500	0.000	0.00	
	Exterior girder, BF from inside	2 1/4	2.300	+ 0.050	+ 2.22	
Lake Austin	Street level TF	2 1/4	2.320	+ 0.070	+ 3.11	1983 (16 years)
	Street level BF	2 1/4	2.317	+ 0.067	+ 2.98	
	Street level Web	1 1/8	1.150	+ 0.025	+ 2.22	
	Near support TF	1 5/8	1.667	+ 0.042	+ 2.58	
	Near support Web	1 1/4	1.263	+ 0.013	+1.04	
Spur 55	Exterior girder web surface from inside	1/2	0.55	+0.05	+10	1979 (20 years)
	Interior girder web	1/2	0.55	+0.05	+10	
	Interior girder BF	2 1/2	2.60	+0.10	+4	
	Exterior girder, BF from inside	2 3/4	2.80	+0.05	+1.82	

All field thickness measurements were equal or greater than the detailed nominal thickness. This situation occurs for two reasons. First, steel plate is always rolled to a thickness greater than nominal. Second, as discussed above, when steel rusts, the rust is thicker than the base metal it replaces. Therefore, the thicker than nominal dimensions recorded in this study were probably a result of the original oversize of the material and the rust present on the steel surfaces.

In a similar research project, Boise State University in Idaho made ultrasonic measurements of several bridges for the Idaho DOT and developed statistics from the data. They cited an average measurement thickness increase of 1.914 % per ten-year period, and used this number as part of their determination that they are satisfied with the performance of weathering steel in their bridges [10].

CHEMICAL ANALYSIS OF RUST SAMPLES

Sampling and Location

Samples of rust flakes were taken from seven locations and were tested for chloride content by a silver nitrate titration method cited in TxDOT Test Method 620-J [12].

The exposure to chloride on these structures varied from high-salt environments, the (Intercoastal Waterway, where the water is brackish – four miles from the Gulf of Mexico) to low (Colorado River west of Austin). None of the urban Austin or Houston bridges had been sanded for ice control in winter weather (with or without salt) in at least a year and a half before the samples were taken. Because most samples were taken from webs, residual salt from previous ice treatments should have been nearly nonexistent. The field visits did not include any weathering steel bridges that receive a lot of deicing compounds.

Results of Tests

Test results on the rust samples ranged from 800 to 2500 ppm. Some of the results deviated so much relative to those expected (as an example, the 800 number just cited should have been less than 100) for the particular location that the test solutions of four samples were re-titrated to check for errors. These results were even more inconsistent. As an example, on retest, two samples from anticipated low to moderate (100-250) chloride sources went from 1500 ppm to 7400 ppm.

Due to the poor correlation of high to low chloride availability with samples from the same structure and poor correlation on retesting of several samples, the results are unreliable and not considered valid. Therefore, chemical analysis of the cited TxDOT weathering steel bridges is not incorporated into this report.

SURFACE TESTING FOR CHLORIDES

Although laboratory analysis of rust samples in solution provided uncertain results, accurate surface chloride levels were obtained on one structure using a surface testing method. On-site detection of salt deposits was conducted on a railroad bridge that spans Route 37 in Corpus Christi, using a commercial chloride test kit that measures chloride in parts-per-million (ppm) on the surface of objects. This test revealed no sign of salt on the surface of fascia webs or on the top and side surfaces of top flanges.

The TxDOT Materials Section laboratory used the same test kit to analyze chloride content on surfaces coated with a known quantity of salt. The results of these control tests validated the accuracy of the commercial kit.

PREPARATION AND CLEANING OF WEATHERING STEEL

Mill scale and other foreign matter should be removed by blast cleaning from any surface where aesthetics are important, such as exposed surfaces of steel bent caps and outside surfaces of fascia girders. It is important to specify an appropriate level of blast cleaning to ensure that all mill scale will be removed. Areas that are not properly cleaned will not oxidize uniformly, resulting in a mottled appearance for several months or even years, depending on the degree of exposure and the local environment. Mill scale is still present on the fascia surfaces of some TxDOT bridges that are over 20 years old. Because the mill scale on weathering steel is much tighter than on ordinary carbon steels, its removal requires a greater effort [4].

TxDOT Blast Cleaning Specifications

In the United States, bridge structures are normally blast-cleaned in accordance with one of the four SSPC requirements. However, TxDOT has its own defined levels of cleaning [13]. At present, one of the TxDOT cleaning levels is required for preparation of the fascia surfaces of weathering steel structures. In this study, the condition of fascia girders was examined in consideration of what would be the most appropriate level of blast cleaning.

TxDOT Specification Item 441.11(9) "Field Finish Requirements for Weathering Steel Structures in Unpainted Applications" requires that all loose mill scale be removed from fascia girders, including the outside surfaces of fascia beams:

After all erection, welding, and slab concrete placement has been completed, the Contractor shall restore the surfaces of all weathering steel to a uniform appearance by solvent cleaning, hand cleaning, power brush cleaning or blast cleaning, as deemed necessary by the Engineer. All outside surfaces of weathering steel fascia beams, including the underside of the bottom flange, the sides and bottom surfaces of steel bent caps or floor beams and all surfaces of bent caps extending beyond the fascia beams shall receive a Class "B" blast cleaning. No marking will be permitted on the outside face of any fascia beam [13].

Item 446.7(2) of the TxDOT Standard Specifications define two types of blast cleaning [13]:

> Class "A" Blast Cleaning - Class "A" Blast Cleaning is defined as the removal of all visible rust, paint, mill scale and other forms of contamination. The blasted area shall exhibit a uniform surface appearance when viewed with the unaided eye (20-20 vision).
>
> Class "B" Blast Cleaning - Class "B" Blast Cleaning is defined as the removal of all oil, grease, dirt, rust scale, loose mill scale, loose rust and loose paint or coatings. Tight mill scale and tightly adhered rust, paint and coatings are permitted to remain.

Field visits indicate that Class "B" Blast Cleaning is not sufficient for aesthetic performance, because it allows staining to continue and does not help form the protective oxide film. Class "A" Blast Cleaning is more appropriate than Class "B" for aesthetics because it requires all mill scale to be removed. However, Class "A" Blast Cleaning is too conservative, and costs from 2 1/2 to 3 times more than Class "B".

SSPC Blast Cleaning Specifications

Most other DOT's and fabricators use the SSPC: The Society for Protective Coatings "SSPC Blast Cleaning Specifications."

The Society for Protective Coatings (SSPC) specifications has four levels of blast cleaning, included as **Appendix F** [11]," which are defined briefly below:

- "Blast Cleaning to White Metal" (SSPC-SP 5): ". . . a white blast cleaned surface, shall be free of all visible oil, grease, dirt, dust, mill scale, rust, paint, oxides, corrosion products, and other foreign matter."

- "Near-White Blast Cleaning" (SSPC-SP 10): " . . . a near-white blast cleaned surface, shall be free of all visible oil, grease, dirt, dust, mill scale, rust, paint, oxides, corrosion products, and other foreign matter, except for staining. Staining shall be limited to no more than 5 percent of each square inch and may consist of light shadows, slight streaks, or minor discoloration caused by stain of rust, stain of mill scale, or stain of previously applied paint."

- "Commercial Blast Cleaning" (SSPC-SP 6): " . . .a commercial blast cleaned surface, shall be free of all visible oil, grease, dirt, dust, mill scale, rust, paint, oxides, corrosion products, and other foreign matter, except for staining. Staining shall be limited to no more than 33 percent of each square inch and may consist of light shadows, slight streaks, or minor discoloration caused by stain of rust, stain of mill scale, or stain of previously applied paint."

- "Brush-off Blast Cleaning" (SSPC-SP 7): " . . .a brush-off blast cleaned surface, shall be free of all visible oil, grease, dirt, dust, loose mill scale, loose rust, and loose paint. Tightly adherent mill scale, rust, and paint may remain on the surface."

A commercial blast-cleaned surface will allow a somewhat uniform weathering of the fully exposed steel and is recommended for most applications, such as that required in 441.11(9) [13] especially if performed in the shop [11].

The cost of "Commercial Blast Cleaning" is least expensive, compared to near-white blast cleaning and blast-cleaning to white metal. A near-white blast cleaned surface provides an intermediate level of surface preparation and provides moderate cost cleaning, approximately 30 percent more than the cost of SSPC-SP6, and should be considered only where a very high degree of uniformity is recommended.

Either the "Blast Cleaning to White Metal" (SSPC-SP 5) and "Near-White Blast Cleaning" (SSPC-SP 10) will provide a much better surface than "Commercial Blast Cleaning" (SSPC-SP 6), but both are very expensive. SSPC-SP-5 is approximately 2 to 3 times the cost of SSPC-SP 6, and is not recommended because such cleaning requires automated equipment and is very difficult to achieve in a fabricator's shop. SSPC-SP 10 is only slightly less stringent that SSPC-SP 5.

The SSPC-SP7 “Brush-off Blast Cleaning” is not recommended (nor discussed here) because it is similar to TxDOT Class “B” blast cleaning, which allows tight mill scale to remain.

Field investigations of TxDOT weathering steel structures indicate that mill scale contributes to the continued corrosion of the surfaces beneath it. Therefore, it is recommended that the TxDOT specification call for SSPC-SP6 “Commercial Blast” instead of Class “A” or Class “B,” to assure that all mill scale has been removed from all fascia surfaces. As discussed earlier, this cleaning method needs to be performed in the shop. Blast cleaning performed at the construction site is prohibitively expensive because of logistical, equipment, safety, traffic control, and environmental considerations.

After blast cleaning is completed and surfaces begin to weather uniformly, only a suitable solvent should be used for further cleaning needs. Spot reblasting should not be used to remove writing, accumulated oil, and grease [13], because it will result in an uneven, nonuniform, protective oxide formation.

Field observations showed that many bridge members were adequately protected by an oxide film, but had stained, mottled, and streaked areas on the fascia beams. Mottled or blotchy areas as shown in **Figure 2**, below, are generally caused by spot blasting to clean small areas of a fascia girder. Incomplete blasting, which allows mill scale to remain on the surfaces will create streaks and blotchy areas such as those seen in **Figure 3**, on the next page.

Figure 2 – Poorly textured weathering steel members after spot reblast

Figure 3 – Streaks and blotchy appearance caused by improper removal of mill scale

Different colors of streaking can be caused by markings that were not removed during fabrication **(Figure 4)** below. Because the streaking discovered during this investigation occurred on members that had proper run-off detailing, it did not contribute to staining of concrete members. However, the discoloration reduced the attractiveness properly matured weathering steel can provide.

Figure 4 – Different colors of staining from markings not removed with solvent after blasting

ECONOMIC ANALYSIS

In its bare, mature state, weathering steel has a unique, natural oxide protective oxide film about the same thickness as a heavy coat of paint. This protective oxide film is dense, tightly adherent, and relatively impervious to further atmospheric corrosion. Minor damage to this oxide film heals itself. Therefore, maintenance is greatly reduced compared to a painted bridge. Bare weathering steel is suitable for many atmospheric environments, including moderate industrial and some marine exposures [4]. Because little or no initial painting or subsequent repainting is required, weathering steel results in significant first cost and life-cycle cost savings.

When considering the suitability of weathering steel, engineers must consider the life-cycle cost of the structure, including initial cost, cost of maintenance, repaint interval, and the time/value of money. According to the Transportation Research Board, the calculation of life-cycle cost shows that bare, maintenance-free weathering steel (initial cost only) should be the more economical [16]. Further, S. Frondistou-Yannas estimated, in 1981, that the cost advantage of uncoated weathering steel main girders, compared to painted steel main girders, ranges from 10 to 20 percent depending on the paint system [7].

On an initial cost basis, uncoated weathering steel is less expensive than either painted carbon steel or painted high-strength low-alloy steel, and the difference increases with increasing sophistication of the paint systems utilized. When the costs of future maintenance painting of steel are taken into account, cost advantage of uncoated weathering steel becomes even greater. As an example, it has been estimated that Pennsylvania realized initial cost savings of about $200 per ton for uncoated weathering steel versus painted carbon and high-strength low-alloy steel for a bridge opened in 1988. Life-cycle cost savings of about $1 million (equal to the initial cost of the superstructure) were also projected [3].

Fabricators have reported that painting bridge steels in their shops represents 10 to 15 percent of their shop time. Without painting, fabrication is faster, material-flow and handling throughout the shop is simplified, and the cost of paint itself is eliminated.

Further, if maintenance coating can be eliminated or significantly reduced, the costs and public inconvenience of managing traffic flow, lane reductions, or outright traffic closure can also be eliminated.

Finally, environmental benefits result from the use of weathering steel. The reduction in initial painting reduces emissions of volatile organic compounds when oil-based coatings are used. The elimination of coating removal and disposal of contaminated blast cleaning debris over the life span of the structure is another significant environmental benefit. In some instances, the estimated cost of the collection and disposal of materials from a structure repainting project were so great that the structure was either abandoned or replaced with a new bridge [18].

The cost savings cited above are only realized if the material performs well. The field investigation of 39 TxDOT weathering steel structures indicates that, despite the lack of an even protective oxide film covering the entire superstructure, the steel is in good condition and is performing well, indicating that the use of weathering steel has provided Texas taxpayers the savings anticipated.

According to S. Frondistou-Yannas, there were about 330,000 steel bridges in the U.S. in 1981. Of these, several thousands must be coated every year to protect them from corrosion, while others have to be rehabilitated and repaired because of past inadequate corrosion protection. Moreover, some new steel bridges are built with special steels that are more resistant to corrosion, and therefore are more expensive. Frondistou-Yannas claims that the total corrosion bill paid by taxpayers for steel bridges of hundreds of millions of dollars annually could be eliminated with pertinent, timely, and reliable information on bridge protection [7].

NATIONAL WEATHERING STEEL SURVEY

As part of this research project, in May of 1999 TxDOT polled the 50 state DOTs and the Ontario Ministry of Transportation. Only one question was asked: "Does your jurisdiction prohibit the use of weathering steel in its steel bridge structures?"

Ontario and 46 states responded that they did not prohibit its use. Only four states answered "Yes." Two or these, Alabama and Georgia, have used it but will not use it again. The other two, Alaska and Arizona, have not used it and will not use it in the future.

Chapter 4 – Weathering Steel Staining

During on-site inspection of weathering steel bridges, significant staining of concrete support structures was observed. This staining was so prevalent that the scope of this research project was broadened to include investigation into how such staining occurs. This chapter discusses this staining and suggests methods to prevent or minimize it. (Minor staining from other sources is discussed at the end of this chapter.)

PROBLEM

Rust-colored stains represent a critical weathering steel performance issue because they mar the appearance of bridges and because they create the perception that the bridge is rusting away. To the travelling public, the sight of rust stains on concrete bridge members may suggest poor design, wasted tax dollars, and/or potential safety problems.

PROBLEM SOURCE

Water flowing over weathering steel contains suspended particles of insoluble iron oxide (rust), particularly when the steel is subjected to frequent rainfall during the early months of exposure. As this water runs over concrete piers and abutments, the rust stains and streaks the concrete. Although the rate at which weathering steel releases oxide particles decreases with the length of exposure [4, 14], the rust particles accumulate on concrete surfaces and the stains get worse.

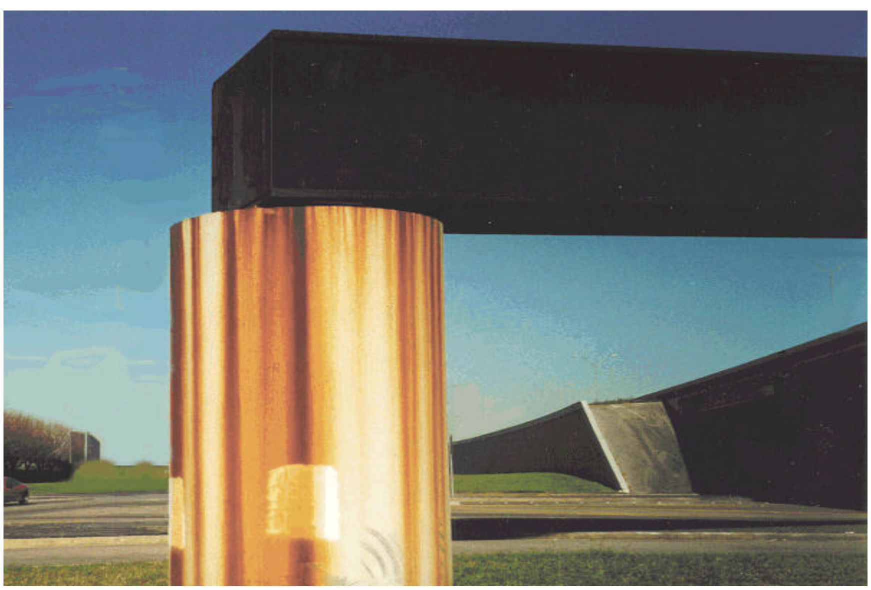

Figure 5 - Continuing rust staining on pier

To investigate whether weathering steel would continue to stain a bridge structure after several years of service, two sections of two piers at Beltway 8 over Ella Boulevard in Houston were coated with a layer of lane-marking spray in May of 1998. In March of 1999, the site was revisited and stain discoloration was observed on both test patches (See **Figure 5,** on previous page).

Samples were taken from each of the paint patches, cutting through all surface coatings to the concrete of the pier. Inspection of these samples showed that each piece had surface layer of staining, a layer of clean white paint, a layer of much darker oxide staining, a layer of clean white pier coating, and finally the concrete itself.

This investigation showed that, in a representative weathering steel structure, the staining process continues. When a structure is not properly detailed with drip caps, a quick paint job to improve appearance will not solve the problem: the run-off will continue, the staining will continue, and the need for re-painting will continue. The solution is to design the structure with drip pans and install them as an integral part of the construction phase, or, on existing structures, retrofit them with drip pans.

Even if subsequent run-off water is diverted, the stains remain, creating aesthetic and perception problems. However, rust staining can be controlled and should not be a reason to avoid the use of weathering steel.

METHODS TO PREVENT OR MINIMIZE STAINING

Effective stain control demands that staining be considered in all phases of a bridge's life – from design, fabrication, construction, through regular maintenance.

Preventing or Minimizing Staining During the Design Phase

Any flow of water over weathering steel members can provide corrosion and subsequent staining. The best way to minimize staining is to incorporate permanent design details that divert run-off water away from adjacent vulnerable materials.

Primary Methods to Control Staining

Drip pans and drip plates are very effective and highly recommended for fascia girders and steel bents. Figures 6 through 11 show various structures with and without drip pans.

Drip Pans

Drip pans direct rust-laden water away from piers. Site visits indicated that using drip pans is the most effective way to prevent staining of concrete abutments and piers. Drip pans made from 1/16" to 1/4" stainless steel and galvanized steel sheet were observed. They performed well when properly installed. The designer should specify the material, thickness, and dimensions.

For steel straddle bents, drip pans should be placed above the elastomeric bearing, under the beam seat, and extend beyond the edge of the pier.

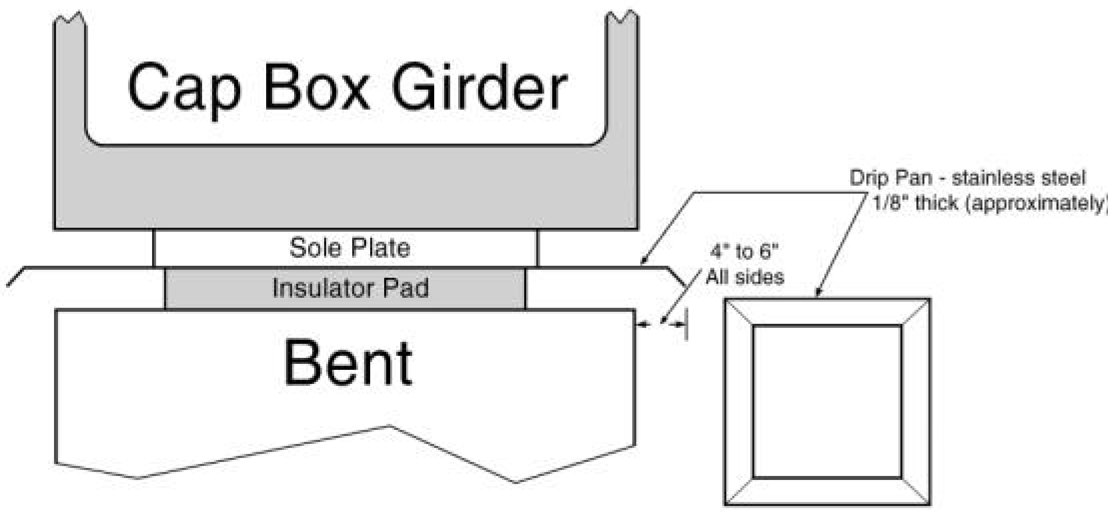

Figure 6 - Well-designed drip plan installation

Figure 7 - Stained concrete due to lack of a drip pan

Figure 8 - Stain-free concrete due to proper installation of well-designed drip pan

Figure 9 - Concrete column without protection of drip pan

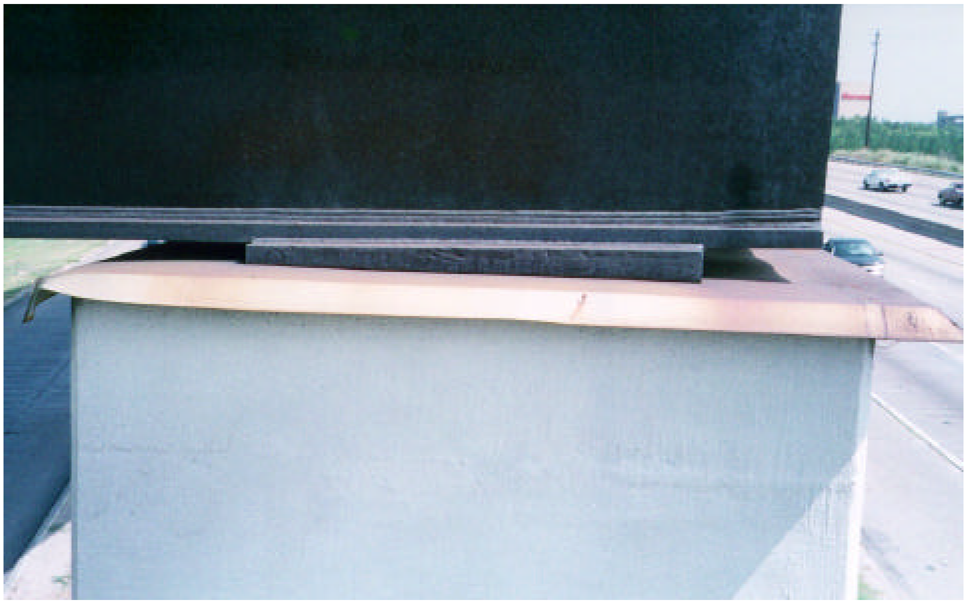

Figure 10 - Concrete column well protected by drip pan with proper overhang

The extension or overhang should be great enough (at least 4" to 6" from each edge of the pier) to prevent run-off water from being blown onto the supporting concrete members. Wherever possible, all four sides should be bent down so water can escape easily. Bending only one or two sides may serve to contain water and dirt.

