California Department of Transportation
Division of Engineering Services
Materials Engineering and Testing Services
Corrosion Technology Branch

CORROSION GUIDELINES

Version 1.0

SEPTEMBER 2003

NOTICE

The contents of this document reflect the views of Materials Engineering and Testing Services which is responsible for the facts and the accuracy of the guidelines presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. **These guidelines do not constitute a standard, specification, or regulation.**

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1. INTRODUCTION

These guidelines outline the corrosion evaluation and recommendation aspects of site investigations for California Department of Transportation (Department) projects. The guidelines list the requirements for field investigations related to corrosion, including requirements for sampling of soil and water, required corrosion testing, reporting of results, requests for assistance, and corrosion mitigation measures (design alternatives).

This document is intended for use by Department staff and consultants, working on the Department's projects, performing field investigations related to corrosion, and/or providing design recommendations that include corrosion mitigation measures. This document supersedes the following reports: *Corrosion Guidelines, January 1996* and *Interim Corrosion Guideline for Foundation Investigations, May 1999.*

Functional groups (within the Department) that are involved with conducting corrosion investigations, collecting field samples, performing project reviews, reviewing corrosion test results, or providing corrosion mitigation measures are identified in Section 2. A flowchart is also included at the end of Section 2 to assist with identifying roles and responsibilities of the various functional groups.

Requirements for consultants providing corrosion assessments and recommendations for Department projects are listed in Section 3. A flowchart identifying consultant interaction with the Department's functional groups related to site investigations for corrosion is also provided in Section 3. Section 3 also contains procedures for providing consultant oversight of items related to corrosion investigations conducted by consultants.

Remaining sections of these guidelines describe the requirements for corrosion assessments of project sites (Sections 4, 5, 6, 7 and 8), lab services provided by the Corrosion Technology Branch (Section 9), typical corrosion mitigation measures for structure elements (Section 10), information on corrosion assessments for existing structures (Section 11), and other miscellaneous topics related to corrosion (Section 12). A document reference list and appendix are included in Sections 13 and 14, respectively.

2. THE DEPARTMENT'S FUNCTIONAL GROUPS ASSISTING WITH CORROSION INVESTIGATIONS

This section outlines the roles and responsibilities of Department staff performing corrosion assessments of project sites. Information pertaining to requirements for consultants providing corrosion investigation services and corrosion mitigation recommendations, and guidance for Department staff providing consultant oversight for these issues are included in Section 3.

The flowchart at the end of this section outlines the roles and responsibilities of the various Department functional units that perform corrosion investigations, collect field samples, report findings, provide corrosion recommendations, and implement corrosion mitigation measures (design alternatives).

The District Materials Branches are responsible for preparing a Materials Report (MR) for all projects that involve pavement structural section recommendations or pavement studies, culverts or other drainage features, corrosion studies, materials, or disposal sites. This policy is defined in Chapter 600 of the *Highway Design Manual (HDM)* (http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm). The District Materials Branches collect soil and water samples for corrosion testing. They perform minimum resistivity and pH testing, but send samples to the Materials Engineering and Testing Services (METS), Corrosion Technology Branch for chloride and sulfate testing, if necessary. Documentation of the corrosion investigation, sampling, corrosion testing, and corrosion recommendations for culverts and drainage structures are the responsibility of the District Materials Branch. The Corrosion Technology Branch can provide report assistance or review, if necessary.

Geotechnical Services (GS) is responsible for preparing a Preliminary Geotechnical Report (PGR) and a Geotechnical Design Report (GDR) for each project that requires a geotechnical investigation. Geotechnical investigations are required for projects involving cut slopes, embankments, earthwork, landslide remediation, retaining walls, sound walls, groundwater studies, erosion control features, sub-excavation, and any other studies involving engineering geology. The PGR and GDR include corrosion mitigation for the project's geotechnical investigations, if applicable. As part of the geotechnical investigation, GS is responsible for conducting a corrosion investigation of the structure site. The corrosion investigation should include sampling of soil and water for corrosion testing, summarizing corrosion test data, and a discussion of the corrosivity of the project site.

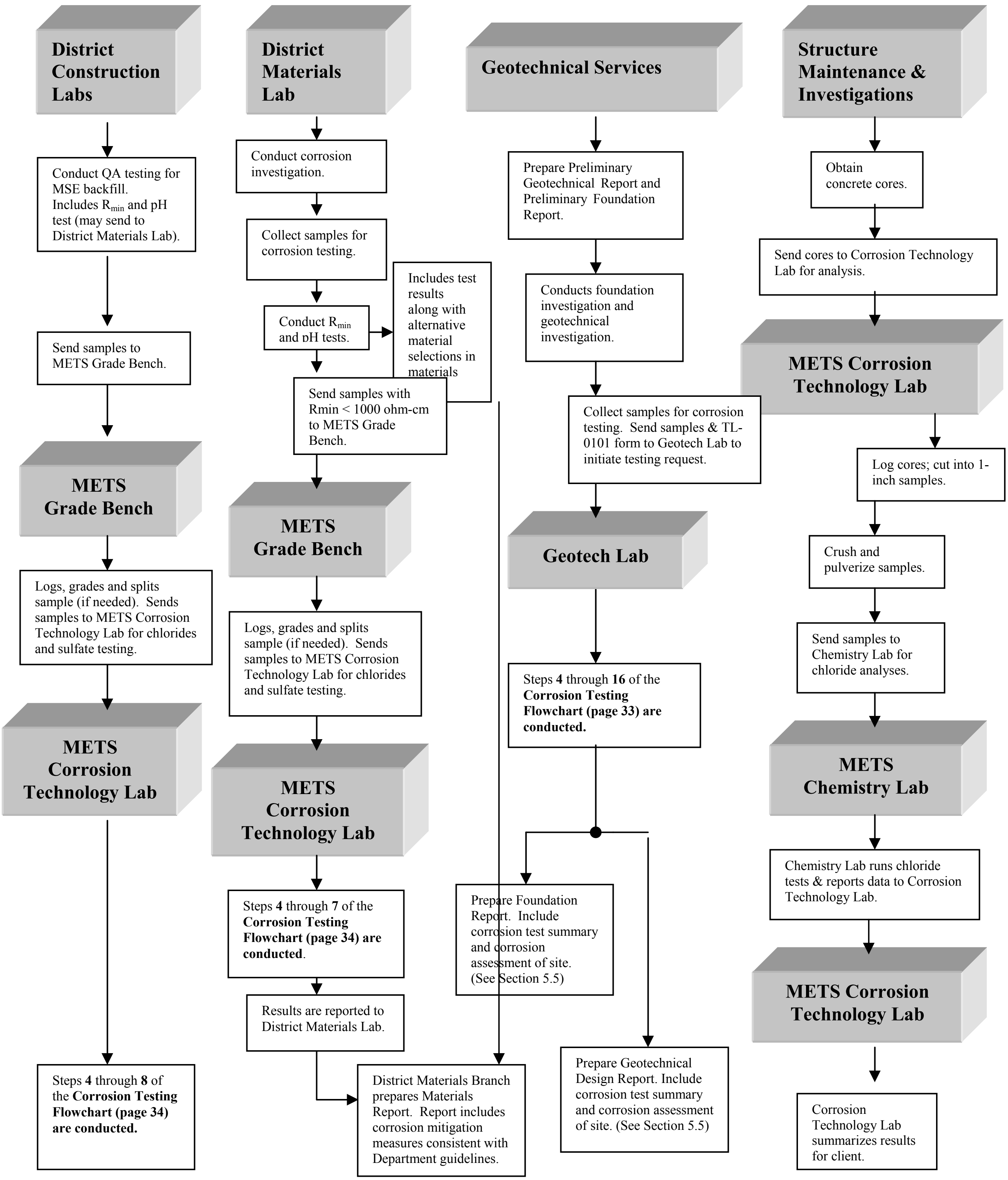
GS is also responsible for conducting a foundation investigation for structures (including bridges, tunnels, retaining walls, mechanically stabilized embankments, sound walls, tie-back walls, overhead signs, maintenance stations, pumping plants/stations, toll plazas, etc.) when new, widening, retrofit, or modifications to existing structures are proposed. A Foundation Report (FR) is required to summarize the results from the investigation. The FR should include corrosion test data and a discussion/consideration of the corrosivity of the site when selecting foundation types.

Generally, corrosion mitigation measures for structures are selected by Division of Engineering Services (DES) design staff, using appropriate measures listed in Department guidelines. Additional assistance regarding selecting appropriate corrosion mitigation measures may be obtained from the Corrosion Technology Branch if needed. Geotechnical Services staff does not routinely provide corrosion mitigation measures in their reports; however, they should be aware of corrosion mitigation requirements when recommending pile/foundation alternatives.

Department guidelines such as the *Bridge Design Specifications (BDS)* and *Bridge Memo-To-Designers*, (http://www.dot.ca.gov/hq/esc/techpubs), *Standard Special Provisions* (http://www.dot.ca.gov/hq/esc/oe/specs_html), *Structure Reference Specifications* (http://www.dot.ca.gov/hq/esc/structurespecs), *Highway Design Manual (HDM*) (http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm), and this document provide corrosion mitigation measures for most corrosive site conditions. For example, concrete cover requirements and concrete mix design requirements for protection of reinforced concrete piles and footings against chlorides are listed in *BDS*, *Article 8.22* "Protection Against Corrosion", Table 8.22.1. The corresponding *Structure Reference Specification S8-C04 (90CORR) _R06-19-01* provides specification wording to apply the provisions in *BDS*, *Article 8.22*.

Additional assistance regarding corrosion investigations or mitigation measures may be obtained from the Corrosion Technology Branch of METS as needed. This includes, but is not limited to, corrosion investigations for Materials Reports, Geotechnical Design Reports, Foundation Reports, and preliminary reports.

Department Functional Group Responsibilities



3. REQUIREMENTS FOR CONSULTANTS PROVIDING CORROSION ASSESSMENTS OF DEPARTMENT PROJECTS

This section outlines the roles and responsibilities of consultants providing corrosion investigation services and corrosion mitigation recommendations for Department projects. In addition, this section can be used by Department staff providing consultant oversight of corrosion investigation services and mitigation recommendations prepared by consultants.

The flowchart at the end of this section outlines the roles and responsibilities of the various Department functional groups assisting consultants performing corrosion investigations, and lists the responsibilities of the consultant.

Foundation investigations are required for all structures (including bridges, tunnels, retaining walls, MSE walls, sound walls, tie-back walls, overhead signs, maintenance stations, pumping plants/stations, toll plazas, etc.).

As discussed in the Department's *Guidelines for Foundation Investigations and Reports,* http://www.dot.ca.gov/hq/esc/osfp/Proj_Dev_and_Des_Info/Proj_Dev_and_Des_Info.htm, which is located under foundations in Chapter 3, *Design Information*, at this website, all foundation investigations require a corrosion investigation and evaluation. Preliminary and final Foundation Reports prepared by consultants should include all available corrosion data for the site and a brief discussion of the data. If corrosion data is not available, or is insufficient to provide conclusive information regarding the corrosivity of the site, then additional corrosion sampling and testing is required per Department guidelines during the field investigation phases.

Consultants under contract to provide design related recommendations should include corrosion recommendations consistent with Department guidelines. Corrosion design recommendations should be based on the worse case test results from the site in accordance with Department guidelines. Sufficient information regarding the number and location of soil borings, sampling, and testing should be included to allow a thorough review of any corrosion recommendations by Department staff.

Requirements for consultants who prepare corrosion investigations for Geotechnical Design Reports and Materials Reports are similar to the requirements for consultants who prepare corrosion investigations for Foundation Reports. In all reports, consultants should provide an assessment of the corrosivity of the site based on review of all relevant corrosion data. Corrosion design recommendations should be based on the worse case test results from the site in accordance with Department guidelines. Sufficient corrosion sampling and testing shall be reported to allow a thorough review by Department staff of the consultant's corrosion mitigation recommendations as well as information regarding the number and location of soil borings.

