7. FOUNDATIONS

Factors that contribute to corrosion include the presence of soluble salts, soil and water resistivity, soil and water pH, and the presence of oxygen. Site specific corrosion investigations are needed to perform a complete assessment of corrosivity. See Section 6.1 of these Guidelines for a definition of a corrosive environment.

Information for existing structures or facilities such as inspection records and as built plans can be found in the Bridge Inspection Records Information System (BIRIS) records maintained by Structure Maintenance & Investigations (SMI). Another source of information is the Corrosion Branch. The Corrosion Branch maintains a database of projects for which corrosion analysis has been done. This information can be useful in determining the scope of corrosion investigation required for any rehabilitation work.

For new alignments or when no maintenance records exist, a thorough review of all site investigations, sampling programs, and corrosion test results will be required to identify appropriate materials for potential corrosion mitigation.

7.1 Soil Sampling for Foundations and Geotechnical Investigations

Sampling a site for corrosion assessment requires that samples of soil and water are obtained from both surface and subsurface material to ensure representation of all soil strata at the site within the limits of the proposed construction. Sampling provides the Designer with the information required to adjust the design of the foundation to protect if necessary, against a corrosive environment. Sampling provides Construction with the necessary corrosion information to determine if mitigation by the Contractor is required after evaluating pile tests for anomalies. Representative sampling for corrosion testing should identify the **worst-**case condition that exists in the materials to be encountered or used. Composite samples, those samples that combine several smaller samples to provide a single sample representing a much larger interval are discouraged.

The following designated procedures shall be used for corrosion sampling during every structure foundation investigation conducted in the field. At least one boring for corrosion purposes should be located as close as possible to each of the proposed deep foundation[1] elements for larger bridge structures. It is recommended that a minimum of one boring at each foundation element should be sufficient for bridges; unless there is a major change in the subsurface material within the proposed substructure area. Sampling should be representative of the depth of the proposed foundation. For example, if a bore hole is drilled to a depth of 70 foot for a proposed Cast-In-Drilled-Hole (CIDH),

[1] Deep Foundations are structural assemblies that transfer load into deeper earth materials, such as piles, driven piles, drilled shafts, or micropiles (Reference 7).

then a single sample at a depth of 18-20 ft might not be sufficient to be considered representative for the entire borehole. The corrosion sampling guidelines listed below should be considered as the minimum requirements for representative sampling.

- The frequency of sampling for corrosivity should be on par with the number of samples taken for other soil tests (such as plasticity) required for the design of deep foundations.

- Typically, 5-7 lbs. of soil material are sufficient for corrosion testing.

- Existing fill or disturbed natural soils including any cut material to be used as fill, backfill, embankment, or other purposes or any borrow (local or import) material should be evaluated for corrosion potential prior to placement. Disturbed soils are typically more corrosive than non-disturbed soils. The samples taken should be representative of the depth of the fill material or disturbed soils.

- One sample at near surface between 1 and 5 ft.

- Below the initial surface material, samples should be taken for each significant change in subsurface material or at representative intervals to the end of the borehole unless groundwater is encountered.

- One sample at the groundwater table or within 5 ft below the groundwater table (if the groundwater table is within the limits of the proposed pile foundation)

- Perched water may not be considered the same as groundwater (see Figure 7.1-1).

- Composite or bulk samples from more than one soil type or formation are not recommended. Since a single corrosive sample defines the entire borehole as corrosive, composite samples potentially dilute the corrosivity of the borehole.

- Combining samples from different boreholes will **not** be accepted for analysis.

- When borings are conducted through permanent free-standing bodies of water (marine or fresh) sampling of the underlying soils for corrosion should not be necessary.

- When sampling for proposed retaining walls with pile foundations, sampling should be representative both vertically (depth of proposed piles) and horizontally along the wall length. This is especially true close to marine environments where tidal fluctuations through the soil over time may have resulted in highly variable zones of corrosivity along the alignment of the proposed project.

- For projects with sign structures, there should be a borehole located near each sign structure with representative samples taken for corrosion analysis.

