Prepared By: Mersedeh Akhoondan

Mersedeh Akhoondan

Prepared By: B C

Brien Clark

Reviewed By: Steve R Fox

Steven Fox

Reviewed By: Dana R Hunt

Dana Hunt

CITY OF SUNNYVALE

WATER POLLUTION CONTROL PLANT

DESIGN STANDARDS

CORROSION

July 2014

carollo

in association with HDR

2700 YGNACIO VALLEY ROAD • SUITE 300 • WALNUT CREEK, CALIFORNIA 94598 • (925) 932-1710 • FAX (925) 930-0208

CITY OF SUNNYVALE

WATER POLLUTION CONTROL PLANT

DESIGN STANDARDS

CORROSION

TABLE OF CONTENTS

Page No.

LIST OF TABLES

1.0 PURPOSE AND CONTENT

This document describes the corrosion engineering design standards to be used for improvement projects at the City of Sunnyvale's (City) Water Pollution Control Plant (WPCP). These standards will be used for preliminary and final design of the WPCP improvements. Included in the standards are recommended materials of construction for various civil, architectural, and structural elements along with recommended coating systems for these elements in various environments. Also included are the methodology for corrosivity classification of the soils at the site and the requirements for cathodic protection based on soil classification. In case this document overlaps and conflicts with governing codes and standards the stricter interpretation or directive shall be followed.

Designer shall coordinate with other design standards prepared for other disciplines.

The design engineer is responsible for the design. The design standards herein shall be reviewed and confirmed for the appropriateness for individual projects. If the design engineer disagrees with the information contained within the design standards or wishes to propose an alternative, the City shall be notified and the design engineer's recommendation discussed prior to implementation.

2.0 STANDARD DEFINITIONS AND ABBREVIATIONS

ºF	Degrees Fahrenheit
CP	Cathodic protection
CPVC	Chlorinated Polyvinylchloride
Corrosion Engineer	Refers to a person who is either a licensed Professional Corrosion Engineer in the State of California or certified as a "Cathodic Protection Specialist" or Corrosion Specialist by NACE International (formerly National Association of Corrosion Engineer, NACE). The qualifications for the Corrosion Engineer shall be submitted to the City for approval prior to commencement of the design work.
FRP	Fiberglass-reinforced plastic
PE	Polyethylene
PP	Polypropylene
PVC	Polyvinylchloride

WPCP	Water Pollution Control Plant
WWTP	Wastewater Treatment Plant

3.0 CODES AND STANDARDS

The latest adopted version by the City of the following codes and standards apply to projects at WPCP. Corrosion engineering design shall be subject to:

- American National Standards Institute (ANSI)
- American Society for Testing and Materials (ASTM)
- American Water Works Association (AWWA)
- Industrial Cable Engineers Association (ICEA)
- NACE International, (formerly National Association of Corrosion Engineers, NACE)
- National Electrical Manufacturers Association (NEMA)
- SSPC: The Society for Protective Coatings (formerly Steel Structures Painting Council, SSPC)

4.0 PROCEDURES AND GUIDELINES

Structural/loading performance of the material in a given service is usually the primary determinate for the selection of that material. Corrosion resistance in that environment is a secondary concern, typically weighed against additional costs that corrosion resistance material can occur. For alloyed material, increases in structural strength typically reduces corrosion resistance and vice versa. Consult the Mechanical Design Standards.

All corrosion engineering will be done in accordance with this document and applicable codes, specifications, and standards, as well as to reflect the judgment and experience of the responsible Professional Engineer. Designers will use the guidelines contained herein unless there is an overriding reason not to use them for particular components of the Project. In that event, documentation must be provided in the calculations or by separate memorandum.

The design shall be sent to the City's Building Department for review and comment at 60, 90, and 100% design stages.

4.1 General

The corrosive environments typically present in a wastewater treatment plant (WWTP) can cause rapid deterioration and premature failures of structures and equipment. There are, however, materials that can be selected to improve performance, reduce maintenance, and extend operating life. At the same time, the plant's overall appearance will be maintained.

Corrosion in a WWTP typically is caused by several conditions, single or in combination, that accelerate deterioration of common materials of construction. These conditions include:

- Complete or partial immersion in wastewater typically contaminated with chlorides, sulfate, phosphate, nitrogen ions and a wide variety of organic compounds.
- Presence of hydrogen sulfide (H_2S) (the severity of this exposure depends on how confined the H_2S is in a particular area) in the presence of moisture to form sulfuric acid.
- Acid environments resulting from condensation of H_2S or from biological byproducts
- Confined areas with high humidity
- Saltwater Infiltration can result in high TDS corrosive water
- Chlorine gas and hypochlorite (bleach) solutions resulting in chlorine fumes.
- Locations subject to salt air from the proximity of the San Francisco Bay.
- Chemicals used to maintain the plant equipment or used in the treatment process.

The severity of the environment typically is greater at the inlet end of the plant and diminishes as wastewater proceeds through the facility.

In addition to the bulk material of constructions, the designer and supplier should evaluate the inner components such as springs that may be exposed to process fluids.

Corrosion can be controlled by first defining the particular environment to which a structure or item of equipment will be exposed. Then, optimum performance and proper corrosion control can be achieved by selecting appropriate materials for construction and applying suitable protective coatings and/or cathodic protection.

Due to the volume of materials required for most wastewater industry facilities, complete use of corrosion-resistant high alloy or specialty metals is not economically feasible. Plastics are inexpensive and can be used extensively, but tend to have less desirable mechanical properties. The key is to choose the appropriate materials for the anticipated service and environment. These design standards are to be used to ensure uniformity and consistency in the selection and corrosion protection of the materials of construction. In each category, two types of exposure will be discussed: atmospheric exposure and immersion exposure, except for buried carbon steel structures and buried metallic pipelines which will include exposure to soils. In addition, special attention will be given to underground structures, chemical storage areas, or other unusual situations. Where appropriate, reference is made to standard details or standard specifications for more specific information. Weathering, oxidation from the sun, and chemical exposure have similar effects to corrosion and should be considered when selecting materials.

Galvanic corrosion is a separate phenomenon where the potential difference between two metals connected electrically in a common electrolyte propagates corrosion of the more active metal. To limit this effect, prevent contact of different metals in the same electrolyte. This can be accomplished by using the same metal or by electrically isolating different metals. If electrical contact between dissimilar metals is unavoidable, attempt to minimize the potential difference between the metals and ensure the more active metal has a larger surface area than the noble metal.

The general guidelines for design considerations are as follows:

- All metal in enclosed airspaces (headspace) shall be Type 316 stainless steel.
- Metal submitted to regular wetting such as that above open tanks or that regularly washed down shall be Type 316 stainless steel.
- Machined and uncoated flange surfaces on pipe connections shall have full gaskets or sleeves to cover any non-corrosion resistant metal faces, edges, and surfaces.
- Prevent contact between dissimilar metals in a common electrolyte to the extent possible.
- Specific requirements for piping materials and coating are addressed in Section 4.5.

Table 1 summarizes the recommended materials of construction.

**Table 1 Recommended Materials of Construction
Corrosion Design Standards
City of Sunnyvale**

Equipment	Preferred Material	Alternative Material
Piping	Mechanical Design Standards – Appendix A Piping Materials Schedule	
Pipe Supports	Type 316 stainless steel, FRP	
Grating, Stair Treads, and Handrails (in chemical storage Areas)	FRP	Stainless steel (except in any chloride environments including chlorine gas, hypochlorite, hypochlorous acid, and hydrochloric acid)
Grating, Stair Treads, and Handrails (in remainder of plant)	Aluminum	Stainless steel
Exposed Fasteners	Type 316 stainless steel	
Ladders	Chemical areas: FRP Submerged: Type 316 stainless steel Other: Aluminum	

Table 1 Recommended Materials of Construction Corrosion Design Standards City of Sunnyvale		
Equipment	**Preferred Material**	**Alternative Material**
Conduit	PVC coated rigid steel (above grade) PVC (below grade)	
Cable Trays	Aluminum, FRP	Painted Steel
Chemical Tanks	HDPE, FRP, XLHDPE, LDPE	
Slide Gates (body and guides)	Type 316 stainless steel	
Sluice Gates – in wastewater	Ni-Resist cast iron with coatings	Type 316 stainless steel
Sluice Gates – in Chlorine Contact Tanks	Type 316 stainless steel (FRP if near chlorine injection point)	

4.2 Fabricated Metals

The descriptions in the sections below provide guidance for the selection of material characteristics for wastewater materials from a corrosion engineering standpoint. The design requirements for structural and mechanical characteristics are addressed in another section of the Design Standards.