Figure 11 - Insufficient drip pan overhang permits run-off to blow onto pier

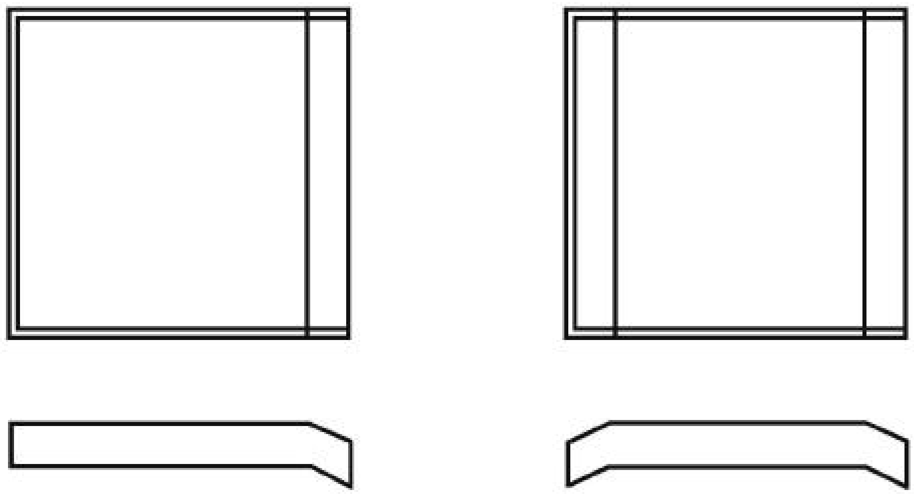

Figure 12 - Undesirable drip pan designs for columns

Although not normally recommended, as shown in **Figure 12**, above, in some locations, such as abutments, drip pans bent up on three sides will keep rusty run-off water from staining.

- **Drip Plates**

A drip plate is a small 'J'-shaped plate slipped over the bottom flange of a girder at a 30 to 45 degree angle. It is welded to both the top and bottom surfaces of the bottom flange and to the girder web, with a 3" vertical profile above and below the flange. Drip plates divert water off the steel before it runs onto another bridge component, such as a bearing pad or concrete pier. Figures 6 through 11 show various structures with and without drip pans.

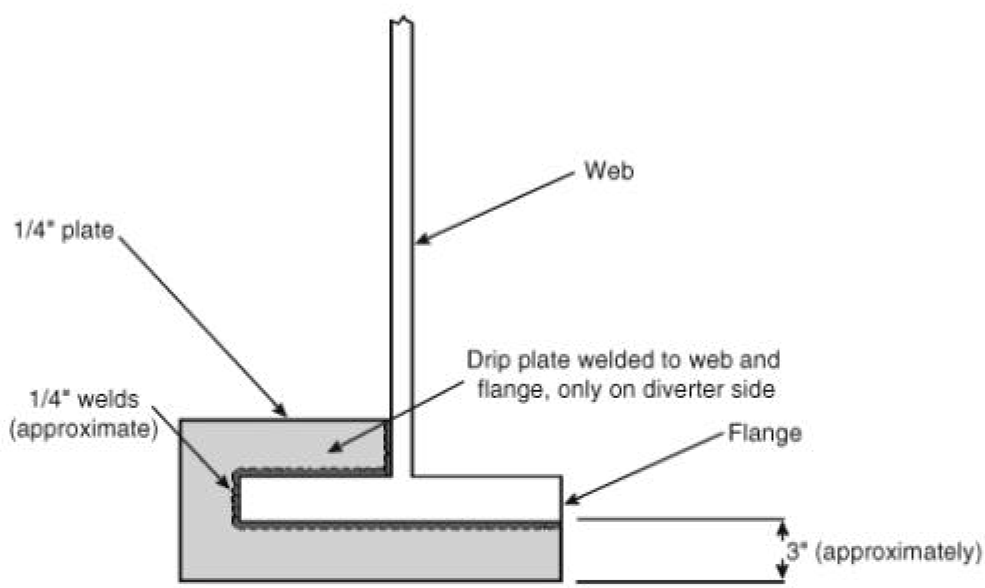

Figure 13 - Drip plate details

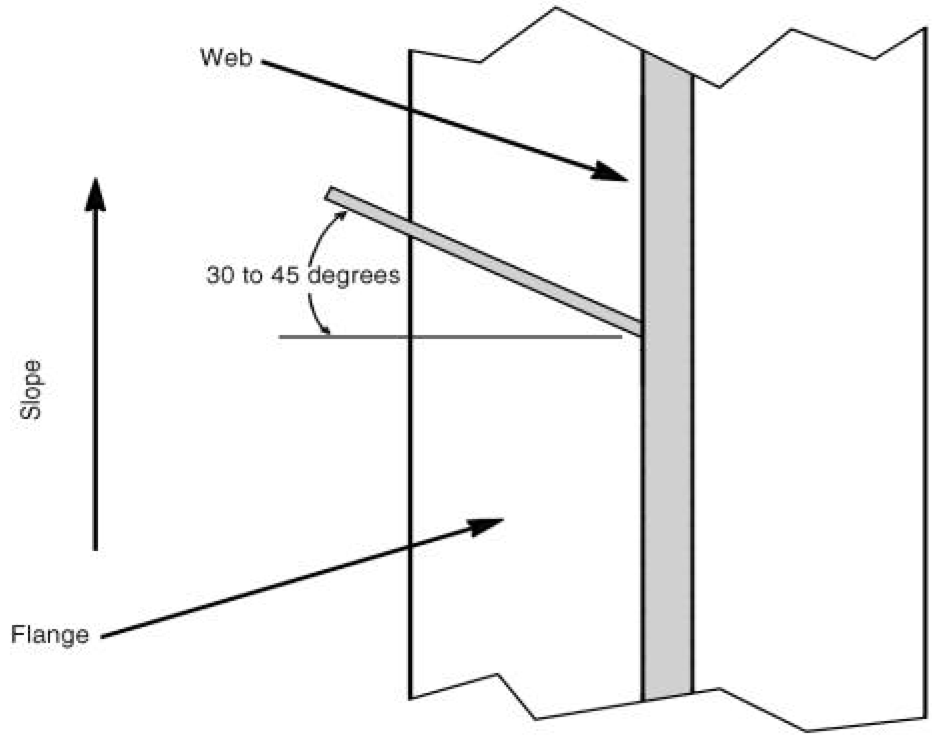

Figure 14 - Proper orientation of a drip plate

Figure 15 - Drip plate not set at proper angle

Figure 16 - Drip plate improperly set at 90^{o}, creating corner for debris accumulation

Drip plates should be fabricated from the same material as the bottom flange to avoid galvanic corrosion. The design engineer should be consulted before drip plates are retrofitted due to the introduction of a stress raiser on the bottom flange by the fillet welds.

Figure 17 - Results of lack of drip plates

Secondary Methods to Control Stains

Other methods to reduce the risk of concrete staining are less effective than drip pans and drip plates, but should be considered during the weathering steel bridge's design phase. As an example, with proper detailing, such as the use of certain types of support, abutments and piers can be protected from staining, as shown in **Figure 18.**

Figure 18 - Results of good design details

- **Troughs**

  Troughs and down-spout systems can be used beneath open finger-type joints as part of a system to discharge run-off away from the superstructure elements. However, these systems require regular maintenance because they may clog and allow water to overflow. Troughs are recommended by the industry, but, during field visits, no troughs were observed.

- **Joint Reduction**

  Joints should be eliminated whenever possible **(Figure 9)**. Bethlehem Steel reports that jointless bridges up to 400' in length with integral abutments have been used successfully. Bridges up to 1600' in length, with joints only at the abutments have performed well. The combination of weathering steel and jointless or minimum-joint decks offers long-term durability and low-maintenance. When joints cannot be avoided, they should be sealed and maintained properly. At any joint where water can flow onto fascia girders, drip pans and drip plates should be used.

Figure 19 - Long span, jointless bridge

- **Sealed Joints**

All joints should be sealed. Neoprene compression seals are commonly used for this application. However, these seals will leak over time due to traffic and bridge movements and require maintenance.

Preformed elastomeric compression joints, shown in **Figure 20,** [4], provide a thorough seal against deck surface water when installed and functioning properly. These joints help prevent water from draining through and staining substructure surfaces [4]. Even when joints are sealed, drip pans and dip plates are still necessary to direct rust-laden water away from piers and other concrete surfaces.

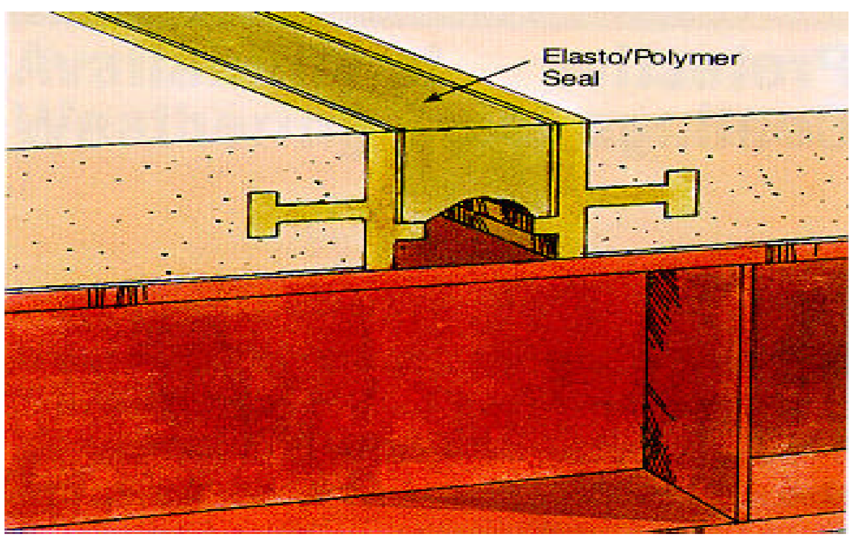

Figure 20 - Polyseal joint

- **Sloping Abutments, Pier Details, and Drains**

  Various combinations of sloping and concave surfaces used on abutments and piers in conjunction with drains provide an alternative method of minimizing staining. The rust-laden run-off water is directed to areas that are not readily visible. Drains then collect this water and carry it away, as shown in **Figure 21**, below.

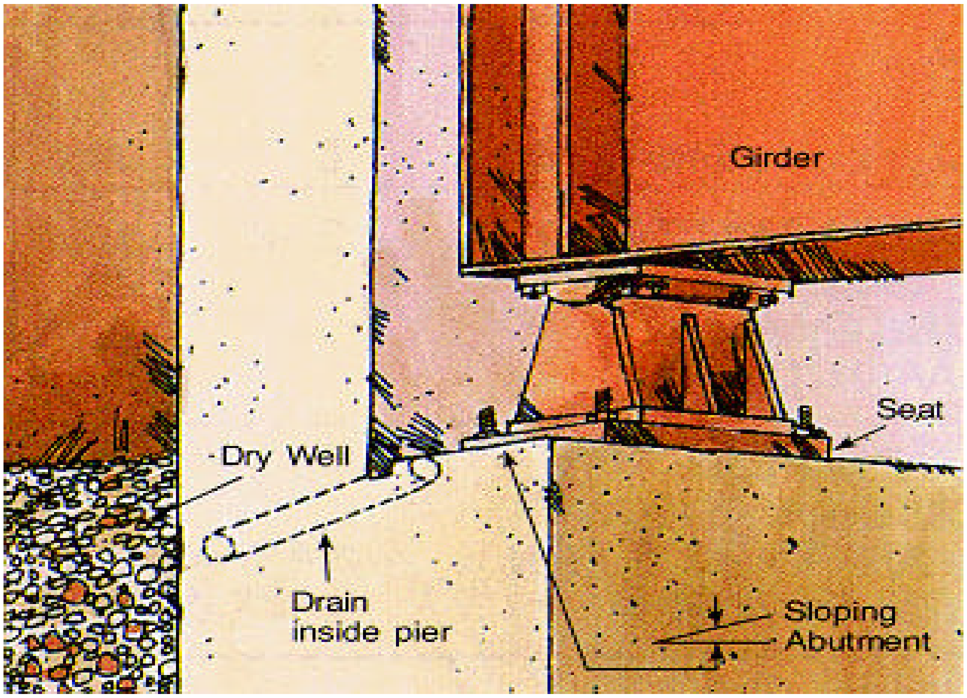

Figure 21 - Drawing of proper drain installation

- **Other suggestions include:**

  - Slope the abutment cap towards the retaining wall and drain the water through a pipe into the dry well behind the wall [4]. Drainpipes must be cleaned periodically to avoid clogging.

  - Minimize scuppers to produce maximize flow through each, thus avoiding blockage. Divert approach roadway drainage from the bridge structure. Provide adequate drainage beneath overpass structures to prevent traffic spray from below.

  - Build a parapet wall on top of piers and abutments. Drain the water through a pipe embedded in the concrete or channel the overflow with a V-groove on vertical surfaces or down the surface of the abutment.

- Avoid directing any water run-off from the roadway onto the top of weathering steel box bents. As shown in **Figure 22,** below**,** run-off from this concrete roadbed escapes through the gap created by a joint in the retaining wall beside the roadway. This water, if not diverted, will tend to flow to the end of the box bent, seriously corroding the top surface and staining concrete beneath the box bent (See **Figure 23**, on the following page). A drip plate diverting this water into a drain pipe would solve this problem.

Figure 22 - Staining associated with drainage located on top of a steel bent

Preventing or Minimizing Staining During the Fabrication Phase

During fabrication, special care must be taken to ensure satisfactory aesthetic appearance of weathering steel. The sooner weathering steel is exposed to wet-and-dry cycles, the sooner the protective oxide film can begin to form. If the fabricator can store the member outside, where it can be exposed to rain and dew followed by drying, it will begin to form a more even and durable coating and a reduction of rust run-off. Occasional wetting down with a hose will also contribute to the coating formation.

Careful blasting of the top surfaces of steel bent caps will allow a better protective oxide film, and reduce rust-laden run-off onto supporting piers **(Figure 23)** on the following page.

Figure 23 - Incomplete blasting of a steel bent cap

Preventing or Minimizing Staining During the Construction Phase

During bridge construction, the most severe staining conditions occur prior to placement of the deck. When water running over the weathering steel superstructure is free to flow onto piers and abutments. To prevent staining during this period, all affected concrete surfaces should be draped, wrapped, or otherwise sheltered with a heavy-gauge water-proof covering, such as polyethylene sheeting, capable of resisting tearing by wind gusts and construction operations [4]. Once the deck is in place and systems are installed to carry away rust-laden water, the plastic sheets can be removed. Only piers without drip pans need to be wrapped.

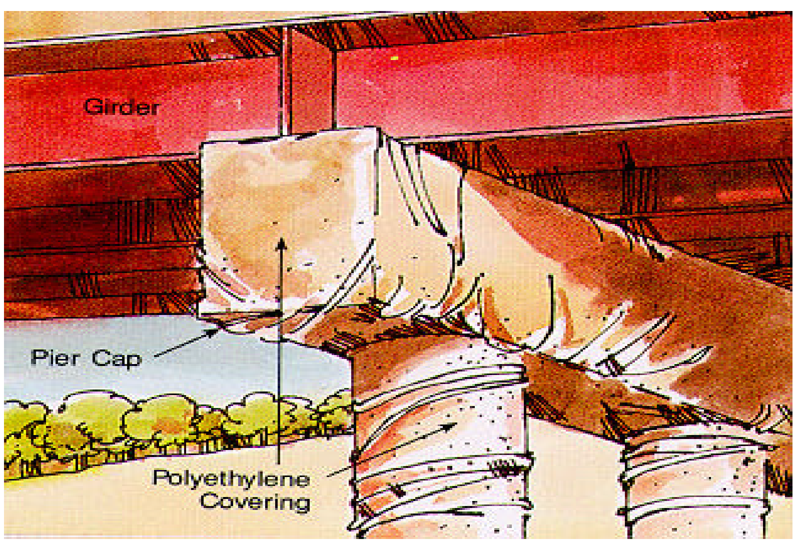

Figure 24 - Wrapping of bents and column

The exterior surfaces of weathering steel are very sensitive. During construction it is important to avoid anything that could inhibit proper drainage or alter the steel's oxidation patterns. Discoloration of the steel or staining of concrete surfaces could result.

Figure 25 (below) shows a good example. Here, temporary welds were placed on the top flange of a weathering steel box bent cap. It appears likely that nonweathering steel consumables were used for the welds. These welds were not properly removed and, after erection, they began to corrode at an accelerated rate, resulting in the stains on this box girder.

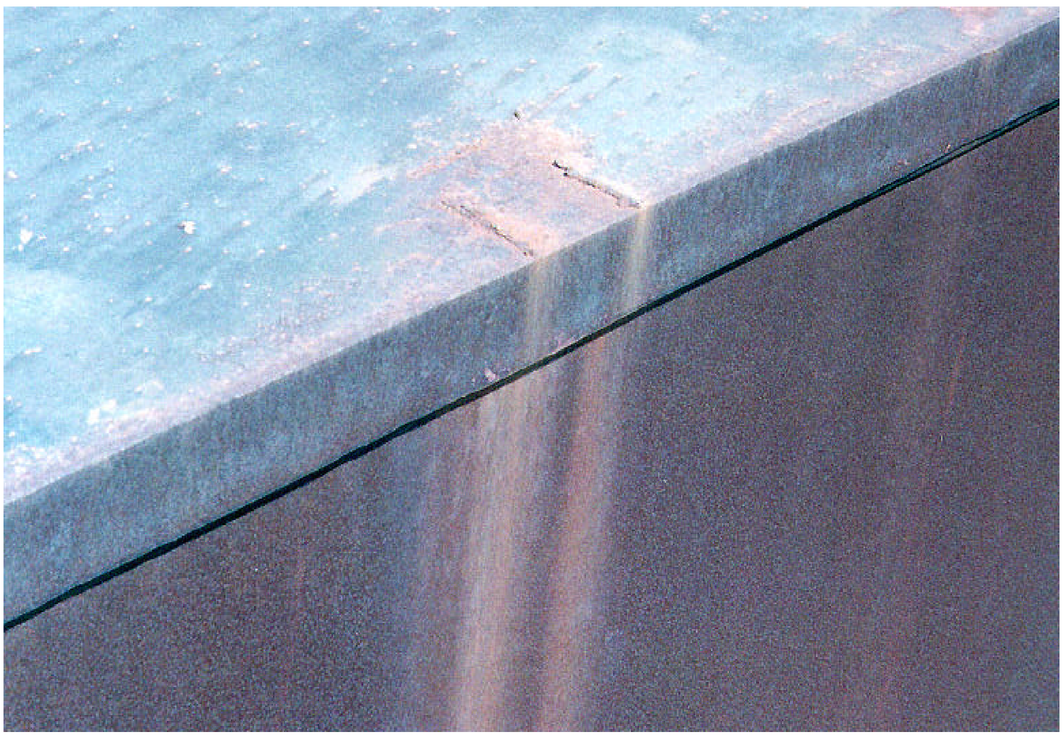

Figure 25 - Welds need to be ground out of surrounding surfaces

Preventing or Minimizing Staining While the Structure is in Service

Retrofitting of Drip Pans and Drip Plates

Drip pans and drip plates, if not part of the original design, can be added to minimize staining. A design drawing of such a pan is shown in **Figure 26** on the following page**.** However, these pans must be properly located and installed to work effectively. **Figure 27** shows such an installation and the lack of run-off staining on the pier it supports.