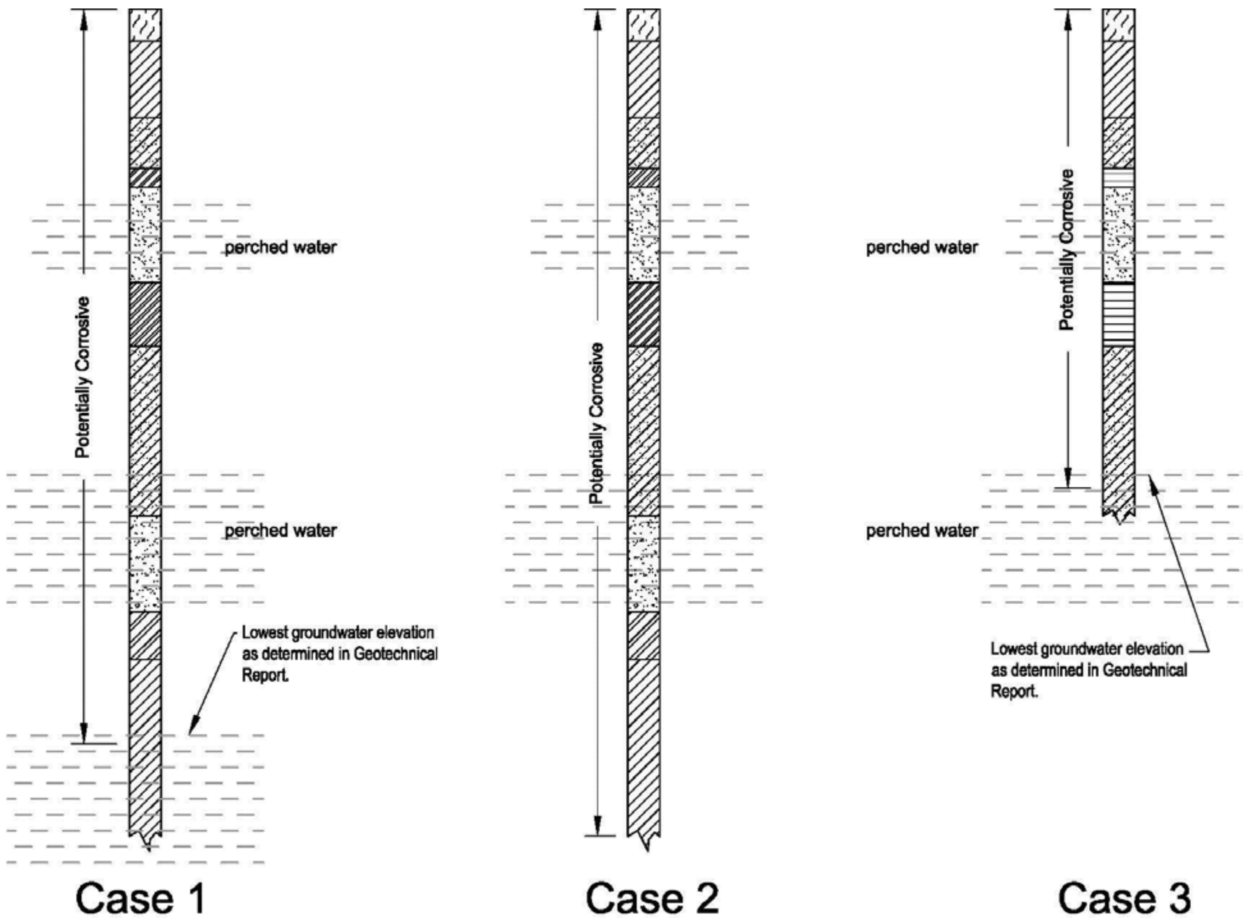

Figure 7.1-1: Cases for perched water.

A. **Case 1.** Pile extends through 1 or more zones of perched water as identified in the Geotechnical Report, terminating below the lowest elevation for regional groundwater at the site as defined by the Geotechnical Report. For Case 1, the hole is treated as "dry" above the groundwater with corrosion potential from the surface to 3 ft below the groundwater elevation.

B. **Case 2.** Pile extends through 1 or more zones of perched water as identified in the **Geotechnical** Report, terminating above the lowest elevation for regional groundwater at the site as defined by the Geotechnical Report. For Case 2, the hole is treated as "dry" with corrosion potential from the surface to the pile tip elevation.

C. **Case 3.** Pile extends through 1 or more zones of perched water as identified in the **Geotechnical** Report, terminating in a perched water zone and above the lowest elevation for regional groundwater at the site as defined by the Geotechnical Report.

For Case 3, the hole is treated as "dry" with corrosion potential from the surface to three feet below the perched water elevation for the zone that the pile tip ends in.

