Washington State Department of Transportation
Bridge and Structures Office

Design Memorandum

TO: All Design Section Staff
FROM: Bijan Khaleghi
DATE: January 6, 2020
SUBJECT: Revised BDM Section 6.7 Corrosion of Steel Foundations and Buried Structures

This design memorandum specifies WSDOT's policy for Corrosion of Steel Foundations and Buried Structures. This memorandum becomes the new BDM Section 6.7 and replaces section 7.10.2H. All current references to 7.10.2H shall now reference section 6.7. The current BDM Section 6.7 will be renumbered to Section 6.8 in its entirety.

Bridge Design Manual Revisions:

6.7 Corrosion of Steel Foundations and Buried Structures

6.7.1 Corrosion of Steel Foundations

The following section provides corrosion rates for the design of steel H-piling, pipe piling, concrete filled steel tubes (CFSTs), and sheet piling. The design wall, flange, and web thickness, as applicable, for structural steel sections shall be reduced for corrosion over a 75-year minimum design life. The remaining steel thickness at 75 years shall be sufficient to resist the anticipated design loads. Minimum corrosion rates for section loss are specified in Table 1 below.

Location	Marine or Non-Marine: Corrosive	Non-Marine: Non-Corrosive
Soil embedded zone (undisturbed soil)	0.001	0.0005
Soil embedded zone (fill or disturbed soils)	0.0015	0.00075
Immersed zone	0.003	0.0015
Tidal zone	0.004	---
Splash zone	0.006	---
Atmospheric	0.002	0.001

Table 1: Section Loss (inch per year)

Definitions of the terms used in Table 1 are as follows:

- Marine - a site is considered a marine environment if the structure is less than 1000 feet measured from the surface or edge of salt or brackish water. Water shall be considered brackish if the chloride concentration is measured at 500 ppm or greater measured at mean tide level or higher.

- Non-Marine: Corrosive - a non-marine site is greater than 1000 feet from salt or brackish water and is considered corrosive if one or more of the following conditions exist based on representative soil and/or water samples:

    1. The chloride concentration is 500 ppm or greater,
    2. The sulfate concentration is 1500 ppm or greater,
    3. The pH is 5.5 or less.

    If none of the following conditions exist, the site is considered non-marine: non-corrosive. Refer to Section 6.7.2.1 for information on appropriate testing procedures.

- Immersed zone - portion of structural steel element which is continuously immersed or submerged in water. Immersed non-marine: non-corrosive are environments with fresh water or are tested and found not to meet the marine or non-marine: corrosive values.
- Tidal zone - portion of structural steel element in a marine environment between the Mean Lower Low Water (MLLW) and the Mean High Water (MHW) based on the MLLW Datum.
- Splash zone - portion of structural steel element in a marine environment located above the MHW plus five additional feet or as otherwise determined for a specific site.
- Atmospheric - portion of structural steel element above the splash zone or above ground line as applicable.

The section loss for H-piling and sheet piling shall be doubled to account for both surfaces being exposed. The interior surface of pipe piling and CFSTs are assumed to be sealed by concrete fill or a soil plug, which prevents sufficient oxygen to support significant corrosion. A micro-pile is considered a subset of pipe piles.

The corrosion rates are based on information published in the CALTRANS March 2018, Corrosion Guidelines, version 3.0, the FHWA NHI-16-009 Design and Construction of Driven Pile Foundations - Volume I, and the Washington State Ferries Terminal Design Manual, 2016.

A site-specific assessment should be performed to determine if a site is considered marine, non-marine: corrosive, or non-corrosive. If a site investigation is not performed, the values for a marine/non-marine: corrosive site shall be used. Sampling of a site for corrosion assessment requires samples of the soil and/or water to be obtained from both the surface and subsurface materials to ensure representation of the strata at the site. Water samples in flowing streams and rivers shall not be taken when the water level is elevated due to storm conditions as they may dilute the chemical concentrations.

