APPENDIX D.

Attribute Index and Commentary

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List of Abbreviations and Acronyms

ADT....... Average Daily Traffic
ADTT....... Average Daily Truck Traffic
CIF....... Constraint-induced Fracture
CF....... Consequence Factor
CP....... Corrosion Protection
CR....... Condition Rating
CS....... Condition State
Delam....... Delamination
ECR .... Epoxy Coated Reinforcing
FHWA .... Federal Highway Administration
LRF .... Load Rating Factor
NBI....... National Bridge Inventory
NBIS....... National Bridge Inspection Standards
NDT....... Nondestructive Testing
NSTM....... Nonredundant Steel Tension Member
OF....... Occurrence Factor
POF....... Probability of Failure
PSC .... Prestressed Concrete
RAP....... Reliability Assessment Panel
RBI....... Risk Based Inspection
R/C .... Reinforced Concrete
SS....... Superstructure
SNBI....... Specification for the National Bridge Inventory
Stl....... Steel
Sub....... Substructure
tpd....... Trucks Per Day
vpd....... Vehicles Per Day

Introduction

This appendix includes attributes and commentary for risk assessment of bridges. This appendix is based on Appendix E of the National Cooperative Highway Research Project (NCHRP) Report 782, "*Proposed Guideline for Reliability-Based Bridge Inspection Practices" (Washer et al., 2014)*. The information has been updated with new attributes, edited, and reformatted. The appendix is intended to help develop risk models for routine highway bridge inspection. The appendix includes an index of common attributes and commentary that explains the rationale supporting each attribute. The appendix also includes example rating criteria with associated scoring.

The listing of attributes included here is not intended to be comprehensive or mandatory. The specific attributes for any risk model should be determined by the Reliability Assessment Panel (RAP). The attribute listing provided here is intended to provide a resource for the RAP to reference, as needed, to help develop risk models for risk-based inspection (RBI). Users should consider adding attributes that are important to their specific inventory. Users are encouraged to document the rationale for including additional attributes in the reliability assessment, along with appropriate criteria and scoring. The suggested rating criteria and scoring shown in this appendix are exemplary in nature and should be adjusted based on the expert judgement of the RAP and the needs of the bridges being analyzed. The number of criteria, total points, and points assigned for each criterion should also be adjusted as needed based on input from the RAP and the needs for the bridges being analyzed.

This commentary is organized into four sections: Screening, Design, Loading and Condition attributes. The Screening section describes attributes that may be used to quickly identify bridges that should not be included in a particular analysis, either because they already have significant damage, or they have attributes that are outside the scope of the analysis being developed. In many cases, these attributes may require engineering analysis beyond that which is typically conducted during a reliability assessment using this Guideline. Screening attributes are characteristics of a bridge or bridge element that:

- Make the likelihood of serious damage unusually high,
- Make the likelihood of serious damage unusually uncertain,
- Identify a bridge with different anticipated deterioration patterns than other bridges in a group or family.

Design attributes are characteristics of a bridge component or element that are part of its design. These attributes typically do not change over time except when renovation, rehabilitation or preservation activities occur. In some cases, preservation or maintenance activities that contribute to the durability of the bridge element may be a design attribute, such as the use of penetrating sealers as a preservation strategy.

Loading attributes are loading characteristics that affect the reliability of a bridge or bridge element such as traffic or environment. These may include structural loading, traffic loading, or environmental loading. Environmental loading may be described in macro terms, such as the general environment in which the bridge is located, or on a local basis, such as the rate of deicing chemical application on a bridge deck.

Condition attributes describe characteristics that relate to the current condition of a bridge or bridge element. These may include element ratings, component ratings, and specific damage modes or mechanisms that significantly affect an element's reliability. For example, if the deterioration mechanism under consideration is corrosion at the bearing areas, the bridge joint's condition may be key in determining the likelihood that corrosion will occur in the bearing area.

Attribute Index

Screening Attributes

S.1 Current Condition Rating

Reason(s) for Attribute

The current condition rating (CR) characterizes the overall condition of the component being rated according to the National Bridge Inventory (NBI) rating scale. Bridge components assessed to be in CR ≤ 4 have been rated to be in poor condition. In some cases, these components may already be on a reduced (12 month or less) inspection frequency. Users may wish to use this criterion to screen bridges already in poor condition and require more in-depth analysis to identify their inspection needs. Users could also assign the Occurrence Factor of "high" without further assessment since the component is already in poor condition.

Assessment Procedure

This screening attribute is scored based on whether the current CR is four or less or greater than four. The current CR from the most recent inspection report should be used.

Example screening criteria and action:

• Current CR is less than or equal to 4.	Screen.
• Current CR is greater than 4.	Continue with procedure.

S.2 Fire Damage

Reason(s) for Attribute

Incidences of fire on or below a highway bridge are not uncommon. This type of damage is most frequently caused by vehicular accidents that result in fire, but secondary causes such as vandalism, terrorism, or other damage initiators should not be discounted. If fire does occur on or below a bridge, an appropriate follow-up assessment should be conducted to determine how the fire has affected the load carrying capacity and the durability characteristics of the main structural members and the deck. This assessment is typically performed during a damage inspection immediately following the incident.

Damage to bridge components resulting from a fire is either immediately apparent during the damage inspection or may manifest within the first 12 - 24 months interval following the fire. Based on this observation, bridges that have experienced a fire may be screened from the reliability assessment until an inspection, which has been conducted approximately 12 months or more after the fire, confirms that the fire has not affected the typical durability characteristics of the bridge components. This screening ensures that damage from the fire has not manifested after the damage inspection.

Assessment Procedure

This attribute is scored based only on the occurrence of a fire on or below the structure being assessed. It is assumed that an appropriate assessment immediately following the fire incident (i.e., damage inspection) has been carried out.

Example screening criteria and action:

• Fire incident has occurred and a damage inspection 12 months after the fire has not occurred.	Not eligible for risk assessment until damage inspection is completed.
• There has been no incidence of fire on or below the bridge, or damage inspection completed.	Continue with procedure.

S.3 Susceptible to Collision

Reason(s) for Attribute

This screening attribute can be used to screen an inventory or a family of bridges to identify those bridges with specific vulnerabilities to random or near-random damage from collision. This attribute is intended to apply to a limited number of bridges for which the risk of collision is unusually high or special. Just because a bridge could be subjected to impact does not mean the likelihood of impact is high, and it could be quite remote. However, there are some structures that have been impacted many times in the past, where a channel or a roadway is particularly difficult to navigate, vertical clearance is inadequate, etc. that are much more likely to be struck. Examples include collisions from barges, debris, or heavy trucks. This attribute would typically be used to screen specific bridges that have an unusual or a unique risk of collision damage from a larger group or family of bridges which do not. In such cases, individual reliability analysis may be required.

Assessment Procedure

This screening attribute should be assessed based on sound engineering judgment and is intended to screen bridges with unusual or special collision risks from an assessment of a group of bridges that do not.

Example screening criteria and action:

- Highly susceptible to collisions. Requires specialized assessment and/or mitigation.
- Structure is not susceptible to collisions. Continue with procedure.

S.4 Flexural Cracking

Reason(s) for Attribute

When the primary load bearing members in a reinforced concrete (R/C) bridge exhibit flexural cracking, it may indicate that the members were either inadequately designed for the required loading, that overloads have occurred, or that deterioration has occurred which has reduced the load bearing capacity of the members. In any case, large flexural cracks can indicate an inadequate load-bearing capacity which may require an engineering analysis to determine the cause of the cracking and the resulting effect on the structure's load capacity. As a result, bridges exhibiting moderate to severe flexural cracking should be screened from the general reliability assessment unless appropriate engineering analysis indicates that the cracking is benign or corrective repairs have been made.

The effects on the strength and the durability of a prestressed concrete (PSC) element due to flexural cracking are generally more significant than for an R/C element.

Assessment Procedure

Flexural cracks will typically present themselves with a vertical orientation either near the bottom flange at mid span or near the top flange over intermediate supports, if the member is continuous.

Engineering judgment must be exercised in determining whether any present flexural cracking is moderate to severe. Crack widths in R/C bridges exceeding 0.006 in. to 0.012 in. reflect the lower bound of “moderate cracking.” The American Concrete Institute Committee Report 224R-01 presents guidance on what could be considered reasonable or tolerable crack widths at the tensile face of R/C structures for typical conditions (ACI, 2001). These values range from 0.006 in. for marine or seawater spray environments to 0.007 in. for structures exposed to deicing chemicals, to 0.012 in. for structures in humid, moist environments. In PSC bridge structural elements, tolerable crack width criteria have been adopted in the Prestressed Concrete Institute (PCI) Manual for the Evaluation and Repair of Precast Prestressed

Concrete Bridge Products (MNL-37-06). The PCI Bridge Committee recommends that flexural cracks greater in width than 0.006 in. should be evaluated to affirm adequate design and performance.

Example screening criteria and action:

• Presence of moderate to severe flexural cracking in reinforced or PSC bridge elements.	Assess individually to determine the source, extent, and effect of cracking.
• Flexural cracking is not present, or it has been determined to be benign or repaired.	Continue with procedure.

S.5 Shear Cracking

Reason(s) for Attribute

If the primary load bearing members in a reinforced or a PSC bridge exhibit shear cracking, it may indicate that the members were either inadequately designed for the required loading, an overload has occurred, or that deterioration has occurred which has reduced the load bearing capacity of the members. In any case, shear cracks may indicate an inadequate load bearing capacity, requiring an engineering analysis to determine the cracking's cause and the resulting effect on the structure's load capacity. As a result, bridges exhibiting cracking attributable to a deficiency in shear strength should be screened from the reliability assessment unless appropriate engineering analysis indicates that the cracking is benign or corrective repairs have been made.

Assessment Procedure

Engineering judgment must be exercised in determining whether any present shear cracking is attributed to a shear strength deficiency. Shear cracks will typically present themselves with a roughly 45° diagonal orientation for conventionally R/C and down to roughly 30 degrees for prestressed elements and will radiate towards the mid-span of the member. The ends of the members and any sections located over piers should be checked for this type of cracking.

Example screening criteria and action:

• Presence of unresolved shear cracking.	Assess individually to determine the source and extent of cracking.
• Shear cracking is not present, or it has been determined to be benign.	Continue with procedure.

S.6 Longitudinal Cracking in Prestressed Elements

Reason(s) for Attribute

This attribute is for the assessment of prestressed bridge elements. Longitudinal cracking in prestressed elements can be indicative of corrosion or fracture of the embedded prestressing strands. As a result, prestressed elements with reported longitudinal cracking should be individually assessed to determine the source of the cracking and the condition of the prestressing strands.

Assessment Procedure

This attribute is assessed based on data in the inspection report and engineering judgment. If longitudinal cracking is reported, further assessment may be required.

Example screening criteria and action:

• Significant longitudinal cracking is present.	Assess individually to determine the source and extent of cracking and condition of strand.
• No significant longitudinal cracking.	Continue with procedure.

S.7 Active Fatigue Cracks Due to Primary Stress Ranges

Reason(s) for Attribute

Active fatigue cracks in steel bridge elements due to primary stresses can propagate quickly and potentially lead to a fracture in the element. These cracks are distinguished from distortion cracks or out-of-plane fatigue cracks, which are more commonly observed, but generally less critical.

Assessment Procedure

If any active fatigue cracks due to primary stresses are found in the element, it is strongly recommended that the element be retrofitted before continuing with this procedure. It is noted that a "stable" fatigue crack can potentially propagate to brittle fracture depending on the toughness of the material, the total applied stress, and the temperature. A fatigue crack can be considered "not active" if previous inspection reports show that the crack has not grown over a set time interval (e.g., the longest inspection interval plus one year). Primary stresses are those stresses (i.e., stress ranges) which are readily calculated using traditional mechanics principles and are typically obtained during design or rating.

Example screening criteria and action:

- Active fatigue crack(s) due to primary stresses present. Retrofit before continuing
- No active fatigue crack(s) due to primary stresses present. Continue with procedure

S.8 Details Susceptible to Constraint Induced Fracture (CIF)

Reason(s) for Attribute

Details susceptible to constraint-induced fracture (CIF) can lead to brittle fracture without any observable cracking. An example of this is the failure of the Hoan Bridge in December 2000 in Milwaukee, WI (Fisher et al., 2001). The bridge had been in service for about 25 years before two of the three girders experienced full-depth fractures, and the third had a crack arrested in the flange. Inspection is not a valid method to prevent these types of failures from occurring (the Hoan Bridge was inspected a few days prior to the failure). Hence, the attribute is included as a screening criterion.

Assessment Procedure

Details susceptible to CIF have a much higher probability of fracture failure than other types of details. It is recommended that CIF details be retrofitted or examined more closely before continuing with this process.

Three conditions have been identified that contribute to an elevated susceptibility to CIF (Coletti, 2021; Connor & Lloyd, 2017)

- a sufficiently high net tensile stress, including consideration of residual stress,
- a high degree of constraint, preventing local yielding, and
- a planar discontinuity approximately perpendicular to the primary flow of tensile stress.

A guideline entitled "*Evaluation of Steel Bridge Details for Susceptibility to Constraint-Induced Fracture*" is available to assist with analyzing steel bridge details (Coletti, 2021). This guide can be used to assess details for CIF.

Example screening criteria and action:

- Structure contains details susceptible to CIF. Retrofit before continuing.
- Structure does not contain details susceptible to CIF. Continue with procedure.

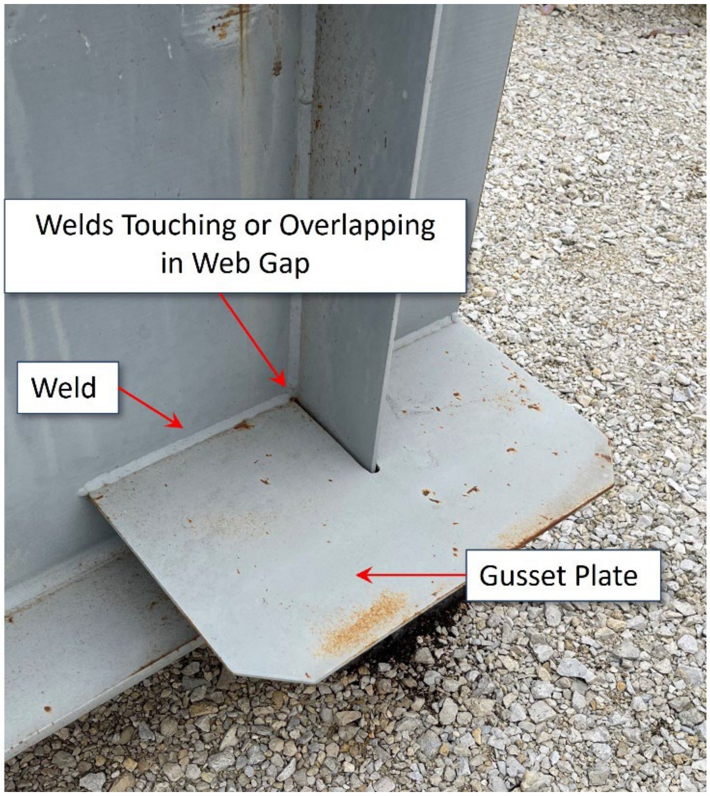

Figure D.1. Photograph of a CIF detail (Photo courtesy of the S-BRITE Center, Purdue University).