4.2.1 Carbon Steel: Atmospheric Exposure

Carbon steel structural elements shall be protected from external corrosion by the use of an adequate coating system. In open areas and dry, non-process areas of the plant, protect structural steel with a suitably specified protective coating system. In general, polyamide epoxies are suitable except when exposed to UV light and aliphatic polyurethanes are suitable for UV light exposure.

In more aggressive environments, such as areas above basins and in buildings with high humidity (including most process areas of the plant), coat structural steel with a suitably specified protective coating system such as novolac epoxies and aromatic polyurethanes.

4.2.2 Carbon Steel: Immersion Exposure

For immersion applications of carbon steel an appropriate protective coating shall be specified. The proper coating will be dictated by the service environment, but novolac epoxies and aromatic polyurethanes are generally suitable for most wastewater immersion service. The designer should also consider using corrosion resistant materials such as Type 316 SST.

4.2.3 Carbon Steel: Buried

The use of carbon steel in underground applications is acceptable if proper corrosion mitigation is provided. Underground pipelines should be protected, suitable protection such as a tape coat system per American Water Works Association standard C214, fusion-bonded epoxy per AWWA C213, aromatic polyurethane per AWWA C222, extruded polyethylene (polyolefin) per AWWA C215, or cement-mortar per AWWA C205.

See Section 4.6 of this document for carbon steel pipelines.

Buried carbon steel structures, other than driven piling, should be protected with an appropriate coating system and supplemented with cathodic protection. Underground storage tanks are not acceptable.

Steel piling driven into undisturbed soil may require corrosion control in the form of a corrosion allowance, coatings and/or cathodic protection. The project Corrosion Engineer should make this determination. If a coating is selected, it shall be abrasion resistant.

Requirements for buried pipes are addressed further in Section 4.5.1.3.

4.2.4 Aluminum

Aluminum alloys are suitable for most atmospheric exposures in wastewater treatment facilities. Aluminum is typically suitable for cable trays, stair treads, grating, and handrails, except in chemical storage areas. Cast aluminum is suitable for electrical boxes and fittings. Aluminum alloys also may be used for duct work in all but the most severe chemical exposures.

Embedding uncoated aluminum in concrete should be avoided. Epoxy–coated carbon steel and stainless steel are suitable embedments in concrete and can be utilized for securing aluminum to concrete where needed. In this case, be sure to always electrically isolate the steel and aluminum to prevent galvanic corrosion. Ensure any coated aluminum embedments are well-coated.

4.2.5 Stainless Steel

Stainless steel can be used successfully in a large variety of applications for wastewater treatment facilities.

Stainless steel aeration piping appears to be resisting exposure to wastewater in both immersed and partially immersed environments. The specific types of stainless steel to be utilized should be determined on a case by case basis. Because high chloride concentrations are often found in the wastewater and salt-laden air, Type 316 stainless steel should be specified for all atmospheric, immersion, or partial immersion applications. Stainless steel is also preferred for embedments in concrete.

4.2.6 Fasteners

For all submerged, splash, and spillage exposures, Type 316 stainless steel fasteners should be specified. In wet, humid exposures (no contact with chloride-containing environments, including wastewater), Type 304 stainless steel is not acceptable. To minimize the risk of galvanic corrosion, the use of dissimilar metals in direct contact should be avoided using electrical isolation (e.g., plastic gaskets and coatings). Stainless steel anchors, embedded in concrete, should be coated with epoxy or with fusion bonded epoxy, in order to reduce the possibility of localized corrosion caused by contact with reinforcing steel. In dry, conditioned environments, hot-dipped galvanized steel fasteners are acceptable.

4.2.7 Copper

Because copper is affected rapidly when exposed to H_2S, which is prevalent in a WWTP, its use should be limited to areas away from the wastewater processes. Although copper can be coated to minimize the effects of H_2S exposure, this is discouraged because copper is difficult to clean and coat.

See 4.6.2.3 for copper piping/tubing application.

4.2.8 Grating

Aluminum is the preferred material for grating and covers in process areas. Stainless steel may be specified for similar applications. In areas where chemicals that are highly alkaline, such as sodium hydroxide and lime, are stored, stainless steel or fiberglass-reinforced plastic (FRP) should be specified for grating. Hot-dipped galvanized steel should not be used.

4.2.9 Handrails and Guardrails

Aluminum should be used for handrails and guardrails in all outdoor areas and indoors areas within the process units. FRP handrails and guardrails should be used in chemical storage areas where they are likely to be exposed to spilling or splashing of chemicals, such as sodium hydroxide, sulfuric acid, or hydrochloric acid.

4.3 Architectural Elements and Structures

4.3.1 Flashing and Roof Accessories

Aluminum or coated steel such as Kynar/PVDF or equal is preferred for all sheet metal that is used in flashing and other roofing accessories.

4.3.2 Doors

In most process buildings with high humidity and where H_2S is present, doors, including frames and hardware, should be Type 304 stainless steel. In chemical storage areas, FRP doors are recommended. Stainless steel should not be used around hydrochloric acid or sodium hypochlorite.

In dry, nonaggressive areas, steel doors are acceptable if coated. Specify epoxy coating in process areas and alkyd enamel in non-process areas.

4.3.3 Window Frames

Type 304 stainless steel should be specified for window frames in process areas. Anodized aluminum, bronzed metals, and PVDF coated metals may be specified in non-process areas. The design engineer shall coordinate with the project architect.

4.3.4 Finish Hardware

All finish hardware should be Type 304 stainless steel.

4.4 Electrical

4.4.1 Raceways

Hot-dipped galvanized steel may be used for interior applications with low humidity and low exposure to hydrogen sulfide. PVC-coated galvanized steel should be specified for exterior exposure and in high-humidity areas. Cable trays may be aluminum or FRP throughout the plant.

4.4.2 Outdoor Equipment

Lighting, instruments, and electrical enclosures should be Type 304 stainless steel or FRP, conforming to the applicable National Electrical Manufacturers Association standards for the conditions of service.

4.5 Mechanical

4.5.1 Piping

4.5.1.1 Atmospheric Exposure

Metallic piping (carbon steel) that is exposed to the various atmospheres in a WWTP requires a protective coating system. As with other surfaces to be coated, the proper surface preparation with a minimum near white finish must be specified for the intended service.

Carbon steel pipe requires a protective coating system. A coating consultant shall be contacted for the suitability and availability of the specified product for the intended service environment. In general, polyamide epoxies are suitable except when exposed to UV light and aliphatic polyurethanes are suitable for UV light exposure.

4.5.1.2 Submerged Pipe

In immersion service (wastewater), Type 316 stainless steel and nonmetallic pipe are recommended. Although coated carbon steel and ductile iron may be used in wastewater immersion, the coatings have limited service life and must be maintained over the service life of the pipe. A white metal blast surface prep is required for carbon steel and non-ductile irons; a special surface preparation is required for ductile iron pipe.

FRP pipe is considered to provide equivalent or greater performance than stainless steel. PVC and chlorinated polyvinyl chloride (CPVC) pipe also can be used within their temperature and pressure limits.

4.5.1.3 Buried Pipe

The methods required to mitigate the corrosion of buried pipe depend on the aggressiveness of the soil at the site and the pipe material. Section 4.6 details testing that is required to determine the corrosivity of soil. The typical pipe materials and environmental compatibility guidelines are addressed next.

4.5.1.3.1 Ductile-Iron Pipe (AWWA C151)

If soil-environment conditions meet the following, then a bonded coating and cathodic protection system shall be specified:

- Saturated soil resistivity <500 ohm-cm.
- Anaerobic conditions with sulfate-reducing bacteria (6.5<pH<7.5) with low redox (negative to +100 millivolts [mV]) and sulfides present.
- Fluctuating water table above the invert of the pipe.