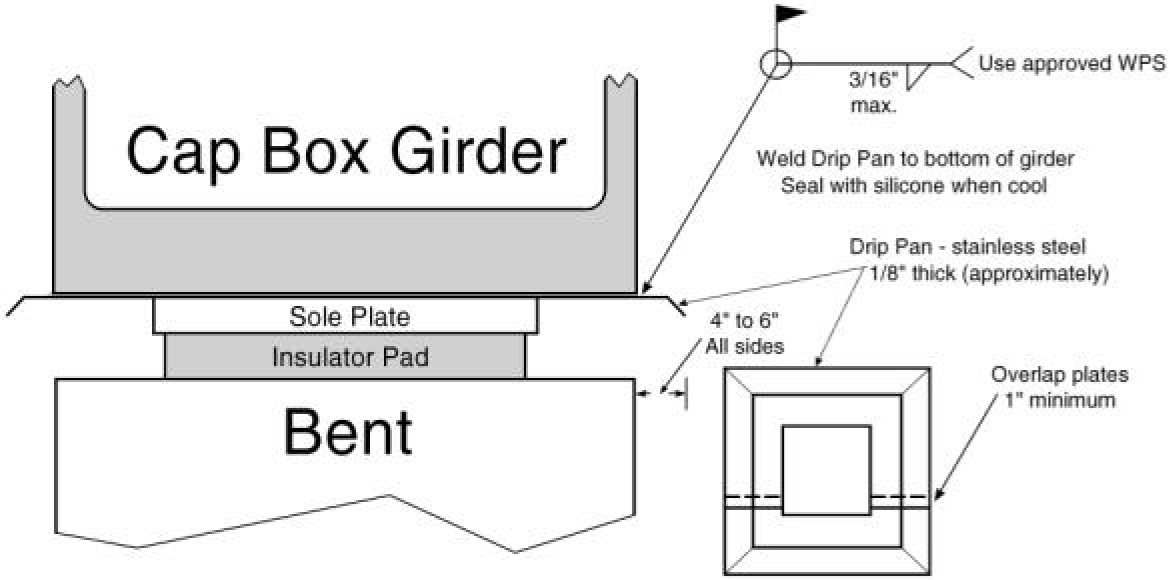

Figure 26 - Diagram of properly-designed retro-fit drip pan

Figure 27 - Properly retrofitted drip pan on pier

It is especially important to ensure proper welding. Burn-through caused by poor welding will allow leakage to stain piers and columns, as shown in **Figure 28,** below. The welder should be qualified, an approved welding procedure should be used, and the welding should be carefully inspected.

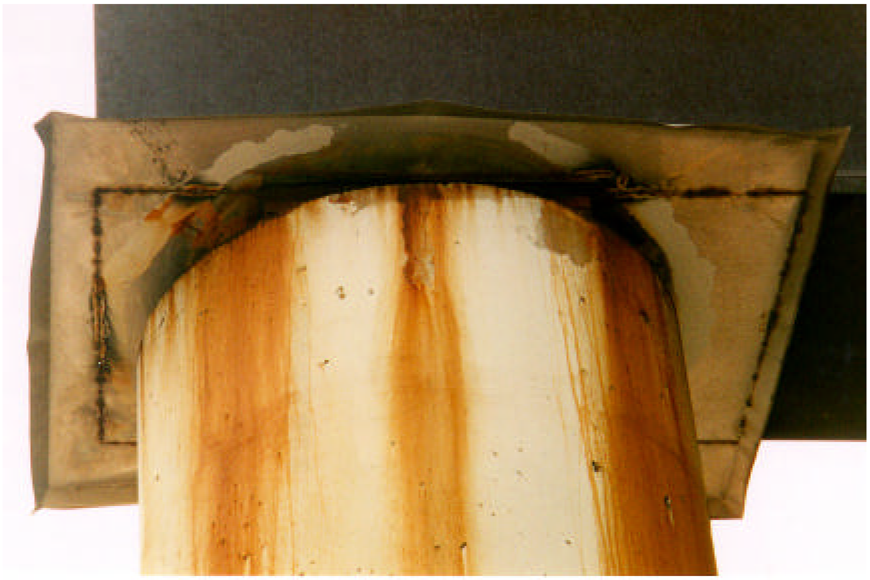

Figure 28 - Improperly retrofitted drip pan on pier allows staining

Notice in **Figure 29** that improper welding has created holes in the drip pan, allowing run-off water to leak through, staining the column below.

Figure 29 - Retrofitted drip pan, showing poor welding

Coatings

Brick, stone, and concrete can be coated with liquid silicone-based sealers or other proprietary formulations to reduce the penetration by rust stain. Although the coating reduces penetration of the rust particles, porous surfaces will still stain, but to a lesser degree [4]. The coatings can cause discoloration. Further, they may break down with time and have to be reapplied to continue protection. Thus, the treatment is not generally economical. The more effective and economical method is to reduce or eliminate the opportunity for staining during the design, fabrication, and construction phases.

Engineers should contact paint suppliers for paint specifications and the latest developments in coatings technology. Coatings are not necessary during construction if water-proof wrapping is properly employed.

Preventing or Minimizing Staining During Inspection and Maintenance

As with all structures, effective inspection and maintenance programs **(See Figure 30)** are essential to the successful performance of weathering steel bridges.

Inspection

Inspectors should inspect drip pans before and after installation, and particular attention should be given to welding, if performed. Attention should also be paid to drainage systems on and beneath the structure and its approaches.

Figure 30 - Example of inadequate maintenance

Maintenance

- Drip pans with any sides bent upward should be hosed down periodically.
- Troughs must be kept open and deteriorating joints resealed.
- Debris, dust, and bird/bat droppings should be periodically flushed from the structure itself, particularly beneath joints and around the bearings.
- Vegetation should be cleared from pier and abutment areas to enhance air circulation and the continual weathering of the steel.

Other Staining

Unsightly staining from bat droppings, as shown in **Figure 31**, below, mar the appearance of an otherwise well-detailed bridge structure.

Figure 31 - Bat droppings on concrete column

If the drip pan is designed with a 3/4" to 1-1/2" spacing between it and the concrete, and with a minimum depth of 5", the result will be a home for bats. Greater or lesser dimensions will not attract bats, thus eliminating the source of this staining.

Unsightly staining, caused by run-off water at a joint in the roadbed, is shown in **Figure 32,** on the following page.

Figure 32 - Staining from road joint run-off, not weathering steel

Stain Removal from Concrete

Stained surfaces of concrete piers and abutments of existing bridges can be cleaned using several methods, including water blast, sand or other abrasive blast, or chemical stain removers.

The water blast process is the least expensive and utilizes high-pressure water (typically over 5,000 psi). This blast should be performed as specified in Section 427.7 – " Construction Methods" of the Texas Department of Transportation Standard Specifications [13].

The engineer needs a full evaluation to determine which method may work best. Note that staining will continue on these surfaces unless the cause of the staining is eliminated.

Rust-stained concrete can be cleaned by abrasive blast cleaning. There are many types of abrasive media or solvents that can be used.

Several chemical stain removers may clean stained areas. Stain removers based on hydrochloric acid or phosphoric acid can be applied to the concrete surface for 10 to 20 minutes and then scrubbed off with a bristle brush. The acid attacks the concrete by destroying a thin layer and, with it, the deposited rust particles. Acid solutions should never be allowed to drain over the steel because they can attack not only the protective oxide but also the steel itself [16]. If chemical stain removers are used to remove stains, they must be handled with proper safety precautions. The manufacturer's recommendations and warnings must always be followed.

Chapter 5 — Conclusions and Recommendations

Weathering steel offers significant advantages to TxDOT for use in bridges. With weathering steel, TxDOT saves the costs of initial and maintenance painting and avoids the traffic disruptions associated with maintenance painting. Further, weathering steel bridges can be aesthetically pleasing.

However, there has been concern at TxDOT about how well weathering steel performs. Weathering steel, unlike other carbon steels, contains additional alloy elements that keep it from rusting away when exposed. The rusting process begins like it does with other steels, but the rusting is only supposed to progress to the point where a tightly adhering oxide layer forms on the surface and prevents further corrosion. At TxDOT, there are varied opinions about whether or not this protective oxide film actually forms and about whether or not the weathering steel bridges are rusting away. Further, a number of the weathering steel bridges in Texas have very significant stains on the concrete columns and abutments. These stains not only support the opinion that weathering steel bridges are rusting away, but also result in ugly bridges.

This research was undertaken to determine how well weathering steel is actually performing on Texas bridges and to address important performance issues, such as staining.

SUMMARY OF OBSERVATIONS

TxDOT has been building weathering steel bridges since 1970, and now has over 100. Field visits were made to a large sample of these bridges. The bridges were examined for presence of protective oxide film, section loss, presence of chlorides, cause and control of staining, and any other apparent corrosion and aesthetic performance issues. The following observations were made during this study.

Presence of a Protective Oxide Film

A protective oxide film has formed at some locations on some bridges. The formation of a protective oxide film is a function of the time and amount of exposure, the temperature, and the type of environment. Where the steel is directly exposed to wet-dry cycles, a protective oxide film is present, but where the steel is not directly exposed to wet-dry cycles, a protective oxide film is not present.

A good example is the Lake Austin bridge on Loop 360. This bridge’s superstructure includes two exposed tied arches; the arches are comprised of rectangular box sections spliced together end to end. The top and sides of these boxes are directly exposed to rain and sun, and they have a well-formed, tightly adhering protective oxide film. However, the undersides of the boxes are not directly exposed to rain and sun, and they do not have a protective oxide film **(Figure 33)**. Instead, the underside surfaces are mostly characterized by mill scale or lightly flaking rust.

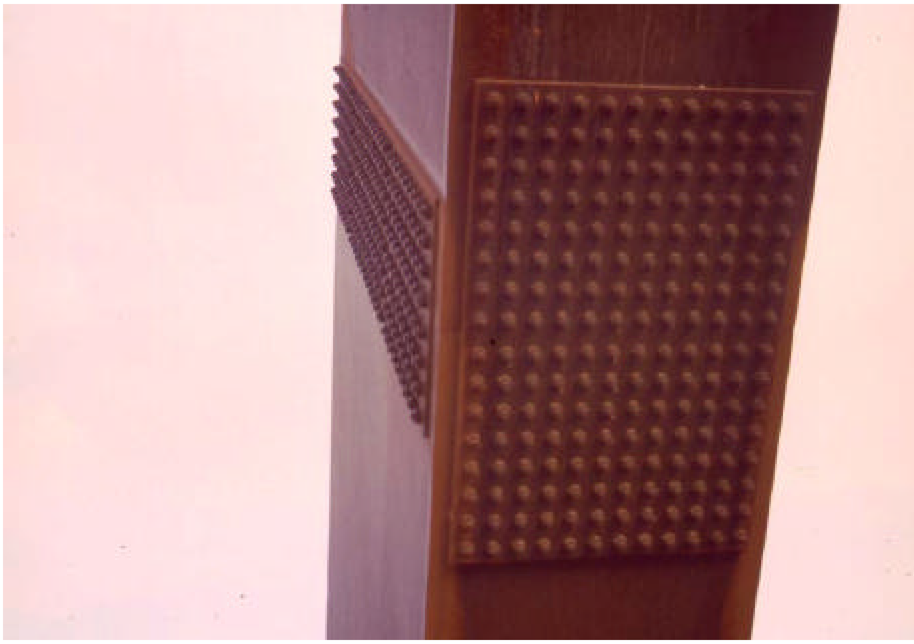

Figure 33 - Underside of weathering steel on Loop 360 Bridge arch

Tightly adhering protective oxide films can also be found on exposed straddle bents and on selected parts of I-girder and trapezoidal box girder direct connectors that are exposed and get direct rain or significant wetting from run-off. The presence of the protective oxide film and corrosion performance of weathering steel on TxDOT bridges can be characterized in three ways:

- Where a protective oxide film is present, the corrosion process has stopped.

- Where a protective oxide film has not formed, the condition is generally characterized by either small rust flakes or by mill scale. Although small flakes and mill scale are less than ideal, both conditions indicate that corrosion is proceeding at a very slow rate where the weathering steel is not directly exposed to wet-dry cycles. Mill scale was still present on some of TxDOT's earliest weathering steel bridges, and these are up to 28 years old.

- In near coastal environments, the performance of weathering steel on exposed surfaces is the same as exposed surfaces in other environments: a tight protective oxide film forms. On the nonexposed surfaces of near-coastal bridges, the performance appears to be different than other bridges in that the rust flakes are larger.

TxDOT does not have any weathering steel bridges right on the coast, but there are a couple of bridges over the Gulf Intercoastal Waterway where the water is brackish. A good example is the bridge on SH 124 north of High Island. This structure is 22 years old and is corroding so slowly that it still has mill scale present on some locations **(Figure 34)**.

Figure 34 - High Island Bridge stiffener with mill scale still visible

Because corrosion progresses so slowly in areas not directly exposed to wet-dry cycles, only fascia surfaces that have been properly blast-cleaned have an attractive, uniform appearance. Where fascia surfaces have not been properly blast-cleaned, mill scale is still present, resulting in a mottled appearance even on bridges over 20 years old.

Staining

Some amount of rusty run-off water will always be present on weathering steel bridges. Where it is not handled properly, this rusty water causes stains on concrete. However, where run-off is accommodated with proper detailing, stains are virtually eliminated.

A number of methods are employed by TxDOT for the control of staining. The most effective are drip pans and drip plates, but they must be detailed and installed correctly for them to prevent staining.

Detailing

Satisfactory performance of weathering steel depends on proper detailing. Surfaces exposed to rain, run-off, splashing, or any other source of moisture need special attention. Flowing water, or water that can mist the surface and then evaporate, is not detrimental to weathering steel. In fact, alternating wetting and drying is beneficial for weathering steel's appearance. However, water that ponds will accelerate corrosion of any steel, whether coated or weathering steel **(See Figure 35, below)**.

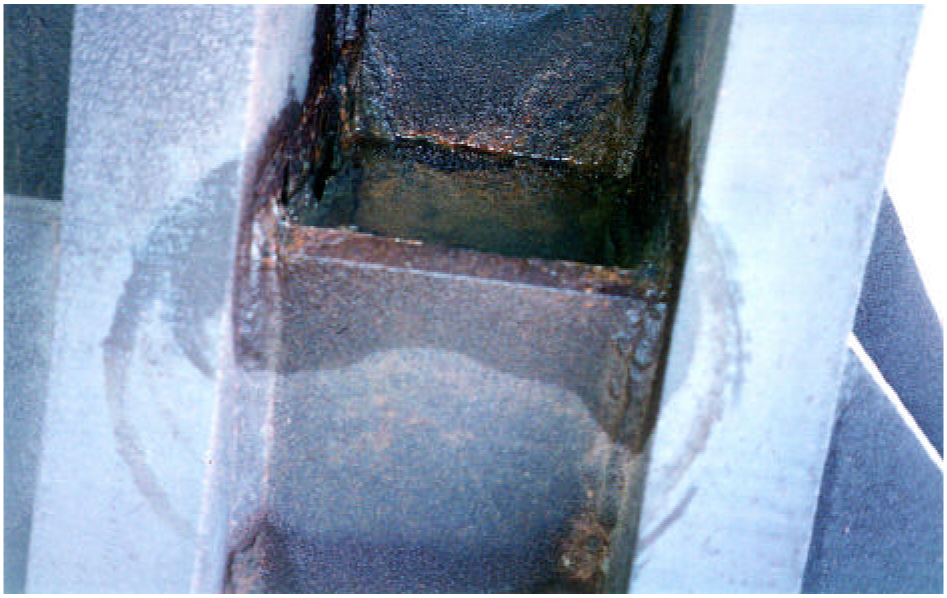

Figure 35 - Poor design detail allows water to pool, causing corrosion

As shown in the longer-range view of the figure below **(Figure 36)**, the lack of drain holes allows water to stand and reduce the life of the bridge and cause areas where run-off can occur **(Figure 37)**.

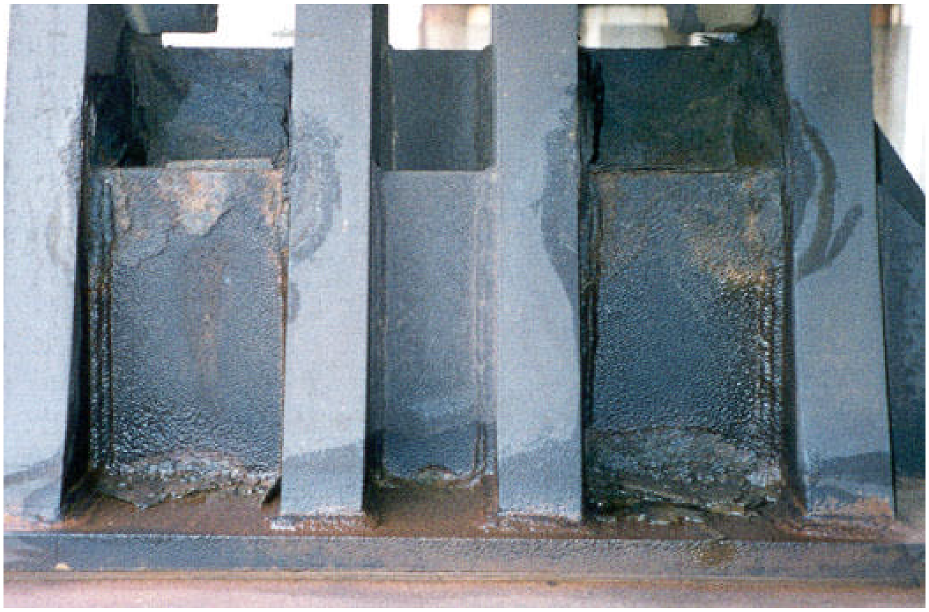

Figure 36 - Detailing this area to include drain holes would have eliminated ponding

Figure 37 - Proper detailing with drain holes allows good drainage

Debris is also detrimental. Debris that collects due to poor detailing tends to absorb moisture and/or inhibit the flow of run-off water, as shown in **Figure 38.**

Figure 38 - Accumulated debris completely restricts water flow

Use of Thickness Measurements for Evaluation of Weathering Steel Performance

Using thickness measurements to analyze section loss is not an effective way of evaluating weathering steel performance unless very significant corrosion has resulted. This is because precise initial thickness dimensions are not available and because steel expands as it corrodes.

CONCLUSIONS

Uncoated weathering steel is a very good material for TxDOT bridges. When it is directly exposed to the environment, a good protective oxide film forms, protecting the steel from further corrosion. In sheltered areas, corrosion proceeds too slowly to form an oxide layer, but this corrosion is so slow that it is not a concern.

Based on the Bridge Superstructure Condition Rating information provided by BRINSAP, which was confirmed by the on-site investigation of 40 weathering steel structures, TxDOT's experience with weathering steel bridges is encouraging, because none of these bridges is rated as 'fair condition' or lower.

In environments where de-icing salts are frequently used, weathering steel will perform well if special care is taken, including use of noncorrosive deicing chemicals and minimizing run-off onto the steel. More details about use of weathering steel in these environments are described in "Recommendations," below.

To achieve a smooth, uniform appearance, it is essential to blast-clean all fascia surfaces, otherwise mill scale will be present on the fascia surfaces for many years. The mill scale is not detrimental to performance of the weathering steel from a corrosion standpoint, but it is not aesthetically pleasing. Mill scale must also be removed from non-fascia surfaces that will be directly exposed to the elements, such as the top flanges of exposed straddle-bent box girders. Otherwise, staining on fascia surfaces will result from corrosion of the exposed non-fascia surfaces.

It is important to implement measures to control staining. It is inherent that some amount of rusty water will wash away from the weathering steel bridge members, both during construction and in-service. It is relatively simple to control staining. However, if the appropriate measures are not implemented, unsightly stains will result.

RECOMMENDATIONS

There are many ways to assure good performance from weathering steel and to reduce or eliminate unsightly concrete staining. Possibilities within the control of the designer, fabricator, and maintenance personnel include:

Design

- Provide drip pans to protect abutments and columns
- Provide drip plates to protect abutments and columns and divert the flow of run-off water
- Use details that take advantage of natural drainage
- Provide adequate drainage beneath overpass structures to prevent ponding and continual traffic spray from below.
- Provide stiffener clips (at least 2" X 2") for proper ventilation and drainage.
- Eliminate details that retain water, dirt, and other debris
- Provide details to divert run-off away from concrete

Fabrication and Construction

1. Blast-clean all outside faces of fascia beams, including the underside of the bottom flange, the sides and bottom surfaces of steel bent caps or floor beams and all surfaces of bent caps extending beyond the fascia beams, using SSPC-SP6 “Commercial Blast Cleaning” [11] in the shop.
2. Eliminate identification markings on the outside face of any fascia beam [13].
3. Apply an adequate protective coating to surfaces that may be subject to standing water
4. Apply an adequate protective coating to weathering steel that will be embedded in soil or gravel pockets. The coating should be one of the types used on carbon steel in the same environments, and extend above the interface of the embedment for several inches [4].

Additional Measures

- Use troughs beneath open finger-type joints as part of a system to discharge run-off away from the superstructure elements. This technique requires future maintenance to be certain troughs do not become clogged.
- Provide adequate drainage and venting to prevent condensation of unsealed tubular and box sections
- Install pipes that are flush with the bottom of box girders designed with drain holes. Pipes should protrude below the outside surface, so moisture doesn’t cause corrosion as the result of capillary moisture movement. See **Figure 39** below.
- Seal tubular and box sections
- Seal joints. Neoprene compression seals are commonly used in this application.
- Minimize joints. Jointless bridges up to 400' in length have been used successfully. Bridges up to 1600' in length, with joints only at the abutments, have performed successfully. The combination of weathering steel and jointless or minimum joint decks offers bridges of long-term durability and low-maintenance cost [4].

Figure 39 - Holes in bottom of box bent without drain pipes, allowing rust to form

In Service

- Periodically clean closed or confined areas where detailing can trap and retain water, dust, corrosives, dead animals, birds, and other debris
- Eliminate sodium chloride as a deicing agent wherever possible and use non-corrosive deicing products.