S.9 Significant Level of Active Corrosion or Section Loss

Reason(s) for Attribute

This attribute is intended to be used to screen bridges that have a significant level of existing or active corrosion sites that make the likelihood of severe corrosion damage relatively high. A significant amount of active corrosion and/or section loss in an element increases the probability of severe corrosion damage developing in the near future. As a result, individual engineering assessments may be required to effectively assess the reliability characteristics for the element. Significant section loss would normally be visible for steel structural members.

Assessment Procedure

If a significant amount of active corrosion with section loss is found on a steel element it is recommended that the element be repaired before continuing with this process. Engineering judgment must be used to determine what is defined as a *significant* amount of active corrosion with section loss and assess its effects. Previous inspection reports and engineering judgment must also be used to determine whether or not the corrosion is active.

Corrosion damage in steel elements that is inactive is explicitly distinguished from corrosion that is active. For example, section loss on a girder web that was the result of a leaking expansion joint that was corrected (the joint was replaced, and the girder was repainted), could be classified as inactive corrosion if the expansion joint repair eliminates the vulnerability to corrosion. It is assumed that the owner has either determined that the existing section loss is insignificant or considered it in the rating procedures and load posting, if needed, is in place.

Example screening criteria and action:

- Significant level of active corrosion and section loss. — Repair before proceeding.
- Active corrosion or section loss is not significant or has been repaired. — Continue.

S.10 Design Features

Reason(s) for Attribute

This attribute is intended to be used to screen bridges that have an unusual or unique design features that make the likelihood of serious damage either unusually high or unusually uncertain, relative to other bridges in the same family, or identify bridges with different anticipated deterioration patterns than other bridges in a group or family. This attribute can be used to subdivide a family of bridges into two or more groups with similar anticipated deterioration patterns, based on specific design features that are not common to each sub-group. Design features for use as screening items should be identified by the RAP. Two examples are provided to illustrate how this attribute might be used.

<u>Bridges with pin and hanger connections:</u> Pin and hanger connections generally have a history of presenting maintenance challenges. As such, it may be desirable to screen a bridge that includes this type of connection from a larger family, such as a family of steel multi-girder bridges.

<u>Jointless bridges:</u> Jointless bridges are typically less susceptible to corrosion-related damage associated with leaking joints in the bearing areas. As such, the deterioration patterns may differ from other bridges of similar materials and general overall design.

Assessment Procedure

Unique or unusual design features should be identified through review of bridge plans or other documentation describing the design features of a bridge.

Example screening criteria and action:

- Bridge has unique or unusual design features. — Screen.
- The bridge does not have unique or unusual design features. — Proceed.

S.11 Rate of Deterioration

Reason(s) for Attribute

Poor construction quality or materials can be revealed by unusually rapid deterioration of a bridge component because defects appear early in the service life of the component. Design details can sometimes create conditions where deterioration or damage develops rapidly in a component. This attribute is intended to identify components that are deteriorating at an unusually high rate and should be excluded from the risk process. The rationale for removing such a bridge or component from the process is that the risk models developed by the RAP is based largely on knowledge and experience with typical bridges and may not adequately address defective materials or poor construction quality.

Assessment Procedure

The deterioration identified by this attribute manifests in reduced CRs for the deck, superstructure, or substructure of a bridge. Therefore, this attribute can be assessed based on the rate of deterioration from an initial CR 9 to a CR 7 or CR 6. Suggested criteria for assessing this attribute are shown below based on 50^{th} percentile results from Kaplan – Meier survival analysis of bridge components in six states. Table D.1 shows results from Kaplan-Meir survival analysis of the bridge inventories in nine states to provide some example data. The data shown are based on the median time-in-condition-rating (TICR) for bridge components based NBI data. As shown in the table, and average TICR for CR 8 and CR 7 is 10 years and 11 years, respectively. Thresholds of 8 years and 18 years for deterioration to CR 7 and CR 6, respectively, were chosen subjectively based on the median values to represent a bridge with accelerated deterioration. However, due to the variation in condition rating practices, individual owners may set this criterion-based analysis of bridge inventory data within their jurisdiction.

Table D.1. Average TICR values based on NBI data for 9 states.

CR	Deck TICR (years)	PSC Superstructure TICR (years)	R/C Superstructure TICR (years)	Steel Superstructure TICR (years)	Substructure TICR (years)	Average (years)
8	8	10	10	9	12	10
7	11	13	13	12	12	11
6	11	11	14	12	8	10

Based on these data, the screening criteria are shown below.

Example screening criteria and action:

- Component deteriorates to CR 7 in 8 years or less or to CR 6 in 18 years or less. — Screen.
- Components deteriorating at a normal rate. — Proceed.

S.12 Fabrication Defects and/or Connection Damage

Reason(s) for Attribute

This attribute is used to identify steel bridges with known fabrication defects or connection damage that may significantly increase the likelihood of cracking when placed in-service. Connection damage that presents stress concentrations or crack-like geometries that could lead to primary member cracking or fracture can be identified using this attribute. Welds with surface defects (cracks) resulting from poor fabrication quality or subsurface defects found through nondestructive testing can also be identified using this attribute.

Assessment Procedure

This attribute must be assessed based on bridge construction and inspection information that records or notes the presence of a damaged connection or existing weld defects in the bridge.

Example screening criteria and action:

- Significant fabrication defect or connection damage. — Screen.
- Minor fabrication defect or connection damage. — Proceed.

S.13 E or E' Details

Reason(s) for Attribute

Bridge details identified as category E or E' have a high susceptibility to fatigue damage due to repetitive loading on the bridge. These details are generally considered to have a high likelihood of cracking. Steel components with category E and E' details are not eligible for extended inspection intervals using the FHWA Method 1 analysis for extended inspection intervals. However, steel components with category E and E' details are not precluded from extended intervals when using Method 2 analysis. Fatigue cracks cannot grow in the absence of loads sufficient to drive crack growth, which are typically related to truck traffic traversing the bridge.

Assessment Procedure

Bridges with E or E' details can be identified by the Specification for the National Bridge Inventory (SNBI) code B.IR.02 = Y or by review of plans for the steel components.

Example screening criteria and action:

- B.IR.02 = Y or plan review indicated E or E' details. Screen.
- No E or E' details present. Proceed.

S.14 Scour Rating

Reason(s) for Attribute

Bridges that a susceptible to scouring undergo periodic underwater inspections at a standard interval of 60 months(FHWA, 2022a). The interval for underwater inspections may be reduced for bridges with existing scour issues and poor channel ratings. Routine inspections may also detect scour issues, such that an extended inspection interval may reduce the overall surveillance of scour. For the FHWA Method 1 analysis for routine inspections, 48-month intervals are not allowed for bridges with certain scour or channel ratings. Therefore, an owner may choose to screen bridges that do not meet the Method 1 criteria i to not reduce the general surveillance of the bridge.

Assessment Procedure

Table D.2 shows the criteria to identify bridges eligible for 48-month intervals according to the NBIS and related FHWA guidance (FHWA, 2022a, 2022b). Bridges that do not meet the criteria shown in Table D.2 can be identified for screening from the risk analysis based on this attribute.

Table D.2. Criteria from the Coding Guide and the SNBI for bridges with low scour risk (FHWA, 1995, 2022c).

Coded Item	NBI Code	SNBI Code	Criteria
Channel Condition	61	B.C.09	≥6
Channel Protection Condition	61	B.C.10	≥6
Scour Vulnerability	113		5, 8, or N
Scour Vulnerability		Item B.AP.03	A or B
Scour Condition Rating		B.C.11	≥6

The screening criteria for this attribute is shown below.

Example screening criteria and action:

- The bridge does not meet the criteria shown in Table D.2. Screen.
- Bridge meets criteria shown in Table D.2. Proceed.

S.15 Waterway Adequacy

Reason(s) for Attribute

This attribute is intended to identify those bridges that have channel condition and / or channel protection condition that may increase the likelihood of scour damage to a bridge or approach roadway. For the FHWA Method 1 analysis for routine inspections, 48-month intervals are not allowed for bridges with certain scour or channel ratings. Therefore, an owner may choose to screen bridges that do not meet the Method 1 criteria to not reduce the general surveillance of the bridge.

Assessment Procedure

Table D.2 shows the criteria to identify bridges eligible for 48-month intervals according to the NBIS and related FHWA guidance (FHWA, 2022a, 2022b). Bridges that do not meet the criteria shown in Table D.2 can be identified for screening from the risk analysis based on this attribute.

Example screening criteria and action:

- The bridge does not meet the criteria shown in Table 2. Screen.
- Bridge meets criteria shown in Table 2. Proceed.

S.16 Current Element Condition State

Reason(s) for Attribute

This attribute is used to identify elements that have quantities of damage in condition state (CS) 4, which indicates a portion of the element is in serious condition and may require engineering review if the element is in the primary load path.

Assessment Procedure

The current element CS attribute is assessed from the element-level inspection results. Users should specify if this screening attribute is appropriately applied to bridge management elements such as bridge joints based on input from the RAP.

Example screening criteria and action:

- Elements of bridge have portions rated in CS 4. Screen.
- There are no elements with portions rated in CS 4. Proceed.

S.17 Construction Quality

Reason(s) for Attribute

This attribute is intended for bridges or bridge components with construction quality issues such as construction defects, poor material quality, or poor design details that have compromised the bridge's reliability or durability. In some cases, construction quality issues may result in a bridge component being assigned a lower CR than expected based on the age of the component, or increased element quantities in CS 3 or CS 4. In other cases, poor construction quality may result in reduced durability of the component that increases the POF or creates uncertainty in future performance of the component.

Assessment Procedure

Poor construction quality is a subjective criterion that requires input from inspectors or field personnel to identify a bridge with construction quality issues for one or more of its components. Accelerated deterioration resulting from poor construction quality may result in reduced CRs or increased quantities in element CS 3 or 4.

Example screening criteria and action:

- Poor construction quality identified. Screen.
- Typical construction quality. Proceed.

S.18 Exposed Strand

Reason(s) for Attribute

High-strength prestressing stand is susceptible to corrosion, cracking, and fracture when exposed to the aggressive environment surrounding a bridge. When encased with concrete the strand is passivated by a protective layer and the high pH of the surrounding concrete. When exposed to the environment by a loss of concrete cover, the strands may deteriorate rapidly and compromise the strength of the member. PSC girders that span a roadway can often experience minor impact damage that removes the concrete cover and exposes the strand.

Assessment Procedure

This attribute should be assessed based on the inspection results for a bridge and supporting documentation such as photographs and notes. Users may include exposed strand as an assessment item in the RBI inspection procedure for PSC bridges. When element-level inspection is used, exposed strands may be reported as defect element 1100, Exposed Strands.

Example screening criteria and action:

- Exposed strands reported from bridge inspection. Screen.
- No exposed strands. Proceed.

S.19 Load Rating Factor

Reason(s) for Attribute

Bridges that have low load rating factors (LRFs) may be more frequently exposed to loads that increase the rate of deterioration and damage in the structure as compared with bridges with load rating factors of 1.0 or greater. Bridges with LRF less than 1.0 may not be damaged or deteriorated but rather were not designed for modern loadings.

Assessment Procedure

This attribute can be assessed based on the inventory rating for the bridge as shown below.

Example screening criteria and action:

- Inventory LRF (B.LR.05 or NBI Item 66 expressed as a rating factor) < 1.0. Screen.
- Inventory LRF ≥ 1.0. Proceed.

S.20 Settlement or Rotation

Reason(s) for Attribute

This attribute is intended to capture settlement or rotation of bridge components that can affect the structure's safety or serviceability. The attribute can be applied to superstructure components or substructure components. For superstructure components, unusual settlement or rotation of the superstructure may be indicative of overloads, compromised strength of superstructure or bearing elements, unexpected load configurations, or damage to supporting elements or components. For substructure elements, settlement or rotation may be indicative of subsidence or other subsurface soil issues, or deterioration of foundation elements such as piles and footings.

Assessment Procedure

This attribute is assessed based on inspection results. For substructure components, the defect element "4000: Settlement" may be used to record the presence of settlement if defects are recorded on element-level inspection reports. Generally, settlement or rotation of the superstructure would only be reported in inspection notes, although the effect of settlement or rotation may be reflected in the CR or CS. Users may include settlement and rotation of superstructure and substructure as an assessment item in the RBI inspection procedures.

Example screening criteria and action:

- Significant settlement or rotation. Screen.
- Minor or no settlement or rotation. Proceed.

S.21 Embedded Girder Ends

Reason(s) for Attribute

Jointless bridges are increasingly used to eliminate joints and improve the durability of the bridges. Jointless bridge designs typically include the end of the bridge girders being embedded in an integral backwall that bears on the soils supporting the bridge approach. If the soil is not well drained or drainage is not directed away from the backwall, the embedded portion of the bridge girders can be exposed to corrosive agents such as water and chlorides. This can lead to corrosion damage and section loss in the bridge girders at the interface with the integral backwall. This attribute is intended to screen bridges with emerging, significant corrosion damage around the embedded ends of the girders due to the uncertainty of future deterioration patterns.

Assessment Procedure

This attribute is assessed based on element-level inspection results and notes in the inspection file indicating section loss at the embedded end of the girder.

Example screening criteria and action:

- Jointless Steel Bridge with Embedded Girders, Significant CS 3, CS 4 Defect element 1000 Located at the embedment. Screen.
- Jointless Steel Bridge with Embedded Girders with typical corrosion patterns located at the embedment. Proceed.

Design Attributes

D.1 Joint Type

Reason(s) for Attribute

Bridge joint types can be categorized as either closed systems or open systems. Compared to open joint systems, closed joint systems provide for higher durability based on the way their designs shield the inner workings of the joint from dirt and debris. This increases the time before a joint begins to leak onto other bridge components. The presence of open-type deck joints increases the probability of chloride contaminated water leaking onto bridge elements below the deck, thus increasing the likelihood of corrosion-related damage.

Assessment Procedure

This attribute is rated based on the presence of open joints.

Example criteria and scoring:

- Open joint system. 10 points.
- Closed joint system. 0 points.

