6. CORROSIVE ENVIRONMENT

The Department has adopted the American Association of State Highway Transportation Officials (AASHTO) ***Load and Resistance Factor Design (LRFD) Bridge Specification*** requirement for a 75-year structure design life. However, culverts and drainage facilities typically require a 50-year maintenance free design life. ***Table 5.10.1-1 Minimum Concrete Cover to Reinforcement (in.) for 75-year Design Life*** of ***Section 5.10.1*** (see References) ***Section 5 Concrete Structures*** of ***California Amendments (to the AASHTO LRFD Bridge Design Specifications)***) provides the four exposure conditions found in California.

A. Non-Corrosive – soils and waters that are not corrosive to metals or concrete and do not meet the requirements in Section 6.1 below for a corrosive site.

B. Non-Marine – Soils and waters that meet the requirements stated below in Section 6.1 for a corrosive site and not within 1000 feet of a marine surface body of water. This exposure describes the soil above and extending down to 3 feet below the current lowest ground water elevation or 3 feet below the lowest recorded/measured ground water elevation. This also applies to corrosive ground water. See Figures 6-B.1 and 6-B.2.

C. Marine

   a. Atmosphere – Structural elements exposed to the atmosphere over land within 1000 ft of ocean or marine water and the atmosphere above the splash zone. Marine water, from corrosion considerations, is any body of water having a chloride content greater than or equal to 500 ppm.

   b. Water Permanently Below MLLW Level – Structural elements permanently immersed 3 ft below the Mean Lower Low Water (MLLW) elevation.

   c. Splash Zone – Structural elements exposed to marine water extending from 3 ft below the MLLW to 20 ft above the Mean Higher High Water (MHHW) elevation and 20 ft from the edge of water at the MHHW. See Figure 6-C.

D. Freeze/Thaw - Structural elements exposed directly to freezing/thawing cycles and or de-icing salts, snow run-off or snow blower spray. See Figure 6-D.

Site specific corrosion investigations are needed to determine the corrosivity of a site and to provide appropriate corrosion mitigation measures to obtain the desired design lives. Some of the factors that contribute to corrosion include the presence of soluble salts in soil and water, pH, the presence of oxygen industrial contamination and microbial activity.