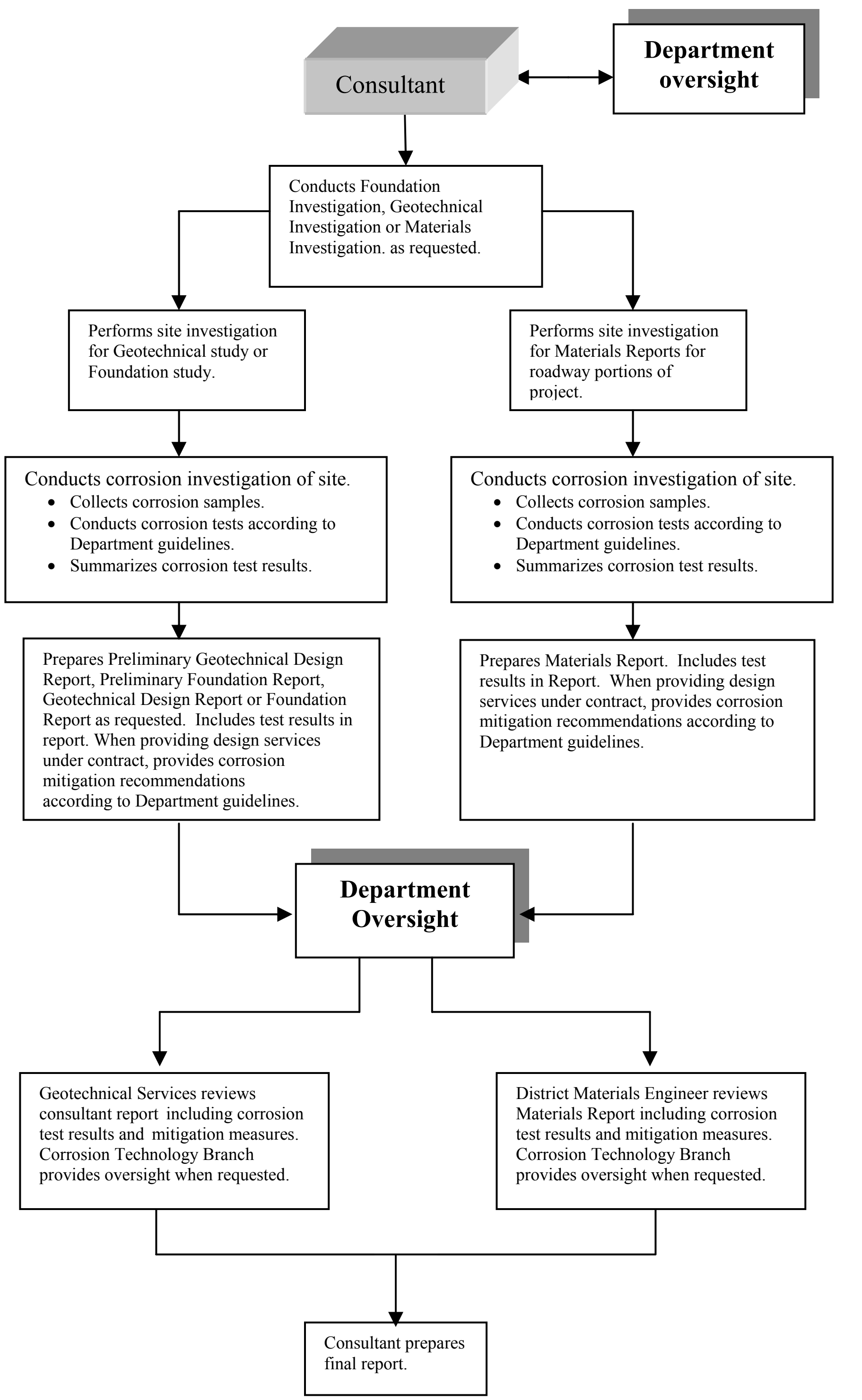
Corrosion testing of soil (both surface and subsurface soil samples) and water samples shall be performed in accordance with the applicable *California Test Methods (CTMs)* (http://www.dot.ca.gov/hq/esc/ctms/index.html). If procedures and equipment other than those specified in the applicable *CTM* are used, those variations must be approved, documented, and presented with the corrosion test results. References to the test methods used for corrosion testing must be included on each page that presents the corrosion test results and analysis. Some variations (like a one-point resistivity test instead of a minimum resistivity test) will not be allowed. If in doubt about whether alternative test methods are acceptable or not, contact the Corrosion Technology Branch of METS before starting any testing.

Minimum resistivity and pH tests are outlined in *CTM 643*. Test procedures for determining water-soluble sulfate and chloride contents are outlined in *CTMs 417* and *422*, respectively. Consultants should follow the guidelines presented in this document for performing corrosion assessments of project sites when performing work for the Department.

The Department provides oversight for investigations performed by consultants. For example, Geotechnical Services provides oversight for foundation and geotechnical investigations performed by consultants. Likewise, the District Materials Branches provide consultant oversight for culvert investigations, including the corrosion aspects of the culvert investigations. Guidelines presented in the *Bridge Design Specifications* and *Bridge Memo-To-Designers* (http://www.dot.ca.gov/hq/esc/techpubs), *Standard Special Provisions* (http://www.dot.ca.gov/hq/esc/oe/specs_html), *Structure Reference Specifications* (http://www.dot.ca.gov/hq/esc/structurespecs), *Highway Design Manual* (http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm), and this document have been developed by the Corrosion Technology Branch in conjunction with other DES offices to address corrosion mitigation requirements.

The Corrosion Technology Branch of METS is available to review all corrosion investigations conducted by consultants, should additional assistance be needed. Upon request from the functional groups performing oversight, the Corrosion Technology Branch will comment on the corrosion aspects of Materials Reports, Geotechnical Design Reports, Foundation Reports, and Preliminary Reports prepared by consultants.

Department/Consultants Interaction Flowchart



4. REQUIREMENTS FOR CONDUCTING CORROSION INVESTIGATIONS OF PROJECT SITES

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. 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. Factors that contribute to corrosion include the presence of soluble salts, soil and water resistivity, soil and water pH, and the presence of oxygen.

4.1 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 is typically a result of contact with soluble salts found in the soil or water. 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 other factors listed above.

Characterizing the corrosivity of an environment is complicated due to the interaction of the variables described above. For example, a metal buried in an aerated or disturbed soil with a particular resistivity and soluble chloride concentration generally will not experience the same amount of corrosion as a similar metal placed in the same soil in a compacted, less aerated state.

Some agencies and organizations characterize the corrosivity of soil or water using a broad range of descriptors such as “severely”, “highly”, “moderately”, or “slightly” to characterize the level of corrosiveness of a material or project site. Although the classification lists vary somewhat in the descriptions used to characterize the soil (e.g., “highly” versus “severely”) and the range of an identifiable parameter (e.g., slightly corrosive being soil resistivity greater than 10,000 ohm-cm as compared to a range of 10,000 ohm cm to 25,000 ohm-cm), most lists use resistivity as a leading indicator of the potential for soil and/or water corrosion.

Rather than characterizing sites as “highly”, “moderately”, “slightly”, or “severely” corrosive, the Department simply uses the terms corrosive and non-corrosive to compare environmental exposure conditions. For example, the term “corrosive” may be used to describe a seawater estuary environment relative to a fresh water lake.

Historically, the Department has defined a corrosive area in terms of the resistivity, pH, and soluble salt content of the soil and/or water as discussed above. Since resistivity serves only as an indicator parameter for the possible presence of soluble salts, it isn't included to define a corrosive area.

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 2000 ppm or greater, or the pH is 5.5 or less.**

If a site is corrosive based on the definition listed above, then corrosion mitigation is required.

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.

For structural elements, the minimum resistivity of soil and/or water indicates the relative quantity of soluble salts present in the soil or water. In general, a minimum resistivity value for soil and/or water less than 1000 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 less than 1,000 ohm-cm are tested by the Chemical Testing Branch of METS for chlorides and sulfates. With the exception of MSE walls, soil and water are not tested for chlorides and sulfates if the minimum resistivity is greater than 1,000 ohm-cm because a minimum resistivity greater than 1,000 ohm-cm indicates that the chloride and sulfate contents are low (i.e., low corrosion potential). See Section 6 of these guidelines regarding corrosion criteria for MSE walls.

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.

Similar to 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. Consequently, the concrete weakens. Cracked concrete is more susceptible to attack by water and other aggressive ions that may accelerate the corrosion process.

The presence of high acidity, pH of 5.5 or less, in soil or water is also considered a corrosive condition. Soil or water with a pH of 5.5 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.

For culverts, appropriate corrosion mitigation measures such as increased wall thickness, coatings, or alternative materials needed to achieve a 50-year design life are selected based on soil and/or water minimum resistivity and pH, as discussed in the *Highway Design Manual*, Chapter 850.

4.2 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.
- A general description of the 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 (Climate Area III environments, where salt is applied to roadways and structures; see Reference 5).
- 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.

Corrosion mitigation measures for sites identified as corrosive should be consistent with Department guidelines. See Section 10 of these guidelines for additional information regarding corrosion mitigation measures.

5. CORROSION ASSESSMENT OF SITE CONDITIONS FOR BRIDGE STRUCTURES

As previously mentioned, 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.

For rehabilitation and realignment projects, the Area Bridge Maintenance Engineers' (ABME) records should be reviewed for information about the history, problems, and required maintenance of existing major structures. This information is essential to identify appropriate mitigation measures.

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.

For rehabilitation or realignment projects, a survey of the existing structures should be made to determine the performance of those materials previously used in that environment. The survey should look for any signs of early deterioration. Telltale signs might be rust stains on reinforced concrete. More advanced deterioration of the reinforcement may be evident as cracked or spalled concrete.

5.1 Corrosion Sampling for Foundation and Geotechnical Investigations for Bridge Structures

Obtaining a **representative sample(s)** for testing may be one of the most important elements of any corrosion investigation. Representative sampling is defined here as obtaining samples of all materials encountered and ensuring that each sample is representative of all portions of each material. If the sample does not represent the true conditions of the material under consideration, the test results and analyses are meaningless (See Reference 21). Representative sampling for corrosion testing should identify the worst case condition that exists in the materials to be encountered or used. Good sampling practices must be a primary consideration for all corrosion investigations.

Field sampling of soil and water for corrosion investigations shall conform to the requirements of *California Test Method (CTM) 643*.

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.

The following designated intervals shall be used for **corrosion sampling** during every structure foundation investigation conducted in the field. Generally, one boring with samples at the designated intervals should be sufficient unless there is a major change in the subsurface material within the proposed substructure area. 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 below for each boring shall be based on valid reasons. Those reasons should be noted in writing in the field logs and in the Foundation 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.

- If fill material is present at the site, samples should be taken of the fill material as well as the native soil.
- One sample at near surface between 0.3 and 1.5 m (1 and 5 ft).
- One sample at the water table (if the water table is within the limits of the proposed pile foundation).
- Take an additional sample for each significant change in subsurface material to a depth of 1 m (3 ft) below the lowest anticipated ground water level (if the water table is within the limits of the proposed pile foundation).
- For concrete piles, take an additional sample for each significant change in subsurface material within the limits of the proposed pile foundation.

Soil Sample Size: The size of the soil sample that should be collected for corrosion testing will depend on whether the laboratory is using the large or small soil box for minimum resistivity testing. In most cases, Geotechnical Services sends samples for corrosion testing to METS. Since the Corrosion Technology Branch at METS uses the small soil box for minimum resistivity testing, 1.2 kg (2.65 lb) of material passing the 2.36-mm (No. 8) sieve is necessary to conduct corrosion testing. This amount of material is enough to test for minimum resistivity, pH, chlorides, and sulfates.

Undisturbed soil samples are not required for corrosion testing, but the sample should be representative of the true condition at that interval. Grab samples from auger borings may be collected from the flights of the augurs, but these samples may be not be representative in deep borings, especially if auguring below the water table. Core samples from wet (mud) rotary drilling are generally representative of the true subsurface conditions, provided that the entire sample comes from the same soil formation and lithology. Composite samples from more than one soil type or formation are not recommended.

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, *Bridge Design Specification 8.22* requires corrosion mitigation for reinforced concrete structures located within 300 m (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.

Subsurface water samples are not normally taken during the drilling operation because of the difficulty in taking the sample. However, if there are wells present that permit sampling, water samples should be considered. Likewise, water samples for corrosion testing can be collected if a piezometer for groundwater measurements is installed. This is especially true when the local rainfall amounts routinely exceed 750 mm (30 in) rainfall per year. High rainfall amounts are generally indicators of acidic conditions that are aggressive to concrete and metal products. On the opposite end of the scale, low rainfall [less than 250 mm (10 in) per year] may account for large quantities of undissolved salts. Some of these salts may be aggressive to the structure under consideration, causing the structure to require mitigation.

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.

When imported material is used as structure backfill, the imported backfill should not be more corrosive than the native soil material. Consequently, the contract special provisions should specify corrosive parameters for the imported fill that are less corrosive than that of the native soil. The imported backfill should be tested in accordance with *CTMs 643, 417,* and *422* prior to placement. This criteria applies to imported soil and lightweight aggregate fill.

Representative samples from other sources (e.g. soils and/or aggregates) might include materials in windrows, stockpiles, borrow pits, conveyor belts, quarries, etc. The sampling technique used to sample these sources can have a significant effect on corrosion test results. Samples incorrectly taken from these sources may not be representative due to segregation of the coarse materials from the fine material. Procedures outlined in *CTM 125*, "Methods for Sampling Highway Materials and Products Used in the Roadway Structural Sections" (http://www.dot.ca.gov/hq/esc/ctms/index.html), provide a guide to proper sampling techniques for these situations (Reference 21). While the title may not be directly related, the procedures are appropriate.