D.2 Load Posting

Reason(s) for Attribute

The presence of a load posting typically indicates that a bridge was either not designed to carry modern loading or the bridge is deteriorated, and its structural capacity has been reduced. A structure of this type may be more likely to experience damage from heavy traffic and dynamic loading. This attribute is intended to consider the contribution of high and possibly even excessive loads on accelerating damage for a given bridge or a family of bridges. Engineering judgment is necessary to evaluate if this attribute is applicable. Considerations include the likelihood of the applied loading being higher than (i.e., illegal) or near the load posting. In some cases, traffic patterns are such that the fact that the bridge is load posted will not affect the rate of damage accumulation on the bridge. For example, a bridge is load posted for the state's legal truck load but is located on a parkway where trucks are prohibited.

Assessment Procedure

This attribute is scored based only on whether or not a bridge has been posted for loading; the level of the rating does not need to be considered. This assessment should consider if the load posting has a significant effect on the durability of the bridge.

Example criteria and scoring:

- Structure is load posted. 20 points.
- Structure is not load posted. 0 points.

D.3 Minimum Vertical Clearance

Reason(s) for Attribute

This attribute is intended to consider the likelihood that a bridge may be impacted by an over height vehicle and damaged such that the deterioration rate of the superstructure elements is increased. For concrete bridges, impacts may damage the embedded reinforcement or prestressing strands, or damage the typical concrete cover exposing the steel to the environment. For steel bridges, impacts can deform members and damage coating systems in the areas of the impact. Impact damage affecting the bridge's structural capacity requires a damage inspection and an assessment beyond a typical routine inspection's scope. Users may wish to use this attribute to include the potential for increased deterioration rates for bridges that experience frequent impact damage.

The minimum vertical clearance of a bridge affects its likelihood of impact by over-height vehicles. A bridge with a lower vertical clearance will be more likely to experience impact damage than a bridge with higher vertical clearance. The likelihood of being hit may also depend on the traffic composition of the roadway below, such as the Average Daily Truck Traffic (ADTT) or functional classification of the roadway. For example, if the roadway below the bridge has a high volume of trucks, the likelihood that the bridge will be impacted by an over-height vehicle and the frequency of impact may both be increased as compared with a bridge with few trucks on the roadway below the bridge.

This attribute is generally based on the total vertical clearance between the bottom of the girders and the riding surface of the roadway below. The functional classification, traffic volumes, or traffic characteristics of the roadway below the bridge may also be considered.

The coding guide includes a table for rating the clearance above the roadway for bridges, which is summarized in Table D.3 (FHWA, 1995). These data could be used for general guidance on minimum vertical clearances for developing attribute criteria based on the vertical clearance and traffic characteristics on the roadway below the bridge.

Table D.3. FHWA Coding Guide Minimum Vertical Clearance provisions for bridge roadways.

	Interstate and Other Freeway (ft)	Other Principal and Minor Arterials (ft)	Major and Minor Collectors and Locals (ft)	Railroad (ft)
9	>17	>16.5	>16.5	>23
8	17	16.5	16.5	23
7	16.75	15.5	15.5	22.5
6	16.5	14.5	14.5	22
5	15.75	14.25	14.25	21
4	15	14	14	20

Assessment Procedure

This attribute should be scored based on the coding guide item 54 or SNBI item B.H.12 for the feature under the bridge. The suggested scoring models shown below consider only the vertical clearance of the bridge. Users may wish to consider the functional classification or the typical traffic patterns below the bridge in their assesement. In the scoring models shown, increased importance is given to clearances for PSC bridges (Table D.4) relative to steel and conventionally R/C bridges (Table D.5). This is due to the potential for strand corrosion when the concrete cover is damaged by impact, and the increased rate of deterioration for strands relative to mild steel. The criteria presented below using a four-tier rating scale for vertical clearance are examplar criteria that can be modified based on input from the RAP.

Table D.4. Example vertical clearance criteria for PSC bridges.

Example Criteria	Example Scoring
Vertical clearance is 15 ft or less	20 points
Vertical clearance is greater than 15 ft to 16 ft	15 points
Vertical clearance is greater than 16 ft to 17 ft	10 points
Vertical clearance is greater than 17 ft or no under traffic present	0 points

Table D.5. Example vertical clearance criteria for steel and R/C bridges.

Example Criteria	Example Scoring
Vertical clearance is 14 ft	15 points
Vertical clearance is between 14 ft and 15 feet	12 points
Vertical clearance is between 15 ft to 17 ft	7 points
Vertical clearance is greater than 17 ft or feature under is not a roadway	0 points

D.4 Poor Deck Drainage and Ponding

Reason(s) for Attribute

This attribute is intended to consider the adverse effects of poorly designed deck drainage systems and the possibility of ponding on the deck surface, as well as for inadequate provisions for preventing scuppers and drains from splashing deicing chemicals onto the superstructure below. Ineffective deck drainage increases the likelihood of bridge elements developing corrosion related damage. This results from drainage onto the superstructure and the substructure elements. Both concrete and steel elements will have an increased susceptibility to corrosion damage when exposed to prolonged periods of wetness and/or frequent wet-dry cycles. The presence of chlorides from deicing chemicals applied to the deck also increases the likelihood of corrosion damage to these elements.

This attribute can also be used to characterize decks with ponding or with drain diversion issues. When water is allowed to sit on the surface of the deck, there is an increase in the likelihood that corrosion of the reinforcing steel will initiate, and damage will propagate. Water and chlorides are more likely to penetrate to the level of the reinforcement when periods of wetness are prolonged, and chloride concentrations at the surface are high.

Assessment Procedure

This attribute is scored based on the drainage design of the bridge and any known ponding or drainage issues, as noted in the inspection report. Drainage systems which normally allow water to run off onto the components below the bridge deck are considered ineffective, regardless of whether they have sustained any damage or not. Deck drains through curb openings, where the water from the decks typically drains onto superstructure elements are an example of poor deck drainage. Decks with ponding issues may need to be individually scored.

Example criteria and scoring:

- Ponding or ineffective drainage. 10 points.
- No problems noted. 0 points.

D.5 Use of Open Decking

Reason(s) for Attribute

An open deck increases the likelihood of corrosion of the steel superstructure. An open deck allows water, deicing chemicals, and other debris to fall directly onto the superstructure instead of running into deck drains and then to downspout pipes, as they would in a closed deck system. As a result, the likelihood of damage occurring in superstructure elements, bearing, and substructure elements is greatly increased. Users may also use this as a screening attribute.

Assessment Procedure

The attribute is scored based on the deck type. Common types of open decks include timber or open grating decks.

Example criteria and scoring:

- Bridge has an open deck. 20 points.
- Bridge does not have an open deck. 0 points.

D.6 Year of Construction

Reason(s) for Attribute

This attribute reflects the influence of bridge age and historic design advances on the most prevalent aging mechanisms in highway bridges – deterioration of concrete associated with corrosion of embedded reinforcement, and corrosion damage and/or fatigue and fracture for steel structures.

The corrosion of embedded reinforcing steel occurs due to the penetration of chlorides, water, and oxygen to the level of the reinforcement. For intact concrete, the penetration of the chlorides is modeled as a diffusion process, using Fick's Law, which depends on time, temperature, the permeability of the concrete, and the concentration of chlorides at the component's surface. Additionally, if the concrete has suffered damage, such as cracking or spalling, chlorides can more easily concentrate at the reinforcement, effectively expediting the corrosion process. The deterioration of embedded reinforcing steel due to corrosion manifests as areas of delamination and spalling. Areas of delamination cannot be observed by visual inspection and may go undetected. The likelihood of subsurface damage will increase over time due to the penetration of chlorides and water to the level of the reinforcing steel.

The quality of the concrete used in bridge construction has generally improved over time due to concrete technology innovation, improvements in quality control and in better supplier understanding of optimal material selection for strength and durability. Therefore, it is reasonable to expect that a concrete component constructed to modern standards is likely to have improved corrosion resistance characteristics compared to older components. Additionally, older structures have been exposed to the surrounding environment for a longer period of time and are therefore more likely to be affected by corrosion. Combined with the increasing likelihood of corrosion damage of the reinforcing steel over time, the overall POF due to corrosion damage increases as the bridge ages.

With respect to steel girders, the year the bridge was designed can provide valuable information about the susceptibility of the bridge to fatigue cracking and fracture. Over the years, there have been numerous changes in design specifications that have resulted in the improved fatigue and fracture resistance of bridges. Four key dates have been identified regarding changes in design specifications: 1975, 1985, 1994, and 2009. These dates were selected for the following reasons:

1975

Fatigue

The “modern” fatigue design provisions, based on the research of Fisher and others, were fully incorporated into the AASHTO Specifications with the 1974 Interims. The basic detail categories have not changed significantly since their introduction. Hence, 1975 was selected as a differentiator regarding fatigue design of steel bridges. Before 1975, fatigue design was based on principles not appropriate for welded structures. Although these early provisions appeared in the 1965 version of the specifications and were in place through 1976, it was felt that it was reasonably conservative to ignore the earlier provisions and set the cutoff date in 1975.

Fracture

In 1974, partly in response to the Point Pleasant Bridge collapse (1967), mandatory Charpy V-Notch (CVN) requirements were set in place for welds and base metals as a part of the AASHTO/AWS Fracture Control Plan. These CVN requirements were to ensure adequate fracture toughness of materials used in bridges. Furthermore, “modern” fatigue design provisions, based on the research of Fisher and others, were fully incorporated into the AASHTO Specifications as previously discussed. Hence, 1975 was selected as a differentiator regarding fatigue and fracture design of steel bridges.

1985

In 1985, AASHTO introduced changes to address and to prevent distortion-induced fatigue cracking. A common example of distortion-induced fatigue cracking is web-gap cracking. Hence, considering the specifications introduced in 1975 and 1985, bridges designed after 1985 are less likely to be susceptible to fatigue due to primary or secondary stress ranges than bridges built prior to these revisions.

1994

In 1994, the AASHTO design specifications changed from load factor design (LFD) to LRFD. The LRFD method is intended to ensure greater reliability in bridge design. There were several changes regarding the load models and the load distribution factors used for the fatigue limit state. These changes were intended to result in a more realistic and reliable fatigue design. Hence, for the fatigue limit state, bridges designed after 1994 would be expected to have improved reliability.

2009

In 2008, language was introduced into the AASHTO LRFD Bridge Design Specifications which directly addressed the issue of constraint induced fracture (CIF). The article provided prescriptive guidance on detailing to ensure that details susceptible to CIF are avoided. It is included in the 2009 and later versions of the AASHTO LRFD Bridge Design Specifications.

Assessment Procedure

The year of construction is intended to characterize the years of environmental exposure a component has experienced or the fatigue susceptibility of the design. The suggested values are intended to put elements into four broad classes which range from very old to relatively new. For elements that have been replaced, the year of the replacement should be used. Elements that have been rehabilitated should use the original construction date. These ranges are advisory; a user may consider modifying these categories based on experience with their bridge inventory or significant changes to construction practices that may have occurred within their state. Table D.6 shows example criteria for R/C deck, PSC Girders, and Substructures. For steel girder criteria (Table D.7, Table D.8), the user should consider if the design specification used in the design of the bridge matched the contemporary specifications at the time, as described above. If, for example, the LRFD provisions of 1994 were not implemented in the state until 2000, then the ranges should be adjusted accordingly.

Table D.6. Example criteria and rating points for R/C decks, PSC Girders, and Substructures.

Criteria	Example Scoring
Built before 1950	10 points
Built between 1950 and 1970	6 points
Built between 1970 and 1990	3 points
Bridge built after 1990	0 points

Table D.7. Example criteria and rating points for fatigue cracking in steel superstructures.

Criteria	Example Scoring
Bridge designed before 1975/unknown	20 points
Bridge designed between 1976 and 1984	10 points
Bridge designed between 1985 and 1993	5 points
Bridge designed after 1994	0 points

Table D.8 Example criteria and rating points for fracture in steel superstructures.

Criteria	Example Scoring
Bridge designed before 1975/unknown	20 points
Bridge designed between 1975 and 1984	10 points
Bridge designed between 1985 and 1993	5 points
Bridge designed between 1994 and 2008	3 points
Bridge designed after 2009	0 points

D.7 Application of Protective Systems

Reason(s) for Attribute

Protective systems such as membranes, overlays, or sealers may be applied to the surface of a concrete element to reduce the ingress of water which may contain dissolved chlorides or other corrosive substances. When these corrosive materials diffuse to the level of the reinforcement, the likelihood of reinforcement corrosion increases which may lead to the propagation of damage. Protective systems delay or prevent this process, reducing the likelihood of corrosion damage. Some overlays have also been shown to delay the development of spalling as a result of an increased resistance to cracking and an increased ability to confine delamination damage (Skeet et al., 1994).

An overlay is defined herein as an additional layer of protective material, which is applied on top of the deck, and which also serves as the riding surface. Overlays may consist of asphalt, latex-modified concrete, low-slump dense concrete, silica fume concrete, polymer concrete, or other materials.

A membrane is defined herein as a barrier placed on top of the concrete deck and then covered by another material, which serves as the riding surface. Common membranes may consist of hot-rubberized asphalt, resin, bitumen-based liquid, or prefabricated sheets.

Sealers are somewhat different from overlays and membranes in that they are applied thinly to concrete surfaces and penetrate the porosity of the concrete to seal it from moisture. Initially, sealers were used to counteract freeze-thaw damage and deicing chemical application related scaling. With the proper use of air-entraining admixtures, the primary purpose of sealers changed to preventing or slowing the ingress of chlorides (Russell, 2004). Types of sealers include silanes, siloxanes, silicates, epoxies, resins, and linseed oil.

Surface coatings such as epoxy, coal tar epoxy, polyurethane, or polyurea, acrylic may also be applied to the concrete elements of a bridge to increase their resistance to water intrusion and consequently reduce their probability of developing corrosion damage. The application of these coatings can improve the durability and corrosion resistance of concrete elements.

Each of these protective systems is intended to delay or prevent corrosion damage in concrete bridge elements. If the protective systems are effective, then the likelihood of corrosion related damage will be reduced compared to unprotected elements of similar design characteristics and environmental conditions. As a result, the application of protective systems may be considered in the reliability assessment.

This attribute can be used to increase the impact of corrosion protection systems on the risk models associated with corrosion damage to concrete elements. For typical applications, the effect of protective systems can be described by the corrosion protection level described by attribute D.29.