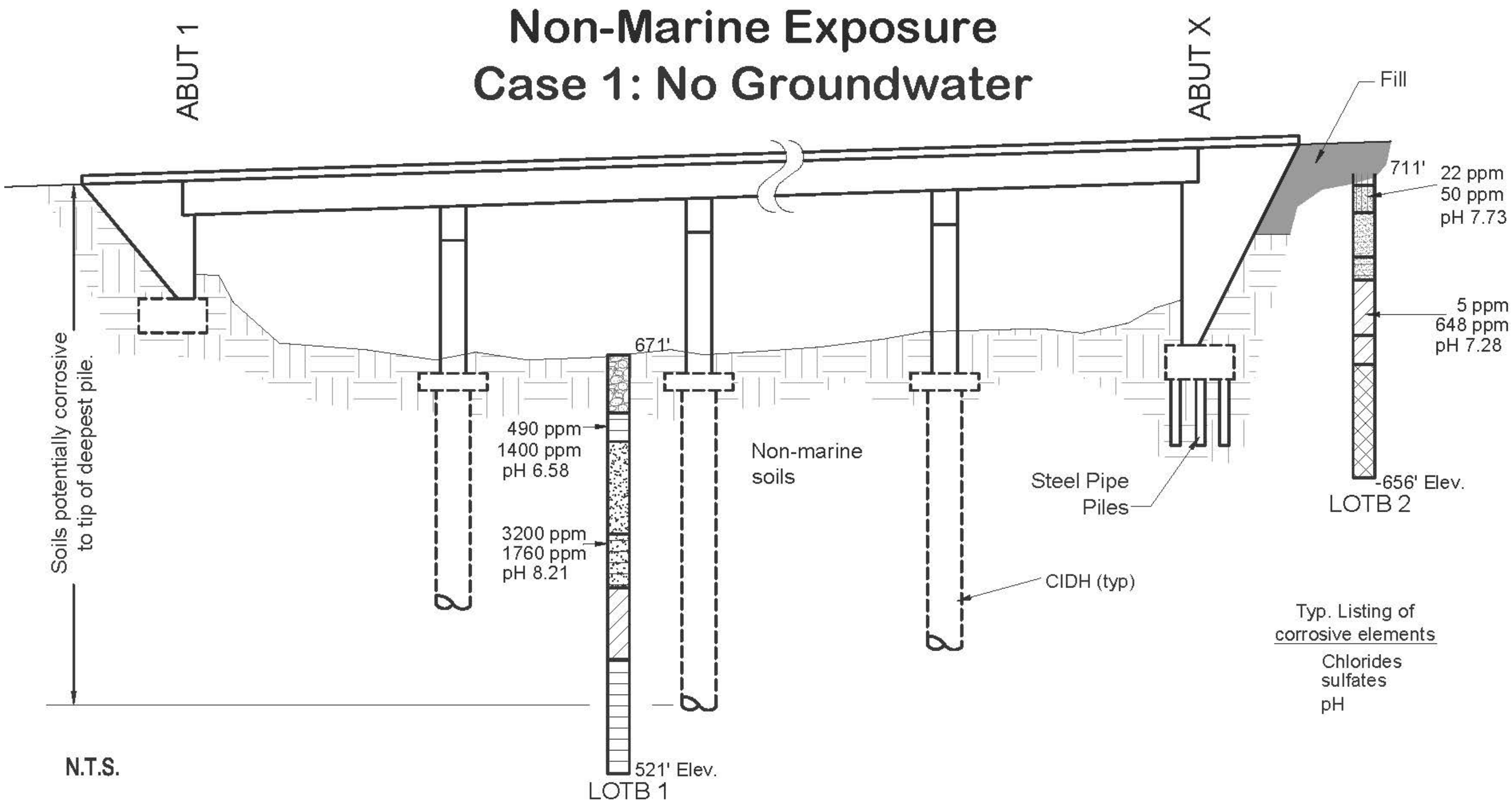

Figure 6-B.1: Non-Marine Exposure Case 1: No Groundwater

Notes:

1. No marine exposure, no freeze-thaw exposure and no groundwater encountered during geotechnical investigation soils are considered potentially corrosive.
2. All soils are considered Non-marine. Soil corrosion potential is based on chloride and sulphate levels in the soil and the pH of the soil.
3. The entire site from Abutment 1 to Abutment X is considered corrosive for all structural elements in contact with the soil based on the tested corrosive sample from LOTB 1. Corrosion mitigation is required for concrete and steel from chlorides and sulphates. Pipe piles require sacrificial steel for the outer portion of the pile only, not the inside of the pile.
4. If no corrosion samples were taken the entire project site is considered corrosive and corrosion mitigation is required for both concrete and steel.
5. Fill material in contact with structural elements is required to be not corrosive.