Specify that the ductile iron pipe be manufactured bare (asphaltic coating-free). Specify National Association of Pipe Fabricators (NAPF) 500-03R06 in lieu of Society for Protective Coatings (SSPC) standards for surface preparation.

4.5.1.3.2 Steel Pipe (AWWA C200, ASTM A53)

Cement-mortar coatings (AWWA C205) on steel pipe shall not be used in soils with a pH of 5 or less, when chloride concentrations exceed 350 ppm (150 ppm in fluctuating groundwater) or when sulfate concentrations are in excess of 2,000 ppm. In this environment, specify a dielectric coating and cathodic protection.

Specify exterior joints in cement-mortar coated steel pipe to be filled with cement-mortar paste that has chemical and structural characteristics as close as possible to the adjacent factory mortar coating.

4.5.1.3.3 Stainless Steel Pipe (AWWA C220, ASTM A312)

Stainless steel piping shall not be buried. If burial is unavoidable, the stainless steel shall be encased with PVC pipe with solvent-welded joints, wax taped in its entirety, or cathodically protected. The amount of cathodic protection current needed can be minimized by coating the piping with a tape coating such as Polyken or equal.

4.5.1.3.4 <u>Reinforced Concrete Pipe (Non pressure)</u>

Where the soil environment (including the anticipated backfill material) has a soluble sulfate content greater than 2,000 ppm, Type V cement, 0.45 maximum water/cement ratio and 4,500 pounds per square inch (psi) minimum strength of concrete shall be specified.

4.5.1.3.5 <u>Reinforced Concrete Pressure Pipe (AWWA C300, C302)</u>

Reinforced concrete pressure pipe (RCPP) shall not be used in soils with a pH of 5.0 or less. If the soil sulfate concentration is in excess of 2,000 ppm, specify Type V cement, 0.45 maximum water/cement ratio and 4,500 pounds per square inch (psi) minimum strength of concrete shall be specified. When the soil chloride concentration is in excess of 350 ppm (150 ppm in fluctuating groundwater), an external dielectric coating shall be specified to overcoat the concrete or an alternative pipeline material shall be specified.

Where the pipe has a steel cylinder, specify all steel components to be electrically continuous.

All joints that incorporate steel components shall be filled with cement-mortar paste that has chemical and structural characteristics as close as possible to the adjacent concrete.

4.5.1.3.6 <u>Concrete Bar-wrapped Cylinder Pipe (AWWA C303)</u>

Concrete bar-wrapped cylinder pipe (CCP) shall not be used in soils with a pH of 5.0 or less. If the soil sulfate concentration is in excess of 2,000 ppm, specify Type V cement. When the chloride concentration is in excess of 350 ppm (150 ppm in fluctuating groundwater), an external dielectric coating shall be specified over the concrete or an alternative pipeline material shall be specified.

All joints that incorporate steel components shall be filled with cement-mortar paste that has chemical and structural characteristics as close as possible to the adjacent concrete.

4.5.1.3.7 <u>Prestressed Concrete Cylinder Pipe (AWWA C301)</u>

Prestressed concrete cylinder pipe (PCCP) shall not be used in soils with a pH of 5 or less. If the pipeline falls within the limits of fluctuating groundwater, specify a dielectric coating over the exterior. If the soil sulfate concentration is in excess of 2,000 ppm, specify Type V cement. When the chloride concentration is in excess of 350 ppm, specify an external dielectric coating applied over the outer cement-mortar coating. Mortar coating shall be 1-inch minimum, with thickness increased as determined necessary for strain-compatibility to avoid cracking during handling.

Incorporate into the pipe design shorting straps or straps placed under the prestressing wires to make all steel components electrically continuous. Specify shorting straps between the wire anchors and steel cylinder. Incorporate electrical bonding of joints and corrosion monitoring test stations.

All joints shall be filled with cement-mortar paste that has chemical and structural characteristics as close as possible to the adjacent concrete core and coating.

4.5.1.4 Nonmetallic Pipe (AWWA C900, C905, C906; ASTM D1785, D3034, D2665, D2661, D2513)

There are many applications in WWTPs where nonmetallic (plastic) materials may be specified. The two types of nonmetallic materials available are thermoplastic materials and thermosetting materials. Thermoplastic materials include PVC, CPVC, polypropylene (PP), acrylonitrile butadiene styrene (ABS), and polyethylene (PE) including both high density polyethylene (HDPE) and medium density polyethylene (MDPE). Thermosetting materials are FRPs, which can be made with a variety of resins.

Thermoplastic materials are restricted by their upper temperature limit. This can vary between approximately 140°F for PVC to approximately 200°F for CPVC or PP (depending on the process fluid). Thermosetting materials, on the other hand, may be rated to 300°F, depending on the pressure and the process fluid.

Nonmetallic pipe has an advantage over most metal pipes because it is resistant to a wide range of environments. However, thermoplastics must be de-rated significantly at temperatures above ambient. FRP pipe offers many advantages over metal pipe and should be considered for many applications.

Do not use nonmetallic piping in soil containing appreciable amounts of hydrocarbon contaminants (petroleum and petroleum products). Provide an adequate UV resistant coating for nonmetallic pipe where the piping is exposed to ultraviolet light, such as sunlight. Refer to Section 4.7 for coating system selection for various materials and exposures.

Coat metallic fittings such as flange rings, bolts, joint harnesses, and flexible couplings with wax tape per AWWA C217. Wax tape includes corrosion inhibitors woven within a thick hydrophobic wax barrier coating. In addition wax tape is well-suited to protect irregular surfaces such as those common to appurtenances and fittings.

4.5.2 <u>Pipe Hangers and Supports</u>

In high-moisture areas, such as directly over water, Type 304 stainless steel should be specified for pipe hangers. In other process areas of the plant, Type 304 stainless steel or coated carbon steel may be used. For dry, conditioned air exposures, hot-dipped galvanized steel may be used.

4.5.3 <u>Pumps and Valves</u>

The columns of vertical turbine pumps should be coated on the interior and exterior. Normal immersion coatings are not recommended in high velocity areas, such as pump bowls and impellers. Pump supplier recommended coatings may be considered if the coating manufacturer attests that the coating can meet the desired service life given the environment, however alloy construction should generally be used for these components. In very abrasive applications, impellers and pump bowls may need to be rubber lined or provided with abrasion resistant coating or special materials of construction used.

4.5.4 Sluice Gates

Accessible sluice gates may be constructed of cast iron or ductile iron. The austenitic nickel-resist (ni-resist) alloy should be specified for water with high TDS, low chlorides, or low pH wastes. Further protection can be provided by specifying the use of protective coatings and galvanic cathodic protection. Bronze seats and wedges are recommended, with Type 316 stainless steel stems, thrust washers, and nuts. If the sluice gates are not readily accessible for repair or replacement, they should be fabricated from Type 316 stainless steel.

4.5.5 Slide and Weir Gates

Type 316 stainless steel is preferred for slide and weir gates. Type 316 stainless steel should also be specified for guides and miscellaneous structural shapes, although many of these components are now available in FRP.

4.6 Corrosion Control Requirements for Buried Structures and Pipelines

4.6.1 Soil Corrosivity Investigation

4.6.1.1 General

In order to determine what corrosion control measures are required for buried pipelines and structures, a soil investigation shall be performed before the structure or pipeline is designed. The report “Geotechnical Study Master Plan and Facilities Upgrade Project Water Pollution Control Plant” by Fugro Consultants, Inc., project No. 04.72130065, can be consulted for preliminary testing that was conducted.

Table 2 indicates the soil corrosivity investigation that must be performed for each project.

**Table 2 Soil Corrosivity Investigation Requirements
Corrosion Design Standards
City of Sunnyvale**

Pipe Type	Soil Corrosivity Investigation
Steel and Ductile Iron	In-situ soil resistivity values at 200 ft. intervals and soil chemical analysis at 500 ft. intervals
Mortar Coated and Concrete Cylinder	In-situ soil resistivity values at 200 ft. intervals and soil chemical analysis at 500 ft. intervals
Non-Metallic Pipe with Metallic Fittings	In-situ soil resistivity values at 200 ft. intervals and soil chemical analysis at 500 ft. intervals
Concrete Structures	Soil chemical analysis at 2 samples / acre

4.6.1.2 Soil Resistivity Measurements

The basic method of performing soil resistivity shall be the Wenner 4-Pin Method. This test shall be performed in accordance with ASTM G57 standard. Use approximate pin spacings of 2.5, 5, 7.5, 10, and 15 feet or as appropriate to straddle the pipe zone at each location so that variations with depth can be evaluated. Calculate strata resistivities from the resistance data using the Barnes Procedure. The soil resistivity measurements and their locations shall be tabulated and submitted for review. A typical data sheet is provided in Table 3.