Assessment Procedure

If protective systems such as membranes, overlays, or sealers have been applied to a concrete element, their effectiveness should be evaluated based on engineering judgment and local experience or test data along with any documented research and field-testing data. Important factors to consider include the effectiveness of the applied system and how often it is applied or maintained. This attribute assumes that overlays and sealers generally have similar effects in terms of corrosion protection for the deck. Users may wish to separate certain overlays or membrane systems, based on their experience. For example, an owner may have experience that indicates that low-slump overlays are having a significant effect on extending the service life of bridge decks. In that case, the owner may wish to increase the importance of this attribute to a moderate or high level and distribute the scoring appropriately. The suggested scoring assumes the protective system is ranked as *low* importance relative to other attributes.

Example criteria and scoring:

- Never applied, poor functioning or non-functioning. 10 points.
- Yes, penetrating sealer, crack sealer, limited effectiveness. 5 points.
- Yes, periodically applied, effective. 0 points.

D.8 Concrete Mix Design

Reason(s) for Attribute

Concrete mix designs, such as those considered to be "high performance concrete," typically have a lower permeability and a higher durability than other traditional concrete mixes. Therefore, high performance mixes provide an increased resistance to deicing chemicals or marine environment-based chloride ion penetration. This in turn can increase the time to corrosion initiation in reinforcing steel. This design attribute is intended to consider the increased durability provided by high performance concrete mixes.

The permeability of a concrete mix depends on several factors including the water to cementitious ratio, the use of densifying additives and the use of mix-improving additives. Supplementary cementitious materials such as fly ash, ground-granulated blast furnace slag, and silica fume have been shown to reduce permeability. Additionally, a properly designed and placed concrete mix with a lower water to cementitious ratio will have a lower permeability.

Materials and criteria that have been identified as being beneficial in enhancing the performance of concrete bridge decks can be found NCHRP Synthesis 333 "Concrete Bridge Deck Performance(Russell, 2004)."

Assessment Procedure

The evaluation of a bridge's concrete mix design should be based on information contained in the bridge's design plans and on engineering judgment. Many different types of concrete mixtures can be considered to be high performance; therefore, users should consider the corrosion resistance characteristics of the particular mixture and assess if the concrete mix used is expected to provide an increased durability relative to a typical concrete mix design. Experience with concrete mixes of similar characteristics should be considered.

Example criteria and scoring:

- The concrete used is not considered high performance. 15 points.
- The concrete used satisfies high performance conditions. 0 points.

D.9 Deck Form Type

Reason(s) for Attribute

Concrete decks constructed with stay in place (SIP) forms have the surface of the deck soffit hidden from visual inspection. Signs of corrosion damage such as efflorescence, rust staining and cracking in the deck soffit cannot typically be observed. As a result, there can be increased uncertainty in the deck condition determined through visual inspection. This attribute is intended to consider the increased level of uncertainty in the deck condition that may exist when SIP forms are used.

Assessment Procedure

This attribute is assessed based on whether the deck has SIP forms.

Example criteria and scoring:

- Stay-in-place forms. 10 points.
- Removable forms. 0 points.

D.10 Deck Overlays

Reason(s) for Attribute

Like SIP forms, deck overlays prevent visual observation of the deck condition. Signs of deterioration, corrosion damage and cracking of the deck cannot typically be observed. As a result, there can be increased uncertainty in the deck condition determined through visual inspection. This attribute is intended to consider the increased level of uncertainty in the deck condition that may exist for decks with overlays.

Assessment Procedure

This attribute is assessed based on whether the deck has an overlay. Overlays increase the durability of concrete components causing a reduction in the overall POF for a component. This deck overlay attribute should only be applied when the reduction in inspection capability is identified by the RAP.

Example criteria and scoring:

- Deck has an overlay. 10 points.
- Bare deck. 0 points.

D.11 Minimum Concrete Cover

Reason(s) for Attribute

This attribute is intended to consider the improved corrosion resistance and the increased durability associated with adequate concrete cover, and the historically poor performance of bridge elements with inadequate cover. The depth of concrete cover shows how far corrosive agents need to travel to reach the embedded steel reinforcement. Several studies have identified that the depth of concrete cover over the top reinforcing steel mat is the most significant factor contributing to the durability of decks (Russell, 2004). The importance of adequate concrete cover is also an important durability factor for other concrete elements. The value used for this attribute should be the actual amount of concrete cover, which may not necessarily be the design cover. If quality control procedures are adequate to ensure that the design cover matches the as-built cover, the design cover may be used. If such quality control procedures have not been utilized or have historically been inadequate, it may be necessary to assess the as-built cover.

In 1970, the general recommendation for concrete cover was a minimum clear concrete cover of 2 in. over the top-most steel. Currently, the AASHTO Standard Specifications for Highway Bridges (2002) requires a minimum concrete cover of 2.5 in. for decks which have no positive corrosion protection and are frequently exposed to deicing chemicals. Positive corrosion protection may include epoxy coated reinforcing (ECR), concrete overlays, and impervious membranes. The AASHTO LRFD Bridge Design Specifications (2009) also requires a minimum concrete cover of 2.5 in. for concrete exposed to deicing chemicals or on deck surfaces subject to stud or chain wear. The concrete cover may be decreased to 1.5 in. when ECR is used.

It is also important to note that the type of damage and the rate of damage development vary with the amount of concrete cover. It has been reported that the type of damage changes from cracks and small localized surface spalls to larger areas of delamination and spalling as the concrete cover increases(Skeet et al., 1994). There is also an increase in the time to corrosion initiation and a reduction in the rate of damage development when cover increases, as shown schematically in Figure D.2. In summary, as concrete cover increases, the time to corrosion initiation increases due to the increased depth of which chloride ions must penetrate to initiate the corrosion process. As corrosion progresses, an increased concrete cover provides confinement that reduces the rate and the type of damage that develops at the surface of the concrete element.

Note that concrete cover greater than three inches can result in increased cracking, providing pathways for water and chlorides. This may be a consideration in special cases where the concrete cover is unusually large.

This attribute can be used to increase the impact of concrete cover on the risk models associated with corrosion damage to concrete elements. For typical applications, the effect of concrete cover can be described by the corrosion protection level described by attribute D.29.

Assessment Procedure

This attribute is scored based on the actual, physical clear cover that the specified bridge element operates with. The user should consider whether quality control practices used at the time of construction were adequate to provide confidence that the as-built concrete cover conforms to the design concrete cover, or if there are indications that the concrete cover may not be adequate. In these cases, the as-built concrete cover may be required and can be easily obtained using a cover meter.

Example criteria and scoring:

- 1.5 in. or less, unknown. 20 points.
- Between 1.5 in. and 2.5 in. 10 points.
- Greater than or equal 2.5 in. 0 points.

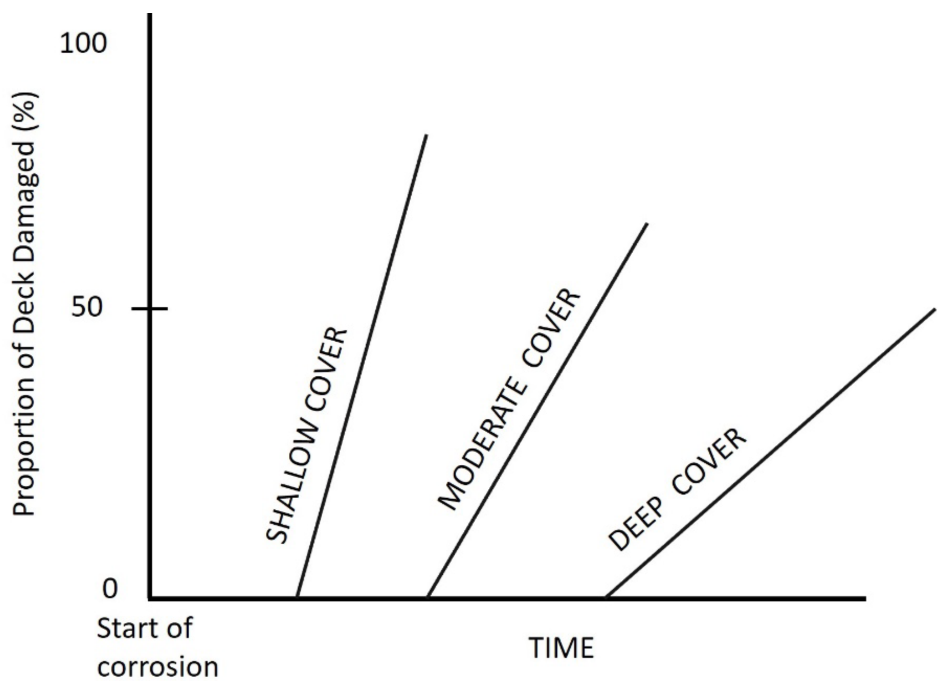

Figure D.2. Effect of concrete cover on the time to corrosion initiation and development of damage (Skeet et al., 1994).

D.12 Reinforcement Type

Reason(s) for Attribute

This attribute is intended to characterize the presence of protective coatings on the embedded reinforcing steel as a barrier to protect it against corrosion. A commonly used barrier is an epoxy coating; however galvanized bars and stainless steel (SS), either as cladding or as solid bars, have also been used.

Uncoated steel reinforcement will corrode easily and significantly when under attack from corrosive elements such as chloride ions, oxygen, and water. Since this exposure is inevitable in an operating structure, one way to slow the corrosion process is to coat the mild steel bars with either an organic or a metallic coating or to use an alternate solid metal bar, such as stainless steel (SS). These coatings or alternate bars help slow the corrosion process by providing either a physical or a metallurgical barrier against the action of the corrosive elements.

The most common barrier coating is fusion-bonded epoxy powder. This type of coating has been used since 1973 and has been the subject of a significant body of research. It has been shown that, in R/C decks, if only the top mat is coated, for every year required to consume a given amount of mild steel, it will take 12 years for the ECR to lose that same amount of metal. If both the top and bottom mats are coated, it may take up to 46 years (Virmani & Clemena, 1998). This significant increase when both mats are coated is due to increased electrical resistance that further slows the progress of corrosion.

Two of the more common metallic coatings used are zinc and SS. Zinc coated bars are also known as galvanized bars. Conflicting reports have been given on the performance of galvanized bars, mostly with respect to varying levels of the water to cement ratio and whether they are used with mild steel bars. Research suggests that galvanized bars may add five more years to the 10 to 15 years required for corrosion induced stress to manifest in unprotected bridge decks (Virmani & Clemena, 1998).

Solid SS or SS-clad mild steel bars have also been used, although to a lesser extent due to their higher costs. Research conducted by the State of Virginia compared the performance of SS clad and SS bars with uncoated carbon steel bars. The research concluded that defect-free SS clad bars performed nearly identically to the solid SS bars. These types of bars were determined to tolerate at least 15 times more chloride than the carbon steel bars (Virmani & Clemena, 1998).

Regardless of the specific coating or reinforcement material used, protected bars generally have a higher resistance to corrosion damage than uncoated, mild steel bars. As such, the scoring for this attribute considers only if the rebar is protected by one of these methods, or if it is not.

This attribute can be used to increase the impact of reinforcement type on the risk models associated with corrosion damage to concrete elements. For typical applications, the effect of reinforcement type can be described by the corrosion protection level described by attribute D.29.

Assessment Procedure

The type of reinforcement is scored based on the presence of barrier coatings or the use of alternative metal for the embedded reinforcement. This information can typically be identified from the structure's design plans. If suitable information is unavailable, engineering judgment should be used.

Example criteria and scoring:

- Reinforcement is uncoated carbon steel. — 15 points.
- Reinforcement has a protective coating or is produced from an alternate corrosion resistant metal (e.g., SS). — 0 points.

D.13 Built-Up Member

Reason(s) for Attribute

Many bridges, especially older structures, contain built-up members. These built-up members are sometimes more susceptible to corrosion than normal rolled steel sections because they contain pockets or crevices which can retain water, salt, debris, etc. This has been known to result in an accelerated corrosion rate since debris and moisture can remain trapped. Bridge washing, if thoroughly performed, can mitigate these effects.

Assessment Procedure

For this attribute, a built-up member refers to riveted or bolted members. Welded members should not be included in this assessment because they do not contain the type of pockets or crevices that can trap corrosion inducing materials.

Example criteria and scoring:

- Element is a built-up member. 15 points.
- Element is not a built-up member. 0 points.

D.14 Constructed of High-Performance Steel

Reason(s) for Attribute

In addition to possessing higher yield strengths than normal steels, high performance steels (HPS) generally have greater fracture toughness than that required by ASTM A709, and of other common bridge steels. Improved fracture toughness results in steel that is more resistant to fracture than normal steels. This is because it is more likely that cracks will propagate at a slower rate, and could even arrest, in HPS compared to normal steels.

At this time, the Charpy V-Notch (CVN) levels required for HPS in ASTM A709 are not established with the objective of achieving any particular level of fracture resistance or crack tolerance. Hence, the benefits provided by using HPS, if the steel just meets the ASTM A709 specification, are limited. Therefore, the suggested ranking of HPS is low in terms of contribution to durability and reliability (10 points), relative to normal steel. This may change as future research becomes available and the minimum required CVN values increase for HPS.

Assessment Procedure

This attribute should be scored based on whether the element is built out of HPS. If there is no documentation or it is unknown if the element is constructed of HPS, the attribute should be scored accordingly.

Example criteria and scoring:

- Element is not constructed of HPS/unknown. 10 points.
- Element is constructed of HPS. 0 points.

D.15 Constructed of Weathering Steel

Reason(s) for Attribute

Weathering steel is a type of steel containing alloying elements that increase its inherent corrosion resistance. For this reason, weathering steels are less susceptible to corrosion than normal black steels. However, this is only true if the steel is used in the proper environment and is detailed properly.

Assessment Procedure

This attribute is scored based on whether the element is constructed using weathering steel and is detailed and located in a way that minimizes the contact of the steel with deicing chemicals and moisture. If it is unknown if the element is comprised of weathering steel, the element should be scored accordingly. The assessment procedure assumes that the steel is used in the proper environment and is detailed properly. Guidance on the appropriate application of uncoated weathering steel can be found in FHWA

Technical Advisory T-5140.22(FHWA, 1989). The document also includes recommendations for maintenance to ensure continued successful performance of the steel.

Example criteria and scoring:

- Element is not constructed of weathering steel or location and detailing may allow impact of ambient or deicing chemicals on steel surfaces. 10 points.
- The element is constructed of weathering steel and properly detailed consistent with FHWA Technical Advisory T-5140.22. 0 points.

D.16 Element Connection Type

Reason(s) for Attribute

Welded connections are usually more susceptible to the effects of fatigue damage than other types of connections, as there is a direct path for cracks to propagate between connected elements. For example, a crack in a flange can grow into the web through the web-to-flange weld. Fatigue cracking is generally of greatest concern for welded details that have low fatigue resistance, such as D, E, and E', along with residual stresses and weld toe defects.