The potential for scour need not be considered when choosing a design corrosion rate as it relates to zones of exposure. It is assumed any significant scour would be repaired and the applicable zone of a structural element would not be changed. However, if abrasion on the section is a concern, additional wall thickness should be considered. Refer to the discussion on abrasion in Section 6.7.2.5 for more guidance.

A protective coating may be applied to the structural steel sections to increase the corrosion protection. If a coating is utilized, then the section loss corrosion is assumed to begin at the end of the effective life of the coating. Coating effective life is generally assumed to be 15 years. An appropriate coating system shall be specified to withstand damage from handling and driving. Contact the WSDOT Steel Specialist for recommendations on paint systems and coating thicknesses for use on steel piling.

6.7.2 Corrosion and Abrasion of Metal Buried Structures

Metal buried structures consist of steel or aluminum structural plate pipes, arches, and boxes and shall be designed in conformance with Section 12 of the AASHTO LRFD Bridge Design Specifications. Once a structural shape, size, material, and gage are selected, the designer shall perform a service life analysis to ensure a minimum structure service life of 75 years is provided. Issues affecting the service life include corrosive action of the exterior and interior environments and abrasive action of the hydraulic flow adjacent to the structure.

6.7.2.1 Corrosion

The design service life analysis shall include a check on both the outside or backfill and the inside or water side environments to determine which governs.

The characteristics of the soil and water in contact with the structure that can contribute to corrosion include, but are not limited to, soluble salts, sulfates, soil and water resistivity, soil and water pH, and the presence of oxygen.

During design, corrosion investigations of in-situ soils, fill material (native or imported) to be used as backfill, soils/materials to be used inside the buried structure and any water flowing into or around the structure shall be performed. Soils shall meet the requirements of Standard Specification 6-20.3(6).

Soil and water sampling and testing procedures shall follow the requirements of the following or other approved test protocol:

1. WSDOT T 417 (resistivity and pH of soil and water)
2. CALTRANS Test 643 (resistivity of soil and water)
3. AASHTO T 288 (resistivity of soil)
4. AASHTO T 289 (soil pH)
5. AASHTO T 290 (sulfate in soil)
6. AASHTO T 291 (chloride in soil)
7. ASTM D 1293 (water pH)
8. CALTRANS Test 417 (soil and water sulfate content)
9. CALTRANS Test 422 (soil and water chloride content)

Water samples shall not be taken when the water level is elevated due to storm conditions as this may dilute chemical concentrations.

6.7.2.2 Steel Structures

For galvanized steel buried structures, once the controlling pH and resistivity values of the environment are determined, the designer shall utilize the chart in Figure 1 to determine the estimated service life of the structure. The chart is based on 18 gage galvanized sheet steel. If a gage thicker than 18 is used, the thickness factor table within the chart can be used as a multiplier on the estimated service life.

Note: CALTRANS developed thickness modification factors up to 8 gage, which were then interpolated out to 1 gage by CONTECH Engineered Solutions. Thicknesses greater than 1 gage shall use the factors for 1 gage.

If the estimated service life is less than 75 years, additional thickness shall be added beyond what is required for structural demands to achieve the 75 year service life.

For aluminized steel buried structures, using aluminum-coated (Type 2) sheet steel in accordance with AASHTO M274, the service life and resistance to corrosion is generally more than galvanized steel structures. A similar chart and methodology can be used for aluminum coated structures and is found in Figure 2. The chart is based on 16 gage aluminized sheet steel. If a gage thicker than 16 is used, the thickness factor table within the chart can be used as a multiplier on the estimated service life. The service life is based on years to first perforation.

Aluminum-coated steel structures should generally only be used when environmental conditions have a pH between 5 and 9 and a resistivity greater than 1500 ohm-cm. Recent studies documented in the National Corrugated Steel Pipe Association (NCSPA) Pipe Selection Guide indicated that 14 gage aluminum-coated structures can achieve over 75 year service life in these environmental conditions. The WSDOT Hydraulics manual also recommends aluminum-coated pipe only be used with pH between 5 and 8.5 and soil resistivity greater than 1000 ohm-cm. These recommendations are based on assumed 50 year service life.

