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CORROSION CONTROL FINAL REPORT
FOR
PRELIMINARY ENGINEERING
OF THE
SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT
METRO RAIL PROJECT

WBS-12AAH, TASK 9

SUBMITTED BY

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ATMOSPHERIC CORROSION

Table of Contents

PAGE

1. INTRODUCTION 6-1

2. CONCLUSIONS 6-1

2.1 Above Grade 6-1
2.2 Tunnels 6-2
2.3 Vehicles 6-2
2.4 Coatings 6-2

3. RECOMMENDATIONS 6-2

3.1 Above Grade Sections 6-2
3.2 Tunnels 6-4
3.3 Vehicles 6-7
3.4 Design 6-7
3.5 Maintenance 6-8

4. DISCUSSION 6-9

4.1 Above Grade Facilities and Considerations 6-9
4.1.1 General 6-9
4.1.2 Local Utility Experience 6-9
4.1.3 Industrial Areas 6-10
4.1.4 Local Climatological Data 6-10
4.1.5 Effects of Air Pollution 6-11
4.2 Metals for Above Grade Construction 6-13
4.2.1 Carbon and Alloy Steel, Cast Iron 6-14
4.2.2 Stainless Steel 6-16
4.2.3 Aluminum Alloys 6-17
4.2.4 Copper Alloys 6-18
4.2.5 Magnesium Alloys 6-18
4.3 Tunnel Areas 6-18
4.3.1 Water Seepage 6-18
4.3.2 Condensation 6-21
4.3.3 Effect of Corrosion on Stray Current Controls 6-22
4.3.4 Tunnel Gases 6-22
4.4 Vehicles 6-25
4.5 Crevice and Bimetallic Corrosion 6-25

5. REFERENCES 6-26

TABLE I 6-29

TABLE II 6-30

TABLE III 6-31

1. INTRODUCTION

The objectives of this study are to identify all non-stray current and non-soil related corrosion factors which will affect the SCRTD Metro Rail Project and to provide criteria and recommendations to minimize the effects of this corrosion. Specific objectives are to:

1) Evaluate the degree of atmospheric corrosion which can be anticipated on above grade facilities such as trackwork, rails and electrical devices at stations, yards, and shops. Recommend appropriate materials of construction and means of corrosion control.

2) Evaluate the degree of atmospheric corrosion which can be anticipated on the rail vehicles. Recommend appropriate materials of construction.

3) Evaluate moisture condensation and ground water seepage into the tunnels and their effect on the corrosion of rails, trackwork components, fasteners, electrical equipment, tunnel liners, structural members, and station components.

Corrosion factors considered include: climatological, air quality, location and type of industries along the rail route, and the geology where tunnels are to be constructed. In order to fulfill the objectives, use was made of published climatological, air quality and corrosion rate data, interviews with local utility personnel and the Geotechnical Investigation Report, Volumes I and II.

Recommendations in this report are based on the stated criterion that there will be no running water in the tunnels but that occasional areas of seepage water might occur.

2. CONCLUSIONS

2.1 Above Grade

2.1.1 Corrosion can be expected on above grade portions of the SCRTD Metro Rail Project.

2.1.2 Corrosion above grade will be the result of: condensation, rainfall, acid rain, acid fog and atmospheric pollutants. Sulfur dioxide is the most aggressive pollutant which will combine with moisture in condensation, rain and fog to create an acidic environment on metals used in the Metro Project during periods of wetness.

2.1.3 Above grade corrosion can be controlled through materials selection, sealants and protective coatings as presented in this report.

2.2 Tunnels

2.2.1 Water seepage into tunnels has the potential of causing severe corrosion because of its low pH and high concentration of ions which promote corrosion.

2.2.2 Condensation of moisture will also corrode metals in the tunnels. Condensation caused corrosion is expected to be more severe during the construction phase when moisture from construction materials (e.g. new concrete) and seepage is highest and ventilation is least. Corrosion by condensation will be enhanced if hydrogen sulfide gas enters the tunnel area.

2.2.3 Corrosion in the tunnels can be controlled through materials selection, sealants, protective coatings, and design to minimize water seepage.

2.3 Vehicles

2.3.1 Metro rail vehicles will be subject to the corrosive effects from both the above grade atmosphere and the tunnel environment. Condensation, rain and fog combined with pollutants will cause deterioration of the vehicles above grade, while splash and contact with seepage water will cause corrosion in the tunnels.

2.3.2 Appearance can be preserved and maintenance costs kept to a minimum with materials selection, coatings, sealants, and design.

2.4 Coatings

All coatings to be used in the system, whether barrier (e.g. epoxies, vinyls, urethanes, acrylics, alkyds) or sacrificial (e.g. galvanizing, aluminum) will deteriorate in time. Maintenance will be required.

3. RECOMMENDATIONS

3.1 Above Grade (Exterior)

3.1.1 Materials (General)

a. Carbon steel - use with a barrier or sacrificial coating.

b. Weathering steel - use with a barrier or sacrificial coating.

c. Alloy steel - use with a barrier or sacrificial coating.

d. Cast irons/alloy cast irons - use with a barrier or sacrificial coating.

e. Stainless steel - use 200 or 300 series stainless steel or chromium-molybdenum ferritic (e.g. Type 444). Types 304, 316 and 444 will provide the best appearance. Use a columbium or titanium stabilized grade (e.g. Type 347) or extra low carbon grade where welding is to be done. Clean and passivate after fabrication and prior to use. Stainless steel can be coated for appearance purposes but it is not necessary for corrosion protection. Use ordinary 400 series stainless steels only in sheltered areas where appearance is unimportant.

f. Aluminum - all aluminum alloys are satisfactory but surfaces should receive a sealed hard anodized finish to minimize pitting corrosion (Finish A4X). Coatings can be used to improve corrosion resistance or for appearance.

g. Copper alloys - utilize a coating where a natural patna is not desired.

h. Magnesium alloys - utilize a protective coating where appearance is critical.

3.1.2 Coatings - Apply in strict accordance with manufacturers' requirements.

3.1.2.1 Carbon steel, weathering steel, cast iron:

a. Hot dip galvanizing (zinc) applied to a thickness no less than 2.0 oz. per sq. ft. Anticipate coating maintenance in 15-20 years. Galvanize as large an assembled section as possible. Repair defects per 3.5e.

b. Flame sprayed zinc applied to a thickness of 0.010 inch or more. Seal with vinyl coating.

c. Aluminum, hot dipped - applied to a thickness of 0.002 inch. Use Type II aluminizing. Anticipate coating maintenance requirements in 15-20 years.

d. Flame sprayed aluminum - applied to a thickness of 0.010 inch or more. Seal with vinyl coating.

e. Aluminum-Zinc (55% aluminum) - anticipate coating maintenance in about 15-20 years.

f. Cadmium - use only in a sheltered air conditioned environment or coat with a barrier system.

g. Inorganic zinc - apply at 2-3 mils (1 mil = 0.001 inch) dry film thickness (DFT). Use a topcoat.

h. Epoxy (coal tar, polyamide, polyamine, epoxy ester, phenoxy) - apply over inorganic zinc (preferred) or compatible primer. This coating will chalk and should not be used where appearance is important. Can be top coated with acrylic or polyurethane.

i. Vinyl - apply over inorganic zinc (preferred) or compatible vinyl system.

j. Polyurethane - apply over an epoxy polyamide primer.

k. Fusion bonded epoxy, polyester, polythylene, nylon - highly recommended for toughness, corrosion protection and appearance retention.

l. Acrylic - apply over an epoxy polyamide primer - not recommended for long-term appearance.

m. Alkyd - not recommended for long-term corrosion protection or appearance retention.

3.1.2.2 Other Metals

Apply coatings to stainless steel, aluminum, copper and magnesium alloys using a suitable primer (e.g. vinyl butyral wash primer, anodizing for aluminum).

a. Polyurethane

b. Vinyl

c. Epoxy - not an appearance coating, as it will chalk. Use a top coat of polyurethane or acrylic where appearance is important.

d. Fusion bonded epoxy, polyester, polyethylene, nylon - applied by fluidized bed or electrostatic spray.

3.2 Tunnels

3.2.1 Minimize water seepage into the tunnels and provide drainage for any water that might enter the tunnel.

3.2.2 Materials (General)

a. Carbon steel, weathering steel, alloy steel, cast iron - use a protective coating as defined in 3.2.3.

b. Galvanized steel - use a protective barrier coating as defined in 3.2.3. Repair defects per 3.5.e.

c. Aluminum - use a sealed hard anodized finish (Finish A4X). Aluminum must have additional barrier coating if exposed to water seepage and the alloy should be resistant to acid chloride stress corrosion cracking (i.e. 2024-T8, 2219-T6, 2219-T8, 6061-T6, 7075-T73, 7075-T736).

d. Copper - coat with a heat cured or thermo-setting lacquer (e.g. epoxy, polyester, silicone, vinyl or urethane) where discoloration would be objectionable. Coat with a high performance barrier coating where exposed to water seepage. Do not use brasses with more than 15 percent zinc where contact with seepage water can occur.

e. Stainless steel - use 300 series stainless steel where stains would be objectionable. Use Type 316, 317, 304, 444, Carpenter 20 or higher grade of stainless steel where contact with seepage water is expected. Use titanium or columbium stabilized (e.g. Type 347) or extra low carbon grades (e.g. 304L, 316L, 317L) where welding is to be done. Use welding rods of a composition equivalent to the base metal. Clean and passivate stainless steel after fabrication and welding. Do not apply a coating to stainless steel subject to continuous contact with water seepage.

f. Non-metals - select from section 4.3.4.

3.2.3 Coatings (use only where intermittent immersion or intermittent contact with seepage water is expected)

a. Inorganic zinc - use as the preferred primer on steel. Topcoat with epoxy.

b. Epoxy (coal tar, polyamide, polyamine, polyester) - preferred top coat. Apply two coats.

c. Urethane - top coat for steel, aluminum, copper. Use an epoxy primer.

d. Vinyl - top coat for steel, aluminum, copper. Use inorganic zinc primer on steel and wash primer on other alloys.

e. Phenolic - system for steel.

f. Fusion bonded epoxy, polyester, nylon - excellent coating for in-tunnel use. Applied by fluidized bed or electrostatic spray.

g. Flame spray aluminum or zinc - apply at a thickness of 0.010 inch minimum. Seal with epoxy and apply epoxy intermediate and topcoats.

h. Cermets (fused aluminum-ceramic, e.g. Sermetel) - good coating for steel fasteners not exposed to water seepage.

3.2.4 Specific Hardware Items:

a. Tunnel liners (carbon steel): coat with an inorganic zinc and coal tar epoxy system.

b. Tunnel fasteners (galvanized steel): coat with a coal tar epoxy.

c. Running Rails:

   1) Case 1 - No water seepage: no action required.

   2) Case 2 - Water seepage limited to specific areas: factory coat those areas exposed to water with coal tar epoxy or polyamide epoxy over an inorganic zinc primer. Coat sides and bottom; repair coating at welds.

d. Contact Rails (aluminum-steel composite):

   1) Case 1 - No water seepage: use a sealant (e.g. wax base) between metals. No other action required.

   2) Case 2 - Limited areas of water seepage: use a sealant (e.g. non-curing polysulfide or wax base) between metals and apply an epoxy coating to the affected areas on non-contact surfaces.

e. Track/Rail fasteners (carbon steel):

   1) No action required to control corrosion (hot dip galvanizing or aluminizing is optional) where there is no seepage. Otherwise apply a protective barrier coating to the entire surface where seepage occurs. Recommended fusion bonded Nylon 11. See Task 5 report.

f. Fencing: hot dip galvanized or aluminized steel with a vinyl coating.

g. Electrical equipment (e.g. switch boxes, transformers, connection cabinets):

   Enclose in an air conditioned environment, if possible. If not possible, use steel coated per 3.2.3, NEMA 4X rated. Cabinets should be internally heated to prevent condensation and all non-immersed components coated with a barrier coating. Consider the use of vapor phase inhibitors on sealed cabinets.

h. Electrical conduit: PVC or PVC coated galvanized steel.

i. Metallic signal fixtures: Steel - coat per 3.2.3. Aluminum - anodize per 3.2.2.

j. Light fixtures: Steel - coat per 3.2.3. Aluminum - anodize per 3.2.2 and coat per 3.2.3.

k. Railings: Aluminum - anodize per 3.2.2. Galvanized steel - coat per 3.2.3.

l. Step edges (steel): hot dip galvanize or aluminize.

m. Doors: Steel - coat per 3.2.3. Steel doors should be internally coated as well to control internal corrosion. Aluminum (preferred) - anodize per 3.2.2.

n. Duct work: hot dip galvanized or aluminized steel unless water seepage on or in ducts is probable. Duct subject to water seepage should be coated per 3.2.3.

o. Vents: coat per 3.2.3.

p. Pumps: coat exterior per 3.2.3. Use non-metallic lined pump impellers and internal parts for pumps handling seepage water.

q. Fire lines: coat exterior per 3.2.3.

r. Vent Shaft equipment: use galvanized steel coated per 3.2.3.

3.3 Vehicles

3.3.1 Outer shell (cladding panels): stainless steel (200 or 300 series) or aluminum (5000 or 6000 series). Aluminum should be anodized.

3.3.2 Structure: aluminum (5000 or 6000 series) or 300 series stainless steel. Note that anodizing aluminum tends to reduce its fatigue strength so that this must be considered. Structural components not subject to weather or view do not require coating.

3.3.3 Underframe components: aluminum (coated per 3.2.3) and steel are satisfactory. Steel must be coated with a high performance system such as inorganic zinc and epoxy or flame sprayed with aluminum and epoxy coated.

3.3.4 Fasteners: use aluminum or 300 series stainless steel where joining aluminum. Use 300 series stainless steel where joining stainless steel. Riveted joints should have drilled holes and elastic panel seals to prevent fretting.