When Not to Use Weathering Steel

Weathering steel is not recommended if:

1. The atmosphere contains concentrated corrosive industrial or chemical fumes

2. The steel is subject to heavy salt-water spray or salt-laden fog

3. The steel is in direct contact with timber decking, because timber retains moisture and may have been treated with salt-bearing preservatives

4. The steel is used for a low urban-area bridge/overpass that will create a tunnel-like configuration over a road on which deicing salt is used. In these situations, road spray from traffic under the bridge causes salt to accumulate on the steel [4].

RECOMMENDED FUTURE RESEARCH

The following research is recommended to further enhance the performance of weathering steel:

- Develop specific criteria, possibly including a checklist, to evaluate sites for weathering steel suitability
- Develop a de-icing technique and de-icing or other similar products that will have a minor, if any, effect on weathering steel
- Explore the use of weathering steel and other materials for drip pans.

Bibliography

1. AISC Marketing, Inc. (1993). *Uncoated Weathering Steel Bridges* (Vol. I, Chapter 9, Highway Structures Design Handbook) Pittsburgh, PA.

2. American Iron and Steel Association (1995). *Performance of Weathering Steel in Highway Bridges – a Third Phase Report* Pittsburgh, PA.

3. Aulthouse, F.D., (1988). Economics of Weathering Steel in Highway Structures. *Article presented at the FHWA Forum on Weathering Steel for Highway Structures.*

4. Bethlehem Steel Corporation (1993) *Weathering Steel* (Booklet 3791) Bethlehem, PA.

5. ANSI/AASHTO/AWS D1.5-96 (1996). *Bridge Welding Code* Washington, D.C. & Miami, FL.

6. Culp, J.D. & Tinklenberg, G.L. (1980). *Interim Report on Effects of Corrosion on Bridges of Unpainted A588 Steel and Paint Steel Types* (Research Report Number R-1142) Michigan Transportation Commission, Lansing, Michigan.

7. Frondistou-Yannas, S. (1981) *Corrosion of Steel Highway Bridges: A simulation of Protection Alternatives and the Resulting Costs* (Paper Number 80) Management and Technology Associates, Newton, Massachusetts.

8. McCrum, R.L. & Arnold, C.J. (1980). *Weathering Steel Guardrail — a Material Performance Evaluation* (Research Report Number R-1155) Michigan Transportation Commission, Lansing, Michigan.

9. Raman, A. & Naszrazadani, S. (1989) *Corrosion Problems in Some Louisiana Bridges and Suggested Remedies* (Paper Number 165) Baton Rouge, Louisiana: Louisiana State University, Department of Mechanical Engineering.

10. Sener, Joseph C., Stanley, Alohn F., Farrar, Matthew M., & Jobes, Richard A. (1997). *Ultrasonic NDT of Bridge Steel and Weathering Steel Bridge Investigation in Idaho* Boise, Idaho: Boise State University, College of Engineering.

11. Steel Structures Painting Council (1985). *Systems and Specification — Steel Structures Painting Manual (Volume 2)* Pittsburgh, PA.

12. Texas Department of Transportation (1997) *Manual of Testing Procedures - Section 6 - Determining Chloride Contents in Soils* Austin, Texas.

13. Texas Department of Transportation (1995) *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges* Austin, Texas.

14. Tinklenberg, G.L. (1986). *Evaluation of Weathering Steel in a Detroit Freeway Environment* (Research Report Number R-1277) Michigan Transportation Commission, Lansing, Michigan.

15. Transportation Research Board — National Research Council (1984). *Performance of Weathering Steel in Bridges* (NCHRP Report 272) Washington, D.C..

16. Transportation Research Board — National Research Council (1989). *Guidelines for the Use of Weathering Steel in Bridges* (NCHRP Report 314) Washington, D.C. 20418.

17. U.S. Department of Transportation — Federal Highway Administration, (May, 1994). *NHI Course Number 13055 — Safety Inspection of In-Service Bridges* (Publication No. FHWA HI-94-033).

18. U.S. Department of Transportation — Federal Highway Administration, (October 3, 1989). *Technical Advisory — Uncoated Weathering Steel In Structures* (Publication No. T5 140.22).

Appendices

Appendix A

Michigan Weathering Steel Guardrail (WSG) Experience

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Michigan Weathering Steel Guardrail (WSG) Experience

In the 1960s, Michigan began using unpainted weathering steel for guardrail, hoping to make WSG maintenance-free by eliminating the need for periodic painting. A test stretch of guardrail was installed in 1963. A cursory examination of this site in 1978 revealed lapped joints bulging from the internal pressure of the corrosion products. Ultrasonic thickness gauge measurements indicated that some areas in the joint had lost up to 40 percent of their original thickness.

Studies performed by major steel companies with respect to the life of WSG have indicated typical thickness losses ranging from "unmeasurable" in the freely exposed central portion of the beam to 1.8 mil/year in the lapped joint area. The results of these studies are questionable because thickness measurements were determined by using micrometers and/or ultrasonic thickness gauges, both of which can give deceptive measurements. Micrometers give no indication of the depth or extent of pitting and, like ultrasonic thickness gauges (UTG), will not only measure the thickness of the good metal but also any added oxide film.

Ultrasonic thickness gauges can even overestimate thickness on a pitted surface. Ultrasonic wave transmission speed is slower in coupling agents used to seat the UTG probe than in the metal itself — thus, the deeper the pits, the greater the overestimate that can occur.

WSG test sections were obtained from two different service environments:

- Test site A was representative of an environment roughly midway between rural and urban, open and exposed to the appropriate environment to encourage proper weathering. The WSG had been in service for 15-1/2 years.

- Site B was a "tunneled" freeway site, where the material had only 4-1/4 years of exposure. The guardrail from this heavily traveled urban site should be representative of what can be expected under extremely poor conditions. Of the two beams taken from this site, one was partially covered with trash and debris. Both were located under overhead bridges. Neither rain nor direct sunlight was available to provide the alternate wetting and drying cycle necessary to create a protective oxide film. The beams were also subject to all manner of roadway pollutants, most notably salt distributed by passing vehicles. Without rainwater to wash the guardrail beams, pollutant deposits continued to build up and act in higher concentrations when moisture was present (dew, traffic spray, etc.).

The WSG joints were removed intact by sectioning the guardrail beams several feet either side of the joint, to evaluate the effects, if any, of the prestressed condition of the joint. The joints were packed solid in all samples from both sites with corrosion products, and most were obviously bulging from the internal pressure.

All full-size guardrail joints were statically pulled apart (in tension) until failure. With a known failure load, calculations were performed to solve for beam thickness, giving an empirically-based number representative of the 'effective' joint thickness at the specific location of failure. The derived failure equations also allowed a means of relating beam thickness to load sustained at failure (i.e., joint strength). Thus a starting thickness, known beam properties, and known corrosion rate for a particular environment would provide sufficient information to plot joint-strength versus age and an "effective corrosion rate."

A very noticeable difference in corrosion rate between a 'typical' (Site A) environment and a highly corrosive (Site B) environment weathering steel was found. These differences can be used to establish estimates of the limits of joint strength performance for the possible range of corrosion rates that can be expected to occur in our multitude of service environments.

The WSG at Site A showed a 20 percent reduction in strength after 15-1/2 years. The more corrosive environment of the B site resulted in an 11 percent reduction in strength after only 4-1/4 years [7].

Appendix B

Copy of Original Survey Form

Survey Concerning Weathering Steel in TxDOT Structures

1. Have you designed any steel bridge utilizing weathering steel members in the past?
Yes ☐ No ☐

2. Are you currently, or will you be designing any bridges using weathering steel in the near future?
Yes ☐ No ☐

3. Do you understand how weathering steel performs?
Yes ☐ No ☐

4. What criteria do you follow to determine if you are going to use weathering steel or not?
☐ Structural considerations
☐ Esthetic considerations
☐ Economical reasons (repaint and maintenance)
☐ Other___________________________________

5. As a part of your normal duties, do you make the decision to use weathering steel for a steel bridge?
Yes ☐ No ☐

6. Have you had any disappointment or complication with weathering steel?
Yes ☐ No ☐
Describe:____

7. Do you approve of or disapprove of painting weathering steel?
approve ☐ disapprove ☐

8. Will you use weathering steel again?
Yes ☐ No ☐

Appendix C

BRINSAP Weathering Steel Bridge Inventory

Inventory of Weathering Steel Bridges — February, 99

99 Structures

Dist.	County	Control	Section	Bridge Number	Facility Carried	Features Intersected	Location	Year Built	Sufficiency	Superstructure Rating
2	220	8	16	243	IH20 WBL	CLEAR FORK TRINITY R	0.6 MI W OF BRYANT IRVIN	01-Jan-81	96.1	7
3	49	45	1	231	US 82 WEST BOUND	AT & SF RR & DIXON ST	0.6 MILE EAST OF IH 35	01-Jan-97	92.2	7
3	49	45	1	232	US 82 EAST BOUND	AT & SF RR & DIXON ST.	0.6 MI EAST OF IH 35	01-Jan-98	97.0	8
10	1	205	7	38	US 79(EB)	TRINITY RIVER	ANDERSON - FREESTONE CL	01-Jan-96	92.4	8
10	1	205	7	63	US 79(WB)	TRINITY RIVER	FREESTONE-ANDERSON CL	01-Jan-95	98.0	8
10	108	719	4	5	FM 85	TRINITY RIVER	HENDERSON - NAVARRO CL	01-Jan-58	100.0	8
12	85	367	2	23	SH 124	INTRACOASTAL CANAL	3.50 MI N OF SH 87	01-Jan-78	83.4	7
12	102	27	13	205	BW 8 DIR CONNECT	BWY 8 & US 59 FR	INTER US 59 & BELTWAY 8	01-Jan-90	100.0	8
12	102	27	13	206	US59 DIR CONNECT	US 59 FR	INTER US 59 & BELTWAY 8	01-Jan-90	96.0	8
12	102	27	13	207	US59 DIR CONNECT	US-59 FRTG & CONN. NE-N	INTER US 59 & BELTWAY 8	01-Jan-90	96.0	8
12	102	27	13	209	US-59 SB MN LN	WESTPARK - S.P.T.C. RR.	8.5MI.SW.OF HOUSTON	01-Jan-93	85.0	8
12	102	27	13	213	US59 WB EX.RAMP"C"	CHIMNEY ROCK	US-59 @ CHIMNEY ROCK	01-Jan-93	84.0	7
12	102	27	13	239	US 59 SB ML	BELLAIRE BLVD	1.6MI SW OF WESTPARK	01-Jan-92	94.0	8
12	102	27	13	240	US 59 NB ML	BELLAIRE BLVD	1.6MI SW OF WESTPARK	01-Jan-92	94.0	8
12	102	27	13	243	US59 AVL/HILLCROFT	US 59 SB ML	2.25MI WEST OF IH610 & 59	01-Jan-92	81.0	8
12	102	27	13	244	HILLCROFT T-RP	US59 SB FR	2.25MI. SW OF IH610 & 59	01-Jan-92	80.0	8
12	102	27	13	247	US 59 ML SB	BISSONNET ST.	1.1MI NE OF BWY 8	01-Jan-92	96.0	8
12	102	27	13	260	BW8 DIR CONNECT	BW8 & CONN. N-SW	INTER US 59 & BELTWAY 8	01-Jan-90	97.0	8
12	102	27	13	272	US 59 NB ML	BISSONNET ST.	1.1 MI. NE OF BWY 8	01-Jan-92	98.0	8
12	102	50	9	142	DACOMA ST HOV RAMP	US 290	0.60 MI N OF IH 610	01-Jan-88		8
12	102	50	9	143	DACOMA ST HOV RAMP	US 290	0.60 MI N OF IH 610	01-Jan-88	88.5	8
12	102	50	9	176	BWSB CONNH US290WB	US290 WBFR	INTER US 290 & BELTWAY 8	01-Jan-90	92.0	8
12	102	50	9	177	US290WB CONNC BWSB	US290	INTER US 290 & BELTWAY 8	01-Jan-90	95.0	8
12	102	50	9	179	BWSB CONNA US290EB	US290	INTER US 290 & BELTWAY 8	01-Jan-90	100.0	8
12	102	50	9	180	BWNB CONNB US290WB	US290	INTER US 290 & BELTWAY 8	01-Jan-90	100.0	8
12	102	110	5	130	HARDY TOLL RD SB	IH 45 ML	0.30 MI S MONTGOMERY C/L	01-Jan-88	98.0	6
12	102	110	5	131	IH-45 NB FR	HARDY TOLL ROAD	0.3 MI S MONTGOMERY C/L	01-Jan-88	79.0	8
12	102	110	6	103	IH 45 NB HOV RAMP	IH 45 NB	0.5 MI N OF WEST RD	01-Jan-89	92.0	8
12	102	110	6	104	IH 45 HOV	IH 45	0.5 MI N OF WEST RD	01-Jan-89	92.0	8

12	102	110	6	105	IH 45 SB HOV RAMP	IH 45	0.5 MI N OF WEST RD	01-Jan-89	89.0	8
12	102	110	6	151	BELTWAY 8 EB ML	IH 45	.7 MI E OF GREENS CROSSIN	01-Jan-89	95.8	6
12	102	110	6	152	BELTWAY 8 WB ML	IH 45	.7 MI E OF GREENS CROSSIN	01-Jan-89	95.8	7
12	102	271	7	445	KATY HOV	IH 10 WB	0.45 MI W OF IH 610	01-Jan-85	95.0	8
12	102	271	7	447	IH10 HOV @ SH6	IH-10	JUST EAST OF SH-6	01-Jan-86	96.0	8
12	102	271	7	458	AVL RAMP CONN.	IH10WB FR	1/2 MI. EAST OF SH6	01-Jan-86	81.0	8
12	102	271	7	461	IH 10 RAMP “F”	IH 10 EBFR & BWY 8 SBFR	AT IH 10 & BWY 8 INTER	01-Jan-89	87.4	8
12	102	271	7	463	IH 10 RAMP “C”	IH 10 & BELTWAY 8	AT IH 10 & BWY 8 INTER	01-Jan-89	87.4	8
12	102	271	7	464	BELTWAY 8 RAMP "G"	IH 10 EBFR & BWY 8 NBFR	AT IH 10 & BWY 8 INTER	01-Jan-89	94.5	8
12	102	271	7	465	IH 10 RAMP "E"	IH 10 WBFR & BWY 8 NBFR	AT IH 10 & BWY 8 INTER	01-Jan-89	87.4	8
12	102	271	7	467	IH 10 RAMP "D"	IH 10 & BELTWAY 8	AT IH 10 & BWY 8 INTER	01-Jan-89	87.4	8
12	102	271	7	468	BELTWAY 8 RAMP "H"	IH 10 WBFR & BWY 8 SBFR	AT IH 10 & BWY 8 INTER	01-Jan-89	94.1	8
12	102	271	14	404	IH610EB TO US59NB	IH610/US59	AT US 59 & IH 610 N LP	01-Jan-79	95.2	7
12	102	271	14	405	US59NB TO IH610WB	IH 610	AT US 59 & IH 610 N LP	01-Jan-79	96.0	7
12	102	271	14	406	IH610WB TO US59SB	IH610/US59	AT US 59 & IH 610 N LP	01-Jan-74	95.6	8
12	102	271	14	408	US59SB TO IH610EB	IH 610	AT US 59 & IH 610 N LP	01-Jan-79	96.0	8
12	102	271	14	449	IH 610 CONN B	IH 610 & SP 548 CONN F	0.00 MI N OF IH 610	01-Jan-88	100.0	8
12	102	271	14	450	IH 610 CONN D	KELLEY ST & HB&T RR	0.00 MI N OF IH 610	01-Jan-88	96.0	8
12	102	271	14	455	IH 610	US 290	0.00 MI S OF US 290	01-Jan-88	77.0	8
12	102	500	3	278	LOCKWOOD HOV RAMP	IH 45 NB FR	2.00 MI SE OF US 59	01-Jan-92		8
12	102	500	3	302	IH 45 HOVL(CONN H)	WHITE OAK BYU/IH 10 WB	@ IH 10 & IH 45	01-Jan-90	99.0	8
12	102	500	3	346	IH 45 SB CONN "H"	IH 45, BELTWAY 8	1.80 MI NW OF FM 1959	01-Jan-96	89.0	9
12	102	508	1	446	IH10E E-N CONN.	IH10 WBFR/CARP.BAYOU	AT IH10E & BW8E INTER.	01-Jan-94	96.0	8
12	102	508	1	450	BW8E N-E CONN	IH10 WBFR & CARP.BYU	AT IH10E & BW8E INTER.	01-Jan-94		6
12	102	720	3	215	BWY 8 EB ML	BN & CRI&P RR & SH 249	0.25 MI E OF FAIRBANKS	01-Jan-90	100.0	6
12	102	720	3	216	BWY 8 WB ML	BN & CRI&P RR & SH 249	0.25 MI E OF FAIRBANKS	01-Jan-89	100.0	7
12	102	2483	1	6	HARDY TOLL RD	W HARDY ST	0.80 MI N OF IH 610	01-Jan-88	100.0	8
12	102	2483	1	7	SP 548 CONN C	KELLEY ST & IH 610	0.00 MI N OF IH 610	01-Jan-88	99.0	8
12	102	2483	1	8	SP 548 CONN E	HARDY ST	0.10 MI N OF IH 610	01-Jan-88	96.0	8
12	102	2483	1	451	SP 548 CONN A	N LOOP FWY & FRISCO ST	0.00 MI N OF IH 610	01-Jan-88	96.3	8
12	102	3256	1	462	BELTWAY 8 RAMP "B"	IH 10 RAMPS C & D	AT IH 10 & BWY 8 INTER	01-Jan-89	94.5	8
12	102	3256	1	466	BELTWAY 8 RAMP "A"	BELTWAY 8 RAMPS C & D	AT IH 10 & BWY 8 INTER	01-Jan-89	94.1	8
12	102	3256	1	476	BELTWAY 8 SB ML	IH 10	1.25 MI W OF GESSNER RD	01-Jan-90	94.0	8
12	102	3256	1	477	BWY 8 NB ML	IH 10	1.25 MI W OF GESSNER RD	01-Jan-89	94.0	8

12	102	3256	2	150	BWY 8 ON RAMP D2	IH 45 FR	0.7 MI E OF GREENS CROSS	01-Jan-89	81.0	6
12	102	3256	2	227	BELTWAY 8 EB	VETERANS MEMORIAL DR	1.4 MI E OF ANTOINE	01-Jan-89	100.0	8
12	102	3256	2	228	BELTWAY 8 WB	VETERANS MEMORIAL DR	1.4 MI E OF ANTOINE	01-Jan-89	100.0	8
12	102	3256	2	243	BELTWAY 8 EB	ELLA BLVD	1.1 MI W OF IH 45	01-Jan-89	96.0	8
12	102	3256	2	244	BELTWAY 8 WB	ELLA BLVD	1.1 MI W OF IH 45	01-Jan-89	96.0	8
12	102	3256	3	345	BWY 8 WB CONN "F"	IH 45 NB FR, BW 8 WB FR	1.80 MI NW OF FM 1959	01-Jan-96	96.0	9
12	102	3256	3	348	BWY 8 WB CONN "L"	IH 45, BELTWAY 8	1.80 MI NW OF FM 1959	01-Jan-96	91.0	8
12	170	110	4	116	LAKE WOODLANDS(EB)	IH45	4.1 MI N OF HARRIS C/L	01-Jan-88	100.0	8
12	170	110	4	117	LAKE WOODLANDS(WB)	IH45	4.1 MI N OF HARRIS C/L	01-Jan-88	100.0	8
12	170	110	4	118	IH45 SBFR	SPRING CRK	AT HARRIS C/L	01-Jan-90	81.1	8
12	170	110	4	119	IH45 SBML	SPRING CRK	AT HARRIS C/L	01-Jan-90	89.1	8
12	170	110	4	120	IH45 NBML	SPRING CRK	AT HARRIS C/L	01-Jan-90	89.1	8
12	170	110	4	121	IH45 NBFR	SPRING CRK	AT HARRIS C/L	01-Jan-90	75.5	8
12	170	110	4	166	IH 45 SBFR	SAN JACINTO RIVER	0.75 MI FROM JCT. FM 1488	01-Jan-97	83.0	8
12	170	110	4	169	IH 45 NBFR	SAN JACINTO RIVER	0.75 MI FROM JCT. FM 1488	01-Jan-97	83.0	8
14	11	265	10	103	LOOP-150	COLORADO RIVER	0.4 MI E OF JCT SH-71	01-Jan-93	98.1	8
14	227	15	13	361	CAMERON RD TO 51ST	E FRTG RD & IH-35 NB	1.0 MI S OF US 290	01-Jan-77	96.7	8
14	227	15	13	363	W FRTG TO E FRTG	IH 35 NB & SB	1.0 MILE SOUTH US-290	01-Jan-77	92.6	8
14	227	113	13	93	LP 360	COLORADO RIVER	0.5 MI S OF RM 2222	01-Jan-83	88.0	7
14	227	113	13	113	US 290 WESTBOUND	MANCHACA/WESTGATE BLVD	US 290/LP 360/LP 343	01-Jan-97	93.7	8
14	227	113	13	114	US 290 EASTBOUND	MANCHACA/WESTGATE BLVD	US 290 LP 360 LP 343	01-Jan-97	93.7	8
14	227	151	6	88	NB 183 - SB LP 1	US 183 (MAINLANES)	US 183/LP 1 INTERCHANGE	01-Jan-90	99.0	8
14	227	151	6	90	SB 183 TO NB LP 1	LOOP 1 MAINLANES	US 183/LP 1 INTERCHANGE	01-Jan-91	93.0	8
14	227	3136	1	89	NB LP1 - NB US 183	US 183 (MAINLANES)	US 183/LP 1 INTERCHANGE	01-Jan-91	99.0	8
14	227	3136	1	91	SB LP 1 / SB US183	MPRR & LP-1 & US-183	US 183 - LP 1 INTERCHANGE	01-Jan-91	99.0	8
14	227	3136	1	126	LOOP 1 E-N CONNECT	US 290 & SH 71	LP 1 & US 290/ SH 71 INT	01-Jan-93	97.0	7
15	15	17	10	329	IH 35 SB ML	IH 410 CONN	4.75 MI S OF SH 218	01-Jan-83	94.0	7
15	15	17	10	330	IH 35 NB ML	IH 410 CONN	4.75 MI S OF SH 218	01-Jan-83	97.0	7
18	57	47	7	261	LINE C	US 75,SB SERV RD,ROSS AV	IH 345 NB TO SPUR 366 WB	01-Jan-83	94.6	7
18	57	196	3	222	CONN B - IH 35E SB	IH-35E SPUR 366	SPUR 366 & IH 35E	01-Jan-81	96.0	7
24	22	498	1	162	PEDESTRIAN	ALPINE CREEK	0.55 MI E OF SH 118	01-Jan-96		8
12	102		77	4	LOCKWOOD DR	BUFFALO BAYOU	0.54 MI S OF CLINTON DR	01-Jan-82	74.3	8
18	57		54	2	AT&SF RR	S GLENBROOK DRIVE	0.20 MI N OF MILLER RD	01-Jan-70		5