<u>6.7.2.3 Aluminum Alloy Structures</u>

Aluminum alloy plate has been shown to be more resistant to corrosion than either galvanized or aluminized steel. A chart for determining service life, similar to that for galvanized and aluminized steel, is located in Figure 3. The chart is based on 16 gage aluminum alloy plate and as with the aluminum-coated chart, the service life is based on years to first perforation. The chart was developed for aluminum pipe (Al-Clad 7072/3004) but is applicable to aluminum structural plate (5050 alloy).

Aluminum alloy plate structures should generally only be used when environmental conditions have a pH between 4.5 and 9 and a resistivity greater than 500 ohm-cm. There is no upper limit on resistivity as soft water is not a concern.

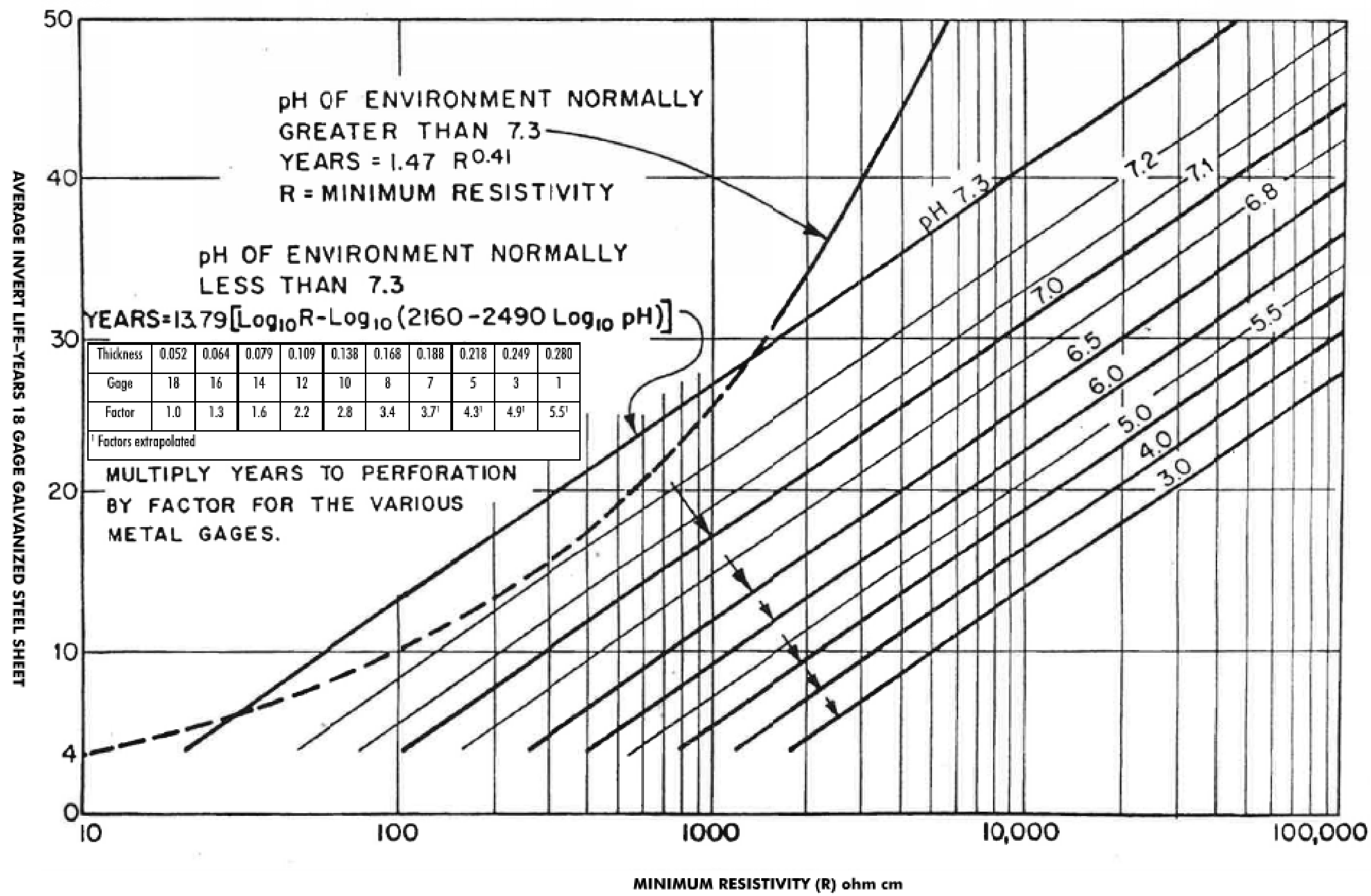

Figure 1: Chart for Estimating Average Invert Life for 18 Gage Plain Galvanized Buried Structures (CALTRANS Highway Design Manual/CONTECH Structural Plate Design Guide)