The project Engineering Geologist or Engineer can make exceptions to the sampling guidelines. In some cases, the project geologist may feel that redundant sampling at the designed intervals is not necessary. The decision not to sample at the recommended intervals as described for each boring shall be based on valid reasons. Those reasons should be noted in writing in the field logs and in the Geotechnical Report. For example, if a soil formation is present at multiple boring locations within the same structure site, it may not be necessary to obtain samples of the same formation from all borings.

The Corrosion Branch reviews pile anomalies for Construction and Foundation Testing and Investigation (see Section 7.6). As part of that review, the Corrosion Branch reviews all corrosion data related to the proposed site. This includes but is not limited to the distance from the borehole to the pile under review, number of boreholes, sampling frequency and depth in boreholes, the depth of each anomaly and the groundwater table. In some cases, the Corrosion Branch has rejected the conclusions of the Geotechnical Report that the soil is not corrosive due to insufficient representative sampling. In those cases, the Corrosion Branch recommended repair or additional testing of the soils adjacent to the pile in question. This can result in a delay of the construction work while the contractor does additional soil sampling and sends in the soils for testing. For those cases when no Geotechnical Report was prepared and anomalies occur, a claim by the Contractor may result.

7.2 Water Sampling for Foundations and Geotechnical Investigations

Water samples should be obtained from surface water bodies at or near the structure site. This includes water from nearby bodies of water even though the structure may not come into direct contact with the water. For example, ***Section 5.10.1*** (see References ***Section 5 Concrete Structures*** of ***California Amendments (to the AASHTO LRFD Bridge Design Specifications)***), requires corrosion mitigation for reinforced concrete structures located within 1000 ft of corrosive water (i.e., surface water with more than 500 ppm chlorides). Consequently, sampling of nearby water is particularly important at coastal locations or if the water body is subject to tidal influence. Use a clean wide-mouth beaker to collect the water sample. Swirl to rinse the beaker and pour out the contents to avoid contamination from the container. Fill the rinsed wide-mouth beaker a second time and retain the sample for laboratory testing. Pour off any film that is on the surface of the sample. One liter of water is sufficient for the laboratory to conduct resistivity, pH, chloride, and sulfate testing. Transport the water sample in a sealed plastic container. The container used to transport the water should also be rinsed with the surface water to avoid contamination from the container.

If a well or piezometer is available for groundwater sampling, a narrow plastic sampling tube or bailer may be lowered into a clean, stabilized borehole. The sampler should be rinsed with the groundwater to avoid contamination from the container. After swirling and rinsing, lower the sampler a second time and retain the sample for laboratory testing. Pour off any film that is on the surface of the sample. One liter of water is sufficient for the laboratory to conduct resistivity, pH, chloride, and sulfate testing. Transport the water sample in a sealed plastic container. The container used to transport the water should also be rinsed with groundwater to avoid contamination from the container.

7.3 Bridge Foundation Scour Assessment Related to Corrosion

Scour is a physical process that can accelerate corrosion of steel piling. If scour is anticipated, the Corrosion Branch can assist in making recommendations for steel piling provided information such as anticipated scour depth and scour frequency is available.

7.4 Reporting Corrosion Test Results for Foundations

For every soil and or water sample submitted to the Corrosion Branch, a Corrosion Test Summary Report is prepared and sent to the Engineer or contact submitting the sample for testing. These reports list the results of the corrosion tests conducted on the soil and/or water samples representative of each proposed structure site. This report also designates whether the site is corrosive or not corrosive based on the criteria established by these guidelines, and specifies the controlling (“worst case”) corrosion parameter test results that are used by the specification writers/designers to provide corrosion mitigation measures for each proposed structure. Geotechnical Services will generally summarize the corrosion test results for site samples in the Foundation Report or Geotechnical Design Report.

7.5 Steel Piles

The corrosion rate of steel piles in soil is influenced by a number of corrosion related parameters. These include soil minimum resistivity, pH, chloride content, sulfate content, sulfide ion content, soil moisture, and oxygen content within the soil. Measurement of these parameters can give an indication of the corrosivity of a soil. Unfortunately, because of the number of factors involved and the complex nature of their interaction, actual corrosion rates of driven steel piles cannot be determined by measuring these parameters. Instead, an estimate of the potential for corrosion can be made by comparing site conditions and soil corrosion parameters at a proposed site with historical information at similar sites.