Table 3 In-Situ Soil Resistivities (Wenner 4-Pen Method)
Corrosion Design Standards
City of Sunnyvale

Pipeline Location:		Sheet:		of	
Pipe Size:		Date:			
Depth to Bottom of Pipe:		By:			

	Sample Depth (‘D’ Ft.)	Location	Pin Spacing (‘D’ Ft.) (1)	Resistance (OHM) (2)	Resistivity (OHM-CM) (1)x(2)x191.5	Corrosion Rating

Also allowable is an electromagnetic conductivity survey (ECS) that is performed in accordance with ASTM D6639, and converted to resistivity. The advantage of ECS is its completeness and efficiency, since continuous soil conductivity data can be collected along the entire length of the alignment without soil contact.

The corrosion control requirements for a particular pipeline, valve or fitting depends on the soil corrosion rating. Table 4 provides the corrosion rating and corresponding corrosion classification based on soil resistivity.

Table 4 Corrosion Rating and Classification
Corrosion Design Standards
City of Sunnyvale

Resistivity (Ohm-cm)	Corrosion Rating	Corrosion Classification
0 – 1,000	1	Severely Corrosive
1,001- 2,000	2	Corrosive
2,001 – 10,000	3	Moderately Corrosive
> 10,000	4	Mildly Corrosive

4.6.1.3 Soil Chemical Analysis

Corrosion control requirements for mortar coated steel and concrete cylinder pipe depends on the pH, chlorides, and sulfates found in the soil in addition to the soil resistivity. Additional corrosion ratings for mortar coated steel and concrete cylinder pipe based on soil chemistry parameters include:

Chlorides: If chlorides of 350 parts per million (ppm) or higher are found in the soil, it shall be given a corrosion rating of 1. If chlorides of 150 ppm or higher are found in the soil where the pipe will be exposed to cyclic groundwater, it shall be given a corrosion rating of 1 as defined in Table 4.

Sulfates: If water soluble sulfate in soil samples exceeds 2,000 ppm and/or sulfate in water samples exceeds 1,500 ppm, the soil shall be given a corrosion rating of 1 as defined in Table 4.

pH: If soils with a pH of less than 5.0 are found, the soil shall be given a corrosion rating of 1 as defined in Table 4.

4.6.1.4 Laboratory Evaluation

Soil samples shall be tested by an approved soils testing laboratory for the below-listed items using ASTM, AWWA, or Caltrans test methods (CTM) as detailed in Table 5. The preparation of the soil sample for corrosion evaluation shall be in accordance with the applicable specification.

Table 5 Standard Methods Used for Soil Corrosive Testing Corrosion Design Standards City of Sunnyvale			
Analysis	AWWA Standard Methods	ASTM	CTM
Soil Electrical Resistivity	N/A	G187 D6639	643
pH	N/A	G51	643
Hardness (Ca or Mg)	N/A	D6919	N/A
Sodium	N/A	D6919	N/A
Conductivity	2510B	D1125	N/A
Carbonate and Bicarbonate Alkalinity	2320-B	D513	N/A
Sulfide (Qualitative and Redox potential)	AWWA C105 Appendix A	N/A	N/A
Chloride	4500-Cr C	D4327	422
Sulfate	4500-SO_4^{2-} E	D4327	417
Ammonium	N/A	D6919	N/A
Nitrate	N/A	D4327	N/A

4.6.1.5 Additional Notes for Special Cases

4.6.1.5.1 <u>Stray Current Areas</u>

To be treated as corrosion rating 1 as defined in Table 4 (All Pipe).

4.6.1.5.2 <u>pH</u>

- pH values of less than 5.0 shall be treated as corrosion rating 1 as defined in Table 4 (All Pipe).
- pH values of less than 5.5 are considered as aggressive to concrete pipe
- pH values of more than 8.5 corrosive to Aluminum or Lead

4.6.1.5.3 <u>Ammonium</u>

Ammonium concentrations of greater than 10 ppm may be aggressive to copper, the soil shall be given a corrosion rating of 1 as defined in Table 4 for copper.

4.6.1.5.4 __Nitrate__

Nitrate concentrations of greater than 50 ppm may be aggressive to copper, the soil shall be given a corrosion rating of 1 as defined in Table 4 for copper

4.6.2 __Corrosion Control Requirements__

4.6.2.1 General

The external corrosion control requirements for various types of pipe are based on the soils corrosion ratings as provided in Table 4 and Section 4.5 of this document.

4.6.2.2 New Water Mains & Extensions

Steel, Ductile Iron, Mortar Coated Steel and Concrete Cylinder Pipe: Each new main extension, of any length, from an existing metallic main, shall be electrically isolated from the existing main via an isolation flange or joint. This requirement may be altered by the City at their sole discretion. The requirements for corrosion control shall be as specified in Table 6. If cathodic protection is required it shall be designed by a Corrosion Engineer.

Table 6 Critical Soil Parameters for Concrete Structures and Pipe
Corrosion Design Standards
City of Sunnyvale

Parameter	Criteria	Comments
Sulfates*: (for concrete structures and pipe)	Moderate sulfates: 0.10 to 0.20 percent in soils; 150 to 1,500 ppm in water	Requires < 8 percent Tricalcium aluminate (Type II cement), maximum 0.50 water-cement ratio, minimum 5,000 psi
	Severe sulfates: >0.20 to 2.0 percent in soil: > 1,500 ppm to 10,000 ppm in water	Requires < 5 percent tricalcium aluminate (Type V cement), maximum 0.45 water-cement ratio, minimum 4,500 psi
	Very severe sulfates: > 2.0 percent in soil: > 10,000 ppm in water	Requires < 5 percent tricalcium aluminate (Type V cement) and addition of Pozzolans, maximum 0.45 water-cement ratio, minimum 4,500 psi
Chlorides*: (for concrete structures and pipe)	Chlorides > 350 ppm in soil or >150 ppm with cyclic groundwater	Evaluate the time to initiation of corrosion for adequate mix design. To increase this time, use low water to cement ratio, adequate depth of cover over the reinforcing steel, substitute Pozzolans for cement, and use calcium nitrite inhibitor. Alternately a barrier coating can be used. Use cathodic protection if recommended by the Corrosion Engineer.

Table 6	Critical Soil Parameters for Concrete Structures and Pipe Corrosion Design Standards City of Sunnyvale	
Parameter	**Criteria**	**Comments**
pH*:	Concrete: pH $\geq$ 5	No additional protection
	pH < 5	Use barrier coating
	Steel: pH < 4.5	Use coating and cathodic protection
	Aluminum or Lead: pH > 8.5	Use barrier coating recommended by the Corrosion Engineer
Ammonium	Copper > 10 ppm	Use barrier coating and/or cathodic protection recommended by the Corrosion Engineer
Nitrate	Copper > 50 ppm	Use coating and/or cathodic protection recommended by the Corrosion Engineer

Notes

(1) *Criteria from the Portland Cement Association and ACI 318
*Criteria from Ameron Concrete Pipe

Non-metallic Pipe: Extensions that are constructed out of non-metallic piping material and that utilize metallic fittings shall be protected with wax tape in accordance with AWWA C217.

4.6.2.3 Copper Service Laterals

Polyvinyl chloride (PVC) jacketed copper tubing or copper tubing with extruded polyethylene may be suitable in certain applications. The choice should be made on the basis of the site.

Copper service laterals shall be electrically isolated from metallic water mains via an isolation fitting placed at the corporation stop. If copper piping is used to connect the water meter to the building or residence, the copper lateral shall also be isolated at the water meter.

4.6.2.4 Test Station Spacing

Test stations shall be spaced at 250 feet maximum intervals for all major metallic transmission and distribution metallic pipelines as directed by the Corrosion Engineer. In addition, test stations may be required at the starting point and ending point for each new pipeline or extensions to existing pipelines, at crossings with foreign metallic pipelines, at cased crossings, at buried insulating flanges, and where necessary to prevent AC or DC interference.