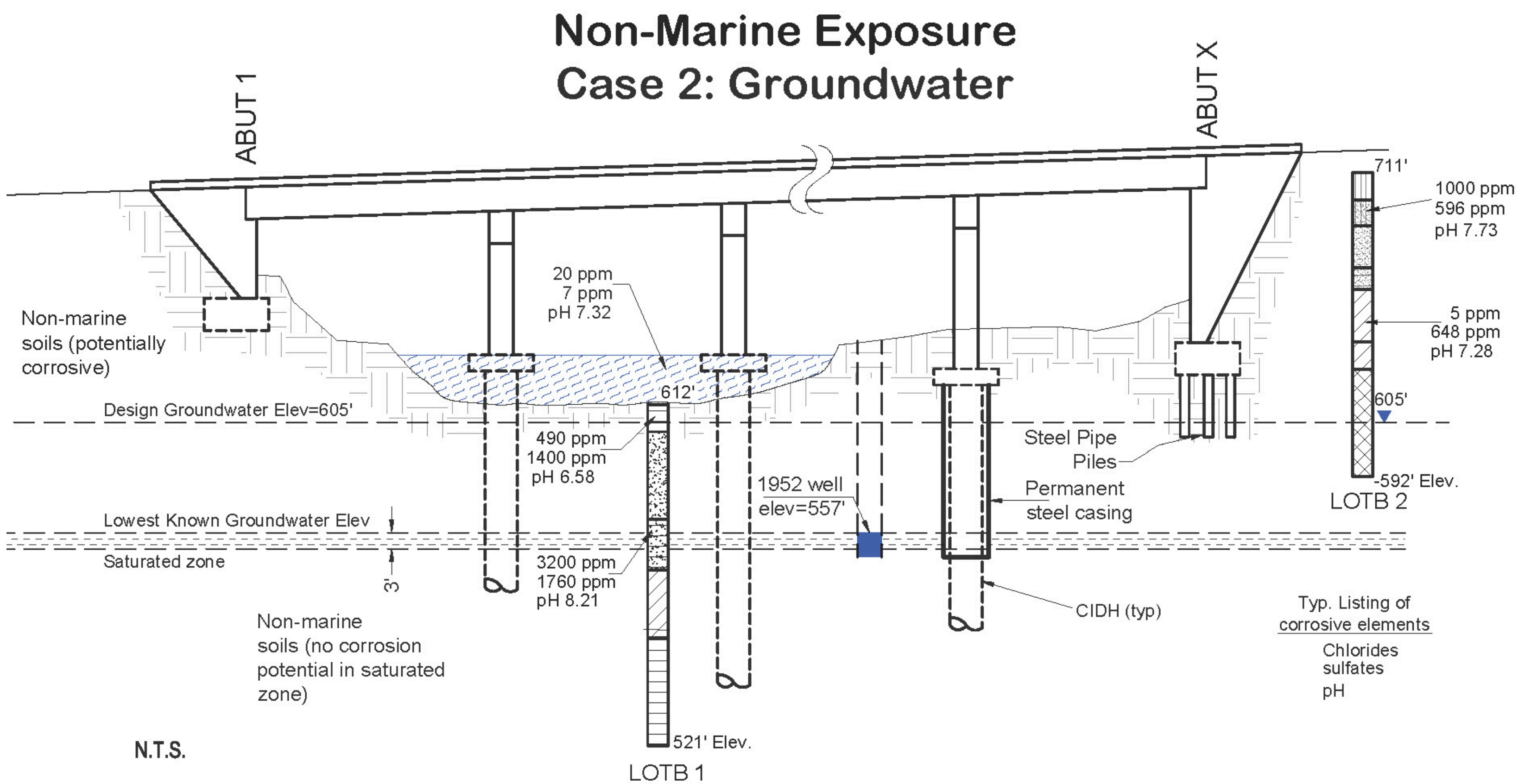

Figure 6-B.2: Non-Marine Exposure Case 2: Groundwater

Notes:

1. No marine exposure, no freeze-thaw exposure. Groundwater encountered during geotechnical investigation.
2. All soils are considered Non-marine. Corrosion in soils is based solely on chloride and sulphate levels in the soil and pH of soil. River water tested not corrosive.
3. The Foundation Report set the groundwater elevation from recent borings at elevation 605'. A 1952 well measurement showed the elevation at 557 ft.
4. Structural elements from the ground surface to 3 feet below the lowest known groundwater elevation require corrosion mitigation from Abutment 1 to Abutment X based on the tested corrosive samples from LTOB 1 and LOTB 2. Pipe piles require sacrificial steel for the outer portion of the pile only, not he inside of the pile.
5. No corrosion potential inside permanent steel casing.