Riveted connections, unlike welded connections, do not offer a direct path for cracks to propagate from one element to another. Using the web-to-flange connection example, cracks in an angle used to make up a flange are not able to grow directly into the web plate because the elements are not fused together. Hence, there is a certain number of redundancies at the member level. Nevertheless, the quality of the rivet hole (e.g., punched vs. drilled) and a lack of consistent pretension in rivets results in these details being classified as category D.

Similar to riveted connections, High Strength (HS) bolted connections are more resistant to a fatigue crack propagating from one component of a member to another, as compared to welded members. A properly tightened HS bolt generates very high compressive forces in the connection. The pretension force is much greater and is much more consistently achieved in a HS bolted connection than in a riveted connection. Due to the significant pretention in a fully tightened A325 or A490 bolt, the hole's quality has little or no effect on the fatigue resistance of the connection (in contrast to riveted joints). As a result, they are classified as category B details.

It is noted that considering the element connection type may appear to be a double penalty when considered in conjunction with D.17 Worst Fatigue Detail Category. However, should cracking occur at a welded detail in a main member, it is more likely to become an issue than in the equivalent bolted detail simply since there is no direct path for cracks to grow from component to component in the bolted joint. Hence, it is considered a “better” condition even though both welded and bolted details may both be classified as category B. Riveted details, which do not have as high a fatigue resistance as HS bolted connections but are not as susceptible to crack propagation as welded joints, have been arbitrarily scored in the middle.

Assessment Procedure

If the element has multiple types of connections, the worst type of connection should be scored for this attribute.

Example criteria and scoring:

- Element connected with welds. 15 points.
- Element connected with rivets. 7 points.
- Element connected with HS bolts. 0 points.

D.17 Worst Fatigue Detail Category

Reason(s) for Attribute

The likelihood of fatigue cracking is influenced by the type of fatigue detail category present. It is generally accepted that poor fatigue details are more likely to develop cracks than more fatigue resistance details. This is implied in the current AASHTO LRFD Bridge Design Specifications, which discourages the use of details lower than category C and encourages design for infinite life. Fortunately, since the introduction of the modern AASHTO fatigue provisions in 1975, the use of poor details (D, E, and E') has been reduced. Hence, details in bridges designed over the past 30 years or so will typically be of higher fatigue resistance.

Assessment Procedure

The worst type of detail subjected to tensile stress ranges in the element or member should be used for this attribute. The AASHTO fatigue details A through E' should be used.

Example criteria and scoring:

- Fatigue detail category E or E'. 20 points.
- Fatigue detail category D. 15 points.
- Fatigue detail category C. 5 points.
- Fatigue detail category A, B, or B'. 0 points.

Assessment Procedure for Connections

If the element has multiple types of connections, the worst type of connection should be scored for this attribute.

Example criteria and scoring:

- Element connected with welds. 15 points.
- Element connected with rivets. 7 points.
- Element connected with HS bolts. 0 points.

D.18 Skew

Reason(s) for Attribute

Bridge skew can introduce unanticipated forces in a bridge deck, deck joints and superstructures. Thermal expansion of the superstructure and deck may introduce uneven strain distributions and/or torsional forces. As a result, bridges with high skew angles may suffer atypical deterioration patterns including cracking in bridge decks, failure of joints and bearings, and distortion-induced cracking at diaphragms(Chajes et al., 2004; Coletti et al., 2011; Fu et al., 2007; Menassa et al., 2007; Tindal & Yoo, 2003).

Assessment Procedure

This attribute is typically scored based on the recorded skew angles for a bridge. Angles of 30 degrees or greater may be used as a value for evaluating the potential for adverse skew angle effects. This attribute may also be used as a screening attribute.

Example criteria and scoring:

- Skew 30° or more. 20 points.
- Skew 20-30°. 10 points.
- Skew less than 20° 0 points

D.19 Presence of Cold Joints

Reason(s) for Attribute

Cold joints or construction joints within a deck span can sometimes result in leakage of water and deicing chemicals through the deck and onto the supporting superstructure. This may result in accelerated deterioration patterns including coating failure and section loss for steel members, corrosion damage in concrete members, and / or corrosion damage in the deck.

Assessment Procedure

This attribute is typically scored based on the presence of known cold joints within the deck span. Data to support this assessment may come from inspection reports, because cold joints that are performing as designed may not be known.

Example criteria and scoring:

- Presence of cold joints. 10 points.
- No known cold joints. 0 points.

D.20 Construction Techniques and Specifications

Reason(s) for Attribute

Construction techniques and specifications have evolved over time to improve the durability and performance characteristics of bridges. Certain construction techniques and specifications used during previous eras may be problematic, and result in deterioration and damage patterns that can be associated with the techniques or specifications in use at the time of bridge construction. For example, reduced bridge deck thickness may have been typical during a certain era. Over time, the reduced deck thickness may be shown to reduce the durability of the bridge deck and result in deck damage such as punch-through. As a result, decks constructed during that era may be more likely to be affected by a certain damage mode than bridges constructed during other eras.

Assessment Procedure

This attribute will typically be identified by RAP members based on experience of bridge inspection and maintenance personnel. Historical records documenting the evolution of design standards and construction techniques may be necessary to identify the specific era, or estimates based on experience may be used. This attribute may also be used as a screening attribute.

- Bridge constructed during identified era. 20 points.
- Bridge not constructed during identified era. 0 points.

D.21 Footing type

Reason(s) for Attribute

Spread-type footings may be susceptible to the adverse effects of scour, soil sliding, or rotations due to uneven settlement or subsidence. In contrast, pile foundations may be unaffected by these phenomena. As such, deterioration patterns and damage modes that affect spread footings may not be relevant for pile foundations.

Assessment Procedure

This attribute can typically be determined from the design drawing available in the bridge file. This attribute may be used as screening criteria for specific damage modes that affect spread footings but would not affect pile foundations.

Example criteria and scoring:

- Spread-type footing. 15 points.
- Pile foundation. 0 points.

D.22 Subsurface Soil Condition

Reason(s) for Attribute

Footings on certain soils may be susceptible to the effects of soil sliding or rotations due to uneven settlement or subsidence. This attribute is typically used with D.21 to reflect the increased likelihood of damage modes such as substructure rotations, cracking, or displacements for bridges in certain geographic regions.

Assessment Procedure

Subsurface soil conditions susceptible to these effects are typically known to geotechnical engineers and/or maintenance personnel. This attribute may be identified based on soil testing results or experience.

- Poor or unknown subsurface soil conditions. 20 points.
- Acceptable soil condition or pile foundations. 0 points.

D.23 Superstructure Flexibility

Reason(s) for Attribute

The flexibility of superstructure components can increase deterioration rates of R/C decks. Research has shown that R/C decks show increased rates of deterioration when placed on steel superstructures as compared with either R/C or PSC superstructures. This attribute is intended to consider the potential for increased deterioration rates for R/C deck when placed on steel superstructures.

Assessment Procedure

This attribute is assessed based on engineering judgement and would typically apply to relatively long-span steel bridges, e.g., 120 ft. spans or greater.

Example criteria and scoring:

- Steel superstructure has high deflections under traffic. 10 points.
- Steel superstructure has typical deflections under traffic. 0 points.

D.24 Structure Type

Reason(s) for Attribute

Risk analysis using Method 2 typically considers families of bridges based on the material used to form the superstructure of the bridge, such as steel bridges, PSC bridges, or R/C bridges, etc. Within any family of bridges there are different types of bridge designs that may present different risk profiles. This attribute can be used consider the elevated likelihood of damage (i.e., POF) represented by a particular type of bridge as compared with the overall family being analyzed by the RAP. For example, PSC adjacent box girder bridges can have different susceptibility to corrosion damage as compared with open PSC sections.

Assessment Procedure

This attribute is assessed based on the RAP analysis of a family of bridges. The analysis of the RAP may be based on general experience with a particular bridge type or on typical design features. For example, the RAP may assess that historically, adjacent box girder bridges have shown a higher deterioration rate as compared with open PSC sections in their inventory. Alternatively, the assessment could be based on the longitudinal joints between adjacent sections that expose the girder webs to leakage though the deck that increases the likelihood of serious damage due to corrosion.

Example criteria and scoring:

- Bridge type presenting elevated likelihood of serious condition. 10 points.
- Other structure types. 0 points.

D.25 Feature Under

Reason(s) for Attribute

Bridges over highway features can have increased exposure to moisture and deicing chemicals as compared with bridges over water or land due to overspray. Bridges over water can have increased exposure to moisture as compared to bridges over land, depending on the elevation of the bridge and the water feature. This attribute can be used to represent the increased exposure to corrosive agents from the feature under the bridge. This attribute may also be used to represent increases in risk due to impact damage from traffic or rail. The attribute is typically paired with other attributes such as vertical clearance of the bridge.

Assessment Procedure

This attribute is assessed based on the feature under the bridge as described by coding item 6, Feature Intersected, or SNBI item B.F.01, Feature Type.

Example criteria and scoring:

- Feature under bridge is a highway. 10 points.
- Feature under is not a highway. 0 points.

D.26 Corrosion Protection Level

Reason(s) for Attribute

Concrete cover, reinforcing steel coating, sealing, and overlays for corrosion protection are commonly identified as a factor affecting the likelihood of corrosion damage for R/C components. To address the commonality of these attributes and simplify the scoring process, the *corrosion protection (CP)* level has been developed to simplify the scoring process. Modeled after the CP levels commonly used for post-tensioned concrete construction, the CP level provides a simple method of describing resistance to corrosion damage based on the reinforcing steel coating type, the depth of cover, and the protection offered by overlays and sealers.

Overlays in this case describe overlays that provide additional concrete cover. An overlay that provides normal concrete cover following a milling or hydro-demolition activity would provide normal cover and would not typically count as an additional layer of protection. However, if the overlay material is a high-performance material that provides improved corrosion protection as compared with typical concrete mixes, a user could consider the overlay to provide an additional CP level.

To determine the CP level the user simply counts the number of protective layers between the surface of the concrete and embedded reinforcing steel. Epoxy coating, normal concrete cover, overlays placed on existing concrete cover, and sealers all represent one layer of corrosion protection. The use of reinforcing bars that are SS, clad SS, galvanizing coating, or FRP bars are counted as two levels of corrosion protection based on the increased resistance to corrosion of these materials.

Table D.9 shows different corrosion protection combinations that fit into the CP levels of 1 through 4. The least amount of corrosion protection is provided by CP 1, which has either 1 or 0 levels of corrosion protection. For example, a bare concrete deck that is unsealed, has uncoated reinforcing bars and normal cover has one layer of corrosion protection (cover) and ranks in the highest category. If the deck also has low cover, it would have zero levels of protection but is scored as CP 1. This is rational since a concrete deck with low cover or uncoated rebar would be particularly susceptible to corrosion damage.

A bare deck with normal cover and EPC reinforcing steel, but without sealing or an overlay would have two layers of protection, rated as CP 2 or "high." In the scoring system, this scores at 50% of the high level, since this is a common method of standard corrosion protection. If there is an additional level of corrosion protection, the corrosion protection level would be CP 3 and would be especially resistant to corrosion as compared to a nominally protected deck (CP 2).

Assessment Procedure

The assessment of this attribute is based on the in-situ corrosion protection for a bridge. The CP level for components may change over time due to installation of overlays, changes in sealing practices, or other surface treatments that add a layer of protection. Inventory data that describe some of the parameters needed to assess the CP level are shown in Table D.10.

Table D.9. Sources of data for assessing the CP level.

SNBI	MBEI
B.SP.10, Wearing surface	Element 510, Wearing surface
B.SP.12, Deck reinforcing protective system	Element 520, Concrete reinforcing steel protective system
	Element 521, Concrete protection coating

The rating for the CP level is more heavily weighted, typically, than other attributes since it combines several potential attributes and has a significant impact on the durability of the R/C elements.

Example criteria and scoring:

- CP 1 30
- CP 2 15
- CP 3 5
- CP 4 0

Table D.10. Examples of CPLs for R/C components.

CP level	Rank	Description	Description
CP 1	Very High	The element has either one layer of protection or no layers of protection. One layer of protection may be from the following: • Cover of at least 2 in. • ECR. • An overlay applied for corrosion protection. • Effective sealing practice.	Little to no corrosion protection
CP 2	High	The element has two layers of protection. Examples: • Typical cover of at least two inches and ECR. • Typical cover, black rebar, and an overlay or sealer. • Low cover with ECR and an overlay or sealer	Nominal corrosion protection
CP 3	Mod.	The element has three layers of corrosion protection. Examples: • Typical cover, ECR, and an overlay or sealer. • Typical cover and galvanized, stainless, or FRP bars.	Improved corrosion protection
CP 4	Low	The element has four layers of protection. Examples: • Typical cover, ECR, overlay and sealer applied. • Typical cover, galvanized, SS, or FRP rebar, and an overlay or sealer.	High level of corrosion protection

Loading Attributes

L.1 Average Daily Traffic (ADT) and Average Daily Truck Traffic (ADTT)

Reason(s) for Attribute

Average Daily Traffic (ADT) represents the traffic volume on a bridge and can have a significant impact on the deterioration rates for bridge decks. The repeated impacts from traffic can cause evolving damage to accelerate and cause rapid deterioration as compared with low ADT bridges. For this reason, the attribute is often included in risk models for bridge decks.

The traffic volume is sometimes used to assess the rate of deicing chemical application based on the rationale that bridges with high traffic volumes receive more aggressive treatment than bridges with low ADT.

The ADTT on a bridge is used to characterize the frequency of occurrence of large external loads on the bridge due to heavy vehicles. Large transport trucks or other heavy vehicles place stress on a bridge as static and dynamic loads, the latter reflecting impact and other dynamic amplification effects.

As ADTT levels increase, the rate of damage formation and accumulation in concrete is typically expected to increase. This is in part because the stresses caused by traffic loads accelerate the effects of the internal expansion forces from reinforcement corrosion (Skeet et al., 1994). These loads, especially when placed on a bridge with existing deterioration, will open cracks and possibly allow corrosive elements to enter the cracks or increase the crack density. Experience has shown that bridge decks exposed to heavy truck traffic generally deteriorate at a much higher rate than decks with little or no truck traffic.

For steel girders, research has shown that trucks produce nearly all fatigue damage in highway bridges. Hence, a bridge with high truck traffic (higher ADTT) will have a higher probability of fatigue damage. Of course, the converse is true; bridges with little or no truck traffic (e.g., HOV bridges) are unlikely to experience fatigue cracking.

It is important to note that ADTT only considers the "load" side of the equation. The likelihood of fatigue cracking also depends on the "resistance" side of the equation, which is addressed by D.16 Element Connection Type and D.17 Worst Fatigue Detail Category. Although ADTT does not provide an exact correlation to the stress ranges an element will experience, it does provide a reasonably good understanding of how quickly fatigue damage may accumulate.