3.3.5 Other satisfactory materials: nylon, fiber reinforced plastics, neoprene.

3.4 Design

a. Avoid configurations which will entrap moisture. Design to permit complete drainage and allow washing of pollutant particles from surfaces by rain or routine washing.

b. Avoid dissimilar metal combinations where possible. Acceptable combinations (subject to engineering review) are:

   Stainless steel - carbon steel

   Stainless steel - aluminum

   Aluminum - Zinc (galvanizing)

   Use a dielectric insulator between dissimilar metal combinations. Sealants and coatings (applied to the cathode) might be appropriate. Specific cases should be reviewed.

c. Avoid crevice areas which will trap moisture and pollutant particles. Crevices should be oriented so that they drain. Crevices should be sealed. Polysulfide, polyurethane, and silicone sealants are satisfactory.

d. Provide ventilation of enclosures to minimize condensation.

e. Do not use tack welds or stitch welds. Seal weld all joints or use a sealant.

3.5 Maintenance

a. Repair coating deterioration when it is discovered. This will prevent coating deterioration from spreading which would result in major maintenance costs. Recoat when 10 percent or more of the surface needs repair.

b. Utilize approved coating maintenance procedures for the coating being repaired.

c. Stainless steel - clean with detergent and non-metallic brushes or scouring pads. Use of steel scouring pads will embed iron particles resulting in unsightly rust stains. Rinse with clean potable water.

d. Aluminum - do not use alkaline cleaners on aluminum surfaces as these will accelerate corrosion. Rinse with clean potable water.

e. Consider a materials testing program with the objective of evaluating the performance of maintenance materials (metals, non-metals and coatings) in the Los Angeles environment.

f. Repair of galvanizing - clean galvanizing and damage area by abrasive blasting. Apply a zinc coating of inorganic zinc or flame sprayed zinc (ref. ASTM specification A780).

g. Wash vehicles frequently in order to remove accumulated pollutant particles.

4. DISCUSSION

4.1 ABOVE GRADE FACILITIES - CONSIDERATIONS

4.1.1 General

In order to evaluate the severity of corrosion than can be expected on SCRTD facilities above grade, information was obtained on:

- local climatological data
- local air quality
- areas of industrial activity near the proposed rail system
- corrosion data published in the technical literature
- local utility experience

4.1.2 Local Utility Experience

Local utilities were contacted to ascertain their experiences with atmospheric corrosion. Experience has shown that local companies are often willing to provide experience not available from other sources except through extensive test programs. Those utilities contacted were:

Southern California Gas Company
Los Angeles, CA

Department of Water and Power
Los Angeles, CA

Pacific Telephone & Telegraph Company
Glendale, CA

Metropolitan Water District of Southern California
Los Angeles, CA

City of Los Angeles Department of Water and Power
Los Angeles, CA

Southern California Rapid Transit District
Los Angeles, CA

These interviews provided a consensus that atmospheric corrosion is not considered a major problem in Los Angeles, except near the Pacific Ocean. The effects of the ocean usually decrease and become less significant further than about 1 mile inland. The closest point of the proposed transit system to the ocean is about 8 miles.

4.1.3 Industrial Areas

There are not any local industrial areas near the proposed rail system which would increase the corrosion rate of the system above that expected over the whole route. Atmospheric corrosion does occur, however, and protection of carbon steel and aluminum is needed to maintain appearance.

Specific factors affecting above grade corrosion and the magnitude of corrosion that can be expected are discussed in the following three sections.

4.1.4 Local Climatological Data

Climatological data was obtained for Los Angeles from the National Oceanic and Atmospheric Administration, Department of Commerce, 1980 Report. The most important factors in the corrosion analysis are the temperature, relative humidity and precipitation. The average annual temperature is 62°F with a range generally between 40°F and 85°F (winter to summer). Relative humidities are maximum during the evening hours with a range of 70-87 percent, and least during daylight hours with a range of 54-69 percent. Precipitation occurs as rainfall, mainly during a seven month period, with an average annual rainfall of 12.47 inches. Wind direction is primarily from the west and west south west. Temperature is important, in that corrosion rate increases with increasing temperatures; however, the most important factor is the temperature combined with the relative humidity. If the temperature drops low enough at any given humidity, the dew point is reached causing a film of water to deposited on the cooler surface. Since corrosion is electrochemical, moisture is needed for the corrosion process to occur. In this respect, the time of wetness is an important factor. An empirical time of wetness relationship is(1):

$$f_w = \exp\left[4.04 - (404/RH)\right]$$

Where f_w is the fractional time of wetness and RH is the relative humidity. Using an average relative humidity of 71 percent, the fractional time of wetness is 0.192. This value can be used to estimate corrosion rates. Air pollution factors must also be considered as will be discussed.

Precipitation provides an electrolyte for the corrosion process but can also clean deposits from the surface and so can lower the corrosion rate in some cases. Wind direction is from the sea, which would tend to bring in salts from the ocean. The closest point of the proposed rail project to the ocean, however, is approximately eight miles away. Airborne salts from the ocean are not expected to be a significant factor in corrosion on the SCRTD Metro Rail Project.

4.1.5 Effects of Air Pollution

4.1.5.1 General

Air pollution data for Los Angeles and its immediate area were obtained from the South Coast Air Quality Management District and technical literature sources. Pollutants monitored by that agency include: sulfur dioxide, suspended particulates, lead, sulfate, carbon monoxide, ozone, nitrogen dioxide and non-methane hydrocarbons. Pollutants are important when considering atmospheric corrosion because they can add to the normal corrosiveness of the atmosphere, as discussed in this report. Nitrogen oxides do not cause corrosion of materials in themselves; however, nitrogen oxides do form nitrates and nitric acid. Nitrates can cause failures of electrical contacts and stress corrosion cracking of nickel brass. Nitric acid can corrode aluminum, brass, bronze, cast iron, steel and zinc. Ozone attacks rubber and elastomers. Non-methane hydrocarbons lead to increased deposition of hydrocarbons and their products on aerosols (particulates, ammonium ions, organics, nitrate ion, sulfate ion and chloride ions). Particulate matter affects corrosion by absorbing moisture and gaseous contaminants and holding them in contact with the substrate. Sulfur dioxide is probably the most corrosive pollutant. It oxidizes to sulfuric acid which is deposited on aerosols or surfaces. Table I lists values of pollutants measured in the Los Angeles area of importance to the SCRTD Metro Rail Project.

4.1.5.2 Acid Rain and Acid Fog

The occurrence of acid rain is becoming better known for its adverse affects on materials. Acid rain occurs when precipitation with a "normal" or nearly neutral pH comes in contact with pollutants in the air, notably sulfur dioxide and nitrogen dioxide. The result is water with an acidic pH. The measure of the acidity or alkalinity of a solution is called the pH. Actually, pH is defined as the negative logarithm (base 10) of the hydrogen ion concentration. Values below 7 are acidic and those above 7 are alkaline and 7 is neutral. The Annual Climatological Data summary does not indicate rainwater acidity, but another source (reference 22) reports the pH of Los Angeles rainwater to be between 4.4 and 5.4. So called "normal" rainwater has a pH of 5.6.

Sulfate and nitrate particles ("acid dust") can also be deposited on surfaces from the atmosphere (25, 26). These particles will become acidic when moistened by condensation or rain. This form of pollution fallout might be expected to play a more important role than acid rain alone in the deterioration of materials in the Los Angeles area.

Acid fog is also reported to occur in Los Angeles(22). In this case, the water droplets in fog also react with sulfur dioxide and nitrogen oxides to form acid. Fog pH was reported to be as low as 2.25 in the Los Angeles area in reference 22, but a more recent fog was reported to have a pH of 1.69(23). The 1980 Climatological Summary report states that "light fog occurs at sometime nearly every month but heavy fog is observed least during the summer and can be expected on about one night or early morning in four during the winter."

It is clear from the present state of knowledge on this subject that pollution caused acid rain, fog and dust will continue for some time (27-30) and that more knowledge is needed before solutions to the problem are achieved. Corrosion caused by pollution is something that must be considered now and in the foreseeable future. It might be advantageous for SCRTD to initiate a materials testing program to evaluate long term effects of Los Angeles pollution on metals, non-metals and coatings. Such a program could be designed to meet the needs of SCRTD in screening and selecting maintenance materials.

4.1.5.3 Corrosion Caused By Pollution

There is no information relating to critical levels of pollutants needed to enhance corrosion. Acidic waters will have a corrosive effect on materials exposed to that environment. Unfortunately, it is difficult to quantify the effect with presently available information.

Qualitatively, the effects of air pollution, acid rain, acid fog and acidic particles can be expected as follows (24):

Carbon Steel - corroded

Galvanized Steel - corroded

Painted Steel - affected

Aluminum Alloys - not corroded if clean, otherwise corrosion occurs at deposits

Stainless Steels - not corroded

The degree of corrosion on these metals is affected by the degree of pollution at the time of exposure, the time of wetness and the pH of the rain or fog. There are some empirically derived relationships between the most critical pollutant, sulfur dioxide and climatological data. These are used where appropriate in the discussions on materials that follow. Examples of the empirical relationships that have been derived are:

1. Carbon steel, ref. 1

   $CR = 325\ (t)^{.5}\ [\exp\ (0.00275(SO_2)-(163.2/RH))]$

2. Weathering steel, ref. 3

   $CR = [5.64\ (SO_2)^{.5} + \exp\ (55.44-(31150/RT)](fw)^{.5}$

3. Galvanized steel, ref. 3

   $CR = [.0182(SO_2) + \exp\ (41.85 - (23240/RT))](fw)$

where CR = corrosion depth, micrometers

SO_2 = average level of sulfates, micrograms per sq. meter

RH = average relative humidity, percent

R = gas constant, 1.9872 cal. per g. mol

T = geometric mean temperature

fw = fractional time of wetness, $fw = \exp\ [(4.04 - (404/RH)]$

t = time, years

Coatings can be degraded by exposure to acid pollution fallout. They can be degraded both in appearance and in protective function. There has not been much work published on the performance of specific coatings under pollution conditions. There is some evidence that standard automotive finishes (alkyd, acrylics) degrade under conditions of acid pollution (31). This agrees with general practice where these coatings are not resistant to acid exposure (19). Section 4.2.1.2 discusses coatings in more detail.

4.2.1 METALS FOR ABOVE GRADE CONSTRUCTION

The technical literature was searched to obtain corrosion data which can be applied to the SCRTD Metro Rail Project. Test data in Los Angeles is available for some engineering metals; the performance of other alloys must be estimated from data obtained at similar locations. Test data from other locations is not necessarily an accurate predictor of corrosion behavior in the Los Angeles area because of environmental differences which are not always reported in the literature. Corrosion performance in Los Angeles should not, however, be more severe than observed at these other locations.

Engineering metals considered include: carbon steel, weathering steel, alloy steel, aluminum coated steel, aluminum-zinc coated steel, zinc coated (galvanized) steel, stainless steel, aluminum, copper and magnesium. When reviewing atmospheric corrosion data, it is important to keep in mind that the corrosion rate is usually maximum during the first few years. Corrosion products and protective films cause the corrosion rate to decrease with time to a steady-state value. Consequently, corrosion rate data was evaluated for the longest exposure period available.

4.2.1 Carbon and Alloy Steel, Cast Iron

4.2.1.1 Uncoated

Carbon steel, for the purposes of this study, is defined as iron with a maximum carbon content of 2 percent, with only residual quantities of other elements, with silicon limited to 0.60 percent and manganese limited to 1.65 percent. The corrosion rate of carbon steel in the Los Angeles environment will be about 0.00034 inch per year after two years(1) and 0.00019 inch per year after 64 month exposure test(2). The depth of corrosion in 25 years will be about 0.005 inch if the steel is unprotected. Carbon steel castings can be expected to corrode at the same rate.

Copper bearing steel contains 0.2 percent copper and weathering steels can contain other alloying elements in small quantities. Corrosion rate calculations based on average sulfur dioxide content, humidity, and temperature predict the corrosion rate to be between 0.00028 and 0.00058 inch per year(3). Measured corrosion rates of copper bearing and weathering steels are 0.00018 and 0.00017 inch per year respectively after 64 months(2) (0.0045 and 0.0043 inch penetration in 25 years respectively). Therefore, weathering and copper bearing steels do not appear to offer a significant advantage over carbon steel in atmospheric exposure in Los Angeles.

Alloy steels are defined as iron alloys containing significant quantities of alloying elements (chromium, nickel, molybdenum, copper) in addition to those found in carbon steel. The corrosion behavior of alloy and low alloy steels and alloy cast irons can be expected to be somewhat better than carbon steel. Cast irons will have a corrosion performance similar to carbon steel.

4.2.1.2 Coated Carbon Steel and Cast Iron

Protection of carbon and alloy steels through the use of coatings would appear to be required primarily to preserve appearance. Coatings applicable to the rail project include: zinc (hot dip galvanizing, electrolytic, metallized), cadmium, aluminum (hot dipped, metallized, vapor deposited), aluminum-zinc, and organic. All of these sacrificial coatings can be expected to be adversely affected by acidic pollution. Calculations taking pollution into account indicate that zinc coated steel will corrode at a rate between 0.000011 and 0.000048 inch per year(3). Actual exposure tests in Los Angeles confirm this predication with an actual corrosion rate of 0.000034 inch per year(4) after 64 months. This means that a 2 ounce per square foot (.0034 inch) galvanizing would be completely depleted in about 100 years. Commercial sheet with 1.25 oz. per sq. ft. (.0021 inch) on both sides, however, would show complete rust in about 30 years. The zinc on a steel fastener plated to a thickness of 0.0005 inch would be depleted in about 14 years.

Caution must be exercised when using average corrosion rates. These rates apply only to the complete deterioration of the coating. In reality, corrosion failure of the coating will occur in a much shorter period of time in localized areas such as in crevices, at edges, in areas where water (or condensation) is trapped and at localized areas on the surface where pitting of the coating has occurred. Comparison of time to initial rust and time to complete rust (coating depletion) in ASTM STP 585(10) indicates that the time to first rust varies between about 0.56 and 0.83 the time for complete depletion. Zinc coated steel chain link fencing (1.77 oz. per sq. ft.) exposed at Port Reyes, CA, for example, displayed first rust after 9.8 years(10) but had yet to show complete rust at the 12 year inspection. Maintenance on hot dip galvanized steel can therefore be expected as soon as 10-15 years.