As stated in the bullet under Section 7.1, existing fill or disturbed soils are typically more corrosive than non-disturbed soils due to the increased amount of oxygen available in a disturbed soil to drive the corrosion process. A disturbed soil is a soil in which digging, backfilling, or other soil upheaval has taken place. Driven steel piles generally have the majority of their length in undisturbed soil. However, excavation and backfilling for footings and pile caps creates a region of disturbed soil near the top of the piles, increasing the availability of oxygen and the probability of corrosion.

A major contributor to increased corrosion rates of driven steel piles in soil is the availability of oxygen. In general, oxygen content is greater near the upper portion of the pile, greater in disturbed soils, and greater in soil near a ground water surface. Soil disturbance in the upper region of the pile may create areas of differential aeration within and just below the disturbed soil zone. This may lead to increased pitting corrosion of the steel piles within or near the disturbed zone.

For steel piling driven into soils (whether disturbed or undisturbed), the region of greatest concern for corrosion is the portion of the pile from the bottom of the pile cap or footing down to 3 feet below the lowest recorded/measured ground water elevation.

Local corrosion cells may exist in some miscellaneous fills that can lead to increased corrosion rates of driven steel piles. These miscellaneous fills include combinations of natural soils (clays and sands), construction debris, ash and cinder material, as well as waste inorganic materials. Increased corrosion rates have been documented in these fills where soil pH was low, 5.50 or less, and soil minimum resistivity was below 1500 ohm-cm. For these reasons, it is always recommended to test any fill material for corrosivity as specified in Section 7.1.

When steel piles are used in corrosive soil or corrosive water, special corrosion protection considerations for the steel may be needed. The extent of corrosion protection for steel piles will depend on the subsurface geology, the location of the groundwater table, and the depth to which the soil has been disturbed. Corrosion protection mitigation may include the need for sacrificial metal (corrosion allowance) or the use of protective coatings and/or cathodic protection.

Steel piling may be used in corrosive soil and water environments provided that adequate corrosion mitigation measures are specified. The Department typically includes a corrosion allowance (sacrificial metal loss) for steel pile foundations. Sacrificial metal or corrosion allowance is the thickness of metal (above what is structurally required for the pile) needed to compensate for the loss of metal that will occur as the pile corrodes. This extra metal thickness is added to all surfaces of the pile exposed to the corrosive soil or water.

The Department currently uses the following corrosion rates for steel piling exposed to corrosive soil and/or water or marine exposures (see Section 6 of these Guidelines) as specified in ***Section 10.7.5*** of ***Section 10: Foundations of California Amendments (to the AASHTO LRFD Bridge Design Specifications)*** (see References).

Soil Embedded Zone	**0.001 in (0.025 mm) per year**
Fill or Disturbed Natural Soils	**0.0015 in (0.0381mm) per year**
Atmospheric Zone (marine)	**0.002 in (0.051 mm) per year**
Immersed Zone (marine)	**0.004 in (0.102 mm) per year**
Splash Zone (marine)	**0.006 in (0.152 mm) per year**

The corrosion rates apply only if the soil and/or water are corrosive. The Soil Embedded Zone does not apply to bed material below marine bodies of water. For a driven pile into the material below the marine water, either the Immersed Zone or the Splash Zone would dictate the steel pile sacrificial thickness. As previously mentioned, the soil below a marine body of water should be analyzed for biological agents such as sulphate reducing bacteria which can greatly accelerate the corrosion rates. The atmospheric zone is defined as a distance of 1000 feet measured from the surface or edge of water at the Mean Higher High Water (MHHW) elevation. If a site is characterized as not corrosive, then no corrosion allowance (sacrificial metal loss) is necessary. This information is also included in Bridge Memo to Designers (see References) Section 10-5 Protection of Reinforcement Against Corrosion Due to Chlorides, Acids and Sulfates.

The corrosion rates listed above should be doubled for steel H-piling since there are two surfaces on either side of the web and flanges that are exposed to the corrosive soil and/or water. For example, the length of a steel H-pile that is immersed in corrosive water and has a 75-year design life should have a corrosion allowance of 0.6 in (15 mm), calculated using

0.004 in/yr. (0.102 mm/yr.) x 75 years x 2 exposure faces.

Steel sheet piles should be treated similar to steel H-piling for determining the amount of sacrificial steel required since there are two surfaces potentially exposed to corrosive elements. Unlike H-piles, the two surfaces of the sheet pile may experience differential corrosion rates dependent on the corrosivity of the elements on either side of the sheet pile. An example would be a steel sheet pile holding back corrosive soils that is exposed to a combination of marine atmosphere and splash zone. Sacrificial steel would have to be added to the surface for the splash zone and conservatively, some sacrificial steel should be considered for the corrosive soil exposure. It is recommended that the Corrosion Branch be contacted to discuss mitigation measures when determining the thickness of sacrificial steel for steel sheet piles.