Appendix D

National Weather Service Tables

Appendix D-1

Normal Daily Temperature, Degrees Fahrenheit Over a 30-Year Span of Time

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Abilene, Tx	42.8	47.4	56.1	65.4	72.7	80.2	84.0	83.2	76.0	66.4	54.9	45.5	64.6
Amarillo, Tx	35.1	39.2	47.1	56.8	65.4	74.1	78.6	76.5	69.1	58.5	46.0	36.9	56.9
Austin, Tx	48.8	52.8	61.5	69.6	75.6	81.3	84.5	84.8	80.2	71.1	60.9	51.6	68.6
Brownsville, Tx	59.4	62.4	68.8	75.3	79.9	83.0	84.5	84.5	81.8	75.7	68.7	62.1	73.8
Corpus Christi, Tx	55.1	58.5	65.6	72.5	77.9	81.9	84.1	84.2	81.0	73.9	65.7	58.3	71.6
Dallas-Fort Worth, Tx	43.4	47.9	56.7	65.5	72.8	81.0	85.3	84.9	77.4	67.2	56.2	46.9	65.4
Del Rio, Tx	50.2	55.1	63.3	71.3	77.3	82.7	85.2	84.8	79.8	70.7	60.4	52.1	69.4
El Paso, Tx	42.8	48.1	55.1	63.4	71.8	80.4	82.3	80.1	74.4	64.0	52.4	44.1	63.2
Galveston, Tx	52.7	55.2	61.7	69.3	75.8	81.1	83.3	83.5	80.0	72.8	64.2	56.4	69.7
Houston, Tx	50.4	53.9	60.6	68.3	74.5	80.4	82.6	82.3	78.2	69.6	61.0	53.5	67.9
Lubbock, Tx	38.8	43.1	51.2	61.1	69.4	77.2	80.0	77.9	71.1	61.4	49.8	40.6	60.1
Midland-Odessa, Tx	42.5	47.1	55.7	64.6	72.8	79.6	82.0	80.8	73.3	64.0	52.6	44.6	63.3
Port Arthur, Tx	50.9	54.4	61.4	68.9	75.2	80.7	82.8	82.6	78.6	69.7	61.2	54.3	68.4
San Angelo, Tx	43.7	48.4	58.1	67.0	74.2	79.5	82.7	81.9	75.4	66.2	55.4	46.0	64.9
San Antonio, Tx	49.3	53.5	61.7	69.3	75.5	82.2	85.0	84.9	79.3	70.2	60.4	52.2	68.6
Victoria, Tx	52.7	56.1	63.3	70.6	76.6	81.7	84.1	84.1	79.6	71.7	62.9	55.6	69.9
Waco, Tx	45.2	49.4	58.2	67.1	74.3	81.5	85.6	85.6	78.6	68.5	57.7	48.3	66.7
Wichita Falls, Tx	39.8	44.7	53.5	63.1	71.2	79.8	85.0	83.6	75.4	64.6	52.4	42.8	63.0

Appendix D-2

Average Relative Humidity (%) — Morning and Afternoon

Data Through 1993	Years		Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec		Annual	
Location/A.M./P.M.	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A
Abilene, Tx	30	30	73	54	73	54	70	48	72	46	79	51	78	50	72	45	74	47	78	53	76	51	74	52	73	53	74	50
Amarillo, Tx	32	32	71	51	73	50	69	42	69	38	75	43	78	45	74	42	78	47	80	49	73	43	73	47	71	49	74	46
Austin, Tx	32	32	79	61	79	59	79	56	82	57	88	61	89	57	88	51	87	50	86	55	84	55	82	57	80	60	84	57
Brownsville, Tx	27	27	88	68	89	63	88	59	88	59	90	61	91	59	91	55	91	55	90	60	89	59	87	61	87	65	89	60
Corpus Christi, Tx	29	29	87	69	88	65	87	61	90	63	92	66	93	63	93	57	92	58	90	61	89	59	87	61	86	64	90	62
Dallas-Fort Worth, Tx	30	30	80	60	79	58	80	56	82	56	87	60	86	55	81	49	80	49	85	55	83	54	81	57	79	59	82	56
Del Rio, Tx	16	16	76	55	74	52	72	48	77	52	83	57	82	55	79	52	80	54	84	57	82	57	80	57	76	54	79	54
El Paso, Tx	33	33	66	35	57	27	47	21	40	16	42	17	46	18	63	30	67	33	68	34	64	30	62	32	66	38	57	28
Galveston, Tx	96	66	85	77	84	74	85	74	86	75	84	73	81	70	81	70	81	69	81	68	80	65	83	72	85	76	83	72
Houston, Tx	24	24	86	64	86	61	87	59	89	58	92	60	92	60	93	57	93	57	93	60	91	56	89	60	87	62	90	60
Lubbock, Tx	46	46	73	50	73	50	68	41	69	39	76	43	78	45	75	47	78	49	81	52	78	48	74	46	72	48	75	47
Midland-Odessa, Tx	30	30	73	48	73	45	66	36	67	34	76	38	78	42	73	42	76	44	81	51	80	46	76	45	72	45	74	43
Port Arthur, Tx	33	33	88	68	87	63	88	62	90	62	92	64	93	64	94	65	94	64	92	64	91	58	89	62	89	67	91	64
San Angelo, Tx	33	33	77	53	76	50	72	44	74	43	81	49	82	50	78	44	79	45	84	54	83	52	80	51	78	52	79	49
San Antonio, Tx	51	51	80	59	80	57	79	53	83	56	88	59	88	56	87	52	86	51	86	54	84	53	81	55	80	57	84	55
Victoria, Tx	32	32	87	65	87	61	86	58	88	59	91	61	92	60	92	56	92	56	92	60	90	56	88	59	87	63	89	60
Waco, Tx	30	30	83	64	83	61	82	58	84	59	88	61	86	55	82	48	82	47	86	54	85	55	84	59	83	62	84	57
Wichita Falls, Tx	33	33	80	57	80	55	79	50	80	49	86	53	85	51	78	44	80	45	86	53	84	51	83	54	81	56	82	52

Appendix D-3

Normal Monthly Precipitation, Inches

NORMALS 1961-90	YRS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
ABILENE, TX	30	1.03	1.16	1.36	1.90	2.97	2.86	2.09	2.80	3.21	2.51	1.48	1.03	24.40
AMARILLO, TX	30	0.50	0.61	0.96	0.99	2.48	3.70	2.62	3.22	1.99	1.37	0.69	0.43	19.56
AUSTIN, TX	30	1.71	2.17	1.87	2.56	4.78	3.72	2.04	2.05	3.30	3.43	2.37	1.88	31.88
BROWNSVILLE, TX	30	1.56	1.06	0.53	1.56	2.94	2.73	1.90	2.77	6.00	2.80	1.51	1.25	26.61
CORPUS CHRISTI, TX	30	1.71	1.96	0.94	1.72	3.33	3.38	2.39	3.31	5.52	3.02	1.59	1.26	30.13
DALLAS-FORT WORTH, TX	30	1.83	2.18	2.77	3.50	4.88	2.98	2.31	2.21	3.39	3.52	2.29	1.84	33.70
DEL RIO, TX	30	0.56	0.95	0.69	1.98	2.03	2.11	1.85	1.47	2.83	2.24	0.92	0.61	18.24
EL PASO, TX	30	0.40	0.41	0.29	0.20	0.25	0.67	1.54	1.58	1.70	0.76	0.44	0.57	8.81
GALVESTON, TX	30	3.26	2.26	2.23	2.43	3.59	4.44	3.96	4.47	5.93	2.84	3.37	3.50	42.28
HOUSTON, TX	30	3.29	2.96	2.92	3.21	5.24	4.96	3.60	3.49	4.89	4.27	3.79	3.45	46.07
LUBBOCK, TX	30	0.39	0.68	0.89	0.97	2.35	2.75	2.37	2.51	2.60	1.86	0.75	0.53	18.65
MIDLAND-ODESSA, TX	30	0.40	0.62	0.58	0.83	1.98	1.55	1.70	1.69	2.62	1.74	0.69	0.56	14.96
PORT ARTHUR, TX	30	4.77	3.38	3.24	3.51	5.71	5.59	5.38	5.34	6.31	4.29	4.85	4.81	57.18
SAN ANGELO, TX	30	0.80	1.07	0.91	1.67	3.00	2.33	1.06	1.93	3.41	2.40	1.08	0.79	20.45
SAN ANTONIO, TX	30	1.71	1.81	1.52	2.50	4.22	3.81	2.16	2.54	3.41	3.17	2.62	1.51	30.98
VICTORIA, TX	30	2.16	2.00	1.55	2.41	4.50	4.89	3.34	3.01	5.60	3.46	2.45	2.04	37.41
WACO, TX	30	1.65	2.09	2.33	3.19	4.58	3.28	1.99	1.68	3.52	3.36	2.43	1.86	31.96
WICHITA FALLS, TX	30	1.04	1.46	2.21	3.01	4.07	3.52	1.72	2.48	3.82	2.74	1.54	1.29	28.90

Appendix D-4

Average Days of Precipitation: .01 Inches or more

DATA THROUGH 1993	YRS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
ABILENE, TX	54	5	5	5	6	8	6	5	6	6	6	4	5	67
AMARILLO, TX	52	4	4	5	5	8	8	8	9	6	5	3	4	69
AUSTIN, TX	52	8	8	7	7	9	7	5	5	7	6	7	8	84
BROWNSVILLE, TX	51	8	6	4	4	5	6	5	7	10	6	6	7	73
CORPUS CHRISTI, TX	54	8	7	5	5	7	6	5	6	9	6	6	7	77
DALLAS-FORT WORTH, TX	40	7	7	7	8	9	7	5	5	7	6	6	7	79
DEL RIO, TX	30	5	5	5	6	7	5	4	4	7	5	4	5	63
EL PASO, TX	54	4	3	2	2	2	3	8	8	5	4	3	4	49
GALVESTON, TX	122	10	8	8	6	6	7	9	9	9	6	8	10	96
HOUSTON, TX	24	11	8	9	7	9	9	9	9	9	7	8	9	106
LUBBOCK, TX	47	4	4	4	4	7	7	7	7	6	5	3	4	63
MIDLAND-ODESSA, TX	46	4	4	3	3	6	5	5	6	6	5	3	3	52
PORT ARTHUR, TX	40	10	9	8	7	8	8	11	12	10	6	8	9	105
SAN ANGELO, TX	46	5	5	4	5	7	5	4	5	6	5	4	4	59
SAN ANTONIO, TX	51	8	8	7	7	9	6	4	5	7	6	7	8	82
VICTORIA, TX	32	8	7	7	6	8	8	8	8	10	6	7	8	90
WACO, TX	50	7	7	7	7	9	7	4	5	6	6	6	6	79
WICHITA FALLS, TX	50	5	6	6	7	9	7	5	6	6	6	5	5	71

Appendix D-5

Mean Number of Days with Minimum Temperature 32 Degrees F or Less

Data Through 1998	Yrs	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abilene	35	17	11	5	*	0	0	0	0	0	*	5	14	51
Amarillo	37	27	22	15	4	*	0	0	0	*	2	15	27	111
Austin	37	8	4	1	0	0	0	0	0	0	*	1	5	19
Brownsville	32	1	*	*	0	0	0	0	0	0	0	*	1	2
Corpus Christi	34	3	1	*	0	0	0	0	0	0	*	*	2	6
Dallas-Fort Worth	35	14	8	3	*	0	0	0	0	0	*	3	10	37
Del Rio	35	6	3	1	0	0	0	0	0	0	*	1	5	16
El Paso	38	19	11	5	1	*	0	0	0	0	*	8	18	61
Galveston	124	2	1	*	0	0	0	0	0	0	0	*	1	3
Houston	29	7	4	1	*	0	0	0	0	0	*	1	5	18
Lubbock	51	25	19	11	2	*	0	0	0	0	1	12	23	93
Midland-Odessa	35	20	13	6	1	0	0	0	0	0	*	7	17	64
Port Arthur	38	6	3	1	*	0	0	0	0	0	*	1	4	14
San Angelo	38	17	10	5	1	0	0	0	0	0	*	5	14	52
San Antonio	56	8	4	2	*	0	0	0	0	0	*	2	6	22
Victoria	37	5	2	*	0	0	0	0	0	0	*	1	3	11
Waco	35	13	7	2	*	0	0	0	0	0	*	3	9	33
Wichita Falls	38	21	13	6	1	0	0	0	0	0	*	6	17	65

* Average frequency of occurrence greater than zero, but smaller than one half.

Appendix D-6

Snowfall (Including Ice Pellets): Average Total in Inches

Data Through 199	Yrs	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abilene	58	1.9	1.0	0.6	T	T	T	T	T	0.0	0.0	0.4	0.7	4.6
Amarillo	57	4.0	3.6	2.5	0.6	T	T	T	0.0	0.0	0.2	1.9	2.7	15.5
Austin	57	0.5	0.3	T	T	T	0.0	0.0	0.0	0.0	0.0	0.1	T	0.9
Brownsville	59	T	T	T	0.0	0.0	0.0	0.0	T	0.0	0.0	T	T	T
Corpus Christi	57	0.0	0.0	T	T	T	0.0	0.0	0.0	0.0	T	T	T	T
Dallas-Fort Worth	43	1.1	0.9	0.2	T	T	0.0	0.0	0.0	0.0	T	0.1	0.2	2.5
Del Rio	32	0.6	0.2	0.1	T	T	0.0	0.0	0.0	0.0	0.0	T	T	0.9
El Paso	57	1.3	0.8	0.4	0.3	T	T	T	0.0	T	0.0	0.9	1.6	5.3
Galveston	124	0.0	0.2	T	T	T	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Houston	64	0.2	0.2	0.0	T	T	T	0.0	030	0.0	0.0	T	T	0.4
Lubbock	50	2.4	2.8	1.4	0.2	T	T	T	0.0	0.0	0.2	1.1	1.8	9.9
Midland-Odessa	50	1.9	0.8	0.4	0.0	T	T	T	T	0.0	0.0	0.4	1.0	4.5
Port Arthur	43	0.1	0.2	0.0	T	T	0.0	T	0.0	0.0	0.0	T	0.0	0.3
San Angelo	49	1.5	0.6	0.2	T	T	T	T	0.0	T	T	0.5	0.2	3.0
San Antonio	54	0.5	0.2	T	T	T	T	0.0	0.0	0.0	T	0.0	0.0	0.7
Victoria	35	0.1	0.0	T	0.0	T	0.0	0.0	T	0.0	0.0	0.0	T	0.1
Waco	53	0.8	0.3	0.1	T	T	0.0	0.0	T	0.0	T	0.1	0.1	1.4
Wichita Falls	53	2.1	1.6	0.8	0.0	T	T	0.0	0.0	0.0	0.0	0.3	0.0	5.8

T = Trace

Appendix E

Field Inspection of TxDOT Bridges

Appendix E

Field Inspection of TxDOT Bridges

Name/Location/Description	Built	Rating
Cameron Road to 51st, Austin Cameron Road - IH35 SB, Austin	1977	8

On the west side, both flanges show mill scale remnants, but the web doesn't have any mill scale, as if it had been preblasted. All parts show flaking in small rust chips. The bottom flanges on inner beams have piles of powder debris or flakes. In addition, nongalvanized bolts were corroded at the bearings.

Name/Location/Description	Built	Rating
I 35 flyover, W. Frontage to E. Frontage – 1 mile S of 290, Austin	1977	8

On the west side of the north end, small areas of mill scale are present on the bottom flanges, top flange, and top two to three inches of web. The top flange is more corroded due to more exposure to dampness from condensation. This end of the structure doesn't have a build up of rust flakes on the bottom flange. The beams do have loose rust flakes. Drip plates were observed on the facing girders only, from the outside only. Galvanized bolts at the bearing were in good conditions.

On the south end, the outside face of the top of the bottom flange looks like a protective oxide film has formed. It is not flaking, but still has mill scale. The outside web, as well as all inside beams, have small flakes all over them. Despite 20+ years weathering, the grinding of edges of flanges and dings from erection are still evident. There has not been enough metal loss to round off the edges. The stencil of structure number on the outside face has not weathered off. Mill scale is still on the bottom flange but is weathering off. The flyover ramp has drip plates installed at an angle (but some may be on wrong side of the cap and pointing the wrong way).

Name/Location/Description	Built	Rating
S 1st over Town Lake, South End, Austin	1951	6

Although this bridge was on the weathering steel bridge inventory, it was impossible to confirm that it is weathering steel because it is painted. Therefore, it was deleted from the weathering steel inventory list provided by BRINSAP. It is a riveted flange construction with its original paint job, wire brush, red lead (TT-P-86, probably) and aluminum topcoat. Most of the paint failure areas still have intact mill scale underneath.

The only major corrosion noticed is at one girder end where a diagonal brace ties into a gusset plate. The corrosion is probably due to water leakage from above. Where mill scale has popped off the steel, it is flaking. Regardless of the kind of steel, this bridge has almost no corrosion, and has been in constant service over a lake for 47 years.

Name/Location/Description	Built	Rating
US 183 - SB Loop 1, Austin	1990	8

The beam-ends are embedded in concrete. The outside faces don't have mill scale, but the bottom flanges and inside webs do. They appear to be weathering to a uniform appearance. The overhang protection is not as noticeable on these structures. The outside edge of the bottom flange, where water collects, is corroding more than the rest of the bottom flange. Mill scale has come off at these edges.

Mill scale on the bottom of the top flange is weathering off. Concrete paint that got on the steel (where beam is set into the concrete) is discoloring and weathering off. The beam-ends collect water on the uphill side, where they are set in concrete. The faces were probably blasted, since no mill scale is visible on the outside webs. No drip plates or pans are visible.

Name/Location/Description	Built	Rating
Loop 360 over Colorado River, Austin	1983	7

Base – South side

Very little flaking is evident - most of the coating has the dense protective oxide film anticipated. Splice plates act as drip plates and leave streaks. Some nooks on the underside are showing small amount of flaking and silicone caulking on bolted plates on top of the shoes is coming off, but caulk in other areas is holding well.

Deck Level

The top face of the arch is not flaking. The middle is more polished looking than its edges, as if something or someone was sliding down it. This surface is slightly rough but no loose rust can be removed as a powder with a scraper.

The east face is not flaking, but it is porous enough that scraping removes fine dust. The south (bottom) face is flaking with small granular dark brown/purplish flakes in the middle of the beam. The rust 6" in from each edge is a light brown. A yellowish stain is running down the whole arch.

The cable hangers (west side) still have very small amounts of mill scale on the top surfaces. The east side hangers have almost no mill scale. There is no visible flaking on these hangers.

The north end of the east arch is the same as the west. The only flaking is at the bottom of the arch. The south ends of both arches are the same as the north ends. There is considerable staining on the concrete median barriers. These stains are diverted to drip points caused by the bolted connections and perpendicular boxes. Paint-outs over graffiti are losing flakes in thin spots. This observation indicates that the steel is flaking slightly, but the flakes come off easily by weathering and are not easily noticeable.

Ground Level – South Side

The surfaces attainable at ground level vary from hard, dense protective oxide film to softer, slightly porous rust, but no flaking is visible. The tightest rust is dark brown to slightly purplish. The color is more yellow where run-off is most prevalent. About two inches of the top outside edges of the arches have formed a dense protective oxide film. This area is probably the heat-affected zone from welding the webs to the flanges. The same effect is visible, but not very noticeable, on bottom weld areas. This effect is not very noticeable on the diagonal boxes.

Table E-1

UT thickness measurement of Loop 360 Bridge from the deck level

TF	2.32”	2.32’	2.32”
BF	2.32”	2.31”	2.32”
Web	1.15”	1.15”	1.15”

UT thickness measurement near the river level

Table E-2

TF	1.66”	1.67”	1.67”
Web	1.26”	1.26”	1.27”

Name/Location/Description	Built	Rating
NB Flyover 290/71 to Loop 1, Austin	1991	8

The top half of the web on the northwest face is different in appearance from the bottom half. An overhang protects the top half from rain, so it gets most of its moisture from condensation, whereas the bottom half gets rain. The bottom of the bottom flange shows stain from water running off the flange and collecting on the lip. The inside beams have condensation drop patterns like most structures. The southeast face has condensation drop patters on the top 6 to 8 inches, then uniform rusting below. The overhang does not protect as well since this is the uphill side. Much more water runs off to the bottom of the bottom flange. The bottom flanges were probably blasted since no mill scale was visible. The lighter areas are those that water does not reach. No drip plates or pans are visible.