Aluminum coatings (Type II, no silicon) will corrode at a rate of about 0.000007 inch per year in an industrial environment and 0.00001 inch per year in a marine environment, according to published test results(5,8). A thickness of .002 inch would then have a calculated life of 200 years (complete depletion) under the more severe marine exposure conditions. Caution must also be exercised when utilizing this test data, as it provides only average corrosion rates. Localized corrosion can be expected at pits, in crevices and at edges, thus requiring a protective coating to provide a good appearance before complete depletion is realized. In the referenced exposure tests at Port Reyes(10), aluminized chain link (0.57 oz. per sq. ft) did not exhibit any rust after 12 years. More thinly coated barbs (0.25-0.39 oz. per sq. ft.) exhibited first rust after 11 years in some cases. The calculated life of a 0.002 inch coating would be 200 years for complete deterioration in a severe marine environment. There is no direct corrosion data for aluminized steel available in Los Angeles so that a direct service life can not be estimated. Aluminum-zinc coatings are available for sheet and wire products and consist of 55 percent aluminum. These would probably not perform as well as the aluminum in Los Angeles but would be superior to galvanizing(5).

Cadmium is electroplated onto steel at a thickness between 0.0001 and 0.005 inch. It generally has poor atmospheric corrosion characteristics and should only be used unprotected in a sheltered environment.

Organic coatings which should perform well in the Los Angeles area include (Reference 21): alkyd (expected life 4-5 years*), acrylic (5 year life), vinyls (4-10 years life), epoxy (4-11 years), inorganic zinc plus epoxy (9-10 years life), polyurethane (10-12 years life*). Life expectancies are approximate and depend on factors such as: generic type of coating system (primer, topcoat) selected, surface preparation, number of coats, and dry film thickness of the coating system. Generally, service life is improved with more coats, greater dry film thickness, better surface preparation, and the use of high performance coating systems. The coating system selected must be based on application, material life expectancy and maintenance cost comparisons. An important factor in the SCRTD Rail System will be coating deterioration by sunlight (ultraviolet radiation). Coating deterioration by acid pollutants is also a factor in the selection of coatings as pollutants tend to degrade coating appearance. All coatings will fade and chalk in time, but superior sunlight and chemical resistance is found in the vinyls and polyurethane coatings. Epoxy coatings fade and chalk considerably when exposed to sunlight and so should be topcoated where appearance is important. Epoxies are resistant to acids caused by pollution. Additional factors in the performance of a coating system other than the generic type (e.g. alkyd, vinyl, epoxy, polyurethane include: the specific formulation (gloss retention, color retention, hiding power, chalking resistance), color selected (dark colors generally show appearance deterioration faster), ease of repair and resistance to abuse. Specific coating formulations under consideration should be able to show a satisfactory performance record in the Los Angeles area.

Phosphate and chromate conversion coatings should be considered as surface preparations for the application of other organic coatings and not as primary corrosion protection. Conversion coatings provide only temporary protection from atmospheric corrosion.

Fusion bonded coatings applied by fluidized bed or electrostatic spray processes (epoxy, polyethylene, polyester, nylon) are satisfactory coatings and should be given consideration where appropriate.

4.2.2 Stainless Steel

Stainless steel is defined as an iron-carbon alloy with more than 12 but less than 30 percent chromium. Stainless steels are divided into several categories with alloying elements to class them as austenitic (200 and 300 series), martensitic (some 400 series), ferritic (some 400 series) and precipitation hardenable. There is no specific data on the corrosion behavior of stainless steels in Los Angeles but they should not be prone to significant corrosion. No rusting should be expected on the austenitic grades or high chromium-molybdenum ferritic grades (Type 444). Discoloration of other 400 series stainless steels is possible, particularly in unsheltered areas. Austenitic grades should be cleaned and passivated ferritic grades (Type 444). Discoloration of other 400 series stainless steels is possible, particularly in unsheltered ferritic grades (Type 444). Discoloration of other 400 series stainless steels is possible, particularly in unsheltered areas. Austenitic grades should be cleaned and passivated before use in order to remove surface contaminants that could cause unsightly rust or discoloration.

Coatings are not recommended on stainless steels in an immersed environment since moisture will penetrate through the coating at defects and this will lead to pitting and crevice corrosion. Coatings are acceptable on stainless steels exposed to non-submerged conditions.

4.2.3 Aluminum Alloys

Aluminum can be expected to corrode at a low rate in Los Angeles. Specific data was not available for Los Angeles but 20 year exposure data obtained in La Jolla (marine environment) indicates the following corrosion rates(6).

Alloy	Corrosion Rate, ipy	Max. Corrosion, Inch, 20 Yrs.
1100-H14	.0000295	.0084
2017-T3	.0000496	.0071
2017-T3 Alclad	.000030	.0014
3003-H14	.000038	.0064
6051-T4	.000036	.0067

Actual corrosion in Los Angeles will likely be less since it is a less severe environment. The data does indicate that pitting is possible. An anodized finish is recommended to maintain appearance. Periodic cleaning might also be necessary. There is no appropriate atmospheric corrosion data available for cast aluminum alloys but similar compositions can be expected to perform similarly to wrought aluminum alloys.

Organic coatings, such as those in 4.2.1.2 are acceptable on aluminum alloys.

* Actual service life as reported by Metroplitan Water District of Southern California

4.2.4 Copper Alloys

Copper and copper alloys can be expected to corrode at a low rate in the Los Angeles atmosphere. Again, specific data is lacking for Los Angeles, but exposure data in the marine environment at La Jolla indicate a maximum corrosion rate of 0.000091 inch per year(6). Actual corrosion rates in Los Angeles should be less. Components in enclosures which might trap moisture condensation could corrode at a faster rate. Provisions should be made to provide ventilation, air conditioning, heating, or coating (e.g. 4.2.1.2) where these conditions exist.

4.2.5 Magnesium Alloys

Corrosion rates for magnesium alloys in Los Angeles are not available. Test exposure data for a similar environment indicates that a corrosion rate between 0.00053 and 0.0017 inch per year can be expected(6,7). Since most magnesium use anticipated for the SCRTD Rail system would be in the form of castings, this degree of corrosion might be acceptable. In the event that thin walled die castings are considered, a protective coating might be desirable (e.g. 4.2.1.2).

4.3 TUNNEL AREAS

4.3.1 Water Seepage

4.3.1.1 General

Water seepage into the tunnel areas is a possibility, particularly in areas where the tunnel is lower than the natural water table. Specific areas where this occurs are:

1. Reach 1, East Portal to mile 1.25
2. Reach 5, mile 8.6 to mile 10.3
3. Reach 6, mile 10.3 to mile 11.6
4. Reach 6, mile 13.1 to mile 13.3
5. Reach 7, mile 13.4 to mile 16.8

Mile boundaries are approximate and are based on our understanding of the tunnel depths. Additionally, the tunnel is beneath the perched water table in Reaches 1, 2, 3, 4, 6 and 7. Water entry is possible in these areas. A rise in the water table north of test hole CEG 34 as a result of wet conditions and recharging was predicted in the geotechnical report. This could cause further water seepage into the tunnels in that area. It is our understanding that the tunnel is to be constructed in such a way that there will be no running water in the tunnel. Local areas of water seepage are still possible.

Data presented in the Geotechnical Investigation Report and the supplemental analyses requested by Waters Consultants indicates that the ground water tends to be rather corrosive. Tables II and III summarize this data for the convenience of the reader. Tables II and III show that much of the ground water contains a high total dissolved solids content, including high concentrations of sulfates and chlorides. Additionally, the data in Table III shows that the water can be acidic. Thus, the ground water in many areas can be corrosive to both metals and concrete used in the tunnels and stations. The Task 4 report, "Soil Corrosion Study", will discuss the effects of the ground water on concrete in detail.

4.3.1.2 Metals

Acidic waters are corrosive to practically any structural metal that might be found in the tunnel or at stations. Steel, cast iron, aluminum and zinc will corrode readily, particularly where the pH drops below 5. Copper alloys will corrode in low concentrations of sulfuric or sulfurous acid, particularly high zinc brasses. It should be recognized that severe corrosion of rails and trackwork components could occur through the action of seepage water. Stainless steels are reasonably resistant to sulfuric and sulfurous acid in dilute concentrations and at ambient tunnel temperatures, particularly grades containing molybdenum. Stainless steels are, however, subject to intergranular corrosion under these conditions. Intergranular corrosion could be expected at welds in non-stabilized and non-low carbon grades. This can be avoided through the use of stabilized (e.g. 347) and extra low carbon grades where welding is to be done. Localized corrosion of the stainless steel, such as pitting and crevice corrosion, are possible under deposits and at joints. Joint design must, therefore, eliminate crevices where water seepage is expected. Stainless steel alloys 316(L) and 317(L) should be used where ground water contact is expected to minimize corrosion under deposits.

Corrosive chloride concentrations are found in the following areas:

GEG Boring No.	Reach
3	1
4	1
6	1
7	2
10	3
11	3
12	3
15	4
16	4
17	4
18	4
19	5
20	5
21	5
29	7
35	8

Chlorides emanate from the oil field brines near the proposed rail system. The chlorides will promote and accelerate localized corrosion on all of the metals that could be used in the tunnels and at the stations. Aluminum and the austenitic grades of stainless steel are generally resistant under aerated free flowing conditions; they are, however, subject to rapid pitting and crevice corrosion under deposits and at joints. Austenitic stainless steels containing stresses are also subject to stress corrosion cracking if carbide precipitation has occurred. Stainless steels with high chromium and molybdenum contents such as Types 317, 444, or Carpenter 20 are much more resistant to localized corrosion than standard stainless grades.

Water resistivities at almost all of the other test borings (exceptions: 8, 13, 20, 28, 34) are sufficiently low to cause rapid corrosion of steels, cast iron, aluminum, zinc and copper. Stainless steels, again, will be subject to localized corrosion. The combination of acidic water, high chloride concentration and low resistivity make any water that seeps into the tunnel very corrosive. Rails, fasteners, electrical equipment and internal surfaces of rails and tunnel liners will be subject to corrosion attack resulting not only in poor appearance, but also eventually loss in function.

Stress corrosion cracking of some aluminum alloys can occur in acid-chloride environment. Alloys and tempers which are resistant to this form of corrosion are: 2024-T8, 2219-T6, 2219-T8, 6061-T6, 7075-T73, and 7075-T736.

4.3.1.3 Coatings

Protective coatings can be used to protect the metal if only occasional periods of exposure are encountered. Coatings are not recommended for conditions of continuous or frequent exposure to water seepage because they can not be expected to provide permanent protection to the metal substrate. Water seepage should be kept to a minimum and kept out of contact with metal structures through design and drainage.

Carbon and alloy steel, aluminum, galvanized steel, aluminized steel, copper alloys, and magnesium alloys can be coated. Stainless steels should not be coated as the coating will promote crevice corrosion and pitting in areas of coating disbondment where intermittent or continuous immersion are encountered.

Appropriate coatings include: vinyl, chlorinated rubber, polyamide epoxy, polyamine epoxy, coal tar epoxy, and polyurethane (also refer to 4.3.4). Coating performance will be greatly improved with a suitable combination of primer and topcoat. The system recommended for carbon and alloy steel is an inorganic zinc primer followed by a two coat minimum of the topcoat. Galvanizing or a metallized zinc coating are also suitable substrates for topcoats on a steel structure but should not be used unprotected where acidic and/or high chloride water is anticipated.

The use of a high performance coating can be more cost effective than a conventional system even though paint, preparation, and application costs are generally higher. High performance coating systems usually require less maintenance and have a longer recoat cycle than conventional paints, resulting in an overall lower cost.

4.3.2 Condensation

4.3.2.1 During Construction

Condensation of moisture from outside air brought into the tunnels can be expected within the tunnel during the construction period. During the summer, with an average temperature around 70°F and a relative humidity range of 60-77 percent, the dewpoint will be between 55 and 60°F, which is not an unlikely temperature range for the tunnels. The dewpoint during winter at ambient outside air temperatures between 55 and 60°F can be expected to range between 38°F and 52°F. Condensation during winter months can be expected at times. Condensation will cause corrosion of metal structures within the tunnel areas, although not as severe as the corrosion potential of seepage water. Contamination of condensed water by chlorides and other matter will increase the corrosivity where it occurs. The degree of corrosion will depend on the length of time the structure is exposed.

4.3.2.2 During Revenue Operations

Continuous ventilation during revenue operations should keep condensation to a minimum. Therefore, minimal corrosion is expected from condensed moisture during these periods. Coatings include: zinc, aluminum, epoxies, polyurethane, acrylics and polyesters.

4.3.2.3 Metals

Unprotected low alloy and carbon steels along with cast iron will be affected. Other materials suitable for use in tunnel and station areas include: anodized aluminum alloys, stainless steels and copper alloys. Austenitic and high molybdenum bearing ferritic grades of stainless steels are particularly suitable in station areas as they will maintain a presentable appearance with minimal maintenance.

4.3.2.4 Coatings

Low carbon and alloy steels along with cast iron should be protected with suitable coatings if they are to be exposed to condensation conditions for an extended period of time. Coatings include: inorganic zinc, galvanizing, metallized zinc, metallized aluminum, bituminous coal tar epoxy, and polyamide epoxy. It is recommended that a topcoat be used with any zinc or aluminum coating, otherwise deterioration of the zinc or aluminum could occur during long construction periods. It is recommended that a primer and at least two coats of the finish coat be used to ensure long performance and long lasting appearance. Fusion bonded powder coatings are also recommended. Porcelain and cement coatings are also satisfactory; however, it is recommended that these not be used in areas where frequent contact with seepage water could occur.

4.3.3 Effect of Corrosion on Stray Current Controls

Corrosion of rails and trackwork components will create corrosion products which will have many times the volume of the original steel. These corrosion products can bridge across insulating materials resulting in current flow to earth. Moisture condensation and conductive seepage water will have the same tendency. These will have the effect of reducing the efficiency of stray current control devices and increasing stray current flow to earth. This is discussed more fully in the Task 5 report, "Stray Current Analysis".