Assessment Procedure

This attribute should be scored based on the Average Daily Truck Traffic.

For steel structures, the scoring limits for ADTT were taken from a recent study on fracture critical bridge titled "*Proposed method for determining the interval for hands-on inspection of steel bridges with fracture critical members*" (Parr et al., 2010). Although these limits were developed mainly with fracture critical bridges in mind, it was decided these could be applied to other highway bridges for the fatigue limit state. The reasoning behind the limits as documented in Parr and Connor's report is as follows:

"The ADTT limit of 15 comes from the fact that for bridges where the ADT is less than 100 vpd, the ADT is generally not reported in the NBIS. During the Purdue University Workshop, it was agreed that an ADTT of 15% (of the ADT) was a reasonably conservative estimate of the proportion of trucks crossing a typical low volume bridge. Hence, 15% of the lowest ADT reported in the NBIS (ADT = 100 vpd) yields an ADTT of 15 trucks per day (tpd).

"The lower bound value of 100 was set such to separate bridges in rural areas versus "moderately" traveled bridges. The upper bound limit of an ADTT equal to 1,000 tpd was obtained by simply increasing the “moderate” limit by a factor of 10. It was included simply to create a boundary between “heavily” and “moderately” traveled bridges.

For concrete bridges, high ADTT will likely have the most significant effect on the durability of the bridge deck. Superstructure components will be affected much less; if designed to modern standards, high ADTT may have little effect on their durability. Deck joints may also deteriorate more rapidly in the presence of high ADTT.

Table D.11, Table D.12, and Table D.13 each show example scoring for ADT and ADTT. Traffic volumes vary widely among different bridge owners. Statistically, ADT values typically have a log-normal distribution with a limited number of bridges having very high ADT, such as bridges in urban areas, and a large population of bridges with low to moderate ADT volumes. Users should adopt different thresholds that are suitable for their inventories. Example statistical values are shown in Table D.11 for ADT. Example threshold values for ADTT are shown in Table D.12 and Table D.13. Either statistical values or thresholds can be used to define criteria for this attribute.

Table D.11. Example criteria for scoring ADT attributes.

Criteria	Example Points
ADT ≥ 75^{th} percentile.	20 points.
50^{th} percentile ≤ ADT < 75^{th} percentile.	10 points.
ADT 50^{th} percentile.	0 points.

Table D.12. Example criteria for scoring ADTT attributes for R/C and PSC bridges.

Criteria	Example Points
ADTT ≥ 5,000 tpd	20 points.
1,000 tpd ≤ ADTT < 5,000 tpd	10 points.
ADTT < 1,000 tpd	5 points.
No heavy trucks	0 points.

Table D.13. Example criteria for scoring ADTT attributes for steel bridges.

Criteria	Example Points
ADTT is greater than 1,000 tpd	20 points
ADTT is between 100 and 1,000 tpd	15 points
ADTT is between 15 and 100 tpd	5 points
ADTT is less than 15 tpd	0 points

L.2 Dynamic Loading from Riding Surface

Reason(s) for Attribute

This attribute is intended to consider the detrimental effects of dynamic loading on the deterioration patterns for concrete bridge decks. This attribute would typically be used to adjust assessments to consider a reduction of the durability of bridge decks with high dynamic loads (i.e., high-speed traffic and high ADTT). This attribute is included to consider cases where the riding surface or the deck joint becomes damaged, such as through the development of potholes, rough patches, or a bump at the end of the bridge, and increased dynamic forces are created due to the traffic loading. These forces place additional stress on the structure leading to a perpetual cycle of damage propagation that accelerates the rate of deterioration for the deck element (McLean et al., 1998).

Assessment Procedure

This attribute is based on engineering judgment. Considerations in assessing this attribute include the roughness of the riding surface, the existence of potholes and patches, durability of deck joints, ADTT, and traffic speeds.

Example criteria and scoring:

- Dynamic forces leading to increased rate of deterioration a significant consideration. 15 points.
- Dynamic forces are not a significant consideration. 0 points.

L.3 Exposure Environment

Reason(s) for Attribute

The environment surrounding a bridge can have a significant effect on the rate of deterioration, particularly corrosion. This attribute is intended to characterize the macro-environment surrounding a bridge, and account for the likelihood of increased deterioration rates in environments that are particularly aggressive, such as coastal or marine environments. Aggressive environments typically have high ambient levels of chlorides, high ambient moisture levels (high humidity or frequent wet/dry cycles, increased temperature), and the presence of other harmful chemicals (i.e., elevated levels of carbon dioxide, sulphates, etc.)

Assessment Procedure

The assessment procedure is similar to other environmental exposure classifications which are already in practice. Marine environments are deemed the most severe due to the high levels of ambient chlorides and moisture. “Moderate” environment is intended to characterize those environments where corrosive agent levels (water and chlorides) are elevated but lower than those found in marine or other severe exposures. Industrial environments are less severe than marine but may contain other harmful chemicals. Under modern regulatory constraints, airborne pollutant levels associated with industrial environments are minimized, and this should be considered in the assessment of industrialized environments. Benign environments are those where application of deicing chemicals is minimal or nonexistent; the environments may be arid, and atmospheric pollutants are typical.

Example criteria and scoring:

- Severe/Marine. 20 points.
- Moderate/Industrial. 10 points.
- Benign. 0 points.

L.4 Likelihood of Overload

Reason(s) for Attribute

This attribute can be used when the likelihood of overload is a consideration for the bridge or a family of bridges being assessed. The likelihood of overload is used to characterize the chance that a bridge will be loaded beyond its inventory load rating. Such overloads generally increase the deterioration rate for structural elements. The probability of this occurring may be greater for bridges with a reduced capacity, such as those that have already been load posted.

Assessment Procedure

This attribute is scored based on how likely it is that a bridge will be overloaded. Sound engineering judgment should be used to assess this attribute.

Example criteria and scoring:

- High likelihood of overload. 20 points.
- Moderate likelihood of overload. 10 points.
- Low likelihood of overload. 0 points.

L.5 Rate of Deicing Chemical Application

Reason(s) for Attribute

This attribute is intended to characterize the quantity of deicing chemicals applied regularly to the deck's surface. The detrimental effects of deicing chemicals on the durability of bridge elements are well known. The intrusion of chloride ions to the level of the reinforcing steel provides an important driving force for corrosion of the reinforcing steel (Silano & Brinckerhoff, 1993). When combined with oxygen and water, higher levels of deicing chemical application generally lead to more rapid and severe reinforcement corrosion rates. Increased chloride concentrations at the concrete's surface increases chloride diffusion rates, shortening the time for the initiation of corrosion in the steel. If faulty deck joints or a substandard drainage system are present which permits water seepage, bridge elements below the deck may also be affected by increased chloride ion levels. This will lead to increased levels of corrosion and consequently to corrosion-related damage.

Assessment Procedure

This attribute can be scored based on the average annual number of applications of deicing chemicals to the deck surface. The application rates may either be expressed quantitatively, if the bridge owner keeps such records, or on a qualitative scale. Factors that could help estimate the rate of salt application include the roadway's ADT, the bridges' service level, and/or the number of freezing weather events the bridge experiences. Typically, bridges with high ADT lie along critical roadways that may receive the focus of local maintenance crews for the application of deicing chemicals, and hence have greater quantities of deicing chemicals applied. The greater the number of weather events, the more frequently deicing chemicals may be applied. Users may have other data or information regarding the application of deicing chemical that can be used to develop rationale identifying those bridges exposed to high levels of deicing chemicals and those where deicing chemical use is minimal.

Example criteria and scoring:

- High (more than 100 applications per year). 20 points.
- Moderate. 15 points.
- Low (less than 15 applications per year). 5 points.
- None. 0 points.

L.6 Subjected to Overspray

Reason(s) for Attribute

Overspray refers to the deicing chemicals on a roadway which are being picked up and dispersed by travelling vehicles onto adjacent highway structures, including bridges and their substructures. Bridges that are located over roadways may receive overspray from the road below. Since overspray typically consists of salt or other deicing chemicals, more exposure increases the likelihood of developing a corrosion problem.

It is noted that L.6 Subjected to Overspray is explicitly considered to be a separate item from L.5 Rate of Deicing Chemical Application. This is because some bridges may not have deicing chemicals directly applied to their decks, but still can be exposed to overspray from below. An example of this would be a rural road over an interstate. However, to address the more severe condition where deicing chemicals are applied to the bridge directly and by overspray, the items are considered separately.

Assessment Procedure

Like the rate of deicing chemical application, a quantitative estimate of overspray exposure may be difficult. The frequency of deicing chemical application on the highway that the bridge crosses (if applicable) can be used to aid in estimating the overspray exposure. The vertical clearance of the bridge is also a consideration. For example, a bridge with greater than 20 feet of vertical clearance over the roadway below may experience minimal effects from overspray. In any case, sound engineering judgment should be used. The suggested scoring scheme is based on the generally more significant effect of overspray on steel bridge elements. These suggested scales should be modified appropriately based on local experience.

Concrete Bridge Deck, Prestressed Girder, Substructure
Example criteria and scoring:

- Severe overspray exposure. 15 points.
- Moderate overspray exposure. 7.5 points.
- Low exposure overspray or not over a roadway. 0 points.

Steel Girder
Example criteria and scoring:

- Severe overspray exposure. 20 points.
- Moderate overspray exposure. 10 points.
- Low exposure overspray or not over a roadway. 0 points.

L.7 Remaining Fatigue Life

Reason(s) for Attribute

The remaining fatigue life of an element is somewhat related to the probability of a fatigue crack propagating to the point of brittle fracture. Obviously, for elements that have longer remaining fatigue lives, there is a lower probability of failure due to fatigue cracking than for elements with shorter remaining fatigue lives.

Assessment Procedure

The remaining fatigue life of an element can be determined using any established method. *Insufficient fatigue life* refers to a fatigue life that is less than the required service life or some other interval defined by the owner (e.g., less than 10 years). It is noted that it is possible to calculate a life of less than the length of time the bridge has been in service (i.e., a "*Negative fatigue life*"). In many cases, although a negative fatigue life has been calculated, there is no evidence of fatigue cracking on the structure. Although a negative fatigue life does not make physical sense, it does suggest that the probability of failure due to fatigue cracking is greater. In such cases, more in-depth evaluation efforts are justified, such as field testing or monitoring to obtain in-service stress range histograms or a more accurate finite element model of the structure. Often, the more in-depth evaluations reveal that there is significant remaining fatigue life.

Sufficient fatigue life refers to a fatigue life that exceeds the expected service life, or a defined life required by the owner (e.g., 10 years until replacement) of the element, but is not infinite. *Infinite life is the case when fatigue cracking is not expected to propagate during the structure's life.* A greater penalty is placed on not knowing the remaining fatigue life than on performing a fatigue analysis which determined a negative fatigue life.

Example criteria and scoring:

- Unknown remaining fatigue life. 10 points.
- Insufficient remaining fatigue life. 7 points.
- Sufficient remaining fatigue life. 3 points.
- Infinite remaining fatigue life. 0 points.

L.8 Overtopping / high water

Reason(s) for Attribute

Certain bridges are susceptible to periodic overtopping or high-water conditions in which the bridge superstructure is partially or totally immersed in water. Such condition may not adversely affect the loading carrying capacity of the structure; however, these conditions may increase the likelihood that A) the structure is impacted by debris or ice in the water, or B) that debris is deposited on the flanges and surrounding the bearing areas of the bridge. Impact from debris or ice in the water may increase the likelihood that a certain bridge suffers impact damage, even though the structure is not over a roadway. Debris deposited on the superstructure or on the bearing area or the substructure will retain moisture and may accelerate corrosion damage.

Assessment Procedure

Bridges likely to be overtopped during high water are typically documented in the NBIS data submitted annually to the FHWA. Experience may also be used to identify bridges susceptible to the adverse effects of high water. This attribute may be assigned different values when considering the effect of impact from debris and the effect of debris being deposited on the superstructure or bearing area of the substructure.

Example criteria and scoring:

- Periodic overtopping / high water. 20 points.
- No overtopping / high water. 0 points.

Condition Attributes

C.1 Current Condition Rating

Reason(s) for Attribute

The CR for a bridge component describes the existing, in-place bridge as compared with the as-built condition. The CRs provide an overall characterization of the general condition of the entire component. It is reasonable to assume that a given element which has already shown signs of damage is more likely to deteriorate to a serious condition than an element showing little or no signs of damage. It is typical for a concrete component with a CR ≤ 5 to have observable corrosion damage in the form of cracking or spalling, (either as open spalls or patched spalls). Such damage provides pathways for the increased penetration of chloride ions and for increased rates of damage accumulation. For steel elements, low CRs are frequently emblematic of significant corrosion damage. Fatigue cracking or member distortions due to unexpected settlement, etc. may be present. Conversely, components with a high CR (CR ≥ 6) typically have lower levels of existing deterioration. Consequently, some consideration should be given to the overall component rating when assessing the durability of the bridge element.

Assessment Procedure

For this attribute, a CR of 5 or less is considered to have a much higher likelihood for accelerated damage than component with higher CRs. A CR of six is considered to have a smaller likelihood of accelerated damage.

Example screening criteria and action:

- CR = 5. 20 points.
- CR = 6. 5 points.
- CR ≥ 7. 0 points.

C.2 Current Element Condition State

Reason(s) for Attribute

When element-level inspections are conducted under the AASHTO Bridge Element Inspection Manual, element CSs are linked to specific evidence of damage or deterioration to the subject bridge element. Elements or portions of elements in CS 1 typically have very little or no evidence of deterioration. Elements or portions of elements in CS 2 have some evidence of damage. As such, it is reasonable to assume that if a given element is entirely in CS 1, the likelihood of severe damage occurring in the near future is lower than an element with portions of the element in CS 2, 3, or 4. This attribute is intended to consider the positive attributes of an element in CS 1.

Assessment Procedure

For this attribute, the current CS for a given bridge element is considered. For elements entirely in CS 1, the scoring of zero points is suggested, for elements where CS 3 is indicated for any portion of the element, a score or 20 points is suggested. Users may wish to utilize appropriate gradations for elements with conditions indicated as CS 2. The severity and the significance of CS 2 varies by element, and the RAP may wish to develop alternative scoring schemes based on specific elements and CS apportionment. Element-level inspection implementation varies at the owner level, and therefore appropriate scoring should be considered by the RAP according to existing inspection practices.

Example criteria and scoring:

- CS 2 is indicated for a significant portion of the element, or CS 3 is indicated for any portion of the element. 20 points.
- CS 2 is indicated for a minor portion of the element. 10 points.
- CS 1 is indicated for entire element. 0 points.