For driven open ended steel pipe piling with embedment into footing at cutoff line or a cast-in-steel-shell pile (CISS) used in corrosive soil and/or water, the corrosion allowance is only needed for the exterior surface of the pile. The driven open ended pile is considered to have a soil plug which prevents the interior wall from being exposed to sufficient oxygen to support significant corrosion. The CISS pile is backfilled with concrete so no sacrificial steel is required on the inside.

The above corrosion rates and allowances for steel pipe piles are also applicable to permanent steel casings and micropiles used at corrosive sites that are intended to carry axial or lateral structural load. When a permanent steel shell as mentioned above is placed in an oversized drilled hole which will be grouted (between the shell and undisturbed ground), the Corrosion Branch should be contacted to discuss corrosion mitigation options. In such situations, it's possible that coatings or corrosion resistant grout could be considered as alternatives to sacrificial steel.

Steel casings do not need a corrosion allowance when they are used only for constructability and are not intended to carry axial or lateral structural load.

The use of coatings on driven steel piles are not considered as an alternative corrosion protection strategy. There is no method for determination that the coating was not damaged during the driving process.

7.6 Cast-In-Drilled-Hole (CIDH) Pile Anomalies

CIDH piles with anomalies may need to be repaired, supplemented, or replaced depending on the extent of anomalies within the CIDH pile. Geotechnical Services Foundation Testing and Investigation Branch provides information regarding the acceptance, rejection, and mitigation requirements for CIDH piles. The Corrosion Branch reviews anomalies indicated on the Pile Design Data Forms (distributed by the Foundation Testing and Investigation Branch) for corrosion potential.

Consideration of corrosion potential is only needed for anomalies that are between the top of the pile down to 3 feet below the lowest recorded/measured ground water elevation for the project site (see Section 7.1). For anomalies outside these limits, and where no stray current source is identified and there is no known microbiologically induced corrosion source known; no consideration of corrosion potential is required. The rationale for this requirement is that sufficient oxygen is not available below the ground water surface to promote significant corrosion of nearly exposed or exposed reinforcement steel at the location of the anomaly.

7.7 Structural Backfill

All structural backfill must be tested per Section 6.1 of these Corrosion Guidelines to determine if it is corrosive or not. There are two options for structural backfill:

1. Clean structural backfill must be tested prior to placement and meet the requirements of Section 6.1 for a not corrosive environment or site.

2. Sites identified as corrosive can waive the clean structural backfill providing the native tested corrosive material is used. Imported structural backfill material must be tested prior to placement and cannot exceed the existing corrosivity of the native material.

For the first option above, the structural backfill must be clean so as to not introduce corrosive elements resulting in deleterious effects on the proposed structure.

The second option above is a site identified as having one or more corrosive elements in the Foundation Report or is a site subject to a corrosive environment such as marine, or freeze/thaw and deicing salts. Structures built in a corrosive environment require corrosion mitigation to achieve a 75-year design life. The following bullets expand on

Option 2.

1. Placement of clean structural backfill provides initial mitigation until the corrosive elements in the native soils migrate through the clean structural backfill coming in contact with the structure.

2. Placement of native corrosive soils as structural backfill is not a concern as the structure has been designed to mitigate for those corrosive elements per the Foundation Report.

3. Imported structural backfill is allowable providing the imported structural backfill is tested prior to placement to ensure that it does not exceed the existing corrosivity of the site.

    - Example:

      The existing site is tested for corrosion and a single sample at

Abutment 1 has a pH of 5.0. The entire site from Abutment 1 to Abutment X is considered corrosive based on the pH. Contractor imports structural backfill which when tested prior to placement has a chloride value of 675 ppm, a sulfate value of 1000 ppm and a pH of 7.6. The proposed import structural backfill material is rejected as the chloride value exceeds both clean structural backfill requirements as well as the tested native material and the structure was not designed for chloride mitigation.

If a site is determined to be corrosive after construction has begun and no corrosion mitigation was provided to the structural elements, then structural backfill must meet the requirements for clean structural backfill per Option 1 above. Depending on the degree of corrosive elements, the Corrosion Branch should be contacted for additional protective mitigation measures such as protective wraps.