5.2 Bridge Structure Scour Assessment Related to Corrosion

Scour can accelerate corrosion of steel piling. If scour is anticipated, the corrosion investigation shall include information such as anticipated scour depth and scour frequency. For steel piling, additional metal thickness or protective coatings may be needed (see Section 10.1).

5.3 Proximity of Bridge Structure Sites to Marine or Brackish Water

During the corrosion investigation, it is important to determine the relative location of the structure or proposed structure to nearby marine or brackish water. This determination is needed, since it will affect the choice of concrete mix design for elements exposed to the atmosphere. The Department considers a structure that is located within a horizontal distance of 300 m (1000 ft) of marine or brackish water to be exposed to marine atmosphere (Reference 6).

A project site may be located within 300 m (1000 ft) of marine or brackish water, but have soil (within the limits of proposed foundations) that is characterized as non-corrosive. For this situation, corrosion mitigation for portions of the structure exposed to corrosive atmosphere is needed despite the non-corrosive soil conditions. Therefore, the proximity of the structure to any body of water must be noted in the corrosion investigation.

As previously stated, surface water samples should be collected for corrosion testing.

5.4 Requesting Corrosion Test Results for Bridge Structures

Corrosion Test Summary Reports are prepared, upon request as explained below, by the Corrosion Technology Branch. 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 non-corrosive based on the criteria established by these guidelines, and specifies the controlling ("worse case") corrosion parameter test results that are used by the specification writers/designers to provide corrosion mitigation measures for each proposed structure.

To request a Corrosion Test Summary Report (a report will be produced for each series of samples that are representative of the proposed structures being investigated), send an **e-mail** to the supervisor in charge of the Corrosion Technology Branch with the following information:

- Bridge name
- Bridge Number
- Dist/Co/Rte/PM
- EA number
- Sample Identification Card (SIC) numbers from the TL-0101 form for the samples representing each discrete structure being proposed for your project site. If your project involves more than one structure, separate the SIC numbers into groups representing each structure. Separate Corrosion Test Summary Reports will be prepared for each structure.
- Realistic deadline when you need the Corrosion Test Summary Report

Corrosion Test Summary Reports will be sent to the Geotechnical Services staff via an e-mail interface program that allows the Corrosion Technology Branch to search its corrosion test results database based on the SIC numbers and project information supplied by the client, format the test results, indicate whether the site is corrosive or not, and if so, present the controlling corrosion test parameter results for each proposed structure that will be included in the corrosion evaluation sections of the Foundation and Geotechnical reports as explained in Section 5.5.

For situations where site-specific corrosion test data is not available, the Corrosion Technology Branch may be contacted for additional assistance.

5.5 Reporting Corrosion Test Results for Bridge Structures in Foundation and Geotechnical Reports

The Geotechnical Services staff , based on their request for corrosion test results as explained in Section 5.4, will receive Corrosion Test Summary Reports for each set of samples representing each proposed structure for the project. Typically, corrosion test results for all samples are summarized and included in the Foundation Report or Geotechnical Design Report. All test data should be shown for the purpose of documenting that representative samples for the site were obtained.

Corrosion mitigation measures for bridge structural elements in contact with corrosive materials at the site are based on the "worse case" test results for the representative samples of the materials at each site. For example, if several surface soil samples obtained from a site contain different levels of soluble chlorides, concrete cover requirements for footings at or near the level where the samples were obtained should be designed using the most corrosive test results. This approach will ensure that a conservative design is considered for foundation elements for the entire structure.

The following examples of recommended wording for both corrosive sites and non-corrosive sites are presented to assist Geotechnical Services staff in reporting site-specific corrosion assessments for proposed structures in Geotechnical and Foundation Reports. The information in the example paragraphs is required so that the specification writer and/or designer can choose paragraphs in *Structure Reference Specification S8-C04 (90CORR)_R06-19-01*, (http://www.dot.ca.gov/hq/esc/structurespecs) that govern corrosion mitigation measures for each structure site.

Example wording for a corrosive site. Include the following paragraphs. Fill in the information in *italics* where applicable:

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

Chloride concentration is greater than or equal to 500 ppm, sulfate concentration is greater than or equal to 2000 ppm, or the pH is 5.5 or less.

Soil and water *(include water if samples were obtained)* samples for the project site were obtained for corrosion analyses at the following locations: *(Insert sample locations. Provide information such as boring hole, station number, bent location,* *etc.)*. Based on the results of the corrosion analyses, the site is considered corrosive. Controlling corrosion test parameter results are as follows:

(List controlling soil and/or water parameter test results from the Corrosion Test Summary Report supplied by the Corrosion Technology Branch of METS).

Indicate whether or not the structure or proposed structure is within 300 m (1000 ft) of salt or brackish water.

Also include the following paragraphs for corrosive sites where applicable:

Reinforced concrete (including piles) requires corrosion mitigation in accordance with *Bridge Design Specifications, Article 8.22*.

When steel piles are specified, sacrificial corrosion allowance is required per Department's *Corrosion Guidelines, Section 10.1*, "Corrosion Mitigation Measures for Steel Piles", available at (http://www.dot.ca.gov/hq/esc/ttsb/corrosion/Index.htm).

Example wording for a non-corrosive site. Include the following paragraphs. Fill in the information in *italics* where applicable:

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

Chloride concentration is greater than or equal to 500 ppm, sulfate concentration is greater than or equal to 2000 ppm, or the pH is 5.5 or less.

Soil and water *(include water if samples were obtained)* samples were obtained for corrosion analyses at the following locations: *(Insert sample locations. Provide information such as boring hole, station number, bent location, etc.).* Based on the results of the corrosion analyses, the site is considered non-corrosive.

Indicate whether or not the structure or proposed structure is within 300 m (1000 ft) of salt or brackish water.

6. CORROSION ASSESSMENT OF SITE CONDITIONS FOR MSE STRUCTURES

Most Mechanically Stabilized Embankment (MSE) structures are proprietary systems that require prior design and material use approvals. The DES Office of Design and Technical Services approves the design. The Corrosion Technology Branch of METS reviews the corrosion aspects of newly proposed systems.

Most MSE structures are equipped with inspection elements that are either galvanized steel rods or straps, depending on the form of soil reinforcement (rod or strap) used in the actual MSE structure construction. Inspection elements are included in the initial construction of MSE structures so that they may be retrieved at a later date and assessed for corrosion and remaining structural capacity. Since the inspection elements are placed at various locations and levels in the wall, and since they are exposed to the same conditions as the actual MSE soil reinforcement, they may be used to provide an estimate of the overall condition of the MSE structure. Inspection elements are typically scheduled for retrieval at 5, 10, 20, 30, 40, and 50-year intervals.

Currently, the maintenance-monitoring program for evaluating the corrosion condition of MSE structures is in the process of being re-evaluated by the Department.

6.1 Corrosion Requirements for MSE Structure Backfill

Standard Special Provision (SSP) 19-600, [Section 10 at the following website (http://www.dot.ca.gov/hq/esc/oe/specs_html)], requires that the structure backfill material for an MSE structure meet the following corrosion related requirements:

- Minimum resistivity must be greater than 1,500 ohm-cm, *CTM 643*
- Chloride concentration must be less than 500 ppm, *CTM 422*
- Sulfate concentration must be less than 2000 ppm, *CTM 417*
- pH must be between 5.5 and 10.0, *CTM 643*

MSE backfill material that meets the above criteria will be considered non-corrosive to both the metallic soil reinforcement as well as the reinforced concrete retaining wall. In addition to specifying non-corrosive soil, the metallic soil reinforcement must be galvanized in accordance with the Department's standard galvanizing requirements (*Standard Specification 75-1.05*).

Additional properties for structure backfill regarding particle size distribution, drainage requirements and soil plasticity are listed in *SSP 19-600*.

6.2 Corrosion Sampling and Testing for MSE Structures

For MSE structures, sampling of soil proposed for backfill material is required to establish that the material proposed meets the minimum requirements.

Field sampling of soil and water for corrosion investigations shall conform to the requirements of *California Test Method (CTM 643).*

The contractor is responsible for using non-corrosive soil and water for MSE wall construction. When a source of backfill material (borrow site) is being proposed for use in constructing an MSE structure, the entire source area should be representatively sampled and tested to establish that all the material within the area to be used for structure backfill meets the minimum requirements. This may require taking many samples to properly describe the corrosivity of the proposed backfill material. If any of the material within a proposed borrow source does not meet the minimum requirements, those areas shall be clearly defined as "off limits".

In addition to "borrow-site" sampling performed by the contractor, the Department requires backfill sampling and testing during construction for quality assurance. *Bridge Construction Memo 145-8.0, Mechanically Stabilized Embankment Wall Construction Checklist, July 2001*, available on the Department's internal website at http://dschq.dot.ca.gov:82/Construction_Records_and_Procedures/Vol_II/145-8.0_BCM.pdf, advises the Structure Representative to obtain one 27-kg (60-lb) sample of backfill material at each level where inspection elements are installed. This amount of material is enough to conduct the corrosion tests (*CTMs 643, 422*, and *417*) as well as the other soil tests required by *SSP 19-600*. The flowchart on page 4 illustrates, as part of the District Construction Labs' responsibilities, the construction inspector's role in quality assurance testing for MSE structures.

SSP 19-600 also states that water used for earthwork or dust control within 150 m (500 ft) of any portion of an MSE structure shall conform to the requirements for water that is used in conventionally reinforced concrete work. This requires that the water have a maximum chloride concentration of 1,000 ppm, and a maximum sulfate concentration of 1,300 ppm.

6.3 Reporting Corrosion Test Results for MSE Structures

As stated in Section 6.1, corrosion requirements for backfill material used for MSE structures must comply with the requirements in *Standard Special Provision (SSP) 19-600*, (Section 10 at the following website http://www.dot.ca.gov/hq/esc/oe/specs_html).

Corrosion test results for backfill samples, submitted to the Corrosion Technology Laboratory for testing, will be reported on a Corrosion Test Summary Report. This report will summarize the corrosion results (minimum resistivity, pH, and chloride and sulfate contents) in addition to indicating whether the samples met the specification requirements for these tests in accordance with *SSP 19-600*.

Staff should keep in mind that although soil at a site may be suitable for use around structure foundation elements, it may not be suitable for use as MSE structure backfill material.

The Corrosion Technology Branch may be contacted to provide additional assistance regarding interpretation of corrosion test results for proposed MSE structure backfill material.

7. SOIL AND ROCK ANCHOR SYSTEMS

Soil and rock anchors typically consist of steel bar-type tendons or strand-type tendons and anchor assemblies that are grouted in cored or drilled holes. Soil or rock anchors are classified as Tieback Anchors, Tiedown Anchors, or Soil Nails. The following information is intended to give some brief background regarding these systems. Additional detailed information can be found in the Department's *Foundation Manual*, available at (http://www.dot.ca.gov/hq/esc/construction/Manuals/Foundation/Foundation.htm).

7.1 Tieback Anchors

Tieback Anchors are used in both temporary and permanent structures. These types of anchors are typically associated with retaining walls and may contain either bar-type or strand-type tendons that are grouted into drilled holes of on-site foundation materials (either soil or rock).

Tieback components consist of the following:

COMPONENT	DESCRIPTION
Bond Length	The portion of prestressing steel fixed in the primary grout bulb through which load is transferred to the surrounding soil or rock. Also known as the anchor zone.
Unbonded Length	The portion of the prestressing steel that is free to elongate elastically and transmit the resisting force from the bond length to the wall.
Prestressing Steel Support Member	This transfers load from the wall reaction to the anchor zone and is generally a prestress rod or strand
Anchorage	This consists of a plate and anchor head or threaded nut and permits stressing and lock-off of the prestressing steel.
Grout	This provides corrosion protection as well as the medium to transfer load from the prestressing steel to the soil or rock.

Tieback Anchors are typically proprietary systems that require working drawings and corrosion protection approval from the DES Office of Design and Technical Services. Corrosion mitigation measures included for these proprietary systems are required regardless of the on-site corrosion test results, due to the critical nature of the components and the "stressed" state of the anchors.

Corrosion mitigation measures for Tieback Anchors are specified in the contract special provisions [refer to *Structure Reference Specifications 50-560 (50TIEB)*, at the following link: (http://www.dot.ca.gov/hq/esc/structurespecs)]. They include the use of PVC, HDPE or polypropylene sheathing, corrosion inhibiting grease and cementitious grout.

The Corrosion Technology Branch of METS is available to provide corrosion assistance to the DES Office of Design and Technical Services regarding the review of newly proposed systems or the corrosion aspects of existing Tieback Anchor designs.

7.2 Tiedown Anchors

Tiedown Anchors are typically foundation anchors for bridge footings that are grouted into cored, formed or drilled holes. They are used to provide additional restraint against rotation of the footings and can be installed in both soil and rock. Components of Tiedown anchors are similar to those of Tieback Anchors.