4.6.2.5 Corrosion Control Requirements

For soil types rated as 1 or 2, galvanic cathodic protection shall be implemented as shown in Table 7.

Table 7	Corrosion Control Requirements (Soil Resistivity (ohm-cm) Corrosion Design Standards City of Sunnyvale			
Pipe Material	**0 – 1,000 Rating 1**	**1,001 – 2,000 Rating 2**	**2,001 – 10,000 Rating 3**	**Greater Than 10,000 Rating 4**
Steel and Ductile Iron Pipe	1. Bonded Coating or Polybag 2. Joint Bonding 3. Test Stations 4. **Cathodic Protection** 5. Electrical Isolation 6. High Resistance Backfill	1. Bonded Coating or Polybag 2. Joint Bonding 3. Test Stations 4. **Cathodic Protection** 5. Electrical Isolation 6. High Resistance Backfill	1. Bonded Coating or Polybag 2. Joint Bonding 3. Test Stations 4. Electrical Isolation 5. High Resistance Backfill	1. Bonded Coating or Polybag 2. Joint Bonding 3. Test Stations 4. Electrical Isolation 5. High Resistance Backfill
Mortar Coated Steel and Concrete Cylinder Pipe	1. Joint Bonding 2. Test Stations 3. **Cathodic Protection** 4. Electrical Isolation	1. Joint Bonding 2. Test Stations 3. Electrical Isolation	1. Joint Bonding 2. Test Stations 3. Electrical Isolation	1. Joint Bonding 2. Test Stations 3. Electrical Isolation
Metallic Valves and Fittings	1. **Fusion Bonded Epoxy Coating** 2. Wax Tape Uncoated Items	1. **Fusion Bonded Epoxy Coating** 2. Wax Tape Uncoated Items	1. Standard Coating 2. Wax Tape Uncoated Items	1. Standard Coating 2. Wax Tape Uncoated Items
Copper Piping	1. Isolation From Ferrous Piping 2. **PVC or Extruded Polyethylene Coating *OR* Tape Coating with Cathodic Protection**	1. Isolation From Ferrous Piping 2. Polyethylene Sleeve	1. Isolation From Ferrous Piping 2. Polyethylene Sleeve	1. Isolation From Ferrous Piping 2. Polyethylene Sleeve
Repair Clamps	1. Stainless Steel 2. Wax Tape	1. Stainless Steel 2. Wax Tape	1. Stainless Steel 2. Wax Tape	1. Stainless Steel 2. Wax Tape

4.6.3 Design

4.6.3.1 Cathodic Protection System Design

Cathodic protection system designs for distribution and transmission pipelines will be performed and stamped by a qualified Corrosion Engineer. This engineer shall be responsible for the design, supervision, and inspection and testing of the cathodic protection system. General guidelines for designing a cathode protection are as follows:

- Cathodic protection shall be designed and evaluated in accordance with relevant standards such as NACE International SP0169 or SP0100 and SP0286.
- Galvanic anode cathodic protection shall be utilized to the extent possible. Impressed current cathodic protection shall only be used when the current demand is high enough such that galvanic anode cathodic protection is not economically feasible.
- Ensure the metal structure desired for cathodic protection is electrically continuous throughout the structure.
- Ensure the metal structure desired for cathodic protection is electrically isolated from all other metals.
- Use an appropriate current requirement for the metal given the environment and coating type.
- Design the cathodic protection system for a minimum service life of 20 years.
- Ensure the cathodic protection system will not cause stray current corrosion on nearby foreign structures.

4.6.4 Materials

4.6.4.1 General

Materials and workmanship shall be in accordance with all applicable state and local codes. The use of a manufacturer's name and model or catalog number is only for the purpose of establishing the standard of quality and general configuration desired. Products of other manufacturers will be considered.

4.6.4.2 Joint Bond Wires

Joint bond wires shall be single-conductor, stranded copper wire with 600-volt HMWPE insulation. Supply all joint bonds complete with a formed copper sleeve on each end of the wire.

- Push-on, Mechanical, Ball or Flanged Joints--No.4 AWG wires, 18 inches long.
- Flexible Coupling Joints--No.4 AWG wires, 24 inches long, with two 12-inch-long insulated No. 8 AWG wire pigtails.
- Insulated Flexible Coupling Joints--No. 4 AWG wire, 18-inch long, with one 12-inch-long No.8 AWG wire pigtail.

- Concrete Cylinder Pipe--Joint bonds shall be supplied by the manufacturer and shall include:
  - Shop manufactured rod-cable-rod bonding cable as shown in the details. Rods shall be welded to the bell-and-spigot on opposite sides of the pipe at the spring line of the pipe.
  - AWG bond wires, for each joint. Total resistance of the bond or bonds at each joint shall not be greater than 150 percent of the linear resistance of a pipe section.

4.6.4.3 Galvanic Anodes

- **High Potential Magnesium Alloy (ASTM B843, Type M1C):** (Soil resistivities > 2,000 ohm-cm)
  - Composition:

▪ Aluminum	0.010% Max
▪ Managanese	0.5 to 1.30%
▪ Zinc	0
▪ Silicon	0
▪ Copper	0.02% Max
▪ Nickel	0.001% Max
▪ Iron	0.03% Max
▪ Total Others	0.05% each or 0.3% Max Total
▪ Magnesium	Remainder

- **Standard Potential Magnesium Alloy (ASTM B843, Type H-1A):** (Soil resistivities 1,000 to 2,000 ohm-cm)
  - Composition:

▪ Aluminum	5.3 to 6.7%
▪ Managanese	0.15 to 0.70%
▪ Zinc	2.5 to 3.5%
▪ Silicon	0.10% Max
▪ Copper	0.02% Max
▪ Nickel	0.002% Max
▪ Iron	0.003% Max
▪ Total Others	0.30% Max Total
▪ Magnesium	Remainder

- **Zinc Anodes (ASTM B418, Type II):** (Soil resistivities < 1,000 ohm-cm)
  - Composition:

▪ Iron	0.0014% Max
▪ Cadmium	0.003% Max
▪ Aluminum	0.005% Max
▪ Lead	0.003% Max

- Copper 0.002% Max
- Zinc Remainder

- Furnish a laboratory analysis guaranteeing that all anodes supplied meet all the requirements of this Specification.

- Supply each anode with No. 12 AWG stranded copper wire with THHN-THWNinsulation, 10 feet long or of sufficient length to route wire to the test station without a splice.

- Silver braze the wire to a galvanized steel rod or strap that is cast into the anode. Seal this connection completely with electrical potting compound. The anode connection shall be stronger than the wire.

- **Anode Backfill:**
  - Composition:
    - Ground Hydrated Gypsum 75 percent
    - Powdered Wyoming Bentonite 20 percent
    - Anhydrous Sodium Sulfate 5 percent
  - Anode backfill shall have a grain size so that 100 percent is capable of passing through a 20-mesh screen and 50 percent will be retained by a 100-mesh screen. The backfill mixture shall be thoroughly mixed and firmly packaged around the galvanic anode within the cloth bag by means of adequate vibration. Provide anode packaged in a plastic or heavy paper bag of sufficient thickness to protect the anode, backfill, and cloth bag during normal shipping and handling.

4.6.4.4 Cathodic Protection Test Stations

Flush mounted test boxes shall have a concrete body cast with a cast iron ring, with a minimum weight of 55 pounds and minimum dimensions of 8-inch-inside diameter and 12 inch length. Brooks Type 1RT Traffic Box, or approved equal. Provide with a 12-pound cast iron lid with the words "CP-Test" cast into the lid.

Terminal boxes shall be high-impact molded Lexan plastic, Model “Big Fink” as manufactured by Cott Manufacturing Company, or approved equal. The test box shall be provided with sufficient terminals for each cable. Provide terminal block with nickel-plated brass studs, washers, and lock washers.