Aside from reducing the efficiency of the stray current controls, water seepage and condensation will deteriorate the materials used for stray current controls. Seepage water should be minimized in order to control this corrosion, otherwise it will be necessary to make extensive use of materials and coatings to control the corrosion.

4.3.4 Tunnel Gases

The Geotechnical Investigation Report presented an analyses of gases which can be expected in the metro tunnels. Table F1-1 of the Geotechnical Investigation Report lists the gases which can be expected in the tunnel as follows: Methane, ethane, propane, n-butane, isobutane, n-pentane, isopentane, C_6+, nitrogen, oxygen, carbon monoxide, carbon dioxide, and hydrogen sulfide. Of these gases, oxygen, carbon dioxide and hydrogen sulfide are of particular interest with regard to corrosion of metals. According to the gas analyses in the Geotechnical Investigation Report, the quantities of these three gases in the borings are at levels equivalent to their concentration in air. Since, however, the tunnels pass through and near oil fields with the possibility of oil seepage, the possibility exists of higher gas concentrations. Hydrogen sulfide is of particular concern. Most of the materials that might be used in the tunnels are resistant to dry hydrogen sulfide. Hydrogen sulfide, however, is slightly soluble in water and will form a weak dibasic acid. The hydrogen sulfide can therefore be expected to dissolve in any water seepage (if not already there) and condensation present. Moist hydrogen sulfide will corrode many of the materials which could be used in the tunnels. Specific corrosion rate data can not be given since the data that is available pertains to high concentrations and continuous exposure. The quantities of hydrogen sulfide that will be present and dissolved in the water within the tunnels are not known and the exposure periods not continuous. An overview, however, of the effects of hydrogen sulfide provides useful information and is as follows:

A. Metals (11-16)

Carbon steel - severe corrosion possible

Cast iron - severe corrosion possible

Alloy cast iron (e.g. Ni Resist.) - corrosion possible

Aluminum - generally resistant, possible cracking

Copper alloys (except brass) - severe corrosion (forms a black non-protective sulfide layer)

Brass (Zn 20%) - better performance than copper

Stainless Steel - 316 good resistance; 302, 303, 304, 305 resistant, pits; 410, 416, 430 - stress cracking, severe corrosion in concentrated solutions

Carpenter 20 - resistant

Zinc - resistant (forms a white protective sulfide layer)

Inconel - corrodes

Titanium - resistant

Monel - corrodes

Hastelloy - resistant

B. Polymers (12,15,17,18)

The following polymers are considered resistant:

PVC (up to 120°F)
flurocarbons
phenolic
polyvinylidene fluoride (Kynar)
polyester
epoxy
polypropylene
polyethylene
nylon
furan
chlorosulphonated polyethylene (Hypalon)
urethane
fiber reinforced plastic

The following polymers will exhibit possible deterioration:

Rubber-neoprene (swelling)
    Viton
    nitrite
Buna N and natural

C. Paints (17,18,19,20)

Paints are acceptable for exposure to splash, spills and short interval contact only. Those which can be used include:

chlorinated rubber
vinyl (should be formulated for exposure to hydrogen sulfide)
organic and inorganic zinc
epoxy (polyamide, polyamine, polyester and coal tar)
urethane
phenolics

Paints which will deteriorate when exposed to wet hydrogen sulfide are:

alkyds
acrylics
epoxy esters

Protection against corrosion by hydrogen sulfide gas dissolved in seepage and condensation is best achieved by using the following alloys: 300 series stainless steels, anodized aluminum, and coated carbon steel (organic or galvanized). Coat galvanized steel with an organic coating. Copper alloys should be used in sealed and protected areas, particularly where appearance is important. Most common polymers, except rubber, appear to be satisfactory. The coating systems recommended in this report for other reasons appear to also offer satisfactory protection against moist hydrogen sulfide in the low concentrations expected in the tunnels.

4.4 VEHICLES

The function and appearance of the rail vehicle are an important part of this project. Operating conditions which these cars will be exposed to will vary in corrosivity depending on the transit system finalized. Corrosion of the vehicles above grade is not expected to be severe. Corrosion below grade will also not be severe as the vehicles will not be subject to moisture accumulation. Below grade operations, however, will subject the vehicles to possible contact with dripping from seepage water. Seepage water could cause corrosion and staining of the vehicles.

Since maintenance costs must be kept low, materials considerations should be toward reducing possible corrosion(9). Vehicle outer shells and exposed fasteners should be fabricated from anodized aluminum and/or austenitic (200, 300 series) stainless steel. Stainless steel should be cleaned and passivated prior to use. Crevice areas, particularly those between dissimilar metals (e.g. aluminum and stainless steel) must be sealed, otherwise crevice and galvanic corrosion are possible which will adversely affect the appearance of the vehicle. Stainless steel construction will minimize chances for staining.

If it is desired to apply a paint to the cars, an anodized aluminum substrate is recommended with a polyurethane coating. The polyurethane will not fade or chalk as readily as other coatings and maintain its gloss longer.

One transit industry problem appears to be maintaining the appearance of aluminum cars. This appears to manifest itself in discoloration and staining and is possibly the result of pollutants and/or soils becoming combined with the protective oxide on the aluminum. One possible solution to this problem is to anodize the aluminum and apply a clear or pigmented polyurethane coating to the surface in order to seal the anodizing and provide a washable surface.

Frequent washing with fresh water and a detergent compatable with the vehicle material will remove the acidic dusts that deposit on vehicle surfaces.

4.5 CREVICE AND BIMETALLIC CORROSION

Crevice and bimetallic corrosion are discussed separately because they are an important aspect of atmospheric corrosion which must be considered in the design of the system. Crevice corrosion is localized corrosion resulting from the formation of a concentration cell in a crevice formed between a metal and a non-metal or between two metal surfaces. Examples of situations where this can occur include: lap joints, under rivets and under bolts, nuts and washers. Stainless steels and aluminum are particularly subject to crevice corrosion, we therefore recommend that a sealant be used wherever moisture can accumulate. This will prevent moisture from entering the crevice, thus eliminating the corrosion cell. Satisfactory sealants include: RTV silicone, polysulfide, butyl rubber and polyurethane.

Bimetallic corrosion is corrosion resulting from dissimilar metal contact with a common electrolyte. The best approach to avoiding this type of corrosion is to eliminate contact between different metals. A secondary approach is to coat the metals prior to contact or use a dielectric insulator such as a plastic washer. Sealants can also be used.

Bimetallic couples exposed to the atmosphere which are generally acceptable without additional protection on the rail project include:

1) Exposed directly to weather -

Stainless Steel - Carbon Steel

2) Sheltered from indirect exposure to the weather -

Stainless Steel - Carbon Steel
Copper Alloys - Stainless Steel

3) Housed inside a building -

Stainless Steel - Carbon Steel
Stainless Steel - Zinc
Stainless Steel - Aluminum
Stainless Steel - Cadmium
Carbon Steel - Zinc
Carbon Steel - Aluminum
Carbon Steel - Cadmium
Copper Alloys - Stainless Steel
Copper Alloys - Carbon Steel

Specific applications must be reviewed to determine the requirements for corrosion protection.

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TABLE I. Pollutants To Be Found Within The SCRTD Metro Rail Project Area

Pollutant	Amount Measured
Nitrogen Oxide	65-119 ppb(1)
Nitrogen Dioxide	35-44 ppb(2,4)
Nitrate Ion	12.5 micro g/cu-m(3)
Ozone	35-118 ppb(2,4,5)
Sulfur Dioxide	39-47 micro g/cu-m(1)
Sulfate	32.8-38.4 micro g/cu-m(2,4)
Particulates	175-248 micro g/cu-m(2,4)
Hydrocarbons	8.3-19 ppm(2,4)
Lead	2.63-3.76 micro g/cu-m(2,4,5)

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4. Exceeds state standard.
5. Exceeds state and federal standard.

TABLE II. Water Quality

CEG Boring No.	Depth ft.	Resistivity ohm-cm	pH	TDS ppm	Sulfate ppm	Chloride ppm
1	25.5	526	7.9	1258	475	100
2	11.0	1408	7.7	412	57	49
3	33.0	164	7.0	3722	152	2000
4	30.0	118	7.6	5085	79	2800
6	19.0	33	7.5	20230	27	12255
9	105.5	1172	7.7	485	82	101
10	23.0	178	7.4	4461	2200	731
11	-	34	7.2	19670	5	11785
12	20.0	101	7.5	6038	40	3300
14	24.0	892	7.9	677	67	120
16	35.0	510	7.4	1139	231	280
16	40.0	82	7.5	6926	25	3300
17	25.5	699	7.6	795	87	240
19	32.0	42	7.0	15425	240	8680
21	19.0	699	7.6	867	263	78
21	19.0	400	7.4	1448	67	577
22	16.2	855	8.0	718	149	122
22	18.3	855	7.7	779	124	107
23	7.5	980	7.5	589	6	74
23A	20.0	769	7.7	863	154	120
25	109.0	1054	7.6	494	65	41
26	31.0	980	7.4	660	161	54
27	27.5	833	7.8	725	245	75
28A	30.0	1087	7.8	805	272	76
29	84.5	122	8.0	5996	2600	1066
30	21.1	1136	7.9	620	202	29
31	28.7	1233	8.6	511	161	50
32	55.0	1502	9.8	587	121	37
32A	7.5	833	8.0	940	434	62
33	21.8	469	7.2	1504	693	94
33	23.3	585	7.5	1154	538	60
35	95.0	216	7.6	2605	19	1423
36	68.3	855	7.6	732	253	66
37	127.4	819	7.0	877	418	49
38	138.0	833	7.8	906	463	34

Source: Geotechnical Investigation Report, Vol. II, Appendix G,
Converse Ward Davis Dixon, Earth Science Associates, Nov. 1981

TDS = total dissolved solids

TABLE III. Water Quality, Supplemental Data

CEG Boring No.	Location Station	Depth ft. approx.	Resistivity ohm-cm	pH	Sulfate ppm	Chloride ppm
5	Union	85	600	3.0	6030	123
5		139	1680	6.1	648	316
7	Civic Ctr.	40	650	6.8	4850	236
7		168	670	6.6	5052	558
8	5th St.	78	10400	5.5	69	29
8		100	375	2.6	14500	56
8		186	1100	6.5	2316	75
13	Vermont Ave.	20	15400	5.4	149	24
13		173	750	6.0	5330	62
15	Western Ave.	70	280	2.6	27000	5110
15		120	500	3.5	7820	411
18	La Brea Ave.	5	2900	6.9	58	31
18		75	580	3.1	7950	40
18		170	380	6.3	5340	2190
20	Fairfax Ave.	44	5300	5.4	444	21
20		105	1400	6.0	239	1176
20		150	480	6.5	1536	2906
24	Santa Monica Blvd.	40	6700	5.8	27	57
24		155	9200	5.6	14	25
28	Hollywood Blvd.	35	8600	5.8	24	26
28		159	10000	5.6	36	26
34	Universal City	40	5400	5.7	214	43
34		55	900	6.2	3434	45
34		193	420	5.5	69	73
1	-	40	1800	5.8	-	-
1		122	600	6.2	-	-
3	-	60	1250	3.6	-	-
3		100	400	6.7	-	-
10	-	40	500	6.6	-	-
10		180	570	3.6	-	-
11	Alarado St.	25	670	3.3	-	-
		145	380	6.4	-	-
23	Beverly Blvd.	90	4500	5.7	-	-
23		156	960	6.5	-	-
32	-	90	4700	7.3	-	-
32		280	8700	6.9	-	-
38	-	60	15000	5.9	-	-
38		180	8300	6.0	-	-

Source: Soil/Rock Chemical Analysis Report prepared by Converse Consultants, Inc. May 26, 1982, Project 80-1280-90.

Data obtained from core samples and/or drill cuttings.

TASK 7

STRAY CURRENT CONTROL RECOMMENDATIONS

Table of Contents

SECTION	DESCRIPTION	PAGE
1.	INTRODUCTION	7-1
2.	RECOMMENDATIONS	7-2
2.1	Tunnel Construction	7-2
2.2	Trackwork Construction	7-4
2.3	Traction Power System	7-6
2.4	Systemwide Testing and Monitoring . .	7-7
2.5	Utilities	7-10
2.6	Yard and Shop Area	7-11
3.	DISCUSSION	7-13
Appendix A	Rail Fastener Resistance Test Procedures	7-A-1

LIST OF DRAWINGS AND FIGURES

NUMBER	DESCRIPTION	
Figure 1	Fault Resistance vs. Fault Current and Negative System Potential	7-A-4
2.1.4	Typical Stray Current Measuring Test Facility	7-A-5
2.1.6	Tunnel Test Electrode Arrangement	7-A-6
2.2.2	Typical Direct Fixation Insulating Rail Fastener	7-A-7
2.3.1	Typical Pedestal For Contact Rail Insulator	7-A-8
2.4.1	Protection Against Excessive Negative System-to-Earth Potentials	7-A-9
2.4.1a	General Operating Conditions For Above	7-A-10
2.4.2	Track-to-Earth Resistance Measurement Scheme	7-A-11

1. INTRODUCTION

The Task 5 report, Analysis of Stray Earth Currents, together with the memorandums "Meeting on Stray Current Analysis" and the supplemental "Response to Comments from P.M. Burgess, Kaiser Engineers on the Task 5 Report" has formed the basis for the recommendations presented herewith for the control of stray earth current.

The Task 5 report pointed out that the most effective method of minimizing the detrimental effects of stray earth currents is through the control of stray currents at the source. The report presented the following combination of factors which would result in minimum levels of stray earth currents:

- Traction power substation spacing.
- Conductance within the positive and negative power distribution circuits.
- Electrical isolation of both the positive and negative circuits from ground.

Considering these factors, the stray current analysis was conducted for several sets of conditions. Since the substation spacing and the conductance of the positive and negative systems is fairly well defined, the primary variation in stray earth currents was analyzed for variations in the effectiveness of the electrical isolation of the system. The analysis pointed out what level of resistance would be required to limit the leakage of current from the rails so that extensive mitigative measures would not be required for area utilities and transit facilities.