C.3 Evidence of Rotation or Settlement

Reason(s) for Attribute

This attribute is intended to consider the effects of unexpected rotation or settlement of abutments and piers. Use of this attribute is for minor settlements or rotations that do not affect the structural capacity but may result in atypical or accelerated deterioration patterns. Significant rotations or settlements may require engineering analysis. The rotation of a bridge substructure beyond its design tolerances may result in damage that is manifested by cracking, skewing, and/or misaligned bridge components. Unexpected settlements may result in cracking that provides pathways for intrusion of water and chlorides, leading to accelerated corrosion of reinforcing steel.

Assessment Procedure

Evidence of rotation or settlement should be rated based on their severity using engineering judgment.

Example criteria and scoring:

- Rotation or settlement resulting in cracking of concrete, misaligned joints, or misaligned members. 15 points.
- Minor evidence of rotation or settlement with the potential to result in unexpected cracking or poor joint performance. 5 points.
- No evidence of rotation. 0 points.

C.4 Joint Condition

Reason(s) for Attribute

The presence of one or more leaking joints will dramatically increase the possibility for corrosion related deterioration on the elements below the deck. This is because joints which are leaking will usually leak chloride-contaminated water directly onto other bridge components such as the superstructure, substructure and bearing areas. This allows corrosion to initiate and propagate at a faster rate in the affected elements.

Assessment Procedure

This attribute should be rated based on either visual observation or on information contained in bridge inspection reports. For this attribute, a leaking joint is considered severe. If a joint has become filled with debris, there is an increased probability that that joint will become damaged and start to leak in the near future. Users should consider historical experience with typical joints in their inventory in evaluating this attribute. For example, if certain typical joint types are expected to have a service life of less than five years, it may be appropriate to assume that this joint is a leaking joint, because even if it is not leaking currently, it is expected to leak in the near future. Open joints should be expected to allow for the passage of water and debris, and thus should be scored accordingly if this effect is unmitigated. For bridges that are jointless, it is assumed that the bridge is performing as intended and deck drainage is not affecting the bearing areas.

Example criteria and scoring:

- Significant amount of leakage at joints. 20 points.
- Joints have moderate leakage or are debris-filled. 15 points.
- Joints are present but not leaking. 5 points.
- The bridge is jointless. 0 points.

C.5 Maintenance Cycle

Reason(s) for Attribute

This attribute is intended to consider the positive benefits of consistent maintenance and preservation activities on the durability and the reliability of bridge elements. Activities such as deck cleaning, maintenance of drainage, debris removal, washing out joints, and periodic application of the sealers help preserve bridge elements and extend their service lives. Conversely, a bridge that does not receive periodic maintenance and preservation activities is likely to experience damage and deterioration much earlier in their service lives and deteriorate at a higher rate relative to a bridge receiving consistent, periodic maintenance.

Assessment Procedure

This attribute is scored based on the bridge maintenance policies and practices within the inventory being assessed. The RAP panel should consider the policies and practices within their state regarding the intensity of maintenance activities within regions, districts or municipalities. For example, state-owned bridges typically receive more consistent and thorough maintenance than locally owned bridges. Bridges located in rural areas may receive less intense maintenance than those located near population centers, etc. The RAP should consider specific situations within their bridge inventory when assessing this attribute and develop criteria for establishing which bridges receive regular maintenance, that can be expected to prevent deterioration, and those bridges which do not.

- Bridge does not receive routine maintenance. 20 points.
- Some limited maintenance activities. 10 points.
- The bridge is regularly maintained. 0 points.

C.6 Previously Impacted

Reason(s) for Attribute

If a bridge has been previously struck or impacted by a vehicle, it is reasonable to assume that there is an increased probability of further impact damage. The element could also have been damaged because of previous impact, which has been shown to decrease, for example, a steel girder's resistance to brittle fracture(Connor et al., 2008). For concrete bridge elements, impacts can compromise the concrete cover, resulting in the exposure of embedded steel elements. As a result, previous impacts should be considered in the analysis for potential impact damage.

Assessment Procedure

This attribute is scored only on whether the bridge was previously impacted. If the impact risks have been mitigated, this should be considered in the analysis.

Example criteria and scoring:

- Bridge has been previously impacted. 20 points.
- The bridge has not been previously impacted. 0 points.

C.7 Effectiveness of Deck Drainage System

Reason(s) for Attribute

The purpose of the deck drainage system is to allow water to drain off the bridge deck effectively, without draining directly onto other elements of the bridge, such as the superstructure and the substructure elements. Drainage systems on in-service bridges can become clogged with debris, resulting in ponding of water on the bridge deck. Damage to in-service drainage systems can result in drainage directly onto the superstructure and substructure elements. In either case, ineffective drainage systems can increase the exposure of bridge elements to deicing chemicals creating a more aggressive environment for corrosion. This attribute is intended to address the increased exposure of bridge elements due to damage, deterioration, or ineffective performance of a deck drainage system. Deck drainage systems with ineffective designs would typically be addressed using attribute D.4. Poor Deck Drainage and Ponding.

Assessment Procedure

This attribute is based on an assessment of the deck drainage system's effectiveness from inspection results.

Example criteria and scoring:

- Limited effectiveness. 15 points.
- Substantially effective. 7.5 points.
- Fully effective. 0 points.

C.8 Corrosion-induced Cracking

Reason(s) for Attribute

This attribute considers the presence of corrosion-induced cracking in concrete bridge elements. Corrosion-induced cracking typically occurs due to the expansion of reinforcing steel caused by corrosion by-products on the bar's surface. This expansion leads to cracking of the concrete, providing pathways for water and chlorides to penetrate to the reinforcement level. Frequently, this type of cracking is accompanied by rust staining. Such evidence of active corrosion would typically be detected during a typical visual inspection of a bridge. The presence of active corrosion increases the likelihood for corrosion damage to occur to a severe extent in the future.

Assessment Procedure

This attribute is scored based on the presence and the severity of corrosion-induced cracking in concrete bridge elements. The determination of the significance of the cracking should be based on engineering judgment.

Example criteria and scoring:

- Significant corrosion-induced cracking. 20 points.
- Moderate corrosion-induced cracking. 10 points.
- Minor corrosion-induced cracking. 5 points.
- No corrosion-induced cracking. 0 points.

C.9 General Cracking

Reason(s) for Assessment

This attribute is used to characterize the presence of non-structural cracks in concrete. These cracks may result from shrinkage, thermal forces, or other non-structural effects. These cracks can provide pathways for intruding chlorides to the reinforcement level. It is generally recognized that cracks perpendicular to the reinforcing bars hasten the corrosion of the intersected reinforcement by facilitating the ingress of moisture, oxygen, and chloride ions. Cracks that follow the line of a reinforcing bar are much more serious since the length of the bar equal to the length of the crack is exposed to corrosive elements. The presence of cracking also reduces the concrete's ability to contain spalling as the reinforcement corrodes. This attribute is used for cracking other than corrosion-induced cracking, which is described in attribute C.8.

Assessment Procedure

The rating of this attribute depends on engineering judgment. More specific guidance to classifying crack sizes and density can be found in the 2010 edition of the AASHTO Bridge Element Inspection Manual.

- Widespread or severe cracking. 15 points.
- Moderate cracking present. 10 points.
- Minor or no cracking present. 0 points.

C.10 Areas of Delamination

Reason(s) for Attribute

Areas of delamination are subsurface cracks in concrete generally parallel to the concrete surface. Areas of delamination are caused by horizontal cracking formation due to volumetric expansion of the reinforcing steel during the corrosion process. Areas of delamination are typically emblematic of the corrosion of embedded steel, and thus provide an early indicator of where future spalling is likely to occur. This attribute is intended to consider that concrete elements with areas of delamination are more likely to experience deterioration and damage in the future, relative to elements where areas of delamination are not present. Detecting delamination areas in concrete can reduce uncertainty in determining if there is active corrosion manifesting in damage to the concrete.

This attribute may also be used to characterize conditions for a deck overlay. Under these conditions, areas of delamination are indicative of a loss of bond between the overlay and the substrate. Overlays that are debonding are likely to deteriorate more rapidly than an overlay with good bonding characteristics.

It is implied that some form of NDE has been conducted to address this attribute, as areas of delamination are not visibly detectable. This typically includes hammer sounding or chain drag but may include other techniques like infrared thermography, impact echo, or other methods.

Assessment Procedure

This attribute is scored based on inspection results that indicate the extent of areas of delamination present in a given concrete element. This attribute should be scored based on the amount of surface area of the structure that includes areas of delamination. Suggested values for the significant levels of delamination are indicated below.

Example criteria and scoring:

- Significant quantity of areas of delamination present (greater than 20% by area) or unknown. 20 points.
- Moderate quantity of areas of delamination present (5% to 20% by area). 10 points.
- Minor, localized areas of delamination (less than 5% by area). 5 points.
- No areas of delamination present. 0 points.

C.11 Presence of Repaired Areas in R/C Decks

Reason(s) for Attribute

Repaired spalls and patches temporarily seal reinforcement exposed by damaged concrete. However, even though the reinforcement is again sealed from the environment, the existing corrosion can continue to propagate. Patches frequently have a relatively short service life, especially when traffic loading is high.

The service life of deck patches ranges from four years to ten years (Weyers et al., 1993), although an FHWA TechBrief indicates that the service life of a patch ranges from four years to only seven years (FHWA, 1999). The service life of the patch depends largely on the corrosivity of the surrounding concrete and the development of the halo effect. When concrete is contaminated with chlorides in concentrations greater than the threshold level in the area surrounding the patches, inadvertent acceleration of the corrosion rate can occur. The patched area acts as a large non-corroding site (i.e., cathodic area) adjacent to corroding sites (i.e., anodic areas), and thus corrosion cells are created.

Assessment Procedure

The presence of repaired areas should be scored based on the total surface area of the bridge that has repaired areas. Engineering judgment should be exercised. If the repaired areas result from impact damage or other non-corrosion related damage, and chlorides levels for the intact concrete are expected to be nominal, a reduced score may be assigned.

Example criteria and scoring:

- Significant number of repaired areas. 15 points.
- Moderate number of repaired areas. 10 points.
- Minor number of repaired areas. 5 points.
- No repaired areas. 0 points.

C.12 Presence of Spalling

Reason(s) for Attribute

This attribute is intended to consider the presence of spalling on concrete bridge elements. Open spalls are sections of concrete separated from the larger mass of concrete and fallen off the structure, usually exposing the underlying reinforcement. Unrepaired spalling allows corrosive elements to directly contact the exposed reinforcement and prestressing steel, if present. This will lead to accelerated rates of corrosion damage in the area surrounding the spall.

Users may wish to include repaired spalls under this attribute or utilize the attribute C.11 Presence of Repaired Areas.

Assessment Procedure

This attribute is scored based on the severity and the extent of spalling as reported in bridge inspection reports. Users should consider the importance of the spalling in terms of the structural performance of the element under consideration in developing their scoring methodology. Spalling that leads to the exposure of prestressing strands is considered significantly more important than spalling in a reinforced element exposing the mild steel bars.

Example criteria and scoring:

- Significant spalling (greater than 10% of area with spalling, rebar or strands exposed). 20 points.

- Moderate spalling (greater than 1 in. deep or 6 in. in diameter or exposed reinforcement). 15 points.
- Minor spalling (less than 1 in. deep or 6 in. in diameter). 5 points.
- No spalling present. 0 points.

C.13 Efflorescence / Staining

Reason(s) for Attribute

This attribute is intended to consider the increased likelihood of corrosion damage associated with the present of efflorescence on the surface of concrete elements. Efflorescence is a white stain on the face of a concrete component which results from the crystallization of dissolved salts. While efflorescence is typically considered an aesthetic problem, it may be indicative of a problem with the concrete mix and may contribute to corrosion initiation. Efflorescence on the soffit of a bridge deck typically indicates that water is passing freely through the deck, likely carrying with it chlorides which may cause corrosion of the reinforcing steel. When rust stains are present, the corrosion of reinforcing steel is assured.

Extensive leaching causes an increase in the porosity and the permeability of the concrete, thus lowering the strength of the concrete and making it more vulnerable to hostile environments (e.g. water saturation and frost damage, or chloride penetration and the corrosion of embedded steel) (Oak Ridge, 2006). Those concretes which are produced using a low water-cement ratio, adequate cement content, proper compaction and curing are the most resistant to leaching that results in efflorescence on the surface of the concrete (Oak Ridge, 2006).

Assessment Procedure

This attribute is scored based on inspection results. The scoring for this attribute is based on efflorescence and whether rust stains from corroding reinforcement are present.

Example criteria and scoring:

- Moderate to severe efflorescence with rust staining; severe efflorescence without rust staining. 20 points.
- Moderate efflorescence without rust staining. 10 points.
- Minor efflorescence. 5 points.
- No efflorescence. 0 points.

C.14 Flexural Cracking

Reason(s) for Attribute

When the primary load bearing members in a concrete bridge exhibit flexural cracking, it may indicate that the members were either inadequately designed for the required loading, that overloads have occurred, or that deterioration has occurred which has reduced the load bearing capacity of the members. In any case, large flexural cracks can indicate an inadequate load-bearing capacity which may require an engineering analysis to determine the cause of the cracking and the resulting effect on the structure's load capacity. As a result, bridges exhibiting moderate to severe flexural cracking should be screened from the general reliability assessment unless appropriate engineering analysis indicates that the cracking is benign. Flexural cracking in a prestressed element is generally more significant than in a R/C element.

In cases where flexural cracking is minor or appropriate assessment has indicated that the cracking is not affecting the adequate load capacity of the element, the cracking provides pathways for the ingress of moisture and chlorides that may cause corrosion of the embedded steel. This attribute is intended to consider the increased likelihood of corrosion resulting from the cracking in the concrete.

Assessment Procedure

Flexural cracks will typically present themselves with a vertical orientation either near the bottom flange at mid span or near the top flange over intermediate supports, if the member is continuous.

Engineering judgment must be exercised in determining whether any present flexural cracking is moderate to severe. Crack widths in R/C bridges exceeding 0.006 in. to 0.012 in. reflect the lower bound of "moderate cracking." The American Concrete Institute Committee Report 224R-01 (ACI, 2001) presents guidance for what could be considered reasonable or tolerable crack widths at the tensile face of R/C structures for typical conditions. These range from 0.006 in. for marine or seawater spray environments to 0.007 in. for structures exposed to deicing chemicals, to 0.012 in. for structures in a humid, moist environment.

In PSC bridge structural elements, tolerable crack width criteria have been adopted in the Precast Prestressed Concrete Institute (PCI) MNL-37-06 Manual for the Evaluation and Repair of Precast Prestressed Concrete Bridge Products (PCI, 2006). The PCI Bridge Committee recommends that flexural cracks greater in width than 0.006 in. should be evaluated to affirm adequate design and performance.