4.6.4.5 Test Station Wire

A minimum of two wire are required per test station. One wire shall be single conductor, No. 10 AWG stranded copper with 600-volt THHN/THWN insulation in SCH 40 PVC conduit with solvent-welded joints, or HMWPE insulation direct-buried and single-conductor. One wire shall be single conductor, No. 8 AWG stranded copper with 600-volt THHN/THWN insulation in SCH 40 PVC conduit with solvent-welded joints, or HMWPE insulation direct-buried.

4.6.4.6 Permanent Reference Electrodes

- Copper-Copper Sulfate Reference Electrodes
  - Suitable for direct soil burial and designed to remain stable for at least 20 years
  - Dimensions: 1.5–inch diameter with minimum sensing surface area of 24 square inches
  - Stable potential within 10-millivolts while a 3 microampere electrical current is applied
  - Contains a barrier to inhibit migration of chloride ions from the soil into the reference electrode.
- Wire: No. 14 AWG stranded copper wire with yellow, 600-volt RHH-RHW insulation.
  - The wire shall be a minimum of 20 feet long or of suffient length to be routed to its terminus without a splice and attached to the electrode core by the manufacturer's standard connection.
  - Connection shall be stronger than the wire.

4.6.4.7 Shunts

Anode metering shunts shall be 0.01 ohm, 8 amp capacity with 1 percent accuracy.

4.6.4.8 Thermite Weld Materials

Thermite weld materials shall consist of wire sleeves, welders, and weld cartridges according to the weld manufacturer's recommendations for each wire size and pipe or fitting size and material. All welding materials and equipment shall be the product of a single manufacturer such as “Cadweld” by Erico Products, Inc., “Thermoweld” by Continental Industries, Inc., or approved equal. Each wire shall be fitted with a copper sleeve for accomplishing the weld if directed by the manufacturer. Interchanging materials of different manufacturers is not acceptable.

4.6.4.9 Ground Clamp

Ground clamp shall be sized to fit the copper tubing and wire size, made out of high copper alloy, and rated for direct burial.

4.6.4.10 Thermite Weld Caps

Coating material to protect wire-to-pipe connections shall be Handy Caps as manufactured by Royston Products or ThermOcap as manufactured by ThermOweld or approved equal.

4.6.4.11 Wire Connectors

One-piece, tin-plated crimp-on and soldered ring connector.

4.6.4.12 Insulated Joints

Insulating joints shall be dielectric unions, flanges, or couplings. The complete assembly shall have an ANSI rating equal to or higher than that of the joint and pipeline. All materials shall be resistant to the intended exposure, operating temperatures, and products in the pipeline.

- Gaskets--$^{1}/_{8}$ inch thick full-faced neoprene faced phenolic.
- Insulating Sleeves--Full-length $^{1}/_{32}$ inches thick Grade G-10 fiberglass epoxy.
- Insulating Washers-- 1/8 inches thick Grade G-10 fiberglass epoxy.
- Washers--Same material as bolts, $^{1}/_{8}$ inch thick.

4.6.4.13 Casing Insulators

Casing insulators shall be molded high-density polyethylene with plastic runners and shall consist of bolted segments, complete with stainless steel bolts for assembly.

4.6.4.14 Casing Seals

Casing seals shall be flexible molded rubber seals and shall be supplied complete with two stainless bands for sealing. Split seals are not acceptable.

4.6.4.15 Wall Seals

Wall seals shall be interlocking links of molded synthetic rubber. The links are to be connected together with stainless steel bolts. The wall seal shall be sized for the pipe size and type and the wall hole.

4.6.4.16 Pipe Backfill

Imported backfill placed around the pipes shall be a good quality backfill with a minimum resistivity of 3,000 ohm-cm, a pH between 6.0 and 8.0, a maximum chloride concentration of 150 ppm, a maximum sulfate concentration of 1,000 ppm, an ammonium concentration less than 10 ppm, and a nitrate concentration less than 50 ppm. Backfill shall be compatible with and not damage the pipe's applied coating system.

4.6.4.17 Coatings for Buried Insulating Flanges

Coat buried insulating flanges with Trenton Wax Tape#1 by The Trenton Corporation or approved equal.

4.6.5 <u>Testing</u>

4.6.5.1 Electrical Continuity Testing

Conduct continuity testing across all buried joints that are required to be bonded both before backfilling and after backfilling.

4.6.5.2 Electrical Isolation

Each insulated joint and cased crossing shall be tested. All damaged or defective insulation parts shall be replaced and retested. All electrical shorts to the casing shall be cleared and retested. Records shall be made of all insulated joints and cased crossing test and submitted for approval.

Make provisions for testing electrically isolation between the pipe and any reinforced concrete structures (vaults, floor penetrations, thrust blocks, etc).

4.6.5.3 Test Stations

Test all test leads to ensure they were installed in accordance with the specifications. All defective test leads shall be repaired and/or replaced and retested. Record baseline potentials prior to activating the cathodic protection system. Records shall be made of all test stations tested and submitted for approval.

4.6.5.4 Cathodic Protection System

Test all cathodically protected pipelines to ensure that the protection levels meet the criteria of the most recent NACE SP0169 or SP0100 standards. Records shall be made of all anode current output and pipe-to-soil potential measurements performed and submitted for approval.

For dielectrically coated pipe, a minimum cathodic polarized potential of -850 mV with respect to a saturated copper-copper sulfate reference electrode shall be achieved.

For concrete of cement-mortar coated pipe, a minimum cathodic polarization of 100 mV shall be achieved.

4.6.5.5 Acceptance

All tests performed shall be reviewed, submitted and approved by the City Engineer or authorized reviewer before the corrosion control work is accepted. The City reserves the right to spot check any or all tests performed by the Contractor. All construction defects must be repaired and retested before the final acceptance is made. All unacceptable tests shall be retested by the Contractor at no additional cost to the City.

4.7 Coatings

Coating carbon steel surfaces is critical in the typical environments found at waste water treatment facilities. The surface of the substrate must be prepared appropriately for the specific application. Incorrect or inadequate surface preparation will reduce the performance of the coating system either through the loss of adhesion (delamination), discontinuities (holidays) in the coating, permeability of the coating, or failure to stop the underlying corrosion process. In general, these failure mechanisms allow corrosion to commence at the failure site. This in turn propagates adjacent coating failure and further corrosion. This cycle can continue until large areas of the coating system are compromised.

4.7.1 Surface Preparation

4.7.1.1 Carbon Steel

Table 8 references the SSPC's surface preparation procedures. In addition to surface preparation, other factors that contribute to a successful coating operation are surface profile, coating application, and environmental controls during the coating operation.

Table 8 Recommended Surface Preparation for Carbon Steel Surfaces
Corrosion Design Standards
City of Sunnyvale

Exposure	Recommended Surface Preparation
Immersion service; interiors of closed tanks, digesters, or other vessels either totally immersed or within the closed vapor space	Abrasive blast to a white metal condition, in accordance with SSPC SP-5
Atmospheric exposure (plant process areas)	Abrasive blast to a near-white metal condition, in accordance with SSPC SP-10
Indoor, conditioned air exposure (nonprocess areas)	Abrasive blast to a commercial blast cleaned surface, SSPC SP-6
Touch-up or in areas restricting abrasive blast operations	Hand tool and power tool cleaning methods; SSPC SP-1, -2, or -11
Existing coatings	Ensure no lead paint is present. If not present, power tool cleaning with feathered edges, SSPC SP-3.

4.7.1.2 Concrete

These surfaces must be carefully prepared before coating can be applied. Cast-in-place concrete surfaces should cure at least 30 days before coating begins. Grease, oil, dirt, salts, form-release agents, loose materials, or other foreign matter should be removed with solvents, detergents, or other cleaning agents. On new concrete, brush-off blasting is the preferred method to remove laitance. If brush-off blasting is impractical, the surface may be etched with muriatic acid. This method is practical only for horizontal surfaces and is not effective for vertical surfaces.

For old concrete surfaces, cleaning with water at pressures exceeding 10,000 pounds per square inch (psi) can be very effective. This method is useful in removing surface contamination and deteriorated concrete. Using a rotating head on the hydro-blast nozzle will also improve the cleaning. Additional cleaning action also can be achieved by adding abrasives to the hydroblast unit. Depending on how deeply the surface has been contaminated, chemical washes, abrasive blasting, or mechanical scarifying may be required. Sandblasting in lieu of water blasting or ultra high water blasting can be employed if the intended coating system is less tolerant to moisture.