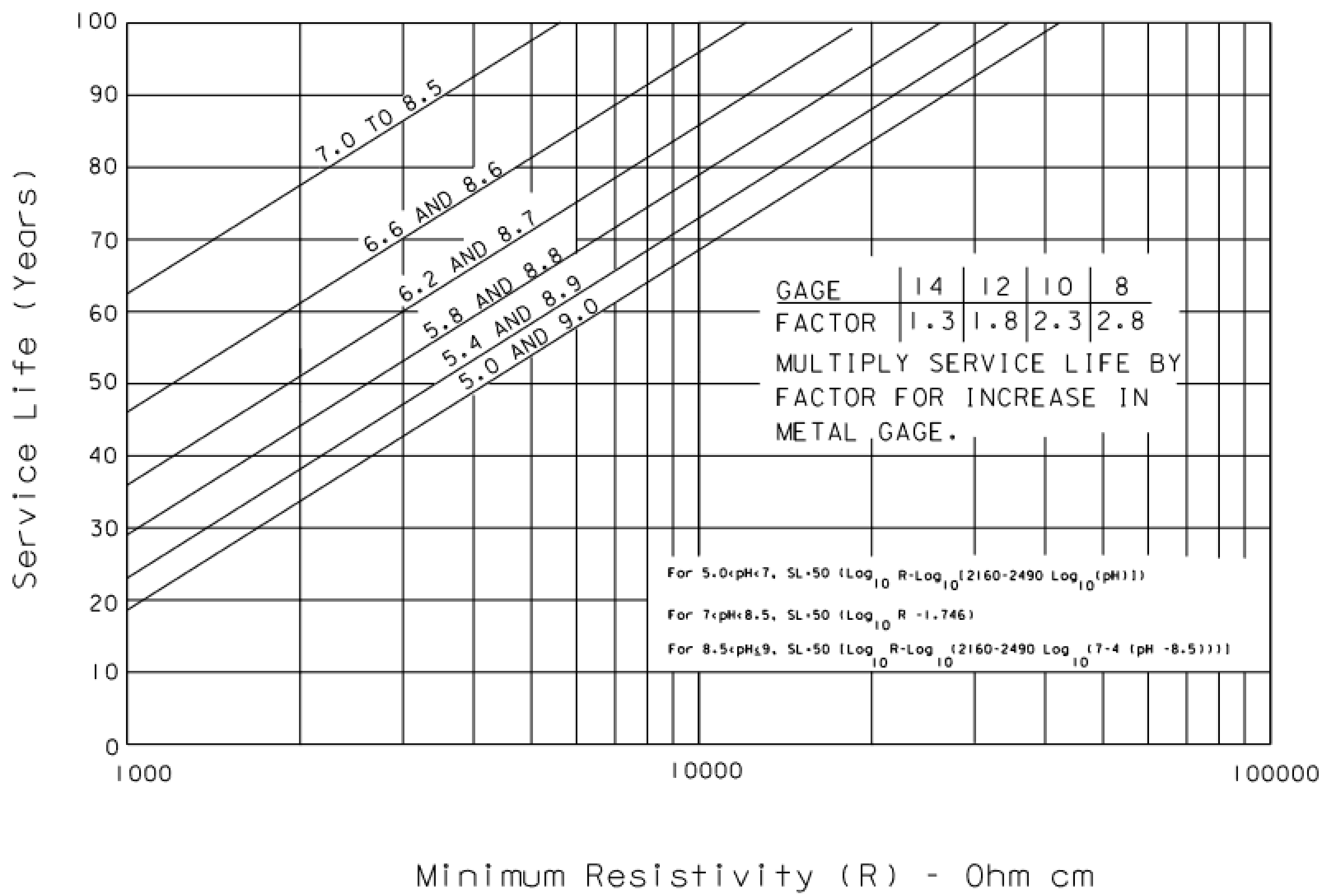

Figure 2: Chart for Estimating Average Invert Life for 16 Gage Aluminized Steel Buried Structures (Florida DOT Drainage Design Guide, 2019)