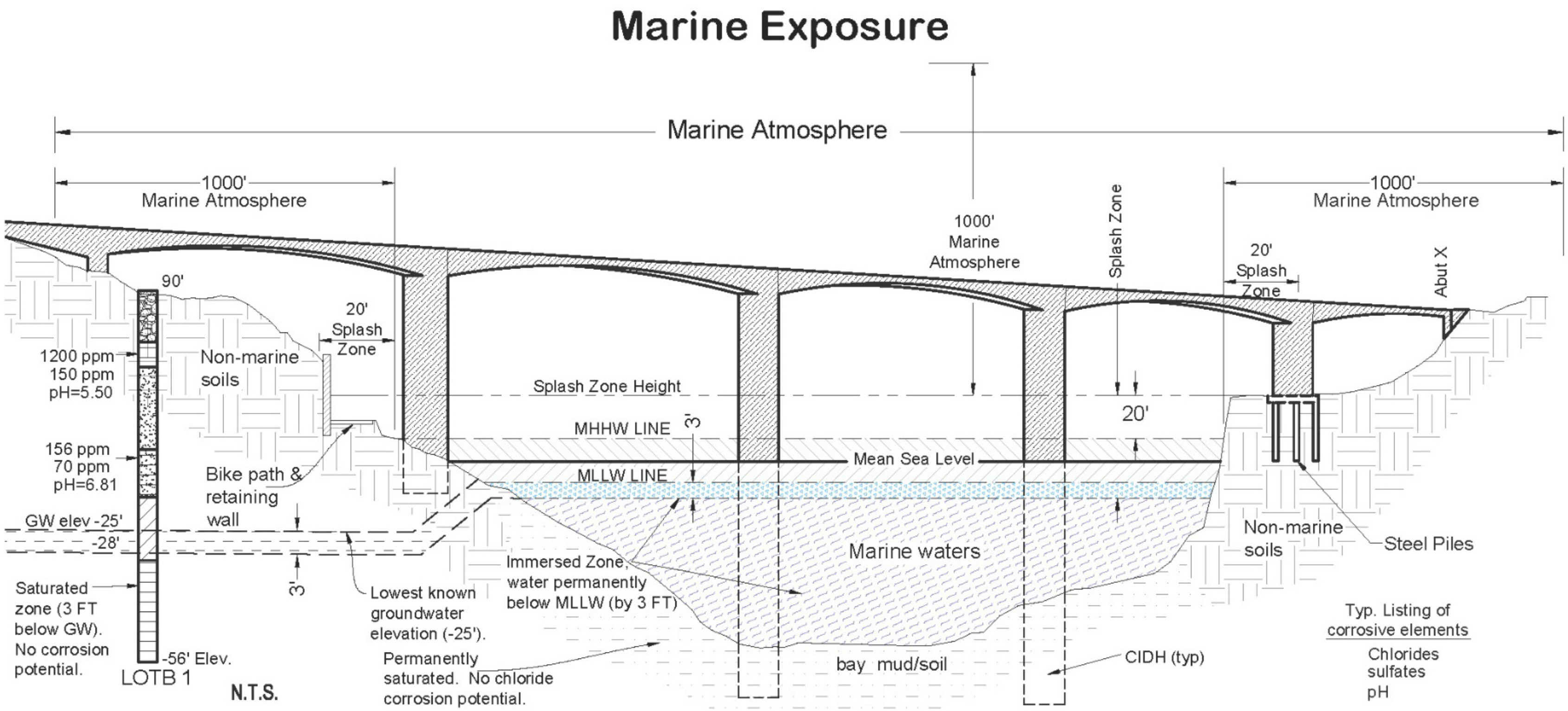

Figure 6-C: Marine Exposure

Notes:

1. Structural elements above ground level require corrosion mitigation for exposure to marine atmosphere, marine waters, splash zone, and immersed marine water zone (including the retaining wall for the bike path).
2. All soils (including bay mud/soil) are considered Non-marine. Corrosion in soils is based solely on chloride and sulphate levels in the soil and pH of soil. Sample testing of soils from LOTB 1 indicates corrosive chlorides levels above 500 ppm. Sulphate levels are below the 1500 ppm to be corrosive for the soils.
3. Structural elements from the ground surface to 3 feet below the lowest known groundwater elevation require corrosion mitigation for chlorides from Abutment 1 to Abutment X based on the tested corrosion sample tested from LOTB 1. Steel piles would require sacrificial steel for corrosion mitigation from chlorides.
4. Soils below the immersed zone are considered saturated and non-corrosive for chlorides. Sulphate reducing bacteria may be present in marine mud/soil and should be taken into design mitigation measures.
5. All structural elements in contact with marine waters or atmosphere require corrosion mitigation for chlorides and or sulphates.