Cavities, cracks, and abrupt depressions must be filled and smoothed before a coating system can be applied to the cleaned concrete. Obviously, water leaks must be plugged with hydraulic cements. The extent to which the surface must be restored will depend on the coating system selected.

4.7.1.3 Plastics

Plastic materials, such as PVC and FRP, require minor surface preparation if they are to be coated. Plastic surfaces should be hand-sanded with a medium-grit sandpaper to provide sufficient anchor profile for the specified coating system.

If a specific color is desired for FRP equipment, the FRP manufacturer preferably will provide a pigmented gel coat on the exterior of the FRP. Pigmented gel coats generally are more durable than coating the surface after installation. PVC and FRP pipe should be color-coded with labels and color bands.

Old FRP structures may require repainting to improve appearance. After many years of exposure to sunlight, FRP surfaces can develop "fiber blooming" as the resin surface breaks down from ultraviolet light. The surface will show glass fibers or become fuzzy. Although fiber blooming is not serious, the surface of FRP will be visually unappealing. This problem can be corrected by coating the surface with the system appropriate for the exposure conditions. Before coating, the FRP surface should be cleaned with water (to remove dirt and loose glass fibers) and dried. Resin-rich areas should be roughened with sandpaper before painting.

4.7.2 Coating Systems

Protective coating systems shall be developed for the specific requirements of the project. Coating selection (including coating material(s) and information on the number of coats and mil thickness of each coat), surface preparation requirements, application process, and post quality control procedure shall be specified for each protective coating system to be used on the project. In addition, a protective coatings table shall be provided which identifies the protective coating system to be used on various items and/or at various locations on the project. The coating systems developed for the project shall be reviewed by a NACE certified coating specialist. Coating of HDPE is not recommended.

The City has developed a standards coating list which includes colors and other information for the designers' consideration. The designer shall obtain and review the latest standards coating list from the City prior to preparing Contract Documents for each project and discuss the information with the City. The designer is responsible for specifying the appropriate protective coatings for each application and project.

4.7.3 Coatings for Metallic Surfaces

4.7.3.1 Inorganic Ceramic (Glass) Linings

Glass linings shall be used for sludge, grit and scum pipelines.

4.7.3.2 Liquid Epoxies (AWWA C210)

In wastewater service, epoxies can be specified for use in submerged service on both steel and concrete.

4.7.3.3 Fusion Bonded Epoxy (AWWA C213, AWWA C116)

Fusion-bonded epoxies can be specified for steel pipe, ductile iron pipe, and for ductile-iron and gray-iron fittings.

4.7.3.4 Ceramic Epoxy

Ceramic epoxies are one of the only classes of coatings that can be specified as a lining for ductile-iron pipe for both potable water and wastewater applications. The use of restraining gaskets shall be prohibited in order to avoid damaging the pipe coating.

4.7.3.5 Polyethylene Encasement (AWWA C105)

Polyethylene encasement shall be specified to protect ductile iron and copper pipe in moderately and mildly corrosive soil, but will need accompanying cathodic protection in more aggressive soil. Consideration for a bonded dielectric coating shall also be given in aggressive soil.

4.7.3.6 Polyolefin Tapes (AWWA C209 and C214)

Prefabricated multi-layer cold-applied polyolefin tape coatings shall be applied in accordance with ANSI/AWWA C214.Total thickness of the coating shall be 80 mils. Specials and field joints shall be coated in accordance with ANSI/AWWA C209 with a total coating thickness of 70 mils minimum.

4.7.3.7 Extruded Polyolefin (AWWA C215)

Extruded polyolefin coatings shall be applied in accordance with ANSI/AWWA C214.Total thickness of the coating shall be 60 mils. Specials and field joints shall be coated in accordance with ANSI/AWWA C216 with a total coating thickness of 60 mils minimum.

4.7.3.8 Polyurethane (AWWA C222)

Aromatic polyurethane coating can be specified for immersion service on metallic components.

4.7.3.9 Sacrificial Metals

Do not specify galvanizing for any service.

4.7.3.10 Wax Tapes (AWWA C217)

Wax tape shall be specified to protect metallic components of a pipeline which are not easily shop coated with a dielectric coating such as flanges, mechanical and restrained joint bolts, nuts and glands, grooved-end couplings, and repair clamps. Wax tape incorporates corrosion inhibitors into the woven hydrophobic wax barrier.

4.7.4 Coatings for Concrete

Any concrete coating shall be specified to be applied during the cooling period of the concrete structure to lessen the tendency for the concrete pores to off-gas.

4.7.4.1 Vinyl and Polypropylene (Sheet Goods)

Plastic liners shall be specified for internal linings of all unit process between the influent sanitary sewers and the primary clarifiers. Specify to avoid cleaning the joints with anything other than what is specified by the manufacturer. Inspection shall be specified to be performed by a qualified inspector.

4.7.4.2 Polyurethane

Aromatic polyurethane coating shall be specified for immersion service in areas where PVC liners are insufficient.

4.7.4.3 Novolac Epoxy

Novolac Epoxy coating shall be specified for secondary containment, acid storage areas, and severe immersion service. Specify a flake lining in severe environments.

4.8 Special Corrosion Mitigation

Many of the structures and much of the equipment at WWTP's are constructed of reinforced concrete. Although Portland cement mixtures resist many environments in the plant, conditions exist that can attack the concrete, generally in areas just above the water line or where the water flow is turbulent or agitated. In these areas, H_2S released from the water can attack the concrete. If the hydrogen sulfide is free to dissipate into the atmosphere, little corrosion occurs. However, if the release of the H_2S is confined in some manner, attack is likely to occur. This problem must be considered when modifying existing structures, particularly if odor-control systems are added. Covers, hoods, or shrouds often will prevent odor from being emitted into the atmosphere; however, removing air from under the covers is not enough to prevent attack from H_2S.

Therefore, the concrete should be protected. T-lock is preferred for new concrete structures and should be considered for hydraulic structures containing wastewater. Each area or piece of equipment in the WWTP that is to be retrofitted with an odor-control system should be evaluated on an individual basis.

4.8.1 Pretreatment Structures

The concrete surfaces in flow-diversion structures and in open channels where flow is turbulent should be coated to a point 1 foot below the minimum water level. The quality of the coating specified for this service depends on how often the structure is taken out of service for maintenance. Most coating systems have a limited life and must be maintained or replaced after a few years of service

Thermoplastic materials that are cast with concrete also can protect concrete in hydrogen sulfide atmospheres. This method of installation mechanically attaches the lining to the concrete, minimizing problems associated with cracks developing in the concrete. Thermoplastics, such as PVC, high-density polyethylene (HDPE), PP, polyvinylidene fluoride (PVDF), and fluorocarbons, are available. These materials also can be used for rehabilitation work, but different techniques must be used for installing them. PVC and HDPE are adequate for most WWTP exposures.

The best coating system can be determined after the specific conditions of service have been defined. Several generic coating systems, including potassium silicate cements, modified epoxy materials (spray and trowel applied), thermoplastic sheets, and plural component polyurethanes, have been used in WWTPs with good success. The choice also depends on whether the coating will be applied to new or old concrete and whether the surface will be dry or damp. Some coating systems are more tolerant of moisture than others. Table 9 summarizes some suitable coating systems.

Table 9 Coating Alternatives for Concrete Surfaces
Corrosion Design Standards
City of Sunnyvale

Condition of Concrete	Coating System
New concrete, normal bug-holes, and pockets	Squeegee surface for bug holes; elastomeric urethane, flake-filled polyester, or reinforced epoxy
Old concrete, minor attack (< ¼ inch)	Elastomer urethane, flake-filled polyester, or reinforced epoxy
Old concrete, heavily attacked (> ½ inch, exposed aggregate)	Membrane/potassium silicate cementitious with anchors, high strength Silica Fume cementitious grouts and mortars, or heavy, trowel applied surface followed by elastomeric urethane, flake-filled polyester, or reinforced epoxy

4.8.2 Clarifier Mechanisms

New or replacement clarifier mechanisms should be specified to provide the best performance. Non-metallic or epoxy coated steel is preferred for these mechanisms because it eliminates the maintenance associated with coatings and cathodic protection. If coated carbon steel is specified, coatings such as epoxy novolac shall be utilized with the use of either impressed current or galvanic type cathodic protection as determined by the Corrosion Engineer.