The analysis showed that a track-to-earth resistance of 1,500 ohms per 1,000 feet of track (2 rails) would limit the stray current and earth potential levels to those which would not create significant detrimental effects (maximum current of 0.1 ampere per 1,000 feet of system or maximum potential gradient of 0.050 volt at 1,000 feet from the system.

The recommendations as presented are based on the results of the above mentioned report and supplemental documents together with certain stated conditions which have already been determined for the construction of the system.

The recommendations are directed primarily to maintaining a high level of track-to-earth resistance for the mainline track system with the maintenance yard electrically isolated from the mainline track. Under these conditions, minimal amounts of supplemental corrosion control measures for the underground tunnel construction and utilities will be required. As a result of establishing a high resistance track system, we have also made recommendations directed towards maintaining safe DC potential levels on the negative system.

2. RECOMMENDATIONS

2.1 Tunnel Construction

2.1.1 General

Control of corrosive stray earth currents associated with operation of the underground portion of the transit system can best be attained by maintaining a high electrical resistance between the negative system (principally running rails) and ground. This high resistance, 1,500 ohms per 1,000 feet of track (2 rails) may be obtained by the use of insulating rail fasteners, maintaining a relatively dry tunnel and ensuring no inadvertent connections to grounded structures. The term dry tunnel does not necessarily mean a tunnel absolutely free of water invasion and/or accumulation. A tunnel may be considered dry when the influx of water is limited to a low level of accumulation (to be determined as gallons/day/ surface area). The water influx shall not be from above the spring line and shall not drop or run directly on the rails and/or rail appurtenances. The volume of water must be limited to the extent that it does not attain a level higher than one-inch below the top surface of the rail fastener grout pad(s). The amount of water influx/accumulation shall be limited to a level which will preclude the existence of a high level of humidity in the tunnel.

2.1.2 Precast Concrete Segmented Ring Tunnel Lining

a. No special effort is required to establish positive electrical continuity of reinforcing within segments or between segments provided that a high resistance between the negative system and ground is attained.

b. No special effort is required to ensure electrical isolation of reinforcing within segments or between segments.

c. Concrete for tunnel liner segments shall meet the following criteria:

(1) Sulfate resistant Type V cement.

(2) Maximum of 200 ppm chloride concentration in mixing water.

(3) Maximum water/cement ratio of .37 by weight in conjunction with the use of an air entrainment admixture resulting in a maximum air content of 6 percent by volume to establish a low permeability concrete.

(4) If admixtures or aggregates containing chlorides are used, the total concentration of chlorides from water, admixture and aggregates shall be determined and submitted for District approval prior to use.

(5) Concrete cover over segment steel reinforcing shall be a minimum of 2-inches on the external surface.

d. External surface of segments shall have a protective coating of coal tar epoxy.

e. Internal surfaces of the concrete ring segments do not require protective coating.

2.1.3 Concrete Invert Construction

a. Steel reinforcement in the invert shall be installed by standard construction methods (wire tied) with no special effort to establish electrical continuity or electrical isolation. Steel reinforcement shall be so placed under the running rails that the installation of rail anchor bolts and/or anchor bolt inserts do not contact the steel reinforcing.

b. No protective coating is required between the precast segment ring sections and the invert concrete or on the exposed surface of the invert concrete.

c. Concrete for invert construction shall be made with mixing water containing less than 200 ppm chlorides, and shall have a minimum 2-inch cover over the top layer of steel reinforcing.

2.1.4 Steel Tunnel Liner In Selected Areas Of Potential Gas And/Or Oil Contamination Of The Tunnel

a. The surface of the steel liner exposed in the interior of the tunnel shall have a protective coating for the prevention of atmospheric corrosion. A coating system such as inorganic zinc with an epoxy top coat will be adequate. If coated prior to placing in tunnel, coating damage from welding shall be repaired such that it is equal to the existing coating.

b. Cement grout to be placed between the steel liner and pre-cast segment rings shall be made with sulfate resistant Type II cement.

c. Install facilities for measuring the magnitude of stray current collected on the steel liner. The facilities shall be installed only on tunnel liners having a length in excess of 2,000 feet. The test facility shall consist of two 12-inch lengths of No. 8 stranded, THW insulated copper wire exothermically welded to the steel liner with a spacing of 300 feet between wires and with the wire pairs at 2,000 foot intervals. The wires shall be located at a convenient height for access on the safety walk side of the tunnel and terminated in suitable junction boxes attached to the liner, see enclosed drawing No. 2.1.4.

2.1.5 Passenger Stations

No special stray current corrosion control measures are required in the station areas other than the use of sulfate resistant concrete as recommended for the precast concrete tunnel liner segments (2.1.2.C). No special measures are required to establish electrical continuity or electrical isolation of steel reinforcing. No special insulation measures are required for the platforms provided they are constructed with a paver tile - grout surface.

2.1.6 Systemwide Tunnel Stray Current Test And Monitoring Facilities

a. Test electrodes shall be installed through the tunnel walls into the earth at approximate 1,000 foot intervals. The electrodes shall be placed in the wall most removed from the adjacent tunnel at an elevation below the top of the tunnel invert. The electrodes may be installed through grout tubes in precast concrete segments or through holes drilled through the steel tunnel liner and precast segments. The steel electrodes shall have a minimum 4-inches of bare steel in contact with earth. The electrodes shall be electrically insulated from the tunnel structure. Test wires shall be connected to the electrodes and segment steel reinforcing or steel tunnel liner depending upon the location of the electrode. The test wires shall be terminated in a test box mounted on the wall on the the safety walk side of the tunnel. The enclosed Drawing No. 2.1.6. shows the general arrangement for electrode installation.

2.2 Trackwork Construction

Measures recommended below are required to establish and maintain an in-service track-to-earth resistance of 1,500 ohms per 1,000 feet (two rails) for main line track system.

2.2.1 Grout Pads For Direct Fixation Rail Fasteners

a. Grout pads shall be constructed of epoxy/polymer modified concrete having a maximum water absorption of 2.0% by weight (ASTM-C140).

b. Top surface of grout pads shall have an elevation above the surface of the invert which will limit the accumulation of water to a maximum level of 1-inch below the top of the grout pad.

c. Grout pads may be constructed individually for each rail fastener or of sufficient length to support several rail fasteners. Drainage channels shall be constructed in the long grout pads to prevent excessive accumulation of water adjacent to the pads.

2.2.2 Direct Fixation Rail Fasteners For Use On Mainline Track

a. Anchor bolts and/or anchor bolt inserts shall have a protective coating of epoxy applied by fluidized bed method.

b. Anchor bolts and/or inserts shall have a minimum separation of one-half inch from grout pad reinforcement and shall not be in metallic contact with steel reinforcing in the grout pad and/or the invert.

c. Direct fixation fasteners, as illustrated in Drawing No. 2.2.2, shall be so constructed that there will be no direct low resistance metallic path between the steel running rail and ground. The following is required to achieve this:

(1) The fastener shall consist of a steel plate(s) embedded in an elastomer material having a resistivity on the order of 10^{14} ohm-centimeters dry, 10^{12} ohm-centimeters after long term water immersion and have a voltage rating to withstand the anticipated maximum voltage.

(2) Preferred arrangement of fastener construction is by a single steel support plate embedded in elastomer on four sides and bottom (no steel plate in direct contact with grout pad).

(3) If two steel plates are used, the bottom plate must be coated with elastomer or epoxy to prevent contact between metal and grout pad.

(4) Install a removable plastic or rubber cap to cover exposed anchor bolt, nut and steel washer.

(6) Fastener shall be constructed free of voids and recesses which will retain and/or make difficult the cleaning of conductive material which will degrade the electrical insulating characteristics of the fastener. The elastomer lip around the top edge of the fastener shall be constructed so that moisture will not form a continuous film from the top surface of the fastener to the grout pad.

d. Fastener assembly as recommended above shall be tested in accordance with the test procedures set forth in Appendix A to ensure that a minimum resistance 10 megohms (dry) is obtained.

2.2.3 Special Trackwork

Track shall be installed on insulating fasteners modified from the above tangent track fastener or on different fasteners all of which meet the above stated resistance criteria that the fastener shall have a minimum resistance of 10 megohms (dry).

2.3 Traction Power System

2.3.1 Positive System

a. Electrically connect the anchor cage for the contact rail insulator base plate anchor bolts to the reinforcing in the insulator support pedestal by bare wire ties as shown on the attached Drawing No. 2.3.1.

b. Coat bottom of bare metal base plate for contact rail insulator with cold-applied bitumen.

c. The contact rail shall have a minimum resistance to earth of 10 megohms per 1,000 feet of rail (individual insulators shall have a dry resistance in excess of 1,000 megohms).

2.3.2 Negative System

a. Inbound and outbound tracks shall be crossbonded as follows for stray current control purposes. Additional crossbonding for train control and/or traction power loss considerations will not materially change stray current conditions.

(1) Install a crossbond at every passenger station or within 100 feet of the end of the platform.

(2) Install a crossbond at every traction power substation. (Normal negative return cable installation will serve this purpose).

(3) Where a substation, with a crossbond, is within 500 feet of the end of a station platform, no additional crossbonding is required at the passenger station.

(4) Where a substation, with a crossbond, is more than 500 feet from the end of a station platform, an additional crossbond is required within 100 feet of the end of the platform away from the substation.

(5) The combination of items 1) through 4) should result in an approximate average spacing between crossbonds of 1 mile or less. The proposed installation of substations between Hollywood Bowl and Universal City and between Universal City and Lankershim will provide adequate crossbonding for these track sections.

(6) An intermediate crossbond should be installed midway between the Fairfax/Santa Monica Station and the Sunset/ La Brea Station, approximate station 661+12.

b. Train control, communication and/or other ancillary systems when connected to the track system shall not reduce the track-to-earth resistance to a level less than 1,500 ohms per 1,000 feet (2 rails).

2.3.3 Substations

a. Space shall be dedicated in close proximity to the negative bus/switchgear assembly in the traction power substation for possible future stray current test facilities. If space is not available in the immediate vicinity of the negative bus, an open conduit shall be installed between the available dedicated space and the negative bus.

b. Access shall be provided to the negative bus for possible future stray current testing by utilities. The access shall consist of a reserved 2-inch conduit in the AC service duct bank extending from ground level into the substation. The conduit shall be capped, with no wire(s) installed, and identified for future stray current testing.

2.4 Systemwide Testing and Monitoring

2.4.1 Negative System Potentials

a. Provide facilities necessary to continuously monitor and record negative system-to-earth potentials at selected locations throughout the transit system. The major features and purpose of this item are as follows:

(1) Establish base line conditions for normal revenue operations and test train simulations.

(2) Establish patterns and magnitudes of negative system-to-earth potentials during simulated abnormal operating conditions through use of variable resistance negative system-to-earth contacts.

(3) Review negative system potentials periodically either by manual review of recording charts or more frequently through data transmission to a central control facility.

(4) Information will be used to alert operations personnel of the need for maintenance or other corrective action on the negative system.

(5) Monitoring can be established through use of continuous recording voltmeters permanently installed at a minimum of seven locations throughout the system. Suggested locations are:

- Union Station TPSS
- 5th and Hill Passenger Station
- Wilshire and Normandie Passenger Station
- Wilshire and La Brea TPSS
- Fairfax and Santa Monica TPSS
- Intermediate TPSS at Approximate Station 875+00
- Lankershim (North Hollywood) TPSS

(6) Recording voltmeters are to be single channel potentiometric servo motor operated with a fixed span of ±100 volts center zero, .5 second full scale response time. Chart drive to be ½-inch per hour with several faster speeds selectable, up to a maximum of approximately 1-inch per minute.

b. Establish a method whereby abnormally large negative system-to-earth potentials can be detected, annunciated, and reduced to a level that will not present a hazard to passengers and SCRTD personnel who may come in contact with the negative system. Our concept of the detection system consists of the following major subsystems at each TPSS as illustrated on Drawing No. 2.4.1. and 2.4.1a. It must be emphasized that the proposed detection scheme described below and shown on Drawing 2.4.1 is presented as a conceptual approach only. It serves to illustrate what must be considered relative to systemwide safety in the event of excessive DC potentials on the negative system. Systems engineering personnel should review this matter carefully to determine the feasibility of the proposed arrangement and whether or not other protective relaying schemes would be more appropriate.

(1) Silicon control rectifiers (SCR or Thyristor) installed between the negative bus and the station ground mat. SCR's to be rated at 1,500 amperes with a reverse

and/or blocking voltage of 800 volts minimum (preliminary values, must be reviewed in detail). The dv/dt rating of the SCR must be reviewed in conjunction with the rate of rise of negative system potentials caused by normal load currents (i.e. train operations) to ensure that normal operating dv/dt characteristics for the negative system do not cause inadvertent SCR activation. Manufacturers' literature cite maximum dv/dt ratings of 200 to 300 volts/usec for SCR's which if exceeded will cause the SCR to conduct even if not triggered.

(2) Potential detection and SCR triggering devices and circuits that will activate the SCR's when the negative system-to-earth potential exceeds a preset and predetermined level (preliminary value of ±80 volts with respect to ground has been established, but will require further evaluation and review by SCRTD personnel).

(3) Installation of a current sensor in the ground connection (between SCR and negative bus) interfaced with AC or DC breakers to deenergize substations adjacent to faults or otherwise indicate and isolate the cause of the excessive voltage. The sensor must be capable of detecting a minimum current flow of 500 amperes (preliminary value, to be reviewed in detail).

2.4.2 Track-To-Earth Resistances

a. Provide facilities, test equipment and personnel to periodically measure negative system-to-earth resistance and relative distribution of test current flow. The test measuring arrangement should consist of the following major subsystems as illustrated on Drawing No. 2.4.2.

(1) Installation of current measuring test points at each traction power substation (approximately 16 locations).

(2) Each test point to consist of two No. 8, THW insulated stranded copper wires attached to one rail of each track spaced 250 feet apart. Test point locations must be interfaced with crossbond locations such that test wire pairs do not span a crossbond and each pair from different tracks are on the same side of the crossbond.

(3) Test wires to be routed to a permanently installed test box positioned for ease of access by maintenance personnel. Test wire pairs from each track should be housed in a common box if possible and appropriately identified.