Name/Location/Description	Built	Rating
SH124 over the Intercoastal Waterway (High Island Bridge)	1978	7

Exterior fascia surfaces look dark brown, porous, and rough. Interior surfaces have flakes about ¼" in size. Clips need to be bigger in size so they won't close due to corrosion.

The inside girders continue to produce flaking of 1/8" to 1/4". The rust under the flakes still looks porous.

The outside faces are not flaking as badly as the inside, but weather is probably removing flakes before they get bigger. The top of the bottom flange, on the outside, has a more dense look. It is more exposed to weather cycles.

The flakes on the diagonal braces are the largest. The diagonal T-brace on the south side of the pier and the east side of the middle girder had a 2" x 4" board on it and a large collection of rust flakes (more than seemed reasonable for the size of member). The back-to-back angles in the diaphragms are starting to fill with pack rust at the bottom, but not badly enough to distort the steel.

The gusset plates where the diagonals tie into the stiffeners and diaphragms are scaling at the bottom and collecting flakes and debris. The vertical gusset plate may have lost 5% to 10% thickness in the bottom 2", where it connects to the girder flange.

Table E-3

UT thickness measurement of SH124 over the Intercoastal Waterway

Int. Web	0.5"	0.5"	0.5"
Int. BF	2.3"	2.3"	2.3"
Diaphragm BF	0.8"	0.8"	0.8"
Ext. Web	0.5"	0.5"	0.5"
BF	2.3"	2.3"	2.3"

NOTE 1: In late 1983 or early 1984, a researcher from Louisiana State University placed a set of chemical treatments on the weathered steel. This was to see if they could stabilize the steel and stop the rusting process. On a visit in December 1987, these test sections were still clearly visible. All evidence of these test sections and their markings had flaked off by the October 1998 visit.

NOTE 2: In November 1979, at the request of Bethlehem Steel, test areas on the outside fascias were sandblasted to remove the mill scale. This work was done to allow the area to form a protective oxide film and stop flaking rust. By 1987, the blasted area was no different from the surrounding surface. On the October 1998 visit, we could not determine where the blasting had occurred. Small, loose rust flakes covered all areas. There was no mill scale remaining. All surfaces have flaked until it is uniform in appearance.

Name/Location/Description	Built	Rating
Spur 55 over Cedar Bayou, outside Baytown	1979	7

The rust flakes are small and granular. When digging into the rust under the flake, the rust is porous. The rust can be easily scratched through to the parent metal. Mill scale still exists on flanges and stiffeners, but not on the web. We don't know if the web was preblasted or if mill scale came off due to flaking. The diaphragm back-to-back angles don't have any pack rust, perhaps because they are 7 to 8 feet above the pier and are not as exposed to wind and weather. Diagonal braces have larger flakes. Horizontal gussets held bird nests but not too many flakes.

Table E-4

UT thickness measurement of Spur 55 over Cedar Bayou

Web, Ext. girder	0.55"	0.55"	0.55"
BF, Ext. girder	2.8"	2.80"	2.80"
Web, Int. girder	0.55"	0.55"	0.55"
BF	2.6"	2.60"	2.60"

Name/Location/Description	Built	Rating
Railroad Bridge over Route 37, Corpus Christi	1987	*

On-site detection of salt deposits was conducted on a railroad bridge that spans Route 37 in Corpus Christi, using a commercial chloride test kit that measures chloride in parts-per-million (ppm) on the surface of objects. This test revealed no evidence of salt on the surface of fascia webs or on the top and side surfaces of top flanges.

* Not a TxDOT structure – no rating available.

Name/Location/Description	Built	Rating
Fitzhugh over railroad, Dallas	1973	8

These structures are single-span boxes over RR tracks. They were made in three sections and field weld spliced. There is no visible mill scale. Either they were blasted properly or all mill scale has weathered off. The boxes do not look as if they have weathered enough to lose mill scale. The outside faces have a few stains that look like concrete stains from pouring the deck. These stains have turned brown but have not come off. Steel appears to be flaking but there is no evident metal loss. There are no condensation drop patterns visible, so the inside faces have a more uniform appearance. There are no drip plates on the outside flanges.

Name/Location/Description	Built	Rating
US 75 SB Access Rd at Ross Av., Dallas	1983	7

The web plates were preblasted, but the flanges and stiffeners still have mill scale. The steel presents a good uniform appearance. There are no drip plates but almost no staining. Outside stiffeners stop water from running along the flange. Mill scale on the bottom of the bottom flange is uniformly gone 2" from the downhill edge (probably due to temperature during cutting). The uphill edge is losing its mill scale in the same 2" zone. Mill scale on the bottom flange of the uphill outside beam is mostly gone due to exposure to weather. The downhill edge of the bottom flange shows the effect of moisture running under the bottom. The outside face has some small flakes. Writing is still easily readable on the inside faces of beams.

Name/Location/Description	Built	Rating
WB Connection NB I 45 to I 345, Dallas	1981	7

The outside faces were blasted, but not the flanges. The web plates were probably preblasted before fabrication. No drip bars were needed due to a web transition just before the bent cap. The vertical stiffeners on the outside face keep water from running along the flange. There is almost no staining on the bent caps. The webs were blasted, even on the inside. The bottom flanges of the outside beams were also blasted except for short sections at the two middle bent caps. This leaves a uniform appearance. There is no concrete stain from placing the deck. There are no condensation drop patters visible from the ground.

Name/Location/Description	Built	Rating
IH20 WBL over Clear Fork of Trinity R, Ft. Worth	1981	7

This structure was not blasted. Although there is mill scale on the fascia beam, it still has a fairly uniform appearance. There are drip plates in the haunches, but there is a little staining on the outside end of the concrete bent caps. The steel shows some small-size flaking. The beams (even outside face) show typical condensation drop patterns on the top flange and down the web.

The mill scale doesn't appear to be flaking off. The erection marks/writing/numbers are still visible. The joints are sealed, which reduced run-off water and subsequent staining. The bent caps, beam-ends, and bearings at the steel/concrete joints are covered with asphalt from above.

Name/Location/Description	Built	Rating
SF Railroad Bridge over Glenbrook, Garland	1970	5

This structure is painted with 720 prime coat/aluminum (if it is a TxDOT coating system) and is showing rusty spots typical of painted carbon steel. The popping mill scale reveals rusty spots. On top of the bottom flange on the outside face where paint came off, the bare steel is not forming flaking rust. Any flakes that are formed are removed by weather. When blistered/undercut paint is cut off the steel, small flakes typical of weathering steel are then exposed.

Name/Location/Description	Built	Rating
US59 NB Flyover from NB 610, Houston	1979	7

The end pier shows a slight stain but the west side bent cap at the west end has created considerable staining on the concrete. The girders have formed dark brown rust but, from the ground, flaking is not apparent. The drip pan on the bent cap shows that the staining is coming from the bearing — not from the drip pan.

Name/Location/Description	Built	Rating
US59 WB Chimney Rock (over entrance ramp), Houston	1993	7

Mill scale was not blasted uniformly on webs and has not weathered off. Beams are dark brown oxide but, from the ground, flaking is not apparent. The bent cap is staining one pier considerably. The stain is coming from the bearing plate area — not from the drip pan. The bottom flange was not blasted and is rusting, but only in a damaged area.

Name/Location/Description	Built	Rating
US 59-SB HOV Lanes (North of Bellaire/Fondren Exit), Houston	1992	8

The beams were blasted and look uniform – there is no staining on piers.

Name/Location/Description	Built	Rating
US 59 NB and SB ML Over Bellaire, Houston	1992	8

Uniform appearance is probably due to having blasted the mill scale off the webs. The flanges were not blasted. The outside face has formed a dark brown oxide but the inside beams are a slightly yellowed shade. There was no staining on the columns at the beam-ends.

Name/Location/Description	Built	Rating
US59 SB ML Over Westpark (NB ML Same), Houston	1993	8

If the mill scale was blasted on these structures, it was not done well, since a lot of mill scale remains. The rusty parts are a dark brown oxide. Drip plates were installed on some of the interior girders to avoid water coming from the space between concrete slabs of the northbound and southbound structures.

Name/Location/Description	Built	Rating
HOV Lane W side of 610 between 290 and I10, Houston	1988	8

The uniform appearance is probably due to having blasted the outside faces. The inside girders seem to be blasted on the webs. It doesn't look like there is a lot of flakiness as seen from the ground below the structure. The box bent caps show some differences due to access to water. The top of the box bent cap changes thickness and water runs off there, creating a differential staining patterns.

Name/Location/Description	Built	Rating
HOV Lane over I10 WB 0.45mi West of 610, Houston	1985	8

The web plates of different sections appear to have been blasted to varying levels of mill scale removal. These variations in blasting leave a non-uniform appearance between the different welded sections. From below the structure, flaking is not apparent. The drip pan on the north pier of box cap is stained. This stain is coming from beneath the drip pan. There is no drip plate to divert water at the end of the beams.

Name/Location/Description	Built	Rating
AVL Lane over I10 East of SH6, Houston	1986	8

The mill scale was blasted off the webs well, but not off the flanges. There is not much stain despite an absence of drip pans or plates. There are many condensation drip patterns.

Name/Location/Description	Built	Rating
HOV 610 and 290 behind Northwest Mall, Houston	1988	8

Strips of stain on the box beam cap, which has a drip pan, suggest the pan was not installed correctly.

Name/Location/Description	Built	Rating
HOV Bridge N of WB 290 where SB 610 exits, Houston	1988	8

The beams are flaking and have a build up of rust flakes on the flange. The drip plates have kept staining off the concrete, but have collected piles of rust flakes against them. The inside beams were not blasted and rust is flaking between mill scale areas.

Name/Location/Description	Built	Rating
US 288 South of 610, ramp between Holmes and Belfort Rds, Houston	N/A	N/A

On the northbound side, the outside faces have a uniform dark brown color. All the beams are covered with small flakes. The inside girders have some buildup of these flakes on the flanges. The remaining mill scale on the inside beams is starting to flake off. Both piers under the box bent cap are showing a little staining coming off the top of the column, not from the drip pan.

On the southbound side, the steel is flaking in the same way as the northbound ramp.

Name/Location/Description	Built	Rating
I 45 SB South of Hwy 8 - Tub Girder Flyover, Houston	1996	9

The webs and flange plates were not blasted. Due to intermittent areas of mill scale, the appearance is non-uniform. The bottom and west sides, visible from below, appear to be flaking.

Name/Location/Description	Built	Rating
610 N Loop NB Ramp to Hardy Toll Road, Houston	1988	8

The girders are flaking. A lot of mill scale is on the inside beams, but the outside beams show some evidence of blasting. Although it is flaking, it does not appear to be losing metal. The drip bar is keeping stain off concrete abutment. There is not much stain on the ground under the drip bar, that shows that this structure is not creating much, if any, staining.

Name/Location/Description	Built	Rating
NB Exit BWY 8 to Airport, Houston	1989	8

The blasted girder faces are uniform in appearance, except for the usual condensation drip patterns from the top flange running down the face. It looks like it still has some flaking. Mill scale appears to be weathering off the bottom flanges. All the columns are interior and show no staining. The end cap isn't stained, but the beam has a drip plate and web section change, so water should not get to the end. The drip plate is perpendicular to the web, not angled — thus it is more likely to capture debris.

Name/Location/Description	Built	Rating
Hwy 8 over Ella Blvd., Houston	1989	8

Most of the steel is a dark brown color with flakiness. The exterior ends, the box bent cap, and the web outside of the beam seats have formed a protective oxide film surface with no flaking. This film surface is a redder color. However, under the beam seat, the color is dark brown and flaking is evident. The beams at the riprap are flaking and mill scale is weathering off, but there are few flakes on the flanges.

On the westbound side the top of the box bent cap still has most of the mill scale. The webs of these box girders don't have mill scale, and are not flaking anymore. The protective oxide film that has developed on the web surface of these box girders is rough but tight. On the northbound side, the box bent caps that are exposed to the rain don't flake anymore and have a rough tight protective oxide film.

Inside the bottom portion of the beam seats, water and moisture can be trapped due to its closed configuration. The deterioration of concrete filling, placed around the edges of the steel plates seating directly on the concrete columns, allows moisture to get beneath the steel plate and accelerate corrosion of the edges, producing more staining.

In general, very tight mill scale was observed in this location, and no flaking was observed on the exposed portion of the box bent cap, except inside the box beam seats.

Name/Location/Description	Built	Rating
IH45 over Spring Creek, Houston	1990	8

There are no drip pans or plates but no stain on the piers. The exterior faces are covered with small loose flakes and show condensation drip patterns. The coating is dark brown. The bottom of the bottom flange is flaking and is mostly dark brown, but has some yellow oxide in a mottled pattern. The inside beams have small flakes covering them and flakes have fallen to the bottom of the web. The anchor bolts show no more flaking than the beam. There is no mill scale visible — it was probably blasted off rather than weathered.

Name/Location/Description	Built	Rating
IH45 over N flyover of San Jacinto River, Houston	1997	8

The mill scale was not blasted off. There is no visible difference in mill scale loss between the span over water and the north spans over land. The bridge has drip plates and pans and has no stain on the piers. We could not see anchor bolts or bearing pads to determine their condition.

The painted steel on the main lanes adjacent to the weathering steel structures is showing no rust. The topcoat on the outside face is starting to fail, but it is not rusting. The painted structures are the main lanes (that are much older) and the weathering steel members are in newer access road bridges.

Name/Location/Description	Built	Rating
IH35 SB and NB at IH410, San Antonio	1983	7

The outside faces were probably blasted because they are uniform and don't have mill scale remaining. The flaking on the outside at the north end is typical small flakes. The inside faces at the north end still have mill scale flaking off in large flakes. These large flakes are thin — not much metal is being lost. The outside face has a drip bar 6" to 8" from a flange transition that probably wasn't needed. It is not angled perpendicularly, but there is no debris buildup at the drip bar. Because there is no rust stain on the riprap below it, this structure is not actively generating soluble oxides. The outside face does not show any condensation drop patterns, nor are they very evident on the inside faces. At the north end of the northbound structure, all anchor bolts are bent away from the abutment, caused when the steel contracted. Rust on the bottom surface of the bottom flange has a white substance in it.

Appendix F

SSPC Data

Steel Structures Painting Council
SURFACE PREPARATION SPECIFICATION NO. 5
White Metal Blast Cleaning

1. Scope

1.1 This specification covers the requirements for White Metal Blast Cleaning of steel surfaces by the use of abrasives.

2. Definition

2.1 A White Metal Blast Cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, mill scale, rust, paint, oxides, corrosion products, and other foreign matter.

2.2 ACCEPTABLE VARIATIONS IN APPEARANCE THAT DO NOT AFFECT SURFACE CLEANLINESS as defined in Section 2.1 include variations caused by type of steel, original surface condition, thickness of the steel, weld metal, mill or fabrication marks, heat treating, heat affected zones, blasting abrasive, and differences in the blast pattern.

2.3 When painting is specified, the surface shall be roughened to a degree suitable for the specified paint system.

2.4 Immediately prior to paint application the surface shall comply with the degree of cleaning as specified herein.

2.5 SSPC-Vis 1 or other visual standards of surface preparation may be specified to supplement the written definition.
*NOTE: Additional information on visual standards is available in section A.4 of the Appendix.

3. Blast Cleaning Abrasives

3.1 The selection of abrasive size and type shall be based on the type, grade, and surface condition of the steel to be cleaned, type of blast cleaning system employed, the finished surface to be produced (cleanliness and roughness), and whether the abrasive will be recycled.

3.2 The cleanliness and size of recycled abrasives shall be maintained to insure compliance with this specification.

3.3 The blast cleaning abrasive shall be dry and free of oil, grease, and other harmful materials at the time of use.

3.4 Any limitations or restrictions on the use of specific abrasives, quantity of contaminants, or degree of embedment shall be included in the procurement documents (project specification) covering the work, since abrasive embedment and abrasives containing contaminants may not be acceptable for some service requirements.
*NOTE: Additional information on abrasive selection is available in Section A.2 of the Appendix.

4. Reference Standards

4.1 If there is a conflict between the cited reference standards and this specification, this specification shall prevail unless otherwise indicated in the procurement documents (project specification).

4.2 The standards referenced in this specification are:

SSPC-SP 1	Solvent Cleaning
SSPC-Vis 1	Pictorial Surface Preparation Standards for Painting Steel Surfaces

5. Procedure Before Blast Cleaning

5.1 Before blast cleaning, visible deposits of oil or grease shall be removed by any of the methods specified in SSPC-SP 1 or other agreed upon methods.

5.2 Before blast cleaning, surface imperfections such as sharp fins, sharp edges, weld spatter, or burning slag should be removed from the surface to the extent required by the procurement documents (project specification).
*NOTE: Additional information on surface imperfections is available in Section A.5 of the Appendix.

6. Blast Cleaning Methods and Operation

6.1 Clean, dry, compressed air shall be used for nozzle blasting. Moisture separators, oil separators, traps or other equipment may be necessary to achieve this requirement.

6.2 Any of the following methods of surface preparation may be used to achieve a White Metal Blast Cleaned surface:

6.2.1 Dry abrasive blasting using compressed air, blast nozzles, and abrasive.

6.2.2 Dry abrasive blasting using a closed cycle, recirculating abrasive system with compressed air, blast nozzle, and abrasive, with or without vacuum for dust and

*Notes are not requirements of this specification.

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abrasive recovery.

6.2.3 Dry abrasive blasting, using a closed cycle, recirculating abrasive system with centrifugal wheels and abrasive.

6.3 Other methods of surface preparation (such as wet abrasive blasting) may be used to achieve a White Metal Blast Cleaned surface by mutual agreement between the party responsible for performing the work and the party responsible for establishing the requirements or his representative.
*NOTE: If wet abrasive blasting is used, information on the use of inhibitors to prevent the formation of rust immediately after wet blast cleaning is contained in Section A.9 of the Appendix.

7. Procedures Following Blast Cleaning and Immediately Prior to Painting

7.1 Visible deposits of oil, grease, or other contaminants shall be removed by any of the methods specified in SSPC-SP 1 or other methods agreed upon by the party responsible for establishing the requirements and the party responsible for performing the work.

7.2 Dust and loose residues shall be removed from prepared surfaces by brushing, blowing off with clean, dry air, vacuum cleaning or other methods agreed upon by the party responsible for establishing the requirements and the party responsible for performing the work. Moisture separators, oil separators, traps, or other equipment may be necessary to achieve clean, dry air.

7.3 After blast cleaning, surface imperfections which remain (i.e., sharp fins, sharp edges, weld spatter, burning slag, scabs, slivers, etc.) shall be removed to the extent required in the procurement documents (project specification). Any damage to the surface profile resulting from the removal of surface imperfections shall be corrected to meet the requirements of section 2.3.
*NOTE: Additional information on surface imperfections is contained in Section A.5 of the Appendix.

7.4 Any visible rust that forms on the surface of the steel after blast cleaning shall be removed by reblasting the rusted areas to meet the requirements of this specification before painting.
*NOTE: Information on rust-back (rerusting) and surface condensation is contained in Sections A.7 and A.8 of the Appendix.

8. Inspection

8.1 Work and materials supplied under this specification are subject to inspection by the party responsible for establishing the requirements or his representative. Materials and work areas shall be accessible to the inspector. The procedures and times of inspection shall be as agreed upon by the party responsible for establishing the requirements and the party responsible for performing the work.

8.2 Conditions not complying with this specification shall be corrected. In case of dispute the arbitration or settlement procedure established in the procurement documents (project specification) shall be followed. If no arbitration or settlement procedure is established, then the procedure established by the American Arbitration Association shall be used.

8.3 The procurement documents (project specification) should establish the responsibility for inspection and for any required affidavit certifying compliance with the specification.

9. Safety and Environmental Requirements

9.1 Blast cleaning is a hazardous operation. Therefore, all work shall be conducted in such a manner to comply with all applicable insurance underwriter, local, state, and federal safety and environmental rules and requirements.
*NOTE: SSPC-PA Guide 3, "A Guide to Safety in Paint Application," addresses safety concerns for coating work.

10. Comments

10.1 While every precaution is taken to insure that all information furnished in SSPC specifications is as accurate, complete, and useful as possible, the Steel Structures Painting Council cannot assume responsibility nor incur any obligation resulting from the use of any materials, paints, or methods specified therein, or of the specification itself.

10.2 Additional information and data relative to this specification are contained in the following brief Appendix. More detailed information and data are presented in a separate document, SSPC-SP COM, "Surface Preparation Commentary." The recommendations contained in the Notes, Appendix, and SSPC-SP COM are believed to represent good practice, but are not to be considered as requirements of the specification. The table below lists the subjects discussed relevant to White Metal Blast Cleaning and appropriate section of SSPC-SP COM.

Subject	Commentary Section
Abrasive Selection	5.
Degree of Cleaning	11.5
Film Thickness	10.
Wet Abrasive Blast Cleaning	9.
Maintenance Painting	3.2
Rust Back (Rerusting)	8.
Surface Profile	6.
Visual Standards	7.
Weld Spatter	4.1

A. Appendix

A.1 FUNCTION — White Metal Blast Cleaning (SSPC-SP 5) provides a greater degree of cleaning than Near-White Blast Cleaning (SSPC-SP 10). It should be used where the highest degree of blast cleaning is required. The primary functions of blast cleaning before painting are: (a) to remove material from the surface that can cause early failure of the coating system, and (b) to obtain a suitable surface roughness.