Tiedown Anchors are typically proprietary systems that require working drawings and corrosion protection approval from the DES Office of Design and Technical Services. Corrosion mitigation measures included in these proprietary systems are required regardless of the on-site corrosion test results, due to the critical nature of the components and the "stressed" state of the anchors.

Corrosion mitigation measures for Tiedown Anchors are specified in the contract special provisions [refer to *Structure Reference Specifications 50-570 (50TIED)*, at the following link: (http://www.dot.ca.gov/hq/esc/structurespecs)]. They include the use of PVC, HDPE or polypropylene sheathing, corrosion inhibiting grease and cementitious grout.

The Corrosion Technology Branch of METS is available to provide corrosion assistance to the DES Office of Design and Technical Services regarding the review of newly proposed systems or the corrosion aspects of existing Tiedown Anchor designs.

7.3 Soil Nails

Soil nailing is a technique that is used to reinforce and strengthen an existing embankment. It is an effective technique used for large excavations. The basic concept is that soil is reinforced with closely spaced, grouted soil anchors or "nails" that are inserted (drilled) into the existing foundation material. Unlike Tieback and Tiedown Anchors, Soil Nails are not post-tensioned. They are forced into tension as the ground deforms laterally in response to the loss of support caused by continued excavation. As with Tieback and Tiedown anchor systems, Soil Nail systems require working drawings and corrosion protection approval from the DES Office of Design and Technical Services.

Corrosion mitigation measures for Soil Nails are provided based on the corrosivity of the site, and are included in *Structure Reference Specification 19-660 (19NAIL)*, (http://www.dot.ca.gov/hq/esc/structurespecs). Depending on the site conditions, corrosion mitigation measures may include sheathing with HDPE, epoxy-coated reinforcement and cementitious grout.

8. CORROSION ASSESSMENT OF SITE CONDITIONS FOR CULVERTS

8.1 Scope of Culvert Investigations

The District Materials Branch (or the consultant under contract) is responsible for conducting a corrosion investigation for drainage facilities. This includes culverts to be repaired or replaced in addition to proposed new sites. For a rehabilitation project, it is common practice to perform a culvert survey of existing drainage facilities to determine the need for clean-out, repair, and/or replacement.

When a culvert has failed prematurely, sampling and testing of in-situ soil and water for selection of appropriate replacement culvert materials is suggested. Representative samples of both the soil and drainage water should be collected and tested. A culvert survey may also identify the need for new culverts where land use has changed drainage patterns. Maintenance personnel may be able to identify the latter more quickly.

The size and effort of a corrosion investigation for drainage facilities will vary with the size of the proposed project. At times, a small project may require more effort to mitigate the corrosion problems than a larger project. It is important to adequately address all of the potential corrosion problems to ensure that the design life of the project will be met.

It is the responsibility of the District Materials Engineer (DME) to prepare a Materials Report which includes the findings of the corrosion investigation and recommendations for allowable alternative culvert materials. It is important that the DME interprets the corrosion test data and provides the design engineer and specification writer with the best choices of alternative materials for the sites being investigated. These selected materials are then designated as the allowable alternative products on the Project Plans and in the Special Provisions for the project. Economics and hydraulics usually determine which alternative products are actually chosen by the contractor

The selection of alternative culvert materials should be in accordance with *Topic 850*, "Physical Standards", of the *Highway Design Manual (HDM)* (http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm) and *California Test Method (CTM) 643*. Culvert material selection (including any coatings, linings, pavings, etc.) should provide corrosion protection for a maintenance free service life. Maintenance-free service life is defined in *Topic 852* of the *HDM* as 50 years (25 years in some cases).

8.2 Corrosion Sampling and Testing for Culverts

Corrosion investigations for culverts should include sampling of in-situ soil within the limits of the proposed culvert, sampling of water that will or may flow into the culvert, and sampling of any fill material that may be used as backfill for the culvert. If a project will have multiple culverts, samples of soil and water should be obtained from each specific location on the project site.

Field sampling of soil and water for corrosion investigations should conform to the requirements of *California Test Method (CTM) 643*. For culverts, field-screening tests identified in *CTM 643*, *Part 1*, "Method of Field Resistivity and Sampling for Laboratory Tests" are used to identify the most aggressive on-site soil samples for corrosion testing. This simple screening test is highly recommended to identify the most aggressive soils at a site and can eliminate the need for obtaining multiple soil samples for lab tests. If suitable field-measuring equipment is not available to perform the screening tests, additional samples may be needed to obtain material that is representative of all material within the proposed limits of the culvert.

The sample size of soil for culvert investigations that should be collected will depend on whether the laboratory is using a large or small soil box for minimum resistivity testing. If the District Materials Lab is conducting the minimum resistivity and pH testing, find out whether they are using the large or small soil box. The Corrosion Technology Branch at METS uses the small soil box. Dimensions for the two types of boxes are illustrated in *CTM 643*.

<u>Sample Size for Large Soil Box:</u> When selecting a soil sample for minimum resistivity and pH testing for a culvert investigation, take a sample that will yield 1.6 kg (3.53 lb) of material passing the 2.36-mm (No. 8) sieve, if the large soil box will be used in the laboratory. If field resistivity measurements approach 1,000 ohm-cm (this is an indication that chloride and sulfate testing will be required), take a sample that will yield 2.3 kg (5 lb) of material passing the 2.36-mm (No. 8) sieve, if the large soil box will be used in the laboratory. One rule of thumb is that a hard hat filled with soil should yield enough material for minimum resistivity testing using the large soil box, as well as for the pH, chloride, and sulfate testing.

<u>Sample Size for Small Soil Box:</u> When selecting a soil sample for minimum resistivity and pH testing for a culvert investigation, take a sample that will yield 500 g (1.10 lb) of material passing the 2.36-mm (No. 8) sieve, if the small soil box will be used in the laboratory. If field resistivity measurements approach 1,000 ohm-cm (this is an indication that chloride and sulfate testing will be required), take a sample that will yield 1.2 kg (2.65 lb) of material passing the 2.36-mm (No. 8) sieve, if the small soil box will be used in the laboratory.

Representative surface water samples taken for proposed off-site drainage should be selected from the live stream or existing standing water at the inlet end of the facility. Surface water samples should also be collected from rivers, streams, wetlands, marshes, lakes, etc., if that water may come into contact with the structure. Water samples should never be taken when the water level is elevated due to recent storm runoff or flooding. Elevated stream flows dilute chemical concentrations in the stream making the sample concentrations appear lower than usual. Selection of the water sample should be in accordance with *CTM 643, Part 2*, "Method of Determining the pH of Water".

A clean, wide-mouth beaker should be used 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 (0.3 gallon) of water is sufficient for the laboratory to conduct minimum 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.

All corrosion testing should be performed in accordance with *California Test Methods (CTMs)*.

Corrosion testing of soil samples (both surface and subsurface soil samples) and water samples shall follow the methods outlined in the following *California Test Methods (CTMs)*:

- *CTM 643*, "Method for Estimating the Service Life of Steel Culverts" for minimum resistivity and pH measurements.
- *CTM 422*, "Method of Testing Soils and Waters for Chloride Content".
- *CTM 417*, "Method of Testing Soils and Waters for Sulfate Content".

When imported material is used as structure backfill for metal products such as steel pipe culverts or reinforced concrete culverts and headwalls, the imported backfill should be less corrosive than the native soil material. Consequently, the contract special provisions should specify corrosive parameters for the imported fill that are less corrosive than those of the native soil. The imported backfill should be tested in accordance with *CTMs 643*, *417*, and *422* prior to placement. This applies to imported soil and lightweight aggregate fill.

Slag based materials high in sulfate concentrations can attack the cement mortar in reinforced concrete pipe. If slag aggregate has been or is proposed for use as culvert backfill, it must be tested to determine its' suitability as structure backfill material.

8.3 Reporting Corrosion Test Results for Culverts

Because there may be several responsible parties for various phases of a corrosion investigation, the results and recommendations may be found in different reports. The results may be contained in the Materials Report, an appendix of the Geotechnical Design Report, or the appendix of the Structures Foundation Report. Additional detailed information to mitigate difficult corrosion problems may also be included in a separate memo or report prepared by the Corrosion Technology Branch of METS. The design engineer needs to be aware of these sources and take the opportunity to review all the information during the design phase of a project. If questions still exist on the corrosion aspects of the project, the Corrosion Technology Branch of METS should be contacted for assistance.

Corrosion Test Summary Reports prepared by the Corrosion Technology Branch of METS will include results of all samples received for testing.

Corrosion investigations for culverts should include the following subjects related to corrosion mitigation:

- A general description of the existing or proposed drainage facilities for both off-site and on-site drainage.
- The results of any culvert survey of existing drainage facilities in the immediate area.
- The presentation of all corrosion test results performed by the District lab, METS lab, and others. If testing has been performed by others, their report shall be included in the appendix.
- Identification of samples which are representative of the materials sampled and tested for each culvert site. Identification of the exact location of each sample.
- A statement regarding which materials were sampled and tested, including the sample location, depth, method of sampling (auger, backhoe, drill rig or shovel) and the classification of sampled material.
- Soil and water test results for minimum resistivity (ohm-cm), pH, sulfates (mg/kg or ppm), and chlorides (mg/kg or ppm). Except for Mechanically Stabilized Embankment (MSE) structures, sulfates and chlorides are typically not tested if the minimum resistivity is greater than 1,000 ohm-cm.
- For corrosion test results of soil and/or water, include the life of a 1.3 mm thick (18 gage) corrugated steel pipe (CSP) in years for each sample as specified in *California Test Method (CTM) 643*. Corrosion test summaries for samples tested by the METS Corrosion Technology Branch will include this information.
- For corrosion test results of soil and/or water, include the recommended thickness/gage of CSP for 50 years of service as specified in *CTM 643*. Alternative bituminous-coated CSP should also be included. The *CULVERT4* Computer program may be used to assist with selecting gage thickness.
- For RCP and box culverts, include the recommended clear concrete cover over the reinforcing steel and concrete mix design for 50 years of service as specified in the *HDM*.
- Include all recommended allowable alternative culvert materials and their thickness for either 25 or 50 years of maintenance-free service according to the provisions of the *HDM*. These recommended materials should also be readily available from vendors.
- Include, if appropriate, any mitigation measures necessary for stray current problems. The DES Office of Electrical, Mechanical, Water, and Wastewater Engineering should be contacted for assistance in mitigating stray current corrosion. See Section 12 of these guidelines for additional information regarding stray current.
- Also include any specific recommendations that may be pertinent to the project or helpful to the designer, specification writer, or construction personnel due to unusual circumstances.

The results of a culvert survey along with the corrosion test results of soil and water collected from the site will provide the District Materials Engineer (DME) with complete information to make alternative material selections. If the service life of existing culverts are known, then the performance history of existing culverts would generally be more reliable than the results of laboratory tests since the performance history is based on the culvert's exposure to corrosion, bedload, and abrasion. For example, soil and water corrosion test results may suggest that uncoated galvanized steel culverts may be appropriate for a particular site. However, if the existing culverts are uncoated galvanized steel but have corroded prematurely, it is obvious that a different material should be used for any new culverts. In other words, the failed performance history of the existing culverts would override the results of the corrosion test results. All elements that affect the life of the culvert must be addressed if the culvert is expected to perform as intended.

When alternative materials are considered for a site, all allowable materials that meet the criteria specified in the *HDM* should be considered. The designer, specification writer or contractor may exclude certain allowable culvert or backfill materials based on availability, economics, etc.

Computer program *CULVERT4* is available on diskette in MS-DOS format to assist the user in making material selections for culverts based on corrosion test results, and the criteria presented in the *HDM* and *CTM 643*. The criteria for selecting culvert materials are included in this program. This computer program, however, is not intended to replace good engineering judgment where site specific conditions would require special considerations. *CULVERT4*, however, does not contain all of the latest revisions to the Department's design standards. Users must be aware of changes subsequent to *CULVERT4*, and must consult the latest version of the Highway Design Manual.

Department staff can obtain a copy of the *CULVERT4* program from the District Materials Branch or District Hydraulics Engineer. Users not employed by the Department may obtain a copy of the *CULVERT4* program from the following source for a cost of approximately $50.00:

McTrans Center
University of Florida
512 Weil Hall
PO Box 116585
Gainesville, Florida 32611-6585
(352) 392-0378
http://mctrans.ce.ufl.edu

8.4 Alternative Culvert Materials

Galvanized Steel Pipe

The selection of galvanized steel pipe is based on the corrosion test results from *California Test Method (CTM) 643* (both soil and water testing) and the criteria presented in Topic 850 of the *HDM*. *CTM 643* defines the years to perforation for a galvanized steel culvert of a given metal thickness (or gage) with a 0.61 kg/m^2 (2 oz/ft^2) zinc galvanized coating. The zinc galvanizing is hot-dip galvanized at 0.3 kg/m^2 per side (1 oz/ft^2 per side). The years to first perforation is the maintenance-free service life and is based solely on the minimum resistivity and pH of the soil and/or water samples. Although *CTM 643* is most often used with galvanized corrugated steel pipe to determine the minimum thickness required to achieve a 50-year maintenance-free service life, it also applies to steel spiral rib pipe and pipe arches.