Note that this attribute is a companion to the screening attribute S.4 Flexural Cracking, where any moderate to severe flexural cracking should exclude the bridge from a risk-based assessment unless appropriate engineering analysis has been completed showing that the cracking is benign or has been repaired. Generally, cracking in prestressed elements is more problematic than cracking in R/C elements.

Example criteria and scoring:

- Crack widths equal to or less than 0.006 in. to 0.012 in., depending on environment for R/C; Crack widths equal to or less than 0.006 in. for PSC. 10 points.
- No flexural cracking. 0 points.

C.15 Shear Cracking

Reason(s) for Attribute

Similar to flexural cracking, if the primary load bearing members in a concrete bridge exhibit shear cracking, it can be assumed that the members were either inadequately designed for the required loading or that deterioration has occurred, which has reduced the load bearing capacity of the members. In either case, large shear cracks can be indicative of an inadequate load bearing capacity which may require an engineering analysis in order to determine the cause of the cracking and the resulting effect on the load capacity. As a result, bridges exhibiting moderate to severe shear cracking should be screened from the reliability assessment unless appropriate engineering analysis indicates that the cracking is benign in terms of the load bearing capacity.

Assessment Procedure

Engineering judgment must be exercised in determining the severity of any present shear cracking. Shear cracks will typically present themselves with a roughly 45° diagonal orientation and will radiate towards the mid-span of the member for conventionally reinforced concrete. For PSC, angles down to roughly 30 degrees may be observed. The ends of the members and any sections located over piers should be checked for this type of cracking. Note that this attribute is a companion to the screening attribute S.5 Shear Cracking, where any moderate to severe shear cracking should exclude the bridge from a risk-based assessment until adequate assessments have been conducted.

Example criteria and scoring:

- Minor, hairline to less than 0.0625 in. shear cracking. 10 points.

- No shear cracking. 0 points.

C.16 Longitudinal Cracking in Prestressed Elements

Reason(s) for Attribute

This attribute is for the assessment of PSC bridge elements. Longitudinal cracking in prestressed elements can be indicative of the corrosion or the fracture of the embedded prestressing strands. As a result, elements with reported longitudinal cracking in the soffit, web, or flange should be individually assessed to determine the source of the cracking and to assess the condition of the prestressing strands (Naito et al., 2010).

Assessment Procedure

Longitudinal cracking in prestressed elements can be indicative of strand corrosion and damage, and as such significant longitudinal cracking is a screening attribute. Use of this attribute in the reliability assessment assumes the cracking in question is minor in nature and has been assessed to determine that significant strand corrosion is not currently present. In this case, the longitudinal cracking provides pathways for the intrusion of moisture and chlorides to the prestressing strands and the mild steel bars. As a result, a prestressed element with minor longitudinal cracking is more likely to experience deterioration and damage than an uncracked element. This attribute is scored based on inspection results.

Example criteria and scoring:

- Minor longitudinal cracking in beam soffit. 15 points.
- No longitudinal cracking in beam soffit. 0 points.

C.17 Coating Condition

Reason(s) for Attribute

This attribute considers the effect of the coating condition on the likelihood of corrosion damage occurring in steel bridge elements. Coatings are applied to steel elements to provide protection from corrosion and for aesthetic reasons. Elements with coatings in good condition, and performing as intended, are generally less susceptible to corrosion damage. Elements with significant rusting and corrosion in areas where that paint system has failed are more likely to experience further corrosion damage in the future.

Assessment Procedure

Depending on the condition of the coating, the likelihood of corrosion damage varies. Coatings typically deteriorate more rapidly when drainage from the bridge deck is allowed to flow onto the steel surface. As a result, conditions for the accelerated corrosion of steel may already exist. If the coating is already in poor condition, the likelihood of severe corrosion damage is greater than for a coating in good condition. If the element is constructed with weathering steel (assuming it is placed in the proper environment and is detailed correctly), it should be scored as though the coating is in good condition. The development of an effective patina for the weathering steel should be confirmed. If element-level inspection is being performed, the CS of the coating element (Element 515) can be used to determine criteria based on the quantity of CS 2, 3, or 4 present based on prior inspections.

Example criteria and scoring:

- Coating system in very poor condition, limited or no effectiveness for corrosion protection, greater than 3% rusting. 10 points.
- The coating system is in poor condition, 1% to 3% rusting, substantially effective for corrosion protection. 5 points.
- Coating is in fair to good condition, effective for corrosion protection. 0 points.

C.18 Condition of Fatigue Cracks

Reason(s) for Attribute

Active fatigue cracks due to primary stress ranges will continue to grow until the member fails, either by brittle or ductile fracture. An arrested or repaired fatigue crack is better than having an active crack, but it is still worse than having no crack at all, as it suggests that the conditions necessary for cracking to initiate were or still may be present in the structure. In other words, other similar details (that have not been preemptively retrofitted) may be susceptible to cracking in the future.

Assessment Procedure

To determine if a fatigue crack is arrested, a comparison must be made between previous inspection reports. To be considered arrested, a crack must have not grown in a specified amount of time (e.g., the inspection interval plus one year). It is noted that although no fatigue cracks may have been observed, a detail still may be highly susceptible to fatigue. Hence, other attributes such as D.16 Element Connection Type, D.17 Worst Fatigue Detail Category, and L.1 ADT / ADTT are included in the assessment procedure to address the susceptibility to cracking.

Example criteria and scoring:

- Fatigue crack exists and is active/unknown (CS 3). 20 points (see S.7).
- Fatigue crack exists and has been arrested or retrofitted (CS 2). 10 points.
- No fatigue cracks are present (CS 1). 0 points.

C.19 Presence of Fatigue Cracks due to Secondary or Out of Plane Stress

Reason(s) for Attribute

Fatigue cracks due to secondary or out-of-plane stresses are the most common type of fatigue cracks found on highway bridges. Most of these cracks occur due to incompatibility or relative movement between bridge components.

Assessment Procedure

The scoring for this attribute is based on the existence or nonexistence of fatigue cracks. Some common types of fatigue cracks due to secondary stresses include web-gap cracks, deck plate cracking in orthotropic bridge decks, and floor beam connections.

Example criteria and scoring:

- Fatigue cracks are present and are active / unknown (CS 3). 15 points.
- Fatigue cracks are present but have been arrested or have been retrofitted (CS 2). 5 points.
- No fatigue cracks are present (CS 1). 0 points.

C.20 Non-Fatigue Related Cracks or Defects

Reason(s) for Attribute

This attribute refers to steel bridge elements that have cracks that are not caused by fatigue. Cracking due to a previous impact, welded connections of secondary members, or other sources can be addressed with this attribute.

Assessment Procedure

This attribute should be scored based on whether cracks or other defects are found in the element. Previous inspection reports should be used when evaluating this attribute.

Example criteria and scoring:

- Non-fatigue related cracks or defects are present. 10 points.
- Non fatigue related cracks or defects are not present. 0 points.

C.21 Presence of Active Corrosion

Reason(s) for Attribute

The presence of visible active corrosion on steel bridge elements indicates that severe corrosion damage in the future is possible since the environment and the bridge features are vulnerable to the initiation and the propagation of corrosion. It is also well known that corrosion damage typically propagates at an accelerated rate, once initiated, and that elements that show no signs of active corrosion are very unlikely to develop severe corrosion damage during the assessment interval of 72 months. Maximum rates of section loss under the most severe marine conditions typically do not exceed 10 mils/year (0.010 in./year). For moderate conditions, rates are typically about 4 mils/year (0.004 in. /year) or less.

Inactive corrosion damage is explicitly distinguished from active corrosion. For example, section loss on a girder web that was the result of a leaking expansion joint that was corrected (the joint was replaced, and the girder was repainted), may be assumed to have inactive corrosion. It is assumed that the owner has determined that the existing section loss is either insignificant or has taken it into account in the load rating procedures.

Assessment Procedure

This attribute should be scored based on the amount of active corrosion present on the element. Engineering judgment should be used to determine if the corrosion is active. This attribute may also be used as a screening tool in a reliability assessment.

Example criteria and scoring:

A significant amount of active corrosion is present. 20 points.
A moderate amount of active corrosion present. 15 points.

- Minor amount of active corrosion present. 7 points.
- No active corrosion present. 0 points.

C.22 Presence of Debris

Reason(s) for Attribute

Debris on bridge elements can substantially increase the probability of corrosion damage by maintaining a moisture-rich environment on the steel's surface. Debris can be especially damaging if it is allowed to remain on the bridge without maintenance action, such as washing or cleaning. This attribute is intended to characterize bridges susceptible to having debris deposited on the flanges, bearings, connections, or other details that results in atypical (e.g., accelerated) deterioration patterns.

Assessment Procedure

This attribute should be assessed based on if debris is present or likely to be present on the element, resulting in an atypical deterioration pattern.

Example criteria and scoring:

- Debris is or is likely to be present. 15 points.
- Debris not likely to be present. 0 points.

C.23 Wear / Abrasion or Rutting

Reason(s) for Attribute

This attribute addresses the specific damage mode of wear, abrasion, or rutting. Rutting is specific to bridge decks. Wear or abrasion may be present in decks or other concrete components. The attribute is intended to reflect the increased exposure of steel reinforcing to corrosive agents when the concrete cover is compromised. Aggregates are exposed to the environment surrounding the bridge and further wear or abrasion is likely to occur. Severe wear and abrasion of substructure elements can significantly increase deterioration rates.

Assessment Procedure

The attribute is scored based on inspection results that indicate the presence of wear, abrasion, or rutting. If defects are recorded as part of element-level inspections, the defect element 1190, "Abrasion / Wear (PSC/RC)", will record the extent of damage in CS.

Example criteria and scoring:

- Abrasion / wear or rutting (CS 3). 20 points.
- Abrasion / wear or rutting (CS 2). 10 points.
- Abrasion / wear or rutting (CS 1). 0 points.

C.24 Bearing Condition

Reason(s) for Attribute

This attribute is intended to consider bearing damage as part of the risk assessment for superstructure and substructure components. Bearings in poor condition may be affected by corrosion damage, indicating there is advance corrosion occurring near the beam supports. Bearings in poor condition may also restrict superstructure movements, introducing thermal stresses that can damage superstructure members. The attribute may also be used to assess if rocker bearings have excessive tilting that does not correspond with ambient environmental conditions.

Assessment Procedure

The attribute can be assessed based on either the CS assigned for the bearing elements, the CR assigned to the bearing elements (B.C.07) or inspection notes.

Example criteria and scoring:

- CR 5, Element CS 3 ≥10%, CS 4>1%. 20 points.
- CR 6, Element CS 1% ≤CS3<10%, CS 2>20%. 10 points.
- CR ≥ 7. 0 points.

C.25 Construction Quality

Reason(s) for Attribute

This attribute is the same as the screening attributes, applied here as part of the risk model. See S.17, construction quality.

Assessment Procedure

This attribute is scoring based on engineering judgement and subjective assessment of construction quality. Construction quality issues may also be reflected in the CS for elements or CR for components; this attribute is intended to identify bridge components where there is a significant and notable lack of quality in construction resulting in identifiable defects or loss of durability for the component.

Example criteria and scoring:

- Poor construction quality identified. 15 points.
- Typical construction quality. 0 points.

C.26 Debris Damage

Reason(s) for Attribute

This attribute is used to consider the increased in risk associated with debris damage to a superstructure or substructure of a bridge. The presence of debris damage indicates that the component under consideration is subject to damage from debris in the waterway. This type of damage indicates an elevated risk of further damage in the future. The relative likelihood of a component with debris damage deteriorating to a serious condition is increased relative to a similar component without debris damage. A component may be further compromised in the future due to additional impacts from debris or experience increased deterioration rates resulting from increased exposure to corrosive agents.

Assessment Procedure

This attribute is scored based on the presence or absence of debris damage in the component being analyzed. The presence of debris damage is not part of either standard condition assessment data collection (CR or CS) such that information regarding debris damage would need to be acquired from inspection notes.

Example criteria and scoring:

- Component has debris damage to the superstructure or substructure. 15 points.
- Component does not have debris damage. 0 points.

C.27 Rate of Deterioration

Reason(s) for Attribute

The rationale for this attribute is described in attribute S.11.

Assessment Procedure

See attribute S.11.

C.28 Presence of Repair Areas

Reason(s) for Attribute

This attribute is intended to capture potentially increased likelihood of deterioration and damage for components that have previously undergone repairs related to the damage mode under consideration. When a component or element has undergone repair, the repair itself may present increased likelihood of deterioration or damage and provides evidence that significant deterioration has previously occurred. As a result, components or elements that have undergone previous repairs are compromised as compared to similar components or elements that have not undergone repairs but have similar condition or element ratings. For example, if a steel pile has been repaired with plates to strengthen an area of significant section loss, the RAP may consider that all the steel piles for that bridge have increased POF, since at least one pile has previously required repair due to advance deterioration. The piles for the bridge would score *high* for this attribute, even if only one pile had been repaired.

This attribute is appropriately applied when the repair is not included in the condition assessment. For example, if a pile is repaired with plates as previously noted, the repair is not included in either the CR or the CS. Alternatively, patches on a bridge deck are included in the definitions of the CS for the deck, such that the repair is reflected in the CS for the element. The RAP should consider if the existing condition assessment adequately considers the presence of a repaired component or element.

Assessment Procedure

The scoring for this attribute depends on the presence or absence of repairs on the component under consideration. Data for this attribute may be found in the bridge files or through inspection results.

Example criteria and scoring:

- Component has been previously repaired. 15 points.
- Component has not been previously repaired. 0 points.

C.29 Nondestructive Testing

Reason(s) for Attribute

The application of nondestructive testing (NDT) technology as part of a condition assessment is assumed to reduce the uncertainty in the condition assessment by revealing damage that may not be observed through visual inspection. This may include predictive NDT (PNDT) such as half-cell potential measurements, ground penetrating radar, or resistivity that assess the potential for corrosion, and damage NDT technologies (DNDT) that assess the actual damage present in the component. DNDE technologies include infrared thermography, automated sounding devices, hammer sounding, impact echo, or other technologies intended to detect and characterize damage present in the component under consideration.

The RAP may consider the reliability of the technology and its intended purpose (PNDT or DNDT) in forming criteria and scoring for this attribute.

Assessment Procedure

This attribute is assessed based on the application of NDT technologies for the component under consideration. The attribute can be scored based only on whether the component has undergone NDT testing or has not undergone NDE testing. RAPs may consider the reliability or type of technology used in forming the criteria and scoring for this attribute. The time interval since the last NDT assessment should also be considered in determining the criteria and scoring. Example criteria and scoring are shown below.

Example criteria and scoring:

- NDT has not been applied. 15 points.
- NDT has been applied to the component in the last six years. 0 points.

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