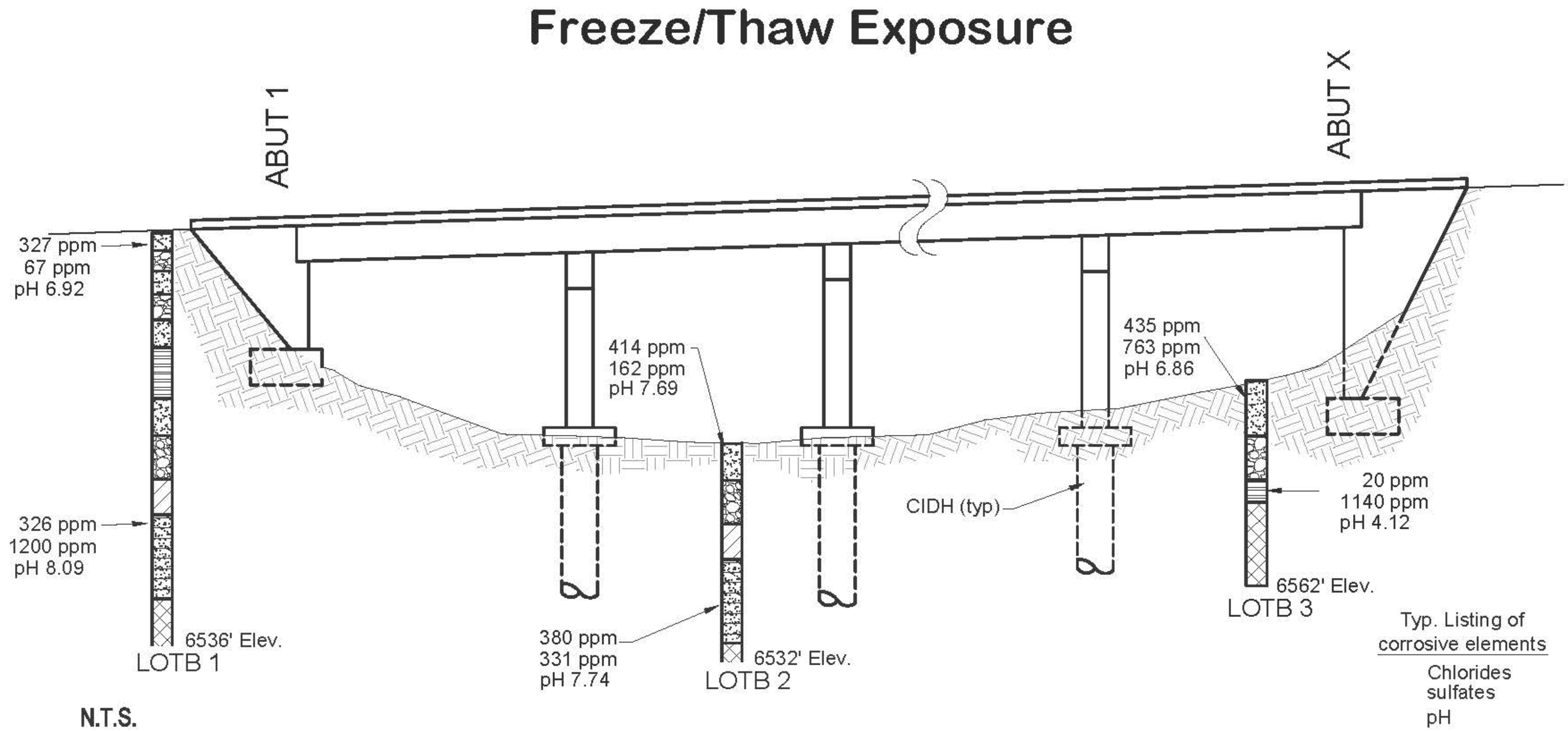

Figure 6-D: Freeze/Thaw Exposure

Notes:

1. Structural elements above ground level require mitigation for freeze/thaw effects (scaling) and deicing salts (corrosive to reinforcement).
2. All soils are considered Non-marine. Corrosion in soils is based solely on chloride and sulphate levels in the soil and pH of soil.
3. See Figures 6-B.1 and 6-B.2 regarding corrosion mitigation below the ground surface and structural elements in contact with the ground.