In corrosive environments, protective coatings, linings, and pavings on the inside and/or outside of steel pipe and culverts can be used to extend the maintenance-free service life. *Topic 850* of the *HDM* and *Section 66-1.03* of the *Standard Specifications* describe the various types of coatings and linings that may be selected to extend the maintenance-free service life. Examples include:

- hot-dipped bituminous coating to both sides of the pipe
- polymeric sheet coating to the soil side of the pipe
- bituminous lining to the inside of the pipe
- bituminous paving of the invert on the inside only
- polymerized asphalt coating which is hot-dipped to cover the bottom 90^o of the inside and outside of the pipe

Any damage to galvanizing, protective coatings, linings, and pavings that occurs during handling, installation, or construction must be rejected or repaired as specified in accordance with manufacturer's recommendations. Damage includes scratches, pinholes, cracks, or coating disbondment.

As noted in the previous section, the computer program, *CULVERT4*, is available for selecting alternative culvert materials based on site conditions.

<u>Aluminum and Aluminized Steel (Type 2) Pipe</u>
Aluminum is an alternative material allowed when corrosion test results and abrasive conditions meet the criteria in *Topic 850* of the *HDM*. Aluminum culverts include corrugated aluminum pipe and pipe arches, aluminum spiral rib pipe, and structural aluminum plate pipe and arches. For a 50-year maintenance-free service life, aluminum can only be used if the pH of the soil, backfill, and drainage water is within the range of 5.5 to 8.5. In addition, the minimum resistivity of the soil, backfill, and drainage water must be 1,500 ohm-cm or greater. Aluminum culverts are usually 1.5 mm thick, not bituminous coated for corrosion or abrasion protection, and not hot-dip galvanized with zinc. Aluminum culvert thickness may be greater in order to support increased loading (such as higher fills). Although aluminum culverts exhibit good corrosion protection, they are not recommended where abrasive channel materials are present or where flow velocities frequently exceed 1.5 m/sec (4.9 ft/sec).

As an alternative to coating steel pipe with zinc (i.e., hot-dip galvanizing), steel pipe can be aluminized (Type 2). Aluminized steel pipe is steel pipe that is protected against corrosion by hot-dipping in an aluminum coating. The Department allows the use of 1.6 mm (16 gage) thick (minimum) aluminized steel (Type 2) pipe for pH values between 5.5 and 8.5 and minimum resistivities in excess of 1,500 ohm-cm. Greater wall thickness would be considered for increased structural needs, but is not needed for corrosion resistance. Bituminous or polymerized coatings are not recommended for corrosion protection of aluminized steel, but may be used for abrasion resistance.

Non-reinforced Concrete Pipe

The use of non-reinforced concrete pipe can be advantageous when reinforcing steel is not required to provide strength. Without reinforcing steel, the presence of chloride and stray current can not compromise the service performance of the pipe. Acidity and sulfates in the soil and/or water, however, can affect this type of pipe by attacking the cement.

Table 854.1A of the *HDM* provides mitigation measures to protect against corrosion due to acids or sulfates. The corrosion mitigation measures improve the concrete mix design by using mineral admixtures, reduced water content, increased cementitious material content, and Type V cement.

Reinforced Concrete Pipe

Reinforced concrete pipe (RCP) is typically precast, performs well under most conditions, and is commonly selected when a corrosive environment exceeds the limits for using corrugated metal pipe. The initiation of corrosion is delayed in RCP due to the concrete cover over the reinforcing steel. For chloride concentrations below 500 ppm, standard design criteria should be used (i.e., standard clear cover and standard concrete mix design). When the chloride concentration at the site reaches 500 ppm in either the soil, or drainage water, mitigation is necessary to protect against chlorides from causing corrosion of the reinforcing steel. If chlorides penetrate the concrete and cause the reinforcing steel to corrode, the concrete will eventually crack, spall, and may fail. Topic 854 of the *HDM* provides corrosion mitigation measures to protect against corrosive environments. The computer program, *CULVERT4*, noted in Section 8.3 of these guidelines, may currently be used for design of precast RCP. In addition, the Corrosion Technology Branch is currently reviewing corrosion mitigation measures for RCP design.

Reinforced Concrete Box Culverts and Arch Culverts

Corrosion protection for reinforced concrete box culverts and arches may be achieved by using guidelines for reinforced concrete structures outlined in the Department's *Bridge Design Specifications (BDS)*, *Article 8.22*, "Protection Against Corrosion". *Tables 8.22.1* and *8.22.2* of *BDS Article 8.22* may be used for concrete cover requirements and mineral admixture requirements (http://www.dot.ca.gov/hq/esc/techpubs). The Department's *Structure Reference Specification S8-C04 (90CORR)_R06-19-01*, (http://www.dot.ca.gov/hq/esc/structurespecs), is used in conjunction with *BDS Article 8.22* to develop project special provisions for reinforced concrete box culverts and arches where corrosion resistant concrete is needed.

Plastic Pipe
Plastic pipe is not subject to corrosion and can be a good performer in areas that are corrosive. When considering plastic pipe, the maximum fill heights listed in *Table 854.8* of the *HDM* should be checked to determine allowable pipe sizes.

In general, exposure to sunlight (ultraviolet rays) has an adverse effect on the service life of plastic pipes and products. For a plastic pipe, ultraviolet (UV) rays from the sun can induce degradation and ultimately cause loss of mechanical properties, which may result in premature failure of the pipe. HDPE and PVC plastic pipes approved for use by the Department have UV inhibitors added for protection against sunlight.

When plastic pipe is installed in areas that may be subject to fire, consider using concrete headwalls or metal flared end sections to reduce the potential damage to the ends of the pipe. Also, accumulated debris and trash may carry a fire into the pipe.

8.5 Cement Slurry, Controlled Low Strength Material (CLSM) or Concrete Backfill for Culverts

When cement slurry, controlled low strength material (CLSM) or concrete is used as structure backfill for pipe culverts, selected pipe culvert material shall conform to the requirements of *Chapter 850* of the *Highway Design Manual* for the in-situ soil and water. Corrosion testing shall be conducted in conformance with the requirements of *California Test Methods 643, 422* and *417*.

When placing culverts in existing roadways, it is sometimes necessary to use fast setting concrete backfill. Anytime an admixture is used to accelerate the set time of concrete that has metal products within the concrete or slurry, only non-chloride admixtures should be considered (i.e., admixtures containing calcium chloride may not be used).

9. REQUESTING CORROSION TECHNOLOGY LAB SERVICES

9.1 Testing Services

The Corrosion Technology Branch provides various laboratory testing services for the Department's functional units. These services include salt spray exposure testing [in accordance with *American Society of Testing Materials* (*ASTM) B 117*] of materials (fencing, coatings, corrosion inhibiting grease, new products, etc.); corrosion testing of soil and water for minimum resistivity, pH, and water soluble sulfates and chlorides (*CTMs 643, 417*, and *422*, respectively); and testing of total chloride concentrations of concrete cores (*CTM 404*). Other specialty tests are performed when appropriate. Contact the Corrosion Technology Branch if you have questions regarding these tests or the interpretation of the test results in these areas.

The Department's District or regional labs conduct their own minimum resistivity and pH tests for soil and water for culvert investigations. Since these labs do not have the capability to run chloride and sulfate tests, soil and water samples having minimum resistivity results of less than 1000 ohm-cm are sent to METS for these tests.

Corrosion testing flowcharts are included at the end of Section 9, pages 31 and 32, outlining the roles and responsibilities regarding corrosion testing for soil and water samples received from Geotechnical Services, and the District Materials Labs or Construction Labs.

Requests for corrosion testing of field samples should be made as soon as possible after the sampling is completed. The Corrosion Technology Branch can provide better service if as much lead-time as possible is given.

Samples may be mailed, shipped, or personally delivered to METS. Samples may be transported in any package or container that is unbreakable, sealed, and tightly wrapped. Canvas bags are often used for soil and concrete cores. Plastic jugs are excellent for water samples.

Delays in testing or reporting of results may occur if a contact person, their telephone, fax, and complete mailing address with zip code are not provided. When questions occur about the information that is submitted with the samples, a responsible person must be contacted and the questions must be answered before testing can begin.

When requesting testing, indicate the **date** the test results are needed. This is important for the Corrosion Technology Branch laboratory staff to schedule work to meet the needs of our customers. If dates are not included or if ASAP is noted without a date, the samples will be handled on a first in, first out schedule. Construction jobs are usually given top priority. When priority testing is needed, please note this concern on the TL-0101 form and include the most realistic date possible. Every effort will be made to meet priority needs. To help us provide prompt service, please do not hold the samples until the results are needed and then request that the work be high priority. Samples held for an excessive length of time will not receive priority testing. Submit samples as soon as possible after they are retrieved so that the Corrosion Lab is given as much lead time as possible.

The Department's Geotechnical Services field personnel should send soil samples (along with the TL-0101 form) for corrosion testing to Geotechnical Services at the following address:

Geotechnical Services
ATTN: Geotechnical Lab, Room 322
5900 Folsom Blvd., Mail Stop 5
Sacramento, CA 95819-4612

The Geotechnical Lab logs in the soil samples and reviews TL-0101 forms for completeness before sending them to the Concrete Lab's Grade Bench for sample preparation, including drying, screening, and splitting of material for requested testing. After preparing the samples, the Grade Bench distributes them to the Corrosion Lab for corrosion testing, and to other units depending on the requested tests.

Soil samples that have already been processed at one of the District Labs do not need to be sent to the Geotechnical Lab, and may be sent directly to the METS Grade Bench at the following address:

Materials Engineering and Testing Services
ATTN: Grade Bench, Room 245
5900 Folsom Blvd., Mail Stop 5
Sacramento, CA 95819-4612

Concrete, water, and any other materials that need corrosion testing should be sent directly to the METS Corrosion Technology Branch at the following address:

Materials Engineering and Testing Services
ATTN: Corrosion Technology Branch, Room 252
5900 Folsom Blvd., Mail Stop 5
Sacramento, CA 95819-4612

Occasionally, samples delivered to METS or Geotechnical Services are left on the receiving dock at the Transportation Laboratory without notifying the proper Branch that will be performing the tests. If samples must be left on the receiving dock, make sure that the outside of each sample container and the accompanying TL-0101 form clearly specify which Branch Lab should receive and test the sample(s). Without proper identification, samples and containers that are not clearly labeled may be delivered to the wrong Branch for testing, be stored with completed test samples, or become lost. Oftentimes, samples must be tested by more than one Branch. When this occurs, it is important to share the complete testing plan with all Branches that will be involved with the sample testing. Our goal is to provide prompt testing services. We need your help to avoid needless delays.

9.2 TL-0101 Form

Department staff requesting corrosion testing should use the TL-0101 form. The TL-0101 form or Sample Identification Card should be completed with all available information entered. Include the name, fax number, and telephone number of the person(s) responsible for sampling and the name and **complete** mailing address of the individual(s) that want to receive the test results. Attach the TL-0101 form to the sample. If necessary, additional information may be included in an attached memo.

It's essential that all information on the TL-0101 form is filled out correctly and the information is legible. It's also important for clients to clearly spell their names and make sure their e-mail profile information is up-to-date.

It is not required to fill out individual TL-0101 forms for each sample if samples are from the same boring, however, copies of original forms must be legible. Please label each sample with the TL 101 Sample Identification Card Number and a unique number to distinguish samples from the same borehole.

All of the following information must be clearly identified in dark ink or pencil on the TL-0101 form:

1. EA: Expense Authorization.
2. SAMPLE OF: Type of sample such as soil, water, concrete core, etc.
3. FOR USE IN: Type of project such as backfill for MSE wall, foundation investigation, soundwall, etc.
4. SAMPLE FROM: Where sample was taken from such as bridge name, bridge #, boring #, bent #, MSE wall name.
5. DEPTH: Depth of sample taken in meters, feet or denoted by elevation. Specify units of measurement.
6. LOCATION OF SOURCE: For example, quarry, streambed, northbound lane, southbound lane, boring #, bent #, station and offset information.
7. NUMBER OF CONTAINERS AND NUMBER OF SAMPLES IN GROUP: For example, five samples from various boring locations on-site.
8. DATE NEEDED: Specify a date that the results are needed. Do not write ASAP, rush, or routine. If a rush is needed, indicate why and write an exact date. For example, PS&E due date of _____, going out to bid on_____, in active construction, etc.
9. REMARKS: Write the tests needed such as minimum resistivity, pH, chlorides, sulfates, etc.
10. DATE SAMPLED: When the samples were taken.
11. BY: Name of person who took the samples.
12. DIST, CO, RTE, PM: District, county, route. Indicate whether post mile or kilometer post are specified.
13. LIMITS: If a District lab performed the minimum resistivity and pH tests, indicate the results.
14. RES. ENGR. OR SUPT: List the full name, title, section, complete mailing address with zip code, phone, and fax number of the person needing the results.