(4) Installation of a stepped DC voltage source (10 to 150 volt) with a current rating of 100 amperes, associated

voltmeter and ammeter, test wires and current interruption facilities (either automatic or manual) to provide test current for measurement of track resistances.

b. The general concept of track resistance testing would include consideration of the following procedural items and system requirements.

(1) Tests must be conducted when there is no load on the mainline system, including auxiliary loads for stored vehicles. This may require that tests be conducted during non-operational periods of the system.

(2) Automatic grounding systems based on rail-to-earth potential such as that proposed in 2.4.1.b must be disconnected prior to testing.

(3) Maintenance or operations personnel would be required to activate or set-up the test voltage source between track and a low resistance ground. (Across the mainline/yard interface is a suggested location).

(4) Maintenance or operations personnel would be required to measure the change in potential at each test wire pair from the rails along the system caused by test current interruption. (Consideration should be given to automating this task through proposed data transmission systems if available).

(5) Results generated from these tests would yield individual track section resistances and thus indicate the need for remedial action.

2.5 Utilities

2.5.1 SCRTD Facilities

a. Non-pressure drain pipe embedded in the invert should be non-metallic. If metallic pipe must be used, no special corrosion control measures will be required.

b. Metallic drainage discharge piping and water and fire piping exposed in the interior of the transit structure do not require special corrosion control measures. However, where piping penetrates the structure walls to connect to outside underground utilities, the following corrosion control measures shall be instituted:

(1) Install piping through the structure wall in a watertight electrically insulating sleeve.

(2) Electrically insulate the interior piping from the piping connected to the exterior utility just inside

the structure wall by the use of a pipeline insulating flange, coupling or union.

c. Underground metallic structures outside the transit structure shall be prepared for stray current testing. This preparation would consist of structures being made electrically continuous by the bonding of mechanical joints and test facilities being installed at the tie-in to existing structures and at other appropriate locations.

2.5.2 Facilities Of Other Than SCRTD Ownership

a. Along Mainline

No specific action will be required by SCRTD. However, test/monitoring facilities should be installed at the discretion of the owner at appropriate locations on replacements and/or relocated structures. Additional corrosion control measures may also be installed by the owners in conformance with their corrosion control programs.

b. Yard Area

Utilities and pipelines in the vicinity of the yard should be reviewed in detail to determine the need for test stations and other facilities to test for stray current effects upon system activation.

2.6 Yard And Shop Area

2.6.1 Yard

a. The mainline track system, both positive and negative, should be electrically separated at the mainline/yard train control interface. (Note: other considerations may require that this separation point be moved somewhat).

(1) This electrical separation point will provide the interface between mainline automatic train control and the yard train control system.

(2) Electrical separation to be achieved by a non-bridgeable gap in the positive system (contact rail) and rail insulating joints in the running rails.

(3) An automatic remote controlled interlock shall be provided for both positive and negative switch arrangements to electrically connect yard to mainline during abnormal situations.

(4) Vehicle couplers shall provide electrical continuity between vehicles to accommodate a minimum 100 ampere flow.

b. Yard track should be of standard timber tie and ballast construction with no intentional ground connections. All interconnects between yard track and railroad track shall be electrically insulated.

c. Yard traction power substation shall contain provisions for stray current mitigation drainage from both yard facilities and outside utilities.

d. Underground Utilities And Structures Within The Yard

(1) Fire and potable water systems shall be of non-metallic piping, if acceptable. The use of non-metallic pipe must be reviewed from a mechanical standpoint to determine acceptability. If piping must be metallic, it must be made electrically continuous with provisions for the drainage of stray currents and possibly cathodic protection (to be determined).

(2) Drainage piping shall be non-metallic and/or concrete and will require no special corrosion control measures.

(3) Conduit shall be non-metallic.

(4) Fencing shall be made electrically continuous.

2.6.2 Shop

a. Shop shall be electrically separated in both the positive and negative power circuits from the yard facilities.

(1) Insulate yard rails from all shop rails which will be grounded inside and/or outside the shop.

(2) Provide separate DC power supply for shop service.

b. Grounding

(1) Steel reinforcing in shop structure shall be electrically connected to shop rails, all of which shall be grounded.

(2) Metallic piping within the rebar grid shall be electrically connected to the reinforcing or grounded rails.

(3) Metallic conduit shall be grounded.

2.6.3 Other

a. Hydraulic lifts and/or elevators having part of their assembly embedded in earth shall be prepared for the control of stray current by insulation from earth and cathodic protection.

b. Use non-metallic piping wherever possible.

3. DISCUSSION

As stated in the introduction, the Task 5 Stray Current Analysis showed that the most effective means of controlling stray earth currents was to minimize their discharge into the earth. This can best be achieved by maintaining a high resistance to earth of both the positive and negative systems.

On the basis of an effective track-to-earth resistance of 1,500 ohms per 1,000 feet of track (two rails), stray current discharged from the rails would be limited to less than 0.1 ampere per 1,000 feet of track. Stray current of this level will not create significant detrimental effects on underground structures. Thus recommendations have been directed toward obtaining and maintaining a high track-to-earth resistance.

In view of the anticipated low level of stray earth current, no special measures are recommended to establish electrical continuity or electrical isolation of steelwork (reinforcing) associated with the tunnel/station construction. However, the installation of test facilities is recommended to provide some means for long term monitoring of the effects on tunnel structures.

Test facilities have been recommended to measure the magnitude of stray current which may be collected on the steel tunnel liners in areas of possible petroleum contamination. This data will be useful in determining the effectiveness of the track resistance and also in evaluating the condition of the steel liner.

Test facilities have also been recommended (test electrodes through the tunnel walls into earth) to provide a means for evaluating the magnitude and effects of stray current on the tunnel structure. The electrodes will provide stable, permanent earth references for measuring these effects. The periodic recording of the voltages occurring between the tunnel structure and earth will provide an insight into the magnitude of stray current effects and their changes over an extended time period.

The recommendations relative to mainline trackwork are directed toward obtaining the most effective electrical insulation possible between the running rails and ground. Thus rather specific measures such as high resistant grout pads and very tightly controlled specifications for direct fixation insulating rail fasteners have been recommended to achieve this goal. Establishing a well insulated track system eliminates the need for extensive electrical bonding of the structural reinforcing at a considerable expense.

This also reduces the long term expense for stray current mitigation measures.

The recommendations relative to the direct fixation rail fasteners are not made with the intent to design the unit but to point out areas in the fastener construction where attention is required to ensure that long-term effective electrical insulation is achieved. Thus with improved electrical insulation, more effective long term service and stray current control can be expected.

The recommendations relative to the traction power system are directed primarily to the prevention of stray current leakage to earth. The crossbonding between tracks as recommended will be adequate from a stray current control standpoint. Additional bonding for traction power purposes will not have significant effect on stray current conditions.

Based on the anticipated low level of stray earth currents, no recommendations are presented for the installation of specific stray current drainage facilities at traction power substations. The need, if any, for such facilities can best be determined by stray current studies conducted after energizing of the transit system. The connection of utilities or other grounded structures to the transit negative system is to be only on a last resort basis.

Underground utilities associated with SCRTD facilities will be limited in number and extent. Stray current corrosion control recommendations are limited to establishing electrical continuity on buried metallic structures and insulating them from the building structures and outside utilities. No specific recommendations are made regarding utility structures of other than SCRTD ownership. Owners of adjacent structures and utilities should consider installing test and monitoring facilities to assist in future evaluation studies. Additional corrosion control measures may be installed by the owners at their discretion.

Stray current control recommendations for the yard and maintenance shop are presented in some detail since this large concentration timber tie and ballast track could create significant stray current effects on surrounding underground structures. The electrical separation of the mainline system, both positive and negative, from the yard system is of primary importance in reducing stray current effects in the yard area. Experience with other transit systems has shown that upon insulating the yard track system from the mainline track system, stray current effects on nearby utilities have been reduced from unacceptable magnitudes to levels which did not require special corrosion control measures.

Another approach to reducing the level of stray currents associated with yard track is to install the yard track on insulated rail fasteners. The use of insulated rail fasteners for yard track is extremely costly and difficult to achieve because of the large amount of special trackwork. Although no special insulating rail fasteners are recommended for yard track, the track system should not be intentionally connected to ground. Low resistance ground connections could result in localized large magnitudes of stray current as the result of train movement within the yard. Shop tracks, which must be grounded for safety reasons, must be electrically isolated from the remainder of the yard tracks and have their own independent power source. This is so that the small levels of stray current interchanged with earth will be localized and will not extend a significant distance from the shop building.

Recommendations presented under Systemwide Test and Monitoring (Recommendation 2.4) are directed towards two major items, namely safety (hazardous DC potentials) and overall maintenance and monitoring of track-to-earth resistance and potentials. Both items require attention, first to assure a safe transit system and second to assure effective stray current control is maintained once established. The need for the recommended action and/or measures is a direct result of establishing a well insulated negative return system.

The first item to be addressed is essentially a safety related matter. Under normal operations, passengers and SCRTD personnel will contact the negative system and ground. This contact will occur through the vehicle, directly to the running rails, or other parts of the negative system and earth (i.e. platforms, inverts, walkways, etc.). Normal operations will result in negative system potentials no greater than 78 volts with respect to ground (above ground potential). While there has been no definitive study of safe DC potentials for the transit industry, work conducted by Dalziel(1) has indicated the following safe potential levels based on "let-go" currents under extreme low body resistance conditions, of 2,000 ohms. We have added an additional 200 ohms to account for the resistance to earth of the contact area, platforms, invert, walkway, etc., based on wet concrete resistivity.

Table I

Men 136 volts DC at 62 ma	R = 2,200 ohms
Women 90 volts DC at 41 ma	R = 2,200 ohms
Children 68 volts DC at 31 ma	R = 2,200 ohms

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(1) "Let-Go Currents and Voltages", C.F. Dalziel and F.P. Massoglia: Transactions IEEE Vol. 75, No. 11, May 1956, pps. 49-56.

These values are the total voltage drop across individual and earth (i.e. platform, invert walkway, etc). Therefore, the voltage across the individual will be somewhat less than that cited, approximately 90% of the value listed. This yields a minimum safe DC level of 76 volts. As stated, normal system potentials will not exceed this value to any significant degree resulting in safe operations, especially when consideration is given to the fact that more realistic individual body resistances will range from 5,000 to 10,000 ohms. Negative system potentials above 80 volts (above or below ground potential) can be considered as unsafe and, therefore, require immediate action relative to the removal of the condition that caused the excessive potential.

One major abnormal operating condition that can cause negative system potentials to earth of 80 volts or greater is a positive-to-earth fault, that because of the resistance of the negative system will be limited to not more than 100 amperes and thus will remain undetected by conventional means.

When there is a positive-to-earth fault, the fault current will cause the entire negative system to be depressed in potential with respect to ground. Since a zero resistance positive-to-earth fault in conjunction with an 8.0 ohm negative-to-earth resistance (95,000 feet of double track at 750 ohms/1000') will result in a fault current of only 100 amperes it will in all likelihood remain undetected. However, the negative system will be depressed with respect to ground potential to 795 volts. Figure 1 shows the relationship between fault resistance, fault current and negative system potential using a simplistic model. While this model neglects such considerations as TPSS regulation and longitudinal resistance of positive and negative circuits, it serves to illustrate that relatively low level fault currents can result in significant negative system-to-earth potentials. Review of the information shown on Figure 1 shows negative system-to-earth potentials in excess of 80 volts will occur for fault resistances less than 72 ohms and fault currents of 10 to 100 amperes. Normally, proposed protective devices and circuits will not activate at these low current levels.

There are other abnormal operating conditions that could result in excessive DC potentials that will not be reduced by the proposed scheme. These conditions include loss of a TPSS or a high resistant positive-to-negative fault. In these instances, especially when there is a TPSS outage, certain operational constraints must be considered. The most important being the avoidance of simultaneous starting of two trains at one location, such that the total load current exceeds that required for a single train with normal acceleration.

Given the possible occurrence of a positive-to-earth fault, we have recommended that the SCRTD consider installation of a detection/protective scheme that will reduce excessive negative system potentials and in some instances remove the source of the fault current. The proposed arrangement is based on use of a silicon controlled rectifier connected between the negative bus and ground at each traction power substation. The underlying principle is to ground the negative system, in a controlled fashion, when the potential exceeds some predetermined value. The general operating characteristics and principles are as follows:

- Monitor the potential between the negative bus and ground at each TPSS through a time/over voltage relay (polarity sensitive DC device).
- If the potential should exceed some preset level (80 volts suggested) the SCR would be triggered depending upon the polarity of the over-voltage.
- When the SCR has been activated, there will be local and remote annunciation of the condition.
- The detection circuit switches to current sensing after the SCR is triggered (see Drawing 2.4.1). Additional action at this stage will be dependent upon the magnitude of the fault current. If above some predetermined level, AC or DC breakers will be opened; if below this level, for a specified time period, secondary annunciation would be completed.

We must emphasize that the proposed detection scheme discussed above and shown on Drawing 2.4.1 is presented as a conceptual approach only. It serves to illustrate what must be considered relative to systemwide safety in the event of excessive DC potentials on the negative system. These would be caused by abnormal conditions in conjunction with a well insulated (as opposed to grounded) track system. Systems engineering personnel should review this matter carefully to determine the feasibility of the proposed arrangement and whether or not other protective relaying schemes can be used.

The second major item addressed under Systemwide Test and Monitoring (Recommendation 2.4) is concerned with establishing "built-in" provisions to monitor and test the principal elements of stray current control for the Metro system. These elements concern negative system to earth potentials and track-to-earth resistance.

In regard to negative system-to-earth potentials, we have recommended installation of permanent strip chart recording voltmeters at seven locations throughout the system. The locations chosen are at five traction power substations and two passenger stations where there are no substations present. The basis for this recommendation is to provide baseline conditions for negative system potential and thus establish a means of alerting operations personnel to changes in potential (through chart review) that may indicate loss of effective stray current control caused by long term deterioration of track insulation. The recommendations also include provisions to simulate the loss of effective track insulation and the impact on systemwide negative potentials-to-earth. This simulation will be accomplished through variable resistance grounding of the negative system at several locations throughout the system.