A.2 ABRASIVE SELECTION — Types of metallic and non-metallic abrasives are discussed in the Surface Preparation Commentary (SSPC-SP COM). It is important to recognize that blasting abrasives may become embedded in or leave residues on the surface of the steel during preparation. While normally such embedment or residues are not detrimental, care should be taken (particularly if the prepared steel is to be used in an immersion environment) to assure that the abrasive is free from detrimental amounts of water soluble, solvent soluble, acid soluble, or other such soluble materials.

A.3 SURFACE PROFILE — Surface profile is the roughness of the surface which results from abrasive blast cleaning. The profile depth (or height) is dependent upon the size, type, and hardness of the abrasive, particle velocity and angle of impact, hardness of the surface, amount of recycling, and the proper maintenance of working mixtures of grit and/or shot.

The allowable minimum/maximum height of profile is usually dependent upon the thickness of the paint to be applied. Large particle sized abrasives (particularly metallic) can produce a profile which may be too deep to be adequately covered by a single thin film coat. Accordingly, it is recommended that the use of larger abrasives be avoided in these cases. However, larger abrasives may be needed for thick film coatings or to facilitate removal of heavy mill scale or rust. If control of profile (minimum/maximum) is deemed to be significant to coatings performance, it should be addressed in the procurement documents (project specification).

Typical maximum profile heights achieved with commercial abrasive media are shown in Table 8 of the Surface Preparation Commentary (SSPC-SP COM). Methods (i.e., comparators, replica tape, depth micrometers) are available to aid in estimating the profile of surfaces blast cleaned with sand, steel grit, and steel shot.

A.4 VISUAL STANDARDS — Note that the use of visual standards in conjunction with this specification is required only when they are specified in the procurement documents (project specification) covering the work. It is recommended, however, that the use of visual standards be made mandatory in the procurement documents (project specification)

SSPC-Vis 1, "Pictorial Surface Preparation Standards for Painting Steel Surfaces," provides color photographs for the various grades of surface preparation as a function of the initial condition of the steel. The following table lists the pictorial standards for this specification that are applicable to the rust grades given.

Rust Grade	Adherent Mill Scale	Rusting Mill Scale	Rusted	Pitted and Rusted
Pictorial Standards	A Sa 3	B Sa 3	C Sa 3	D Sa 3

Many other visual standards are available and are described in Section 7 of the Commentary (SSPC-SP COM).

A.5 SURFACE IMPERFECTIONS — Surface imperfections can cause premature failure when the service is severe. Coatings tend to pull away from sharp edges and projections, leaving little or no coating to protect the underlying steel. Other features which are difficult to properly cover and protect include crevices, weld porosity, laminations, etc. The high cost of the methods to remedy the surface imperfections requires weighing the benefits of edge rounding, weld spatter removal, etc., versus a potential coating failure.

Poorly adhering contaminants, such as weld slag residues, loose weld spatter, and some minor surface laminations, may be removed during the blast cleaning operation. Other surface defects (steel laminations, weld porosities, or deep corrosion pits) may not be evident until the surface preparation has been completed. Therefore, proper planning for such surface repair work is essential since the timing of the repairs may occur before, during, or after the blast cleaning operation. Section 4 of the Commentary (SSPC-SP COM) contains additional information on surface imperfections.

A.6 CHEMICAL CONTAMINATION — Steel contaminated with soluble salts (i.e., chlorides and sulfates) develops rust-back rapidly at intermediate and high humidities. These soluble salts can be present on the steel surface prior to blast cleaning as a result of atmospheric contamination. In addition, contaminants can be deposited on the steel surface during blast cleaning whenever the abrasive is contaminated. Therefore, rust-back can be minimized by removing these salts from the steel surface, preferably before blast cleaning, and eliminating sources of recontamination during and after blast cleaning. Identification of the contaminants along with their concentrations may be obtained from laboratory and field tests. A number of tests for soluble salts are now under study by the SSPC, ASTM, Maritime Administration, and ISO.

A.7 RUST-BACK — Rust-back (rerusting) occurs when freshly cleaned steel is exposed to conditions of high humidity, moisture, contamination, or a corrosive atmosphere. The time interval between blast cleaning and rust-back will vary greatly from one environment to another. Under mild ambient conditions it is best to blast clean and coat a surface the same day. Severe conditions may require coating more quickly while for exposure under controlled conditions the coating time may be extended. Under no circumstances should the steel be permitted to rust-back before painting regardless of the time elapsed (see Appendix A.6).

A.8 DEW POINT — Moisture condenses on any surface that is colder than the dew point of the surrounding air. It is, therefore, recommended that the temperature of steel surface be at least 5 degrees F (3 degrees C) above the dew point during dry blast cleaning operations. It is advisable to visually inspect for moisture and periodically check the surface temperature and dew point during blast cleaning operations. It is advisable to visually inspect for moisture and periodically check the surface temperature and dew point during blast cleaning operations. It is important that the application of paint over a damp surface be avoided.

A.9 WET ABRASIVE BLAST CLEANING — Steel that is wet abrasive blast cleaned may rust rapidly. Clean water should be used for rinsing (studies have shown that water of at least 15,000 ohm-cm resistivity is preferred). It may be necessary that inhibitors be added to the water or applied to the surface immediately after blast cleaning to temporarily prevent rust formation. The coating should then be applied before any rusting is visible. One inhibitive treatment for blast cleaned surfaces is water containing 0.32% sodium nitrite and 1.28% by weight secondary ammonium phosphate (dibasic).
CAUTION: Some inhibitive treatments may interfere with the performance of certain coating systems.

A.10 FILM THICKNESS — It is essential that ample coating be applied after blast cleaning to adequately cover the peaks of the surface profile. The dry paint film thickness above the peaks of the profile should equal the thickness known to be needed for the desired protection. If the dry film thickness over the peaks is inadequate, premature rust-through or failure will occur. To assure that coating thicknesses are properly measured, refer to SSPC-PA 2, "Measurement of Dry Paint Thickness with Magnetic Gages."

A.11 MAINTENANCE AND REPAIR PAINTING — When this specification is used in maintenance painting, specific instructions should be given on the extent of surface to be blast cleaned or spot blast cleaned to this degree of cleanliness. SSPC-PA Guide 4, "Guide to Maintenance Repainting with Oil Base or Alkyd Painting Systems," provides a description of accepted practices for retaining old sound paint, removing unsound paint, feathering, and spot cleaning.

Steel Structures Painting Council
SURFACE PREPARATION SPECIFICATION NO. 6
Commercial Blast Cleaning

1. Scope

1.1 This specification covers the requirements for Commercial Blast Cleaning of steel surfaces by the use of abrasives.

2. Definition

2.1 A Commercial Blast Cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, mill scale, rust, paint, oxides, corrosion products, and other foreign matter, except for staining, as noted in Section 2.2.

2.2 Staining shall be limited to no more than 33 percent of each square inch of surface area and may consist of light shadows, slight streaks, or minor discolorations caused by stains of rust, stains of mill scale, or stains of previously applied paint. Slight residues of rust and paint may also be left in the bottoms of pits if the original surface is pitted.

2.3 ACCEPTABLE VARIATIONS IN APPEARANCE THAT DO NOT AFFECT SURFACE CLEANLINESS as defined in Sections 2.1 and 2.2 include variations caused by type of steel, original surface condition, thickness of the steel, weld metal, mill or fabrication marks, heat treating, heat affected zones, blasting abrasive, and differences in the blast pattern.

2.4 When painting is specified, the surface shall be roughened to a degree suitable for the specified paint system.

2.5 Immediately prior to paint application, the surface shall comply with the degree of cleaning as specified herein.

2.6 SSPC-Vis 1 or other visual standards of surface preparation may be specified to supplement the written definition.
*NOTE: Additional information on visual standards is available in Section A.4 of the Appendix.

3. Blast Cleaning Abrasives

3.1 The selection of abrasive size and type shall be based on the type, grade, and surface condition of the steel to be cleaned, type of blast cleaning system employed, the finished surface to be produced (cleanliness and roughness), and whether the abrasive will be recycled.

*Notes are not requirements of this specification.

3.2 The cleanliness and size of recycled abrasives shall be maintained to insure compliance with this specification.

3.3 The blast cleaning abrasive shall be dry and free of oil, grease, and other harmful materials at the time of use.

3.4 Any limitations or restrictions on the use of specific abrasives, quantity of contaminants, or degree of embedment shall be included in the procurement documents (project specification) covering the work, since abrasive embedment and abrasives containing contaminants may not be acceptable for some service requirements.
*NOTE: Additional information on abrasive selection is available in Section A.2 of the Appendix.

4. Reference Standards

4.1 If there is a conflict between the cited reference standards and this specification, this specification shall prevail unless otherwise indicated in the procurement documents (project specification).

4.2 The standards referenced in this specification are:

SSPC-SP 1	Solvent Cleaning
SSPC-Vis 1	Pictorial Surface Preparation Standards for Painting Steel Surfaces

5. Procedure Before Blast Cleaning

5.1 Before blast cleaning, visible deposits of oil or grease shall be removed by any of the methods specified in SSPC-SP 1 or other agreed upon methods.

5.2 Before blast cleaning, surface imperfections such as sharp fins, sharp edges, weld spatter, or burning slag should be removed from the surface to the extent required by the procurement documents (project specification).
*NOTE: Additional information on surface imperfections is available in Section A.5 of the Appendix.

6. Blast Cleaning Methods and Operation

6.1 Clean, dry, compressed air shall be used for nozzle blasting. Moisture separators, oil separators, traps or other equipment may be necessary to achieve this requirement.

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6.2 Any of the following methods of surface preparation may be used to achieve a Commercial Blast Cleaned surface:

6.2.1 Dry abrasive blasting using compressed air, blast nozzles, and abrasive.

6.2.2 Dry abrasive blasting using a closed cycle, recirculating abrasive system with compressed air, blast nozzle, and abrasive, with or without vacuum for dust and abrasive recovery.

6.2.3 Dry abrasive blasting, using a closed cycle, recirculating abrasive system with centrifugal wheels and abrasive.

6.3 Other methods of surface preparation (such as wet abrasive blasting) may be used to achieve a Commercial Blast Cleaned surface by mutual agreement between the party responsible for performing the work and the party responsible for establishing the requirements or his representative.
*NOTE: If wet abrasive blasting is used, information on the use of inhibitors to prevent the formation of rust immediately after wet blast cleaning is contained in Section A.9 of the Appendix.

7. Procedures Following Blast Cleaning and Immediately Prior to Painting

7.1 Visible deposits of oil, grease, or other contaminants shall be removed by any of the methods specified in SSPC-SP 1 or other methods agreed upon by the party responsible for establishing the requirements and the party responsible for performing the work.

7.2 Dust and loose residues shall be removed from prepared surfaces by brushing, blowing off with clean, dry air, vacuum cleaning or other methods agreed upon by the party responsible for establishing the requirements and the party responsible for performing the work. Moisture separators, oil separators, traps, or other equipment may be necessary to achieve clean, dry air.

7.3 After blast cleaning, surface imperfections which remain (i.e., sharp fins, sharp edges, weld spatter, burning slag, scabs, slivers, etc.) shall be removed to the extent required in the procurement documents (project specification). Any damage to the surface profile resulting from the removal of surface imperfections shall be corrected to meet the requirements of Section 2.4.
*NOTE: Additional information on surface imperfections is contained in Section A.5 of the Appendix.

7.4 Any visible rust that forms on the surface of the steel after blast cleaning shall be removed by reblasting the rusted areas to meet the requirements of this specification before painting.
*NOTE: Information on rust-back (rerusting) and surface condensation is contained in Sections A.7 and A.8 of the Appendix.

8. Inspection

8.1 Work and materials supplied under this specification are subject to inspection by the party responsible for establishing the requirements or his representative. Materials and work areas shall be accessible to the inspector. The procedures and times of inspection shall be as agreed upon by the party responsible for establishing the requirements and the party responsible for performing the work.

8.2 Conditions not complying with this specification shall be corrected. In case of dispute the arbitration or settlement procedure established in the procurement documents (project specification) shall be followed. If no arbitration or settlement procedure is established, then the procedure established by the American Arbitration Association shall be used.

8.3 The procurement documents (project specification) should establish the responsibility for inspection and for any required affidavit certifying compliance with the specification.

9. Safety and Environmental Requirements

9.1 Blast cleaning is a hazardous operation. Therefore, all work shall be conducted in such a manner to comply with all applicable insurance underwriter, local, state, and federal safety and environmental rules and requirements.
*NOTE: SSPC-PA Guide 3, "A Guide to Safety in Paint Application," addresses safety concerns for coating work.

10. Comments

10.1 While every precaution is taken to insure that all information furnished in SSPC specifications is as accurate, complete, and useful as possible, the Steel Structures Painting Council cannot assume responsibility nor incur any obligation resulting from the use of any materials, paints, or methods specified therein, or of the specification itself.

10.2 Additional information and data relative to this specification are contained in the following brief Appendix. More detailed information and data are presented in a separate document, SSPC-SP COM, "Surface Preparation Commentary." The recommendations contained in the Notes, Appendix, and SSPC-SP COM are believed to represent good practice, but are not to be considered as requirements of the specification. The table below lists the subjects discussed relevant to Commercial Blast Cleaning and appropriate section of SSPC-SP COM.

A. Appendix

A.1 FUNCTION — Commercial Blast Cleaning (SSPC-SP 6) provides a greater degree of cleaning than Brush-Off Blast Cleaning (SSPC-SP 7) but less than Near-White Blast Cleaning (SSPC-SP 10). It should be used where a high but not perfect degree of blast cleaning is required. The primary functions of blast cleaning before painting are: (a) to remove material from the surface that can cause early failure of the coating system, and (b) to obtain a suitable surface roughness.

A.2 ABRASIVE SELECTION — Types of metallic and non-metallic abrasives are discussed in the Surface Preparation Commentary (SSPC-SP COM). It is important to recognize that blasting abrasives may become embedded in or leave residues on the surface of the steel during preparation. While normally such embedment or residues are not detrimental, care should be taken (particularly if the prepared steel is to be used in an immersion environment) to assure that the abrasive is free from detrimental amounts of water soluble, solvent soluble, acid soluble, or other such soluble materials.

A.3 SURFACE PROFILE — Surface profile is the roughness of the surface which results from abrasive blast cleaning. The profile depth (or height) is dependent upon the size, type, and hardness of the abrasive, particle velocity and angle of impact, hardness of the surface, amount of recycling, and the proper maintenance of working mixtures of grit and/or shot.

The allowable minimum/maximum height of profile is usually dependent upon the thickness of the paint to be applied. Large particle sized abrasives (particularly metallic) can produce a profile which may be too deep to be adequately covered by a single thin film coat. Accordingly, it is recommended that the use of larger abrasives be avoided in these cases. However, larger abrasives may be needed for thick film coatings or to facilitate removal of heavy mill scale or rust. If control of profile (minimum/maximum) is deemed to be significant to coatings performance, it should be addressed in the procurement documents (project specification).

Typical maximum profile heights achieved with commercial abrasive media are shown in Table 8 of the Surface Preparation Commentary (SSPC-SP COM). Methods (i.e., comparators, replica tape, depth micrometers) are available to aid in estimating the profile of surfaces blast cleaned with sand, steel grit, and steel shot.

A.4 VISUAL STANDARDS — Note that the use of visual standards in conjunction with this specification is required only when they are specified in the procurement documents (project specification) covering the work. It is recommended, however, that the use of visual standards be made mandatory in the procurement documents (project specification).

SSPC-Vis 1, "Pictorial Surface Preparation Standards for Painting Steel Surfaces," provides color photographs for the various grades of surface preparation as a function of the initial condition of the steel. The following table lists the pictorial standards for this specification that are applicable to the rust grades listed below.

Rust Grade	Rusted	Pitted and Rusted
Pictorial Standards	C Sa 2	D Sa 2

Many other visual standards are available and are described in Section 7 of the Commentary (SSPC-SP COM).

A.5 SURFACE IMPERFECTIONS — Surface imperfections can cause premature failure when the service is severe. Coatings tend to pull away from sharp edges and projections, leaving little or no coating to protect the underlying steel. Other features which are difficult to properly cover and protect include crevices, weld porosity, laminations, etc. The high cost of the methods to remedy the surface imperfections requires weighing the benefits of edge rounding, weld spatter removal, etc., versus a potential coating failure.

Poorly adhering contaminants, such as weld slag residues, loose weld spatter, and some minor surface laminations, may be removed during the blast cleaning operation. Other surface defects (steel laminations, weld porosities, or deep corrosion pits) may not be evident until the surface preparation has been completed. Therefore, proper planning for such surface repair work is essential since the timing of the repairs may occur before, during, or after the blast cleaning operation. Section 4 of the Commentary (SSPC-SP COM) contains additional information on surface imperfections.

A.6 CHEMICAL CONTAMINATION — Steel contaminated with soluble salts (i.e., chlorides and sulfates) develops rust-back rapidly at intermediate and high humidities. These soluble salts can be present on the steel surface prior to blast cleaning as a result of atmospheric contamination. In addition, contaminants can be deposited on the steel surface during blast cleaning whenever the abrasive is contaminated. Therefore, rust-back can be minimized by removing these salts from the steel surface, preferably before blast cleaning, and eliminating sources of recontamination during and after blast cleaning. Identification of the contaminants along with their concentrations may be obtained from laboratory and field tests. A number of tests for soluble salts are now under study by the SSPC, ASTM, Maritime Administration, and ISO.

A.7 RUST-BACK — Rust-back (rerusting) occurs when freshly cleaned steel is exposed to conditions of high humidity, moisture, contamination, or a corrosive atmosphere. The time interval between blast cleaning and rust-back will vary greatly from one environment to another. Under mild ambient conditions it is best to blast clean and coat a surface the same day. Severe conditions may require coating more quickly while for exposure under controlled conditions the coating time may be extended. Under no circumstances should the steel be permitted to rust-back before painting regardless of the time elapsed (see Appendix A.6).

A.8 DEW POINT — Moisture condenses on any surface that is colder than the dew point of the surrounding air. It is, therefore, recommended that the temperature of steel surface be at least 5 degrees F (3 degrees C) above the dew point during dry blast cleaning operations. It is advisable to visually inspect for moisture and periodically check the surface temperature and dew point during blast cleaning operations. It is important that the application of paint over a damp surface be avoided.

A.9 WET ABRASIVE BLAST CLEANING — Steel that is wet abrasive blast cleaned may rust rapidly. Clean water should be used for rinsing (studies have shown that water of at least 15,000 ohm-cm resistivity is preferred). It may be necessary that inhibitors be added to the water or applied to the surface immediately after blast cleaning to temporarily prevent rust formation. The coating should then be applied before any rusting is visible. One inhibitive treatment for blast cleaned surfaces is water containing 0.32% sodium nitrite and 1.28% by weight secondary ammonium phosphate (dibasic).
CAUTION: Some inhibitive treatments may interfere with the performance of certain coating systems.

A.10 FILM THICKNESS — It is essential that ample coating be applied after blast cleaning to adequately cover the peaks of the surface profile. The dry paint film thickness above the peaks of the profile should equal the thickness known to be needed for the desired protection. If the dry film thickness over the peaks is inadequate, premature rust-through or failure will occur. To assure that coating thicknesses are properly measured, refer to SSPC-PA 2, "Measurement of Dry Paint Thickness with Magnetic Gages."

A.11 MAINTENANCE AND REPAIR PAINTING — When this specification is used in maintenance painting, specific instructions should be given on the extent of surface to be blast cleaned or spot blast cleaned to this degree of cleanliness. SSPC-PA Guide 4, "Guide to Maintenance Repainting with Oil Base or Alkyd Painting Systems," provides a description of accepted practices for retaining old sound paint, removing unsound paint, feathering, and spot cleaning.

SSPC-SP 7
March 1, 1985

Steel Structures Painting Council
SURFACE PREPARATION SPECIFICATION NO. 7
Brush-Off Blast Cleaning

1. Scope

1.1 This specification covers the requirements for Brush-Off Blast Cleaning of steel surfaces by the use of abrasives.

2. Definition

2.1 A Brush-Off Blast Cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, loose mill scale, loose rust, and loose paint. Tightly adherent mill scale, rust, and paint may remain on the surface. Mill scale, rust, and paint are considered tightly adherent if they cannot be removed by lifting with a dull putty knife.

2.2 The entire surface shall be subjected to the abrasive blast. The remaining mill scale, rust, or paint shall be tight.

2.3 When painting is specified, the surface shall be roughened to a degree suitable for the specified paint system.

2.4 Immediately prior to paint application, the surface shall comply with the degree of cleaning as specified herein.

2.5 SSPC-Vis 1 or other visual standards of surface preparation may be specified to supplement the written definition.
*NOTE: Additional information on visual standards is available in Section A.4 of the Appendix.

3. Blast Cleaning Abrasives

3.1 The selection of abrasive size and type shall be based on the type, grade, and surface condition of the steel to be cleaned, type of blast cleaning system employed, the finished surface to be produced (cleanliness and roughness), and whether the abrasive will be recycled.

3.2 The cleanliness and size of recycled abrasives shall be maintained to insure compliance with this specification.

3.3 The blast cleaning abrasive shall be dry and free of oil, grease, and other harmful materials at the time of use.

3.4 Any limitations or restrictions on the use of specific abrasives, quantity of contaminants, or degree of embedment shall be included in the procurement documents (project specification) covering the work, since abrasive embedment and abrasives containing contaminants may not be acceptable for some service requirements.
*NOTE: Additional information on abrasive selection is available in Section A.2 of the Appendix.