9.3 Corrosion Technology Lab's Test Results Database

The Corrosion Technology Branch of METS maintains a computer database of all laboratory corrosion test results for the tests it conducts and the results reported to the branch by the district labs. This allows the Corrosion Technology Branch to provide the

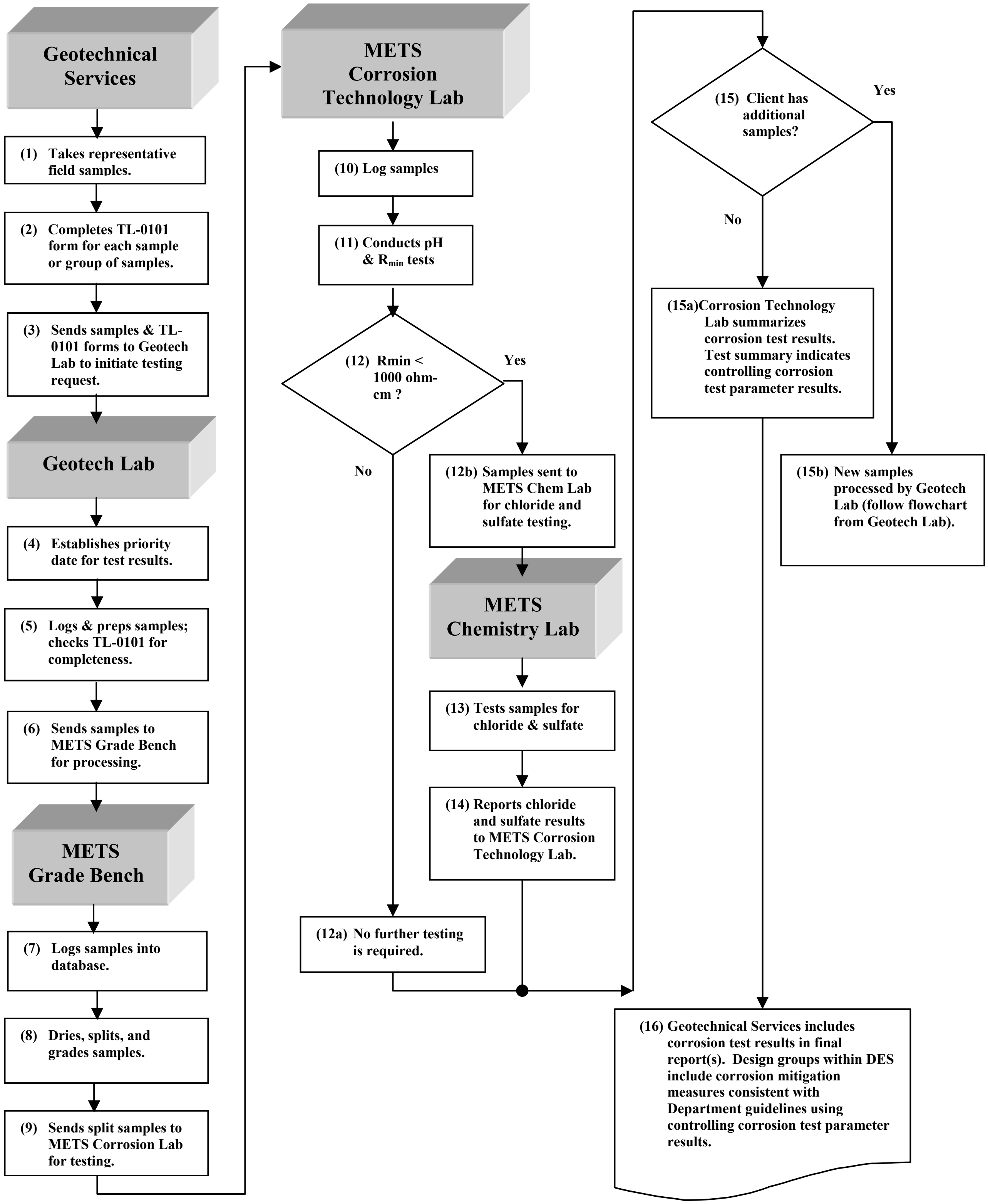
Districts and others with quick and easy retrieval of historical testing records for use in planning, contract litigation, etc.

If there is a possibility that testing has been performed in the past along a project alignment, the Corrosion Technology Branch may be contacted to perform a search of its database for previous test results. It may be beneficial to summarize past results rather than do additional, repetitive sampling and testing.

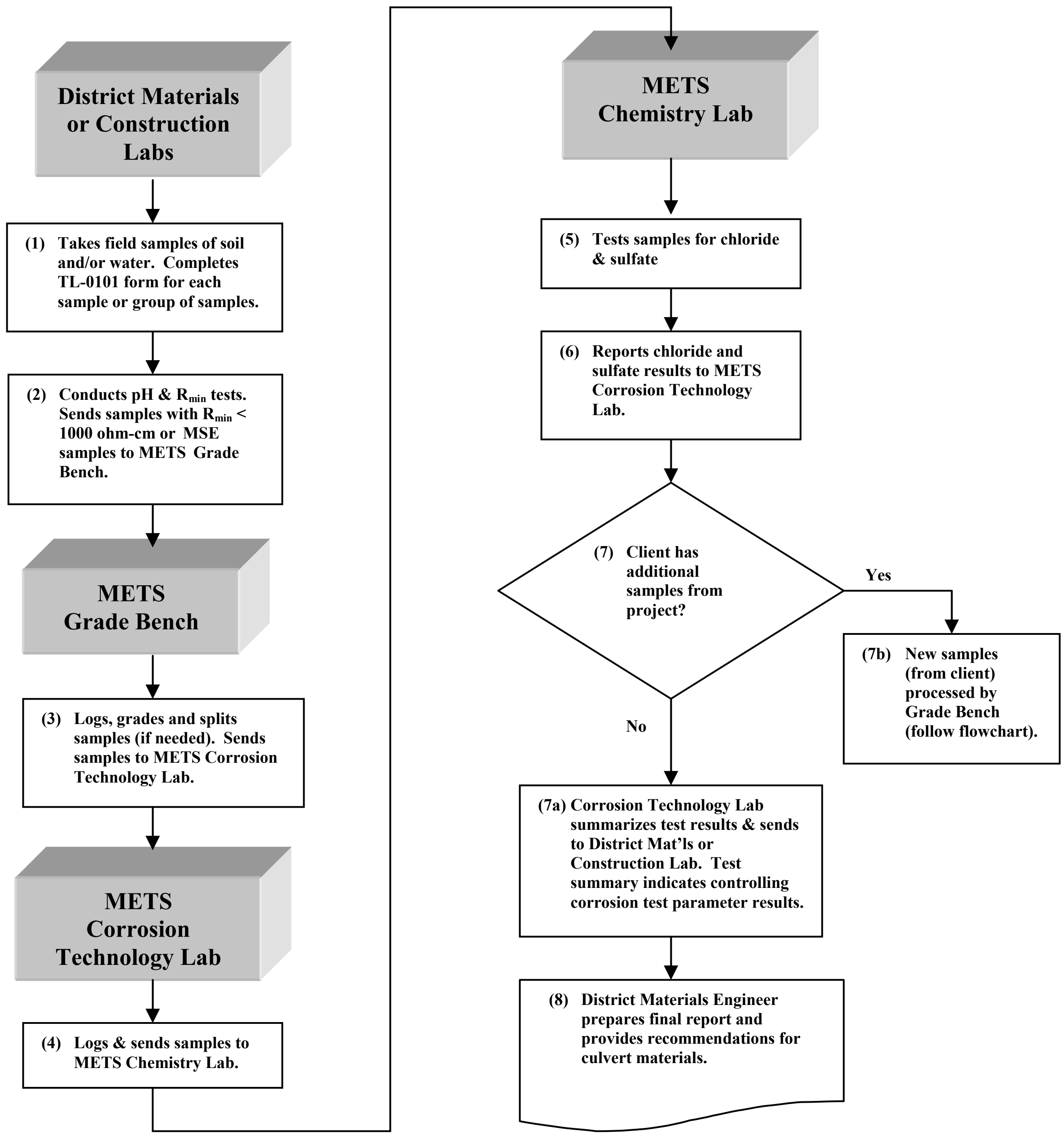
After a sample has been tested, the information is entered into the Corrosion Technology Branch database and a formatted summary sheet of all test data is created. The corrosion test summary report will contain test results for all samples received for a particular project site, indicate whether or not the site is corrosive, and identify the most corrosive parameters (worse case scenario) from all samples received for the site.

Unused portions of sampled material will be kept in the Corrosion Lab for approximately 90 days after the test results are reported. After 90 days, the materials will be discarded. If needed, arrangements can be made to return the unused portions after testing. Requests to return the unused sample material should be made at the time of the requested services for corrosion testing.

Corrosion Testing Flowchart for Soil and Water Samples Received from Geotechnical Services



Corrosion Testing Flowchart for Soil and Water Samples Received from District Materials Labs or Construction Labs



10. CORROSION MITIGATION MEASURES

The following section provides some useful information regarding corrosion mitigation measures for structural elements. As previously mentioned, Department guidelines such as the *Bridge Design Specifications*, *Memos to Designers*, *Standard Specifications*, *Special Provisions*, *Bridge Design Reference Specifications*, and the *Highway Design Manual* have been developed to cover these topics. The purpose of the information provided in this section is to provide additional background information regarding corrosion mitigation in addition to the listed Department guidelines.

10.1 Corrosion Mitigation Measures for 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.

In general, the corrosion behavior of structural steel in soil can be divided into two categories, corrosion in disturbed soil and corrosion in undisturbed soil. 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 create 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.

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, 5.5 or less, and soil minimum resistivity was below 1,000 ohm-cm. For these reasons, it is always recommended to test fill material for corrosivity.

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.

Soil Embedded Zone	**0.025 mm (0.001 in) per year**
Immersed Zone	**0.100 mm (0.004 in) per year**
Scour Zone	**0.125 mm (0.005 in) per year**

The corrosion rates apply only if the soil and/or water are corrosive. If a site is characterized as non-corrosive, then no corrosion allowance (sacrificial metal loss) is necessary. This information is also included in *Bridge Memo to Designers 3-1*, (http://www.dot.ca.gov/hq/esc/techpubs).

For steel piling driven into undisturbed soil, the region of greatest concern for corrosion is the portion of the pile from the bottom of the pile cap or footing down to 1 m (3 ft) below the water table. This region of undisturbed soil typically has a replenishable source of oxygen needed to sustain corrosion. A corrosion rate of 0.025 mm per year should be used for the length of pile in this region. No corrosion rate is required for the length of pile outside of this region.

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 15 mm (0.6 in), calculated using 0.1 mm/yr (0.004 in/yr) x 75 years x 2 exposure faces.

For steel pipe piling, used in corrosive soil and/or water, the corrosion allowance is only needed for the exterior surface of the pile. The interior surface of the pile (soil plug side) will not be exposed to sufficient oxygen to support significant corrosion.

The above corrosion rates and allowances for piles are also applicable to permanent steel shells, used at corrosive sites that are intended to carry axial or lateral structural load.

However, 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 may be considered as an alternative corrosion protection strategy. Before this alternative is selected, however, the need to protect the coating from damage during the driving operation, coating repair strategies, and the method of field coating pile splice sections should be considered. Contact the Corrosion Technology Branch of METS for assistance with selecting coating alternatives.
When coatings are proposed to mitigate corrosion of steel piles, the effect of the coating on the skin friction capacity of the pile should also be considered. Contact the DES Geotechnical Services for assistance with concerns related to reduced skin friction capacities of piles.

10.2 Corrosion Mitigation Measures for Reinforced Concrete

Uncontaminated, high quality concrete normally provides excellent corrosion protection for reinforcing steel. The high pH environment, greater than 12.5, of the concrete keeps the reinforcing steel in a non-active corrosion state. Intrusion of chlorides into the concrete through contact with chloride-contaminated soil, water or marine atmosphere, however, may lead to corrosion of the embedded reinforcing steel.

Contact of the concrete with soil or water containing sulfates can, over time, cause deterioration, increased porosity, and decreased pH of the concrete. In addition to the obvious loss of integrity of the concrete, this degradation may also lead to accelerated corrosion of the reinforcing steel.