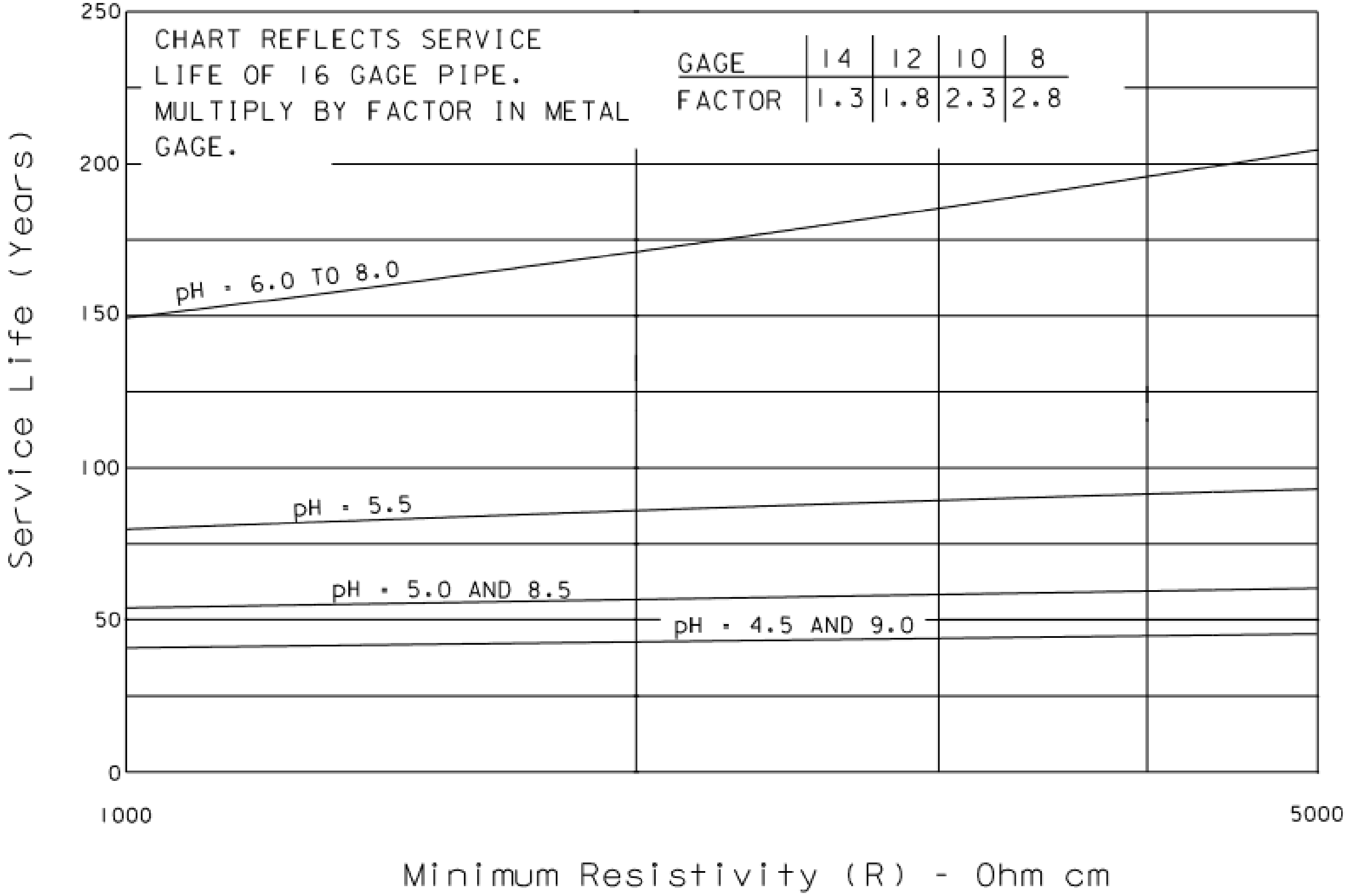

Figure 3: Chart for Estimating Average Invert Life for 16 Gage Aluminum Alloy Buried Structures (Florida DOT Drainage Design Guide, 2019)

6.7.2.4 Alternative Coatings and Mitigation for De-icing Salts

Alternate coatings for buried metal structures, such as polymer, asphalt, concrete linings, and others are also available but are not discussed in detail in this section. The designer will need to evaluate the corrosion and abrasive potential and select the appropriate coating to achieve a 75 year service design life. If a coating is utilized, then the section loss corrosion and/or abrasion is assumed to begin at the end of the effective life of the coating. Any alternative coating selected shall be approved by the WSDOT Bridge Design Office.

When de-icing salts are used on a regular basis on the roadway above the buried structure, consideration should be given to providing a polymeric membrane over the structure or other means to direct and shed water away from the top of the structure. Methods for mitigating de-icing salts shall be approved by the WSDOT Bridge Design Office. Regional WSDOT Maintenance staff shall be consulted to determine the type and frequency of de-icing salts used for the site specific location.

6.7.2.5 Abrasion

In addition to service life analysis for corrosion, abrasion of the invert and side walls shall be investigated. The designer shall consider the potential for lateral stream migration when considering abrasion on side walls. Abrasion risk and mitigation shall be considered the same for galvanized or aluminized steel and for aluminum plate structures. Three factors that must combine to cause abrasion include:

1. Abrasive bed load
2. Sufficient stream velocity to carry the bed load
3. Flow duration and frequency