We envision that the recording charts would be reviewed frequently during initial system start-up and revenue operations, perhaps weekly or more frequently. Once baseline conditions have been established, recording chart review could be done less frequently depending on results being obtained.

The other major aspect of systemwide testing consists of providing permanent facilities that will allow for the periodic measurement of track-to-earth resistances throughout the system. The rationale here is that track resistances would be measured at some predetermined frequency, perhaps monthly unless the previously discussed potential monitors indicate a loss of effective isolation. In this instance, track resistance measurements would be made as necessary to determine if the problem is localized or wide-spread. The major components required for the track resistance measurement arrangement proposed consist of permanently installed test wires attached to one rail of each track at approximately 16 locations throughout the system and a test current/voltage source with automatic unattended cycling. The test current source would be used to impress a current between track and ground (yard track for example). This current, in conjunction with the test voltage, would establish the overall track-to-earth resistance. In addition, the test wire pairs would be used to measure the percentage of current returning from each track section thus establishing a systemwide distribution of track resistances indicating particular areas that may require further review.

There are several important aspects of the proposed arrangement that must be emphasized.

- The measurements must be made when there is no load on the mainline negative system. Any load would show up on the reading at a test wire pair making it difficult to measure the amount of test current present.

- Measurements at test wire pairs would most likely be made by one or more individuals using portable voltmeters. Therefore, testing time and test facility access become critical if tests are to be made during the non-operational periods of the system.

For this reason, we have suggested that rail test facilities be made accessible from one trackway allowing one or more individuals to ride the trackway, stopping at the test facilities to make the measurements and then proceeding to the next test location. The actual procedures, vehicle requirements and method of data acquisition will require detailed study. The arrangement has been presented for SCRTD consideration of an important maintenance and monitoring aspect of stray current corrosion control.

Appendix A

Rail Fastener Resistance Test Procedures

1. General

The primary measure for the control of stray earth currents on SCRTD Metro Rail Project will be effective electrical insulation of the negative system (primarily running rails) from ground. A resistance value of 1,500 ohms per 1,000 feet of track (two rails) has been recommended as an effective value. Certain recommendations relative to construction of insulating rail fasteners have been included in the Task 7, Stray Current Control Recommendations Report. This Appendix presents detailed test procedures for evaluating the effectiveness of the electrical resistance qualities of the fasteners.

2. The electrical resistance of the elastomer material proposed for use in the rail fasteners shall be determined in accordance with ASTM Specification D257-78, "DC Resistance or Conductance of Insulating Materials". The resistivity shall be stated as a minimum of 10^{12} ohm-cm. The resistance of the fastener elastomeric material to water absorption shall be determined in accordance with ASTM D570-77, "Water Absorption of Plastics". The elastomeric material should show an increase in weight of less than 0.1 percent when exposed to water. The resistivity measurements should be repeated on the elastomer after the water resistance absorption tests.

3. Electrical Resistance Tests On The Completed And Assembled Rail Insulating Device

The following testing procedure should be considered for testing the complete rail fasteners. The test should be conducted on a minimum of six fasteners, some of which should have been subjected to mechanical tests which could result in a degrading of the electrical insulating properties, by resulting in cracked or otherwise damaged insulating components.

3.1 The insulated rail fastening device including a short length (18-inches) of 115-pound rail and rail clips shall be assembled on a polymer modified grout pad on a concrete test block simulating invert concrete. Six units should be so assembled. The rail section lengths shall be greater than the width of the concrete blocks (a minimum of 1.5 feet). The concrete blocks shall be placed upright in a bare (uncoated) metal trough with a minimum clearance of 4-inches between the walls of the trough and the other blocks, if more than one block is positioned in one trough. The trough shall be leveled and water poured into the trough taking care to ensure the fastener components are not wetted. The water may be tap water. Water shall be placed in the trough to fill it to approximately 1-inch below the top of the grout pad, measured at the center of the rail. The water shall be maintained at this level for the duration of the tests.

3.2 Immediately upon filling the trough, the resistance shall be measured between each of the six rail assemblies and the metal trough using a 500 volt "Meggar" Insulator Tester as manufactured by James J. Biddle Co., Philadelphia, PA, or equal. The measurements shall be repeated three times a day scheduled for a minimum of three days or until the resistance stabilizes for a period of three consecutive measurements (±5%). The rail fasteners shall have not less than 10 megohm insulation resistance between any rail and the metal trough under these conditions.

3.3 The fasteners shall be subjected to a fine mist spray for one hour's time which will provide the water at a rate of 1-inch per hour for the area covered. The water used shall have a resistivity within the 10,000 to 20,000 ohm-cm range and a temperature in the 60° to 80°F range. (The water accumulation within the trough shall not be allowed to exceed the stated level of 1-inch below the top of the block). Within five minutes of stopping the spray, the resistance of each fastener shall be measured in accordance with the previously established procedure. The resistance measurements shall be repeated three times at 15 minute intervals. The general environmental condition during this period shall be within the range of 60°F to 80°F and a relative humidity of 70 to 90%. The electrical resistance of the fasteners during these tests shall not be less than 400,000 ohms.

3.4 The fasteners shall be subjected to heat lamps placed directly above the fasteners to dry them. The positioning of the lamps and the heating intensity shall be adjusted to ensure the rail and fastener components do not exceed 110°F. The resistance of the fasteners shall be measured at regular intervals (starting at ½ hour intervals for a minimum of five measurements) until the resistance returns to the original dry minimum of 10 megohms, which must be restored within a maximum of 10 hours. At no time shall the fasteners be wiped, brushed or in any way cleaned of any residue which may collect during these tests.

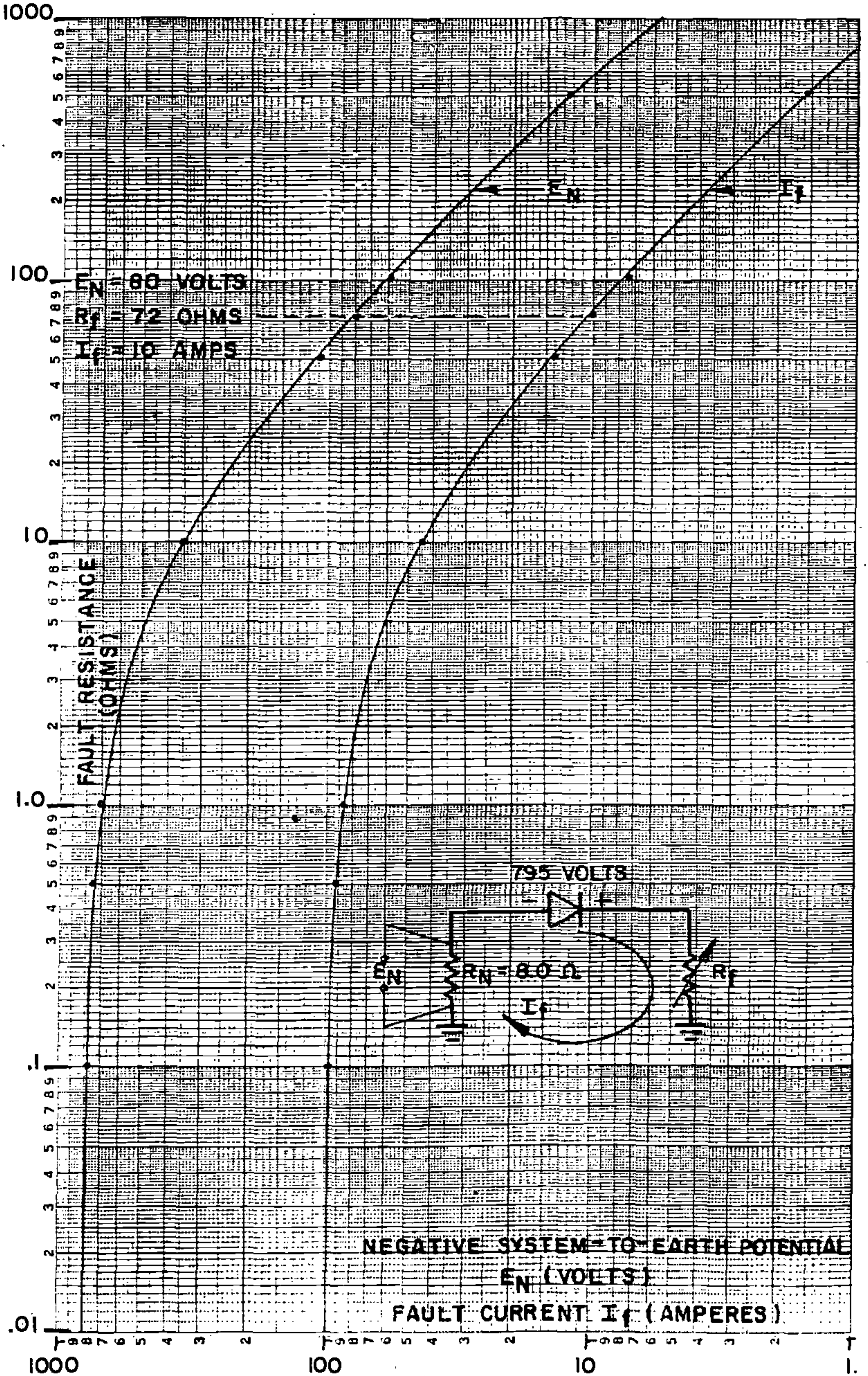
3.5 The tests described in 3.3 and 3.4 shall be repeated three times on the same fasteners without cleaning or disturbing the test conditions in any manner.

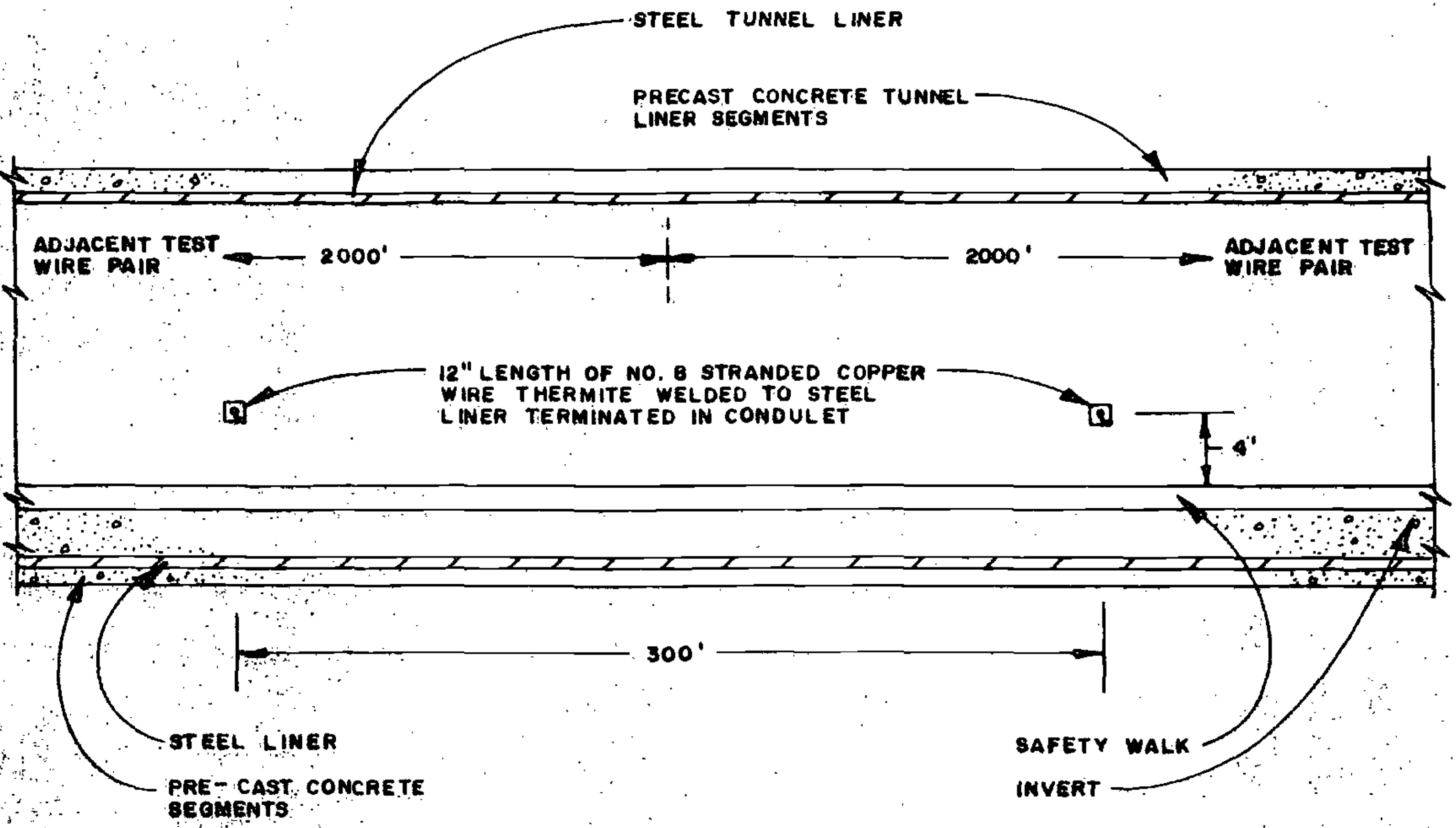
3.6 Acceptance shall consist of obtaining the resistance values stated under the conditions and time constraints noted.

4. The test procedure requirements, as stated, will require some consideration by the manufacturer relative to the electrical leakage paths such as undercutting the edges of the insulating components (primarily the elastomer material) to interrupt the electrical path from moisture accumulation on a smooth surface. Also the elimination and/or sealing of crevices or openings in the fastener which would permit the accumulation of dirt, rail filings and moisture should be thoroughly investigated. Experience and analysis indicates that the recommended measures are practical and will result in a definite improvement in the electrical resistance characteristics of these fasteners at little extra cost. This extra testing is well justified for the SCRTD Metro System since the control of stray earth currents is being predicated on maintaining a high degree of track-to-earth resistance.