Corrosion protection of reinforced concrete is required in accordance with *Bridge Design Specification (BDS), Article 8.22* (http://www.dot.ca.gov/hq/esc/techpubs). *BDS, Article 8.22* specifies the use of increased clear concrete cover over the reinforcing steel, corrosion resistant concrete mix designs, and epoxy coated reinforcing steel for corrosion protection of reinforced concrete exposed to chloride environments. *BDS, Article 8.22* also provides mitigation measures to protect against corrosion due to acids or sulfates. Corrosion mitigation measures presented in *BDS, Article 8.22* are specifically intended for bridge structures and substructures that have design lives of 75 years.

Structure Reference Specification S8-C04(90CORR)_R06-19-01, (http://www.dot.ca.gov/hq/esc/structurespecs), provides specification language for corrosion resistant concrete mix designs that address corrosive conditions specified in *BDS, Article 8.22, Tables 8.22.1 and 8.22.2*.

In addition to the concrete cover requirements specified in *BDS, Article 8.22, BDS Articles 4.5.16.7, 4.5.17.8, and 4.6.6.2.5* (http://www.dot.ca.gov/hq/esc/techpubs) provide additional information regarding concrete cover requirements for piles.

Concrete mixes used by the Department to mitigate chlorides are based on the diffusion rate of chlorides using Fick's Second Law of Diffusion. Dense concrete mixes that are less permeable slow the diffusion of chlorides through concrete. Therefore, the time for chlorides in the soil or water to reach the reinforcing steel is increased. It is desirable to slow the rate of chloride diffusion in reinforced concrete because high chloride contents at the level of the reinforcing steel will cause the reinforcing steel to corrode.

The use of mineral admixtures (such as flyash, silica fume, metakaolin, etc.), reduced water content, and increased cementitious material content result in high-density, durable concrete. Additional thickness of clear cover over the reinforcing steel also increases the time it takes for chlorides to reach the level of the reinforcement. *Bridge Memo to Designers 10-5* (http://www.dot.ca.gov/hq/esc/techpubs) provides additional guidance regarding protection against corrosion for reinforced concrete due to chlorides, sulfates, and acids.

In addition to low permeability concrete and increased cover to delay the initiation of corrosion, the Department also specifies epoxy-coated reinforcing steel (ECR) for reinforced concrete subjected to high concentrations of deicing salt (Climate Area III) and salt or ocean water.

Protective coatings for reinforced concrete surfaces, such as dampproofing and waterproofing may also be used as mitigation measures. See Section 10.4 of these guidelines for additional information regarding these treatments.

Reinforced concrete superstructures along the coast can corrode due to marine atmospheric exposure if not properly designed. The Department defines marine atmosphere as that atmosphere within 300 m (1000 ft) of ocean or tidal water. Tidal water, for this application, is any body of surface water having a chloride content of 500 ppm or greater. Corrosion mitigation measures for marine atmospherically exposed concrete are also provided in *BDS, Article 8.22*.

10.3 Epoxy-coated Reinforcing Steel

The Department currently has specifications for two types of epoxy-coated reinforcing steel (ECR): Pre-fabricated ECR (purple or gray in color) and post-fabricated ECR (green in color).

Pre-fabricated ECR is specified for reinforced concrete that is in direct contact with water containing 500 ppm or more of chlorides, or in the marine splash zone. It is generally not used if only the soil is corrosive. For this type of coating, the reinforcing steel is cut to size and bent to shape (i.e., pre-fabricated) prior to being coated with a protective fusion bonded epoxy coating. Pre-fabricated ECR is not intended to be bent or rebent after being coated. Epoxy powder formulations meeting the requirements of *ASTM Designation: A 934/ A 934M* are "less-flexible", highly cross-linked coatings that contain special organic fillers which greatly enhance their resistance to water penetration, lower their susceptibility to loss of coating adhesion and underfilm corrosion, and provide greater resistance to ultraviolet (UV) radiation. These formulations are better suited to protect reinforcing steel in concrete placed in continuously wet marine environments when compared to post-fabricated epoxy powder formulations. *Structure Reference Specification 52M_PURP* has been developed to include the use of *ASTM Designation: A 934/ A 934M* epoxy powders. *Bridge Memo-To-Designers 10-6* (http://www.dot.ca.gov/hq/esc/techpubs) provides additional guidance regarding the use of epoxy-coated reinforcement.

Post-fabricated ECR formulations meet the requirements of *ASTM Designation: A 775/ A 775M*. Section 52-1.02B of the Department's *Standard Specifications* (http://www.dot.ca.gov/hq/esc/oe/specs_html/index.html) has been developed to include the use of epoxy-coated reinforcement coated in accordance with *ASTM Designation: A 775/ A 775M*. For this type of ECR, straight bars or wire are coated and subsequently cut and bent to shape. Post-fabricated ECR is generally used in Climate Area III where deicing salts are used. *Bridge Memo-To-Designers 8-2* (http://www.dot.ca.gov/hq/esc/techpubs) provides additional information regarding climate areas within the State.

10.4 Dampproofing and Waterproofing

When a coating is required to minimize exposure of concrete, reinforced concrete, or metal surfaces to moisture, dampproofing or waterproofing should be considered. *Standard Specification 54-1.03* describes both methods in detail (See Ref. 10). Dampproofing requires the concrete surface to be cleaned and treated with a solvent-based primer, then mopped with two coats of hot asphalt. Waterproofing is similar to dampproofing, but provides even more corrosion protection. In addition to cleaning and treating with a solvent-based primer, two layers of glass fabric membrane and three mop applications of hot asphalt are required for waterproofing concrete structures.

Because of air quality restrictions in some geographical regions, ASTM Designated material D-41, a solvent-based primer, may not be allowed. When the ASTM D-41 primer cannot be used, slow curing emulsion alternatives SS1H or CSS1H, specified in Section 94 of the *Standard Specifications*, are acceptable.

Dampproofing and waterproofing may be considered for a concrete surface or for a column retrofit when a steel shell is used. Generally, corrosion can occur where the soil is in contact with the surface to be protected; therefore, it may only be necessary to treat those surfaces in contact with soil. Dampproofing and waterproofing may also be considered for protecting concrete surfaces exposed to highly acidic soil and/or water. These treatments may also be used as mitigation measures to protect RCP from stray current by coating the inside and outside of the pipe.

10.5 Rockfall Mitigation

Rockfall protection facilities in corrosive environments should be protected against corrosion. Corrosive environments are generally located within 300 m (1000 ft) of ocean or tidal water. Tidal water, for this application, is any body of surface water having a chloride content of 500 ppm or greater. Rockfall facilities in Climate Area III that are exposed to deicing salts, snow runoff, or snow blower spray should also have corrosion protection. *Bridge Memo-To-Designers 8-2* (http://www.dot.ca.gov/hq/esc/techpubs) provides additional information regarding climate areas within the State.

There are many types of rockfall mitigation measures. There are two types of systems involving wire and cable structures, referred to as static and dynamic systems. The static systems, referred to as drapery systems, lay on the slope. In this design, the rocks move slowly downslope into a ditch. There is assumed to be little damage to the wire or cable. Therefore, in corrosive environments the wire and cable are galvanized and plastic coated.

For dynamic systems in corrosive environments, since the wire and cable are damaged by the rockfall, stainless steel should be specified for these components.

Rockfall protection facilities should incorporate the following mitigation measures in corrosive environments. In accordance with the plans, special provisions, and type of system as explained above, wire mesh fabric, wire rope, and cable should be galvanized steel and coated with PVC or another approved material; or made of stainless steel. All anchors, bolts, nuts, washers, clamps, and similar exposed metal should be made of stainless steel. Care must be taken to ensure that the PVC or other coatings are not damaged during installation, especially at intersections with fasteners and clamps.

There are two Department contacts for rockfall mitigation issues. Contact either John Duffy at (805) 549-3663 or (805) 773-0556, or Tim Beck at (916) 227-7184 for questions or assistance regarding specifications for these types of projects. Both contacts are Geotechnical Services staff from the Office of Geotechnical Design – North.

10.6 Gabions

For assistance regarding the corrosion evaluation and mitigation measures for gabions, refer to the *Gabion Mesh Corrosion* publication available at the following Division of Design website, http://www.dot.ca.gov/hq/oppd/guidance.htm. To access this report, right click on the document and select "save target as" to save downloaded PDF-formatted document to your hard drive.

11. CORROSION ASSESSMENT OF EXISTING STRUCTURES

Rehabilitation of structures is the responsibility of the Maintenance Program's Office of Structure Maintenance and Investigations. In areas where structures are exposed to chlorides as the result of using deicing salts, corrosion deterioration is monitored. Systematically, the chloride content of representative cores from bridge decks and substructures is determined The results of these tests are used to develop various rehabilitation strategies.

Reinforced concrete core samples are forwarded directly to the Corrosion Technology Branch of METS for processing and testing. Processing concrete for corrosion testing typically involves cutting the core into 25 mm (1.0 in) segments, crushing the segments, and pulverizing each segment as a separate sample so that it will pass a 150 *u*m (No. 100) size sieve. Chemical analyses, in accordance with *California Test Method 404*, "Method of Test for the Chemical Analysis of Portland Cement" (http://www.dot.ca.gov/hq/esc/ctms/index.html), are then performed on the minus 150 *u*m material. Typically, samples are analyzed for chloride content, but other compounds such as sulfates may also be tested. Test results for chloride and sulfate are calculated in ppm or the equivalent kg/m^3 of concrete.

The Corrosion Technology Branch reports the chloride test results for the concrete cores for each 25 mm (1.0 in) sample on a corrosion test summary report.

The level of chloride concentration in concrete at or near the depth of the steel reinforcement is used to estimate the condition of the steel (to determine whether it is corroding or not), and to determine the amount of concrete that would need to be removed during rehabilitation. It should be noted that cores taken at locations with cracks in the concrete or through delaminated areas generally have higher chloride concentrations compared to cores removed from non-cracked locations. For this reason, it is suggested that cores be taken at both non-delaminated/non-cracked locations as well as delaminated/cracked locations to better assess the chloride level of the structure. The following rules of thumb are offered here for information only regarding chloride concentration and condition of reinforcing steel:

Chloride Concentration in Reinforced Concrete

kg/m^3	lb/yd^3	Assumed Condition
0 to 0.7	0 to 1.2	Passive (non-corroding)
0.9 to 1.8	1.2 to 3.0	Corrosion initiation
> 1.8	> 3.0	Active corrosion

For example, consider a concrete core that was taken from a bridge deck that has 50 mm (2 in) of clear concrete cover to the top mat of reinforcing steel. If the second segment from the top of the core, 25 mm (1 in) to 50 mm (2 in) segment, has a chloride content 2.4 kg/m^3 (4 lb/yd^3), then it is assumed that the top mat of rebar is actively corroding. Since there is 50 mm (2 in) of cover to the top mat, the rebar is surrounded by concrete that has a chloride loading of 2.4 kg/m^3 (4 lb/yd^3) which is greater than the 1.8 kg/m^3 (3.0 lb/yd^3) threshold for active corrosion.

12. MISCELLANEOUS TOPICS

12.1 Stray Current Mitigation

Stray current in the soil has been around since the first outdoor electrical installations. Although alternating current (AC) can cause corrosion, it is generally considered insignificant (more than a thousand times less) when compared to corrosion from direct current (DC). Since someone would normally receive an electrical shock from AC before corrosion would become a problem, this section will only address issues from DC stray currents.

Stray current corrosion (interference corrosion) is corrosion caused by direct current from an external source that travels through paths other than the intended circuit. Accelerated corrosion may result if the current is collected by a structure and leaves to enter the soil.

Stray currents in bridge structure elements can be caused in two ways, either through direct connection or through a soil gradient.

Direct connection involves attaching a pipeline, electric railway track, or high-voltage contact system to bridge structure elements. Installation requires an approved insulator between the pipe or rail and the bridge element, and the high-voltage contact system requires double insulation for safety. Since concrete is not an insulator, a failed insulator, even if connected only to the concrete, will cause corrosion in bridge structure elements.

Discharging current into the soil produces soil gradients. The most common source is a cathodic protection system for a pipeline, which produces a steady DC voltage in the soil near the anode(s). By contrast, the DC soil voltage near a traction power substation (TPSS) is zero for a totally ungrounded TPSS, pulsing for a diode-grounded TPSS, and pulsing/reversing for some heavy rail TPSS.

Proposals for pipelines attached to bridge structures or located within two pipe diameters should be submitted for review. Also, notification of pipeline cathodic protection anode bed(s) located near a bridge (within one bridge length) should be included in the proposal.

Measures must be taken to mitigate possible stray current problems whenever they are anticipated or suspected. The DES Office of Electrical, Mechanical, Water, and Wastewater Engineering should be contacted to review proposals and to provide assistance in mitigating stray current problems.

The above considerations given for bridge structures also apply to long steel culverts and pipes.