4.9 Corrosion Control during Construction

During the period of construction, all materials delivered to the site should be protected against corrosion during storage and after installation. Electrical and I&C equipment are extremely susceptible to corrosion during the construction period. This equipment should be packaged and protected with desiccant and vapor-phase inhibitors.

Mechanical, structural, process, and architectural equipment should be coated before being shipped to the site. Once on the site, the equipment should be stored properly and protected from the elements. Purchasing specifications should require that equipment be packaged properly for shipment and storage at the construction site. The packaging should include the appropriate preservatives, desiccants, inhibitors, and wrapping to protect against corrosion and deterioration.

4.10 Chemical Storage and Handling

The primary chemicals typically stored and handled at WWTPs include:

- Chlorine (dry)
- Sodium hydroxide
- Sulfuric acid (66° Baume)
- Hydrochloric acid (35 percent)
- Polymers
- Lime
- Potassium permanganate
- Sodium hypochlorite
- Miscellaneous industrial solvents

These chemicals will be purchased in bulk and stored at the plant. Table 10 presents general guidelines for materials of construction for these chemicals. Because of the aggressive nature of these chemicals, the concrete containment areas around the bulk storage tanks should be protected adequately. Recommended means of protecting concrete containment or spill areas are given in Table 11.

Table 10 Coating Alternatives for Concrete Surfaces
Corrosion Design Standards
City of Sunnyvale

Chemical	Tanks	Pumps	Piping
Sodium hydroxide (NaOH)	Carbon Steel, FRP	Cast steel	Carbon steel, nonmetallic
Sulfuric acid	Carbon steel with baked phenolic lining	Alloy 20	Type 316 stainless steel
Hydrochloric acid	Rubber-lined steel	Nonmetallic or Hastelloy B	FRP, PVC, PP

Table 10 Coating Alternatives for Concrete Surfaces Corrosion Design Standards City of Sunnyvale			
Chemical	**Tanks**	**Pumps**	**Piping**
Chlorine (dry)	N/A (tanks car delivery)	N/A	Carbon steel
Chlorine solution N/A	N/A	N/A	PVC, PP, FRP
Polymer	FRP, PE	Nonmetallic	FRP, PVC, PP
Lime	Carbon Steel	Cast steel, ductile iron	Carbon steel, PVC, FRP
Potassium permanganate	FRP	Nonmetallic	PVC, FRP
Sodium hypochlorite	FRP (5)	Nonmetallic	PVC, PP, FRP
Miscellaneous Solvents	Carbon steel	Cast steel, ductile iron	Carbon steel, stainless steel

FRP = Fiberglass-reinforced plastic PVC = Polyvinylchloride
PP = Polypropylene PE = Polyethylene

Notes:

(1) The first material listed is preferred.
(2) 50% NaOH freezes at approximately 55°F. Dilution may be preferred for process operations.
(3) The design of the sulfuric acid facility should follow the recommended practices given in NACE RP0391-2001.
(4) Sodium hypochlorite will decompose at elevated temperatures. Store indoors or under canopies.
(5) Special fabrication procedures for FRP required for this service.
(6) Some chlorinated solvents can hydrolyze at ambient temperatures win the presence of water to form acids that will cause corrosion. Take precautions to avoid contamination with water.

Table 11 Chemical Protection for Concrete Containment Areas Corrosion Design Standards City of Sunnyvale	
Chemical Exposure	**Protection Material**
Sodium hydroxide	Nonskid epoxy; System No. 21
Sulfuric acid	Acid brick with potassium silicate mortar in defined spill areas; reinforced novolac epoxy in other areas
Hydrochloric acid	Reinforced polyester or vinylester
Liquid chlorine	N/A
Chlorine solution	N/A
Polymer	Nonskid epoxy coating
Lime	Penetrating epoxy sealer or nonskid epoxy coating
Potassium permanganate	Reinforced vinyl ester
Sodium hypochlorite	Nonskid epoxy coating
Miscellaneous solvents	Reinforced epoxy (polymer alloys), vinyl ester, or novolac epoxy, depending on specific solvent used

4.11 Abrasion Applications

A number of conditions can cause abrasive wear. Typically, it results from the action of hard particles on a surface, influenced by a force that is oblique to the surface. Three common forms of abrasive wear are erosion abrasion, grinding abrasion, and gouging abrasion.

Erosion abrasion usually occurs under low velocities with very little impact present. This type of abrasion may be found in screw conveyors handling grit. Grinding abrasion involves abrasive fragments, such as might be found in ball mills. This type of abrasion is not likely to occur in a WWTP unless limestone is ground for process applications. The third form of abrasion, gouging abrasion, is recognized by the grooves or gouges visible on the wearing surfaces. Heavy impact usually is associated with this form of abrasion.

Each case of abrasive wear must be evaluated to determine the exact cause and, thus, the best solution to the problem. Either the conditions of service should be altered to change the abrasive environment, or a more wear-resistant material should be selected for the worn component. The most obvious solution is to use materials that will not wear under the specific conditions, such as applying hard-facing to wear surfaces or specifying abrasion-resistant alloys for the particular component. Some alloys can be heat treated to make the alloy harder (although, in some cases, only the surface hardens) and, thus, more abrasion resistant.

A number of wear-resistant alloys are available that can be applied to wearing surfaces. These alloys can be flame-sprayed on the surface or applied as weld-overlays. Machining of the surface may be required, but in many instance the component can be placed back into service after the hard-facing has been applied.

For most applications in a WWTP, the use of a harder alloy or the application of hard-face on the wearing surface is adequate. Sheet-rubber linings also have been used successfully in abrasion applications. However, each case must be considered individually.

4.12 High-Temperature Applications

For high-temperature applications, the alloy's corrosion resistance is only one consideration of materials selection. Other properties of the alloy, such as creep resistance, thermal expansion, thermal shock, and thermal stability, also must be considered. The specific composition of the atmosphere is another important factor. Depending upon the conditions of exposure, oxidation, carburization, and sulfidation will affect how materials perform at elevated temperatures.

4.13 Inspection

When working with special corrosion-resistant materials or when applying corrosion mitigation techniques, all these materials must be fabricated and installed correctly. Fabrication and installation must be inspected closely to ensure that specifications are met and high quality is attained.

When dealing with corrosion control, the protective coating system may be the most crucial but most often ignored operation. A successful coating operation depends on the combined efforts of the coating contractor, the coating manufacturer, and the facility owner. The keys to this success are holding a preconstruction conference, inspecting the coating material, measuring and monitoring the environmental conditions, inspecting the preparation of surfaces, and inspecting the coating application. The cleanliness and profile of the surface also are important to a successful coating operation. For all bonded coatings, inspection shall be specified using a NACE CIP III third-party inspector during surface preparation, application, final acceptance, and installation.

Inspections of all major FRP equipment by a third party are recommended. For critical equipment, acoustical emission testing shall be provided.

Fabricating equipment from alloys also imposes additional requirements. Welding alloys is more difficult than welding carbon steel. Welders must be qualified, and the quality of their weldments should be inspected. Stainless steel alloys can be contaminated with iron by improper fabrication techniques and improper cleaning and repassivation after fabrication. American Society for Testing and Materials (ASTM) Standard A380, Cleaning and Descaling Stainless Steel Parts, Equipment, and Systems, must be enforced for all stainless steel fabrications. Testing for iron contamination, as described in ASTM A380, should be a part of the inspection procedure.

Because cathodic protection often can be inspected or verified only by using special methods, certified corrosion specialists are required. The following testing procedures shall be incorporated into the design specifications as applicable.

- Testing of all insulated pipe flanges.
- Electrical isolation testing between the project structure and foreign metallic structures.
- Casing isolation testing.
- Testing of exothermic welds.
- Electrical continuity testing.
- Test station testing.
- Wax tape coating inspection.
- Baseline potentials before activation of the cathodic protection system.
- Cathodic protection system activation.

A final report shall be submitted containing all approved submittals and test results during the course of the project. All items testing during the project shall be retested during the final system checkout.

5.0 REFERENCES

None.

6.0 ATTACHMENTS

None.