The WSDOT Hydraulics Manual (M23-03.06, 2019) provides guidelines for abrasion levels and the general site characteristics, which are described below:

1. Level 1 - Nonabrasive: areas of little or no bed load and very low velocities of 3 feet per second (fps) or less. Slopes are generally less than 1%. This condition can be assumed for the soil side of the structure.
2. Level 2 - Low abrasive: areas of minor bed loads of sand, silts and clays with velocities less than 6 fps and slopes generally range from 1% to 2%.
3. Level 3 - Moderate abrasive: areas of moderate bed loads of sand and gravel with stone sizes up to approximately 3 inches and velocities between 6 and 15 fps. Slopes generally range from 2% to 4%.
4. Level 4 - Severe abrasive: areas of heavy bed loads of sand, gravel, and rock with stone sizes up to 12 inches and larger and velocities exceeding 15 fps. Slopes are generally greater than 4%.

Stream velocities shall be based upon typical flows and water surface elevations for a 2-year event, minimum.

For Abrasion Levels 1 and 2, no additional protection is required.

For Abrasion Level 3, the thickness of the material shall be increased by one or two gages (approximately 1/64 inch) and/or a concrete lining shall be used. Alternatively, other protection such as streambed material or stilling basins are acceptable with the approval of the WSDOT Bridge Design Office.

For Abrasion Level 4, abrasion protection shall be provided such as increased gage thickness, alternative materials, coatings, concrete linings, etc. and shall require approval of the WSDOT Bridge Design Office.

If you have any questions regarding this policy memorandum, please contact Geoff Swett SwettG@wsdot.wa.gov at (360) 705-7157, or Bijan.Khaleghi@wsdot.wa.gov at (360)705-7181.

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