12.2 Dust Palliatives

At some construction sites dust palliatives may be applied for dust control. Prior to application, it must be determined whether the dust palliative will create a corrosion problem or be deleterious to concrete due to salt content in the palliative. Chlorides in the dust palliative can cause corrosion of pavement dowels, reinforced concrete, or steel structures. Also, sulfates in the dust palliative can attack portland cement concrete pavement or concrete structures. There can be high accumulations of sulfates and chlorides, particularly if the dust palliative is applied in multiple applications.

Contact the Corrosion Technology Branch, if necessary for assistance related to the corrosion potential of dust palliative additives.

12.3 Encroachment Permits

An encroachment permit issued by the Department, or issued by a local agency in certain circumstances, is a permissive authority to enter State highway right of way and to construct approved facilities or conduct specified activities. An encroachment permit must be obtained from one of the District Encroachment Permit offices prior to construction or encroachment. Some construction encroachments may involve corrosion issues. For example, utility, pipeline, or culvert installations under a State highway should be reviewed for corrosion protection prior to permits being issued.

Encroachment permit applications that include installing gas gathering, transmission and/or distribution piping systems must indicate that they comply with all applicable California Public Utilities Commission (CPUC), Federal Pipeline Safety and Local Agency regulations.

Encroachment permit applications that include installing water gathering, transmission and/or distribution piping systems must indicate that they comply with all applicable California Public Utilities Commission (CPUC), Water Works Association (AWWA), Federal Pipeline Safety and Local Agency regulations.

If the encroachment permit application involves corrosion issues, the District Encroachment Permit office may request the Corrosion Technology Branch of METS to conduct a technical review. The Corrosion Technology Branch can review the environmental conditions, materials, corrosion protection, and cathodic protection (if any) associated with the installation or construction. Although each project must be handled on a case-by-case basis, at a minimum, the applicant should submit supporting documentation to the District Encroachment Permit office such as plans and specifications for the project, cathodic protection details, soil and water corrosion test results, geologic logs of soil borings, etc.

Depending on the complexity of the project, it may take several weeks for the Corrosion Technology Branch to conduct a thorough corrosion review of the corrosion-related aspects of the encroachment permit. Upon completion of the corrosion review, the Corrosion Technology Branch will submit review comments to the District Encroachment Permit office. If the applicant has not included sufficient corrosion protection in the project, additional corrosion protection recommendations will be provided by the Corrosion Technology Branch to the District Encroachment Permit office for the applicant.

12.4 Miscellaneous Metals

Miscellaneous metal parts and components are often used in roadway facilities and transportation structures. Fasteners, concrete anchors, plates, and frames are just a few examples. Typical corrosion protection includes zinc galvanizing in accordance with the Standard Specifications. However, in corrosive environments such as in coastal areas, the splash zone, or underwater, improved corrosion protection may be necessary. Stainless steel is often specified instead of galvanized steel. For critical components in corrosive environments, stainless steel Type 316 is preferred. Stainless steel Type 316 contains molybdenum that improves its corrosion protection over more commonly used stainless steels such as Type 304.

If you have questions regarding materials selection for miscellaneous metal parts and components, contact the Corrosion Technology Branch of METS for assistance.

12.5 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. *Bridge Construction Memo (BCM) 130-9.0*, available at the Department's internal website, http://dschq.dot.ca.gov:82/Construction_Records_and_Procedures/Vol_II/130-9.0_BCM.pdf, provides information regarding the acceptance, rejection, and mitigation requirements for CIDH piles. As described in Section D of the Pile Design Data Form (Attachment No. 3 of *BCM 130-9.0*), consideration of corrosion potential is only needed for anomalies that are between the top of the pile and 1 m (3 ft) below the lowest possible ground water surface. For anomalies outside these limits, and where no stray current source is identified, no consideration of corrosion potential is required. The rationale for this requirement (excluding the issue of possible corrosion from outside electrical sources) is that sufficient oxygen is not available below the ground water surface to promote significant corrosion of nearly exposed or exposed steel (such as reinforcement at or near a pile anomaly).

Note that even though corrosion potential may be low, repair of CIDH pile anomalies may still be required for other structural or geotechnical reasons.

13. REFERENCES

The following corrosion references are taken from various Department documents and are presented here for the convenience of the users of these guidelines.

1. *Highway Design Manual, Topic 850, Physical Standards* (http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm).

2. *Bridge Design Specifications, Section 4, Foundations* (http://www.dot.ca.gov/hq/esc/techpubs).

3. *Bridge Design Specifications, Section 8.22, Protection Against Corrosion* (http://www.dot.ca.gov/hq/esc/techpubs).

4. *Memo To Designers, 3-1, Corrosion, Deep Foundations* (http://www.dot.ca.gov/hq/esc/techpubs).

5. *Memo To Designers, 8-2, Protection Against Deicing Chemicals and Freeze-Thaw Environment* (http://www.dot.ca.gov/hq/esc/techpubs).

6. *Memo To Designers, 10-5, Protection of Reinforcement Against Corrosion Due to Chlorides, Acids, and Sulfates* (http://www.dot.ca.gov/hq/esc/techpubs).

7. *Memo To Designers 10-6, Use of Prefabricated Epoxy Coated Reinforcement in Marine Environment* (http://www.dot.ca.gov/hq/esc/techpubs).

8. *Standard Special Provisions S8-M25 or S8-M26, Slag Aggregate, Districts 7, 8, 11 and 12* (Sec_08_Mtls/ at website http://www.dot.ca.gov/hq/esc/oe/specs_html).

9. *Bridge Construction Memo 130-9.0, Mitigation of CIDH Piles Constructed Using the Slurry Displacement Method*, available at the Department's internal website at http://dschq.dot.ca.gov:82/Construction_Records_and_Procedures/Vol_II/130-9.0_BCM.pdf.

10. *Standard Specifications Section 54, Waterproofing and Dampproofing* (http://www.dot.ca.gov/hq/esc/oe/specs_html).

11. *Standard Special Provision 65-010 and 65-100, Miscellaneous Requirements for Reinforced Concrete Pipe* (http://www.dot.ca.gov/hq/esc/oe/specs_html).

12. *Structures Reference Specification 50-560 (50TIEB), Tieback Anchors* (http://www.dot.ca.gov/hq/esc/structurespecs).

13. *Structures Reference Specification, 50-570 (50-TIED), Tiedown Anchors* (http://www.dot.ca.gov/hq/esc/structurespecs).

14. *Structures Reference Specification, 19-660 (19NAIL), Soil Nail Assembly* (http://www.dot.ca.gov/hq/esc/structurespecs).

15. *Standard Special Provision 19-600, Earth Retaining Structures*, *Requirements for Mechanically Stabilized Embankments (MSE walls)*, available in Section 10 at website http://www.dot.ca.gov/hq/esc/oe/specs_html).

16. *Bridge Construction Memo 145-8.0, Mechanically Stabilized Embankment Wall Construction Checklist, July 2001*, available on the Department's internal website at http://dschq.dot.ca.gov:82/Construction_Records_and_Procedures/Vol_II/145-8.0_BCM.pdf.

17. *California Test Method 643, Method for Estimating the Service Life of Steel Culverts* (http://www.dot.ca.gov/hq/esc/ctms/index.html).

18. *California Test Method 422, Method of Testing Soils and Waters for Chloride Content* (http://www.dot.ca.gov/hq/esc/ctms/index.html).

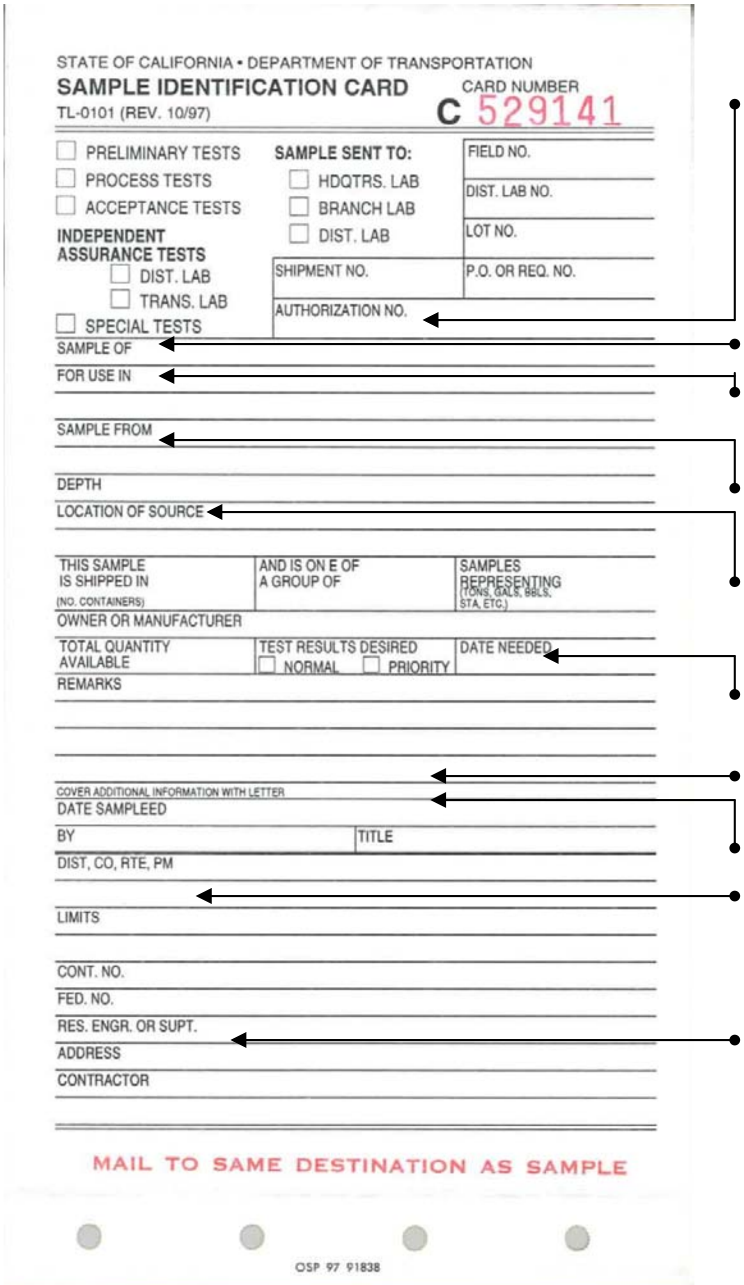
19. *California Test Method 417, Method of Testing Soils and Waters for Sulfate Content* (http://www.dot.ca.gov/hq/esc/ctms/index.html).

20. *California Test Method 404, Method of Test for the Chemical Analysis of Portland Cement, Fly Ash, Pozzolan, Blended Cement* (http://www.dot.ca.gov/hq/esc/ctms/index.html).

21. *California Test Method 125, Methods for Sampling Highway Materials and Products Used in the Roadway Structural Sections* (http://www.dot.ca.gov/hq/esc/ctms/index.html).

14. APPENDIX

14.1 TL-0101 Form



STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION
SAMPLE IDENTIFICATION CARD
TL-0101 (REV. 10/97)
CARD NUMBER C 529141

☐ PRELIMINARY TESTS
☐ PROCESS TESTS
☐ ACCEPTANCE TESTS
INDEPENDENT ASSURANCE TESTS
☐ DIST. LAB
☐ TRANS. LAB
☐ SPECIAL TESTS

SAMPLE SENT TO:
☐ HDQTRS. LAB
☐ BRANCH LAB
☐ DIST. LAB

FIELD NO.
DIST. LAB NO.
LOT NO.
SHIPMENT NO.
P.O. OR REQ. NO.
AUTHORIZATION NO.
SAMPLE OF
FOR USE IN
SAMPLE FROM
DEPTH
LOCATION OF SOURCE
THIS SAMPLE IS SHIPPED IN (NO. CONTAINERS) | AND IS ON E OF A GROUP OF | SAMPLES REPRESENTING (TONS, GALS, BBLS, STA, ETC.)
OWNER OR MANUFACTURER
TOTAL QUANTITY AVAILABLE | TEST RESULTS DESIRED ☐ NORMAL ☐ PRIORITY | DATE NEEDED
REMARKS
COVER ADDITIONAL INFORMATION WITH LETTER
DATE SAMPLEED
BY | TITLE
DIST, CO, RTE, PM
LIMITS
CONT. NO.
FED. NO.
RES. ENGR. OR SUPT.
ADDRESS
CONTRACTOR

MAIL TO SAME DESTINATION AS SAMPLE

OSP 97 91838

- Must include EA to process samples.
- Type of sample (soil, water, concrete, etc.)
- Type of project (i.e., backfill for MSE wall, foundation investigation, soundwall, etc.)
- Bridge name and number, boring hole number, bent number, station, etc.
- Additional site specific info. (i.e., streambed, stockpile, core/sample location, etc.).
- Required information for tracking purposes.
- List tests needed (i.e., min resistivity, pH, chloride, sulfate).
- Required information.
- Required information.
  Specify whether PM or KP is provided.
- Required information for reporting of test results. Include full name, address, phone number, and fax number.