4. Reference Standards

4.1 If there is a conflict between the cited reference standards and this specification, this specification shall prevail unless otherwise indicated in the procurement documents (project specification).

4.2 The standards referenced in this specification are:

SSPC-SP 1	Solvent Cleaning
SSPC-Vis 1	Pictorial Surface Preparation Standards for Painting Steel Surfaces

5. Procedure Before Blast Cleaning

5.1 Before blast cleaning, visible deposits of oil or grease shall be removed by any of the methods specified in SSPC-SP 1 or other agreed upon methods.

6. Blast Cleaning Methods and Operation

6.1 Clean, dry, compressed air shall be used for nozzle blasting. Moisture separators, oil separators, traps or other equipment may be necessary to achieve this requirement.

6.2 Any of the following methods of surface preparation may be used to achieve a Brush-Off Blast Cleaned surface:

6.2.1 Dry abrasive blasting using compressed air, blast nozzles, and abrasive.

6.2.2 Dry abrasive blasting using a closed cycle, recirculating abrasive system with compressed air, blast nozzle, and abrasive, with or without vacuum for dust and abrasive recovery.

6.2.3 Dry abrasive blasting, using a closed cycle, recirculating abrasive system with centrifugal wheels and abrasive.

6.3 Other methods of surface preparation (such as wet abrasive blasting) may be used to achieve a Brush- Off Blast Cleaned surface by mutual agreement between the

*Notes are not requirements of this specification.

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party responsible for performing the work and the party responsible for establishing the requirements or his representative.
*NOTE: If wet abrasive blasting is used, information on the use of inhibitors to prevent the formation of rust immediately after wet blast cleaning is contained in Section A.8 of the Appendix

7. Procedures Following Blast Cleaning and Immediately Prior to Painting

7.1 Visible deposits of oil, grease, or other contaminants shall be removed by any of the methods specified in SSPC-SP 1 or other methods agreed upon by the party responsible for establishing the requirements and the party responsible for performing the work.

7.2 Dust and loose residues shall be removed from prepared surfaces by brushing, blowing off with clean, dry air, vacuum cleaning or other methods agreed upon by the party responsible for establishing the requirements and the party responsible for performing the work. Moisture separators, oil separators, traps, or other equipment may be necessary to achieve clean, dry air.

8. Inspection

8.1 Work and materials supplied under this specification are subject to inspection by the party responsible for establishing the requirements or his representative. Materials and work areas shall be accessible to the inspector. The procedures and times of inspection shall be as agreed upon by the party responsible for establishing the requirements and the party responsible for performing the work.

8.2 Conditions not complying with this specification shall be corrected. In case of dispute the arbitration or settlement procedure established in the procurement documents (project specification) shall be followed. If no arbitration or settlement procedure is established, then the procedure established by the American Arbitration Association shall be used.

8.3 The procurement documents (project specification) should establish the responsibility for inspection and for any required affidavit certifying compliance with the specification.

9. Safety and Environmental Requirements

9.1 Blast cleaning is a hazardous operation. Therefore, all work shall be conducted in such a manner to comply with all applicable insurance underwriter, local, state, and federal safety and environmental rules and requirements.
*NOTE: SSPC-PA Guide 3, "A Guide to Safety in Paint Application," addresses safety concerns for coating work.

10. Comments

10.1 While every precaution is taken to insure that all information furnished in SSPC specifications is as accurate, complete, and useful as possible, the Steel Structures Painting Council cannot assume responsibility nor incur any obligation resulting from the use of any materials, paints, or methods specified therein, or of the specification itself.

10.2 Additional information and data relative to this specification are contained in the following brief Appendix. More detailed information and data are presented in a separate document, SSPC-SP COM, "Surface Preparation Commentary." The recommendations contained in the Notes, Appendix, and SSPC-SP COM are believed to represent good practice, but are not to be considered as requirements of the specification. The table below lists the subjects discussed relevant to Brush-Off Blast Cleaning and appropriate section of SSPC-SP COM.

Subject	Commentary Section
Abrasive Selection	5.
Degree of Cleaning	11.7
Film Thickness	10.
Wet Abrasive Blast Cleaning	9.
Maintenance Painting	3.2
Rust Back (Rerusting)	8.
Surface Profile	6.
Visual Standards	7.
Weld Spatter	4.1

A. Appendix

A.1 FUNCTION — Brush-Off Blast Cleaning (SSPC-SP 7) provides a lesser degree of cleaning than Commercial Blast Cleaning (SSPC-SP 6). It should be used where the service environment is mild enough to permit tight mill scale, paint, rust, and other foreign matter to remain on the surface. The primary functions of blast cleaning before painting are: (a) to remove material from the surface that can cause early failure of the coating system, and (b) to obtain a suitable surface roughness.

A.2 ABRASIVE SELECTION — Types of metallic and non-metallic abrasives are discussed in the Surface Preparation Commentary (SSPC-SP COM).

A.3 SURFACE PROFILE — Surface profile is the roughness of the surface which results from abrasive blast cleaning. The profile depth (or height) is dependent upon the size, type, and hardness of the abrasive, particle velocity and angle of impact, hardness of the surface, amount of recycling, and the proper maintenance of working mixtures of grit and/or shot.

A.4 VISUAL STANDARDS — Note that the use of visual standards in conjunction with this specification is required only when they are specified in the procurement documents (project specification) covering the work. It is recommended, however, that the use of visual standards be made mandatory in the procurement documents (project specification).

SSPC-Vis 1, "Pictorial Surface Preparation Standards for Painting Steel Surfaces," provides color photographs for the various grades of surface preparation as a function of the initial condition of the steel. The following table lists the pictorial standards for this specification that are applicable to the rust grades listed below.

Rust Grade	Rusting Mill Scale	Rusted	Pitted and Rusted
Pictorial Standards	B Sa 1	C Sa 1	D Sa 1

Many other visual standards are available and are described in Section 7 of the Commentary (SSPC-SP COM).

A.5 DEW POINT — Moisture condenses on any surface that is colder than the dew point of the surrounding air. It is, therefore, recommended that the temperature of steel surface be at least 5 degrees F (3 degrees C) above the dew point during dry blast cleaning operations. It is advisable to visually inspect for moisture and periodically check the surface temperature and dew point during blast cleaning operations. It is important that the application of paint over a damp surface be avoided.

A.6 WET ABRASIVE BLAST CLEANING — Steel that is wet abrasive blast cleaned may rust rapidly. Clean water should be used for rinsing (studies have shown that water of at least 15,000 ohm-cm resistivity is preferred). It may be necessary that inhibitors be added to the water or applied to the surface immediately after blast cleaning to temporarily prevent rust formation. The coating should then be applied before any rusting is visible. One inhibitive treatment for blast cleaned surfaces is water containing 0.32% sodium nitrite and 1.28% by weight secondary ammonium phosphate (dibasic).
CAUTION: Some inhibitive treatments may interfere with the performance of certain coating systems.

A.7 FILM THICKNESS — It is essential that ample coating be applied after blast cleaning to adequately cover the peaks of the surface profile. The dry paint film thickness above the peaks of the profile should equal the thickness known to be needed for the desired protection. If the dry film thickness over the peaks is inadequate, premature rust-through or failure will occur. To assure that coating thicknesses are properly measured, refer to SSPC-PA 2, "Measurement of Dry Paint Thickness with Magnetic Gages."

A.8 MAINTENANCE AND REPAIR PAINTING — When this specification is used in maintenance painting, specific instructions should be given on the extent of surface to be blast cleaned or spot blast cleaned to this degree of cleanliness. SSPC-PA Guide 4, "Guide to Maintenance Repainting with Oil Base or Alkyd Painting Systems," provides a description of accepted practices for retaining old sound paint, removing unsound paint, feathering, and spot cleaning.

Steel Structures Painting Council
SURFACE PREPARATION SPECIFICATION NO. 10
Near-White Blast Cleaning

1. Scope

1.1 This specification covers the requirements for Near-White Blast Cleaning of steel surfaces by the use of abrasives.

2. Definition

2.1 A Near-White Blast Cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, mill scale, rust, paint, oxides, corrosion products, and other foreign matter, except for staining as noted in Section 2.2.

2.2 Staining shall be limited to no more than 5 percent of each square inch of surface area and may consist of light shadows, slight streaks, or minor discolorations caused by stains of rust, stains of mill scale, or stains of previously applied paint.

2.3 ACCEPTABLE VARIATIONS IN APPEARANCE THAT DO NOT AFFECT SURFACE CLEANLINESS as defined in Sections 2.1 and 2.2 include variations caused by type of steel, original surface condition, thickness of the steel, weld metal, mill or fabrication marks, heat treating, heat affected zones, blasting abrasives, and differences in the blast pattern.

2.4 When painting is specified, the surface shall be roughened to a degree suitable for the specified paint system.

2.5 Immediately prior to paint application, the surface shall comply with the degree of cleaning as specified herein.

2.6 SSPC-Vis 1 or other visual standards of surface preparation may be specified to supplement the written definitlon.
*NOTE: Additional information on visual standards is available in Section A.4 of the Appendix.

3. Blast Cleaning Abrasives

3.1 The selection of abrasive size and type shall be based on the type, grade, and surface condition of the steel to be cleaned, type of blast cleaning system employed, the finished surface to be produced (cleanliness and roughness), and whether the abrasive will be recycled.

3.2 The cleanliness and size of recycled abrasives shall be maintained to insure compliance with this specification.

3.3 The blast cleaning abrasive shall be dry and free of oil, grease, and other harmful materials at the time of use.

3.4 Any limitations or restrictions on the use of specific abrasives, quantity of contaminants, or degree of embedment shall be included in the procurement documents (project specification) covering the work, since abrasive embedment and abrasives containing contaminants may not be acceptable for some service requirements.
*NOTE: Additional information on abrasive selection is available in Section A.2 of the Appendix.

4. Reference Standards

4.1 If there is a conflict between the cited reference standards and this specification, this specification shall prevail unless otherwise indicated in the procurement documents (project specification).

4.2 The standards referenced in this specification are:

SSPC-SP 1	Solvent Cleaning
SSPC-Vis 1	Pictorial Surface Preparation Standards for Painting Steel Surfaces

5. Procedure Before Blast Cleaning

5.1 Before blast cleaning, visible deposits of oil or grease shall be removed by any of the methods specified in SSPC-SP 1 or other agreed upon methods.

5.2 Before blast cleaning, surface imperfections such as sharp fins, sharp edges, weld spatter, or burning slag should be removed from the surface to the extent required by the procurement documents (project specification).
*NOTE: Additional information on surface imperfections is available in Section A.5 of the Appendix.

6. Blast Cleaning Methods and Operation

6.1 Clean, dry, compressed air shall be used for nozzle blasting. Moisture separators, oil separators, traps

*Notes are not requirements of this specification.

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or other equipment may be necessary to achieve this requirement.

6.2 Any of the following methods of surface preparation may be used to achieve a Near-White Blast Cleaned surface:

6.2.1 Dry abrasive blasting using compressed air, blast nozzles, and abrasive.

6.2.2 Dry abrasive blasting using a closed cycle, recirculating abrasive system with compressed air, blast nozzle, and abrasive, with or without vacuum for dust and abrasive recovery.

6.2.3 Dry abrasive blasting, using a closed cycle, recirculating abrasive system with centrifugal wheels and abrasive.

6.3 Other methods of surface preparation (such as wet abrasive blasting) may be used to achieve a Near-White Blast Cleaned surface by mutual agreement between the party responsible for performing the work and the party responsible for establishing the requirements or his representative.
*NOTE: If wet abrasive blasting is used, information on the use of inhibitors to prevent the formation of rust immediately after wet blast cleaning is contained in Section A.9 of the Appendix

7. Procedures Following Blast Cleaning and Immediately Prior to Painting

7.1 Visible deposits of oil, grease, or other contaminants shall be removed by any of the methods specified in SSPC-SP 1 or other methods agreed upon by the party responsible for establishing the requirements and the party responsible for performing the work.

7.2 Dust and loose residues shall be removed from prepared surfaces by brushing, blowing off with clean, dry air, vacuum cleaning or other methods agreed upon by the party responsible for establishing the requirements and the party responsible for performing the work. Moisture separators, oil separators, traps, or other equipment may be necessary to achieve clean, dry air.

7.3 After blast cleaning, surface imperfections which remain (i.e., sharp fins, sharp edges, weld spatter, burning slag, scabs, slivers, etc.) shall be removed to the extent required in the procurement documents (project specification). Any damage to the surface profile resulting from the removal of surface imperfections shall be corrected to meet the requirements of Section 2.4.
*NOTE: Additional information on surface imperfections is contained in Section A.5 of the Appendix.

7.4 Any visible rust that forms on the surface of the steel after blast cleaning shall be removed by reblasting the rusted areas to meet the requirements of this specification before painting.
*NOTE: Information on rust-back (rerusting) and surface condensation is contained in Sections A.7 and A.8 of the Appendix.

8. Inspection

8.1 Work and materials supplied under this specification are subject to inspection by the party responsible for establishing the requirements or his representative. Materials and work areas shall be accessible to the inspector. The procedures and times of inspection shall be as agreed upon by the party responsible for establishing the requirements and the party responsible for performing the work.

8.2 Conditions not complying with this specification shall be corrected. In case of dispute the arbitration or settlement procedure established in the procurement documents (project specification) shall be followed. If no arbitration or settlement procedure is established, then the procedure established by the American Arbitration Association shall be used.

8.3 The procurement documents (project specification) should establish the responsibility for inspection and for any required affidavit certifying compliance with the specification.

9. Safety and Environmental Requirements

9.1 Blast cleaning is a hazardous operation. Therefore, all work shall be conducted in such a manner to comply with all applicable insurance underwriter, local, state, and federal safety and environmental rules and requirements.
*NOTE: SSPC-PA Guide 3, "A Guide to Safety in Paint Application," addresses safety concerns for coating work.

10. Comments

10.1 While every precaution is taken to insure that all information furnished in SSPC specifications is as accurate, complete, and useful as possible, the Steel Structures Painting Council cannot assume responsibility nor incur any obligation resulting from the use of any materials, paints, or methods specified therein, or of the specification itself.

10.2 Additional information and data relative to this specification are contained in the following brief Appendix. More detailed information and data are presented in a separate document, SSPC-SP COM, "Surface Preparation Commentary." The recommendations contained in the Notes, Appendix, and SSPC-SP COM are believed to represent good practice, but are not to be considered as requirements of the specification. The table below lists the subjects discussed relevant to Near-White Blast Cleaning and appropriate section of SSPC-SP COM.

Subject	Commentary Section
Abrasive Selection	5.
Degree of Cleaning	11.10
Film Thickness	10.
Wet Abrasive Blast Cleaning	9.
Maintenance Painting	3.2
Rust Back (Rerusting)	8.
Surface Profile	6.
Visual Standards	7.
Weld Spatter	4.1

A. Appendix

A.1 FUNCTION — Near-White Blast Cleaning (SSPC-SP 10) provides a greater degree of cleaning than Commercial Blast Cleaning (SSPC-SP 6) but less than White Metal Blast Cleaning (SSPC-SP 5). It should be used where a high degree of blast cleaning is required. The primary functions of blast cleaning before painting are: (a) to remove material from the surface that can cause early failure of the coating system, and (b) to obtain a suitable surface roughness.

A.2 ABRASIVE SELECTION — Types of metallic and non-metallic abrasives are discussed in the Surface Preparation Commentary (SSPC-SP COM). It is important to recognize that blasting abrasives may become embedded in or leave residues on the surface of the steel during preparation. While normally such embedment or residues are not detrimental, care should be taken (particularly if the prepared steel is to be used in an immersion environment) to assure that the abrasive is free from detrimental amounts of water soluble, solvent soluble, acid soluble, or other such soluble materials.

A.3 SURFACE PROFILE — Surface profile is the roughness of the surface which results from abrasive blast cleaning. The profile depth (or height) is dependent upon the size, type, and hardness of the abrasive, particle velocity and angle of impact, hardness of the surface, amount of recycling, and the proper maintenance of working mixtures of grit and/or shot.

The allowable minimum/maximum height of profile is usually dependent upon the thickness of the paint to be applied. Large particle sized abrasives (particularly metallic) can produce a profile which may be too deep to be adequately covered by a single thin film coat. Accordingly, it is recommended that the use of larger abrasives be avoided in these cases. However, larger abrasives may be needed for thick film coatings or to facilitate removal of heavy mill scale or rust. If control of profile (minimum/maximum) is deemed to be significant to coatings performance, it should be addressed in the procurement documents (project specification).

Typical maximum profile heights achieved with commercial abrasive media are shown in Table 8 of the Surface Preparation Commentary (SSPC-SP COM). Methods (i.e., comparators, replica tape, depth micrometers) are available to aid in estimating the profile of surfaces blast cleaned with sand, steel grit, and steel shot.

A.4 VISUAL STANDARDS — Note that the use of visual standards in conjunction with this specification is required only when they are specified in the procurement documents (project specification) covering the work. It is recommended, however, that the use of visual standards be made mandatory in the procurement documents (project specification).

SSPC-Vis 1, "Pictorial Surface Preparation Standards for Painting Steel Surfaces," provides color photographs for the various grades of surface preparation as a function of the initial condition of the steel. The following table lists the pictorial standards for this specification that are applicable to the rust grades listed below.

Rust Grade	Adherent Mill Scale	Rusting Mill Scale	Rusted	Pitted and Rusted
Pictorial Standards	A Sa 2-½	B Sa 2-½	C Sa 2-½	D Sa 2-½

Many other visual standards are available and are described in Section 7 of the Commentary (SSPC-SP COM).

A.5 SURFACE IMPERFECTIONS — Surface imperfections can cause premature failure when the service is severe. Coatings tend to pull away from sharp edges and projections, leaving little or no coating to protect the underlying steel. Other features which are difficult to properly cover and protect include crevices, weld porosity, laminations, etc. The high cost of the methods to remedy the surface imperfections requires weighing the benefits of edge rounding, weld spatter removal, etc., versus a potential coating failure.

Poorly adhering contaminants, such as weld slag residues, loose weld spatter, and some minor surface laminations, may be removed during the blast cleaning operation. Other surface defects (steel laminations, weld porosities, or deep corrosion pits) may not be evident until the surface preparation has been completed. Therefore, proper planning for such surface repair work is essential since the timing of the repairs may occur before, during, or after the blast cleaning operation. Section 4 of the Commentary (SSPC-SP COM) contains additional information on surface imperfections.

A.6 CHEMICAL CONTAMINATION — Steel contaminated with soluble salts (i.e., chlorides and sulfates) develops rust-back rapidly at intermediate and high humidities. These soluble salts can be present on the steel surface prior to blast cleaning as a result of atmospheric contamination. In addition, contaminants can be deposited on the steel surface during blast cleaning whenever the abrasive is contaminated. Therefore, rust-back can be minimized by removing these salts from the steel surface, preferably before blast cleaning and eliminating sources of recontamination during and after blast cleaning. Identification of the contaminants along with their concentrations may be obtained from laboratory and field tests. A number of tests for soluble salts are now under study by the SSPC, ASTM, Maritime Administration, and ISO.

A.7 RUST-BACK — Rust-back (rerusting) occurs when freshly cleaned steel is exposed to conditions of high humidity, moisture, contamination, or a corrosive atmosphere. The time interval between blast cleaning and rust-back will vary greatly from one environment to another. Under mild ambient conditions it is best to blast clean and coat a surface the same day. Severe conditions may require coating more quickly while for exposure under controlled conditions the coating time may be extended. Under no circumstances should the steel be permitted to rust-back before painting regardless of the time elapsed (see Appendix A.6).

A.8 DEW POINT — Moisture condenses on any surface that is colder than the dew point of the surrounding air. It is, therefore, recommended that the temperature of steel surface be at least 5 degrees F (3 degrees C) above the dew point during dry blast cleaning operations. It is advisable to visually inspect for moisture and periodically check the surface temperature and dew point during blast cleaning operations. It is important that the application of paint over a damp surface be avoided.

A.9 WET ABRASIVE BLAST CLEANING — Steel that is wet abrasive blast cleaned may rust rapidly. Clean water should be used for rinsing (studies have shown that water of at least 15,000 ohm-cm resistivity is preferred). It may be necessary that inhibitors be added to the water or applied to the surface immediately after blast cleaning to temporarily prevent rust formation. The coating should then be applied before any rusting is visible. One inhibitive treatment for blast cleaned surfaces is water containing 0.32% sodium nitrite and 1.28% by weight secondary ammonium phosphate (dibasic).
CAUTION: Some inhibitive treatments may interfere with the performance of certain coating systems.

A.10 FILM THICKNESS — It is essential that ample coating be applied after blast cleaning to adequately cover the peaks of the surface profile. The dry paint film thickness above the peaks of the profile should equal the thickness known to be needed for the desired protection. If the dry film thickness over the peaks is inadequate, premature rust-through or failure will occur. To assure that coating thicknesses are properly measured, refer to SSPC-PA 2, "Measurement of Dry Paint Thickness with Magnetic Gages."

A.11 MAINTENANCE AND REPAIR PAINTING — When this specification is used in maintenance painting, specific instructions should be given on the extent of surface to be blast cleaned or spot blast cleaned to this degree of cleanliness. SSPC-PA Guide 4, "Guide to Maintenance Repainting with Oil Base or Alkyd Painting Systems," provides a description of accepted practices for retaining old sound paint, removing unsound paint, feathering, and spot cleaning.