6.1 The Department's Definition of a Corrosive Environment

Corrosion of metals is an electrochemical process involving oxidation (anodic) and reduction (cathodic) reactions on metal surfaces. For metals in soil or water, corrosion other than galvanic between two metals, is typically a result of contact with soluble salts

found in the soil or water or atmosphere. This process requires moisture to form solutions of the soluble salts. Factors that influence the rate and amount of corrosion include the amount of moisture, the conductivity of the solution (soil and/or water), the hydrogen activity of the solution (pH), and the oxygen concentration (aeration). Other factors such as soil organic content, soil porosity, and texture indirectly affect corrosion of metals in soil by affecting the factors listed above.

The Department defines a corrosive area in terms of the resistivity, pH, and soluble salt content of the soil and/or water. Resistivity serves as an indicator parameter for the possible presence of soluble salts. It is **not included as a parameter** to define a corrosive area for **structures except** for MSE walls (see Section 8 of these Guidelines). In general, the higher the resistivity, the lower the rate for corrosion. A minimum resistivity value for soil and/or water less than or equal to 1500 ohm-cm indicates the presence of high quantities of soluble salts and a higher propensity for corrosion. Soil and water that have a minimum resistivity equal to or less than 1500 ohm-cm and or a pH equal to or less than 5.50 are required to be tested by a certified lab for chlorides and sulfates per CT 417 and CT 422. The Department uses the terms "corrosive" and "not corrosive" to describe the environment.

For structural elements, the Department considers a site to be corrosive if one or more of the following conditions exist for the representative soil and/or water samples taken at the site:

> **Chloride concentration is 500 ppm or greater, sulfate concentration is 1500 ppm or greater, or the pH is 5.50 or less.**

For bridge structural elements, the term “site” above extends from Abutment 1 to Abutment X. For structural elements, appropriate corrosion mitigation measures for “corrosive” conditions are selected depending on the service environment, amount of aggressive ion salts (chloride or sulfate), pH level and the desired service life of the structure.

Chloride ions from saltwater, soil, or from de-icing salts can lead to corrosion of steel reinforcement in concrete and steel structures by breaking down the normally present protective layer of oxides (passive layer) present on the steel surface.

Like chlorides, sulfate ions may also lead to accelerated corrosion of steel reinforcement. In addition to causing metals to corrode, high amounts of sulfates are deleterious to concrete. Sulfates react with lime in the concrete to form expansive products that cause the concrete to soften and crack. Cracked concrete is more susceptible to attack by water and other aggressive ions that may accelerate the corrosion process. Sulfides in the soil can be an indicator of sulfate reducing bacteria which can lower the soil pH to more acidic levels, increasing the corrosion rates. Soils (bay muds) below a marine body of water should be tested for biological agents such as sulfate reducing bacteria so that mitigation measures can be taken.

The presence of high acidity, pH of 5.50 or less, in soil or water is also considered a corrosive condition. Soil or water with a pH of 5.50 or less can react with the lime in concrete to form soluble reaction products that can easily leach out of the concrete. The result is a more porous, weaker concrete. Acidic conditions often cause discoloration of the concrete surface. A yellowish or rust color distributed over the concrete surface should be investigated.

6.2 Survey of Site Conditions

In general, corrosion investigations, whether performed by Department staff or by consultants, should include a survey of the following site conditions:

- Extent of corrosive soils and water at the site.
- Presence of on-site fill material.
- Condition of any existing structures in the immediate vicinity that may impact the proposed structures. For example, do existing culverts show signs of corrosion or deterioration such as cracked concrete, exposed reinforcement, rust stains, failed coatings, or excessive wear due to abrasion?
- Proximity of the structure or proposed structure to salt or brackish water.
- Proximity of the structure or proposed structure to marine atmosphere.
- Presence of abrasive water or high-water flow (needed for scour consideration of structure foundations and abrasive water flows in culverts).
- Proximity to natural features such as mineral springs or local geothermal activity.
- Exposure of the structure or proposed structure to deicing salts (freeze/thaw environments, where deicing salt is applied to roadways and structures).
- Presence of existing utilities such as light rail, or cathodic protection systems

on pipelines, structures and underground storage tanks which may impose stray electrical current in the soil.