FIGURE 1

S.C.R.T.D. / LOS ANGELES





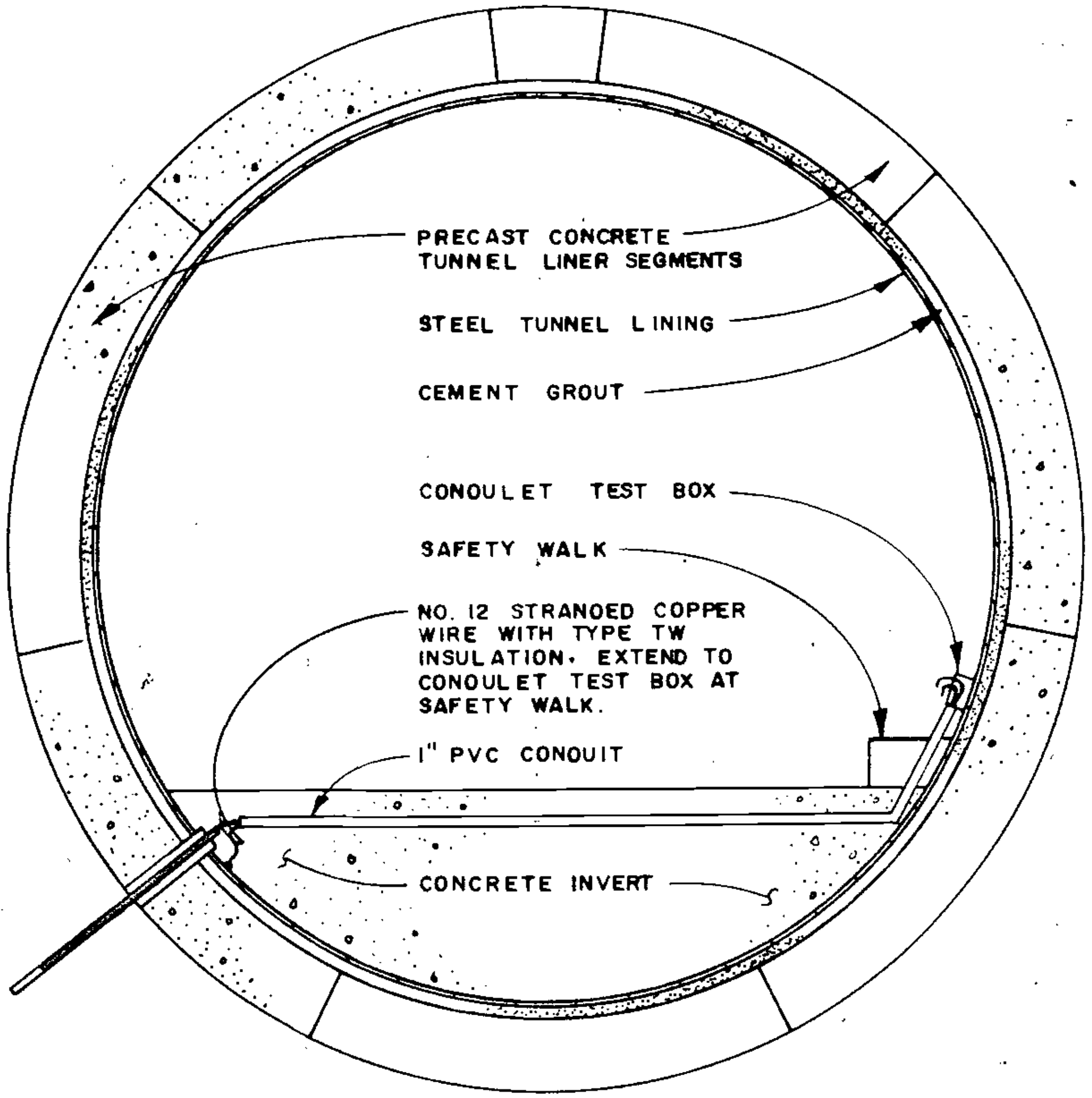
NOTE: TEST FACILITIES AT 2000' INTERVALS

TYPICAL STRAY CURRENT MEASURING TEST FACILITY

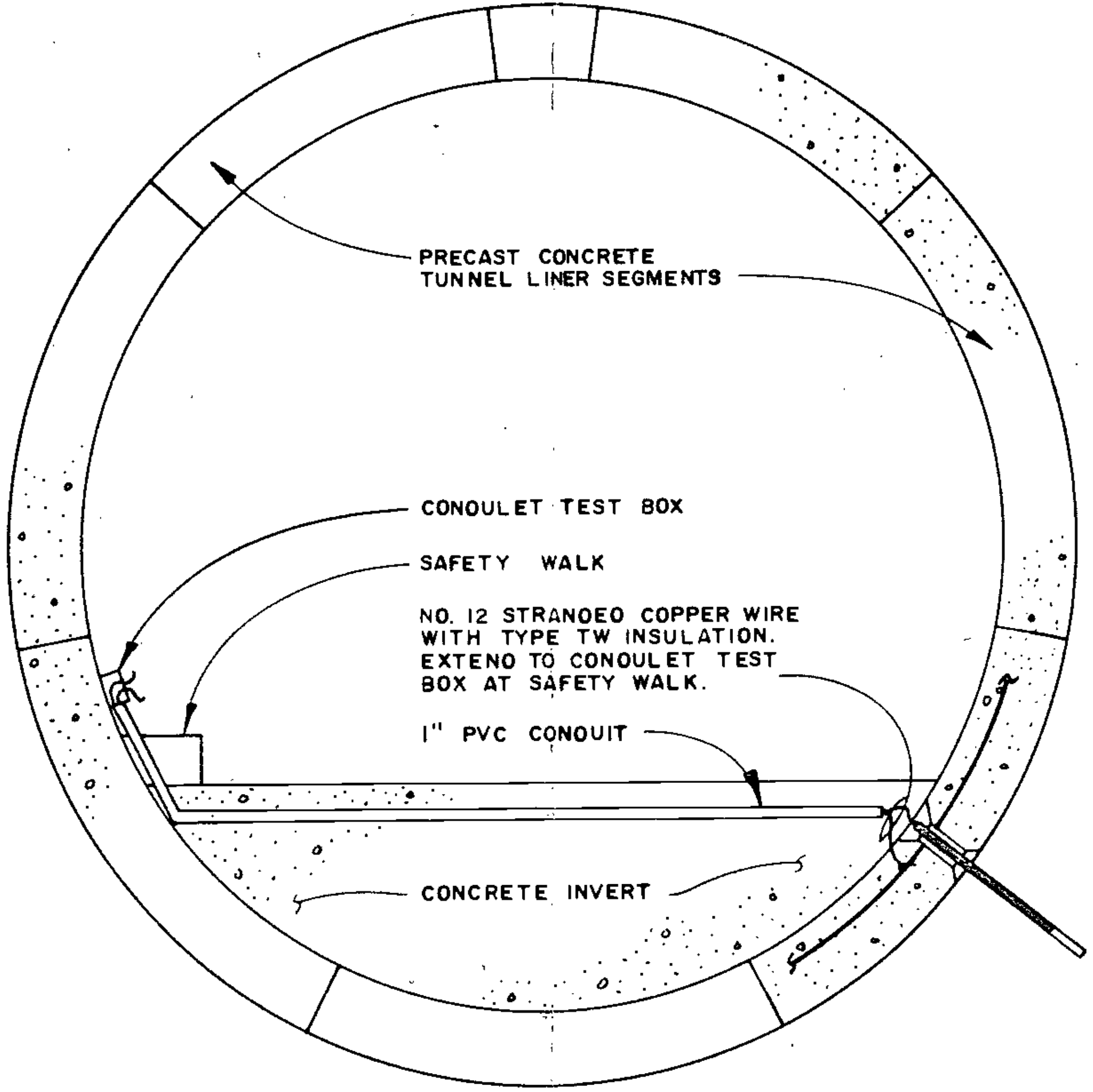
DWG. NO. 2.1.4

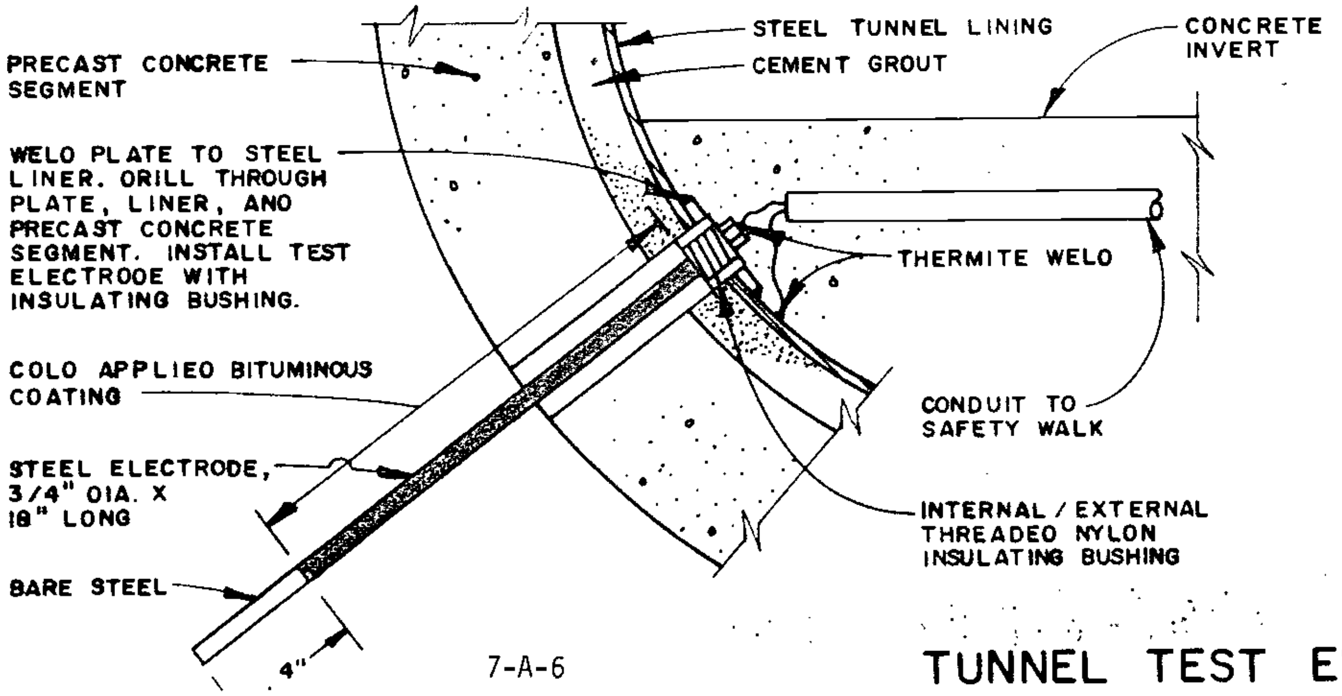
DWG. NO. 2.1.6

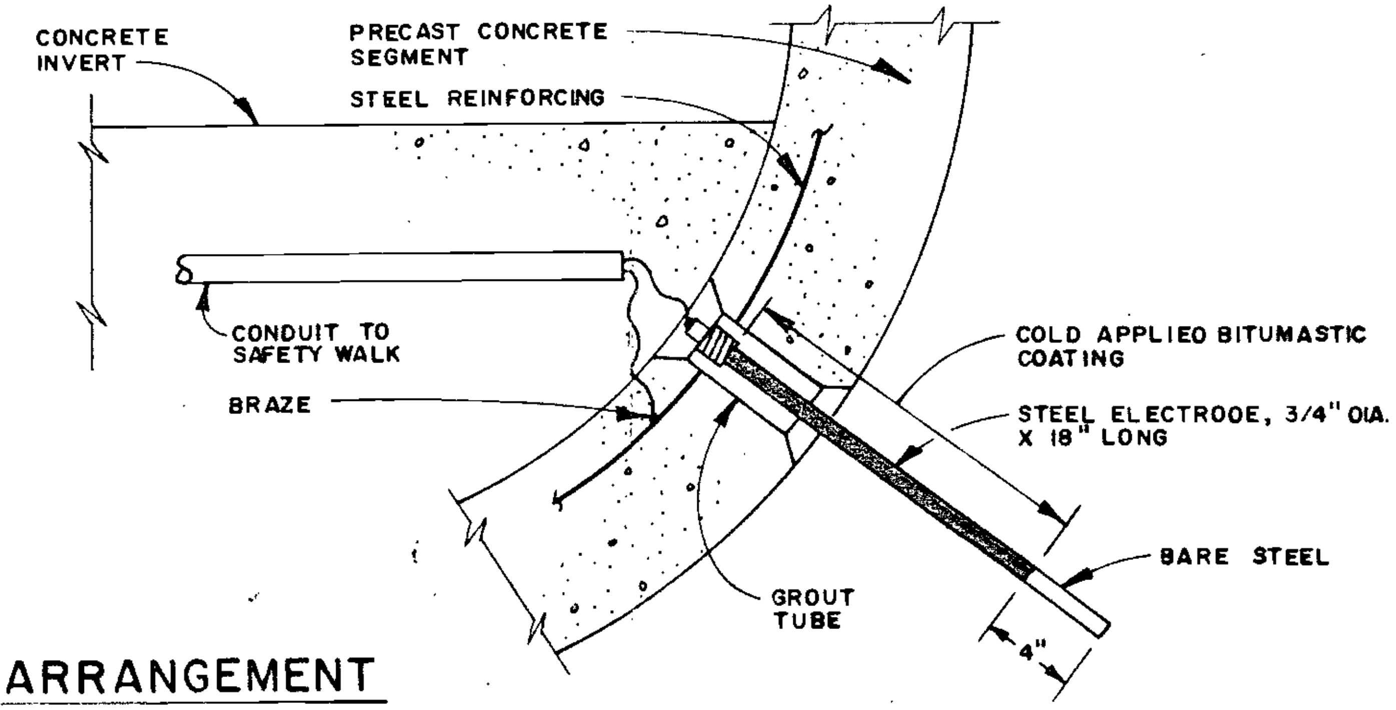
STEEL LINED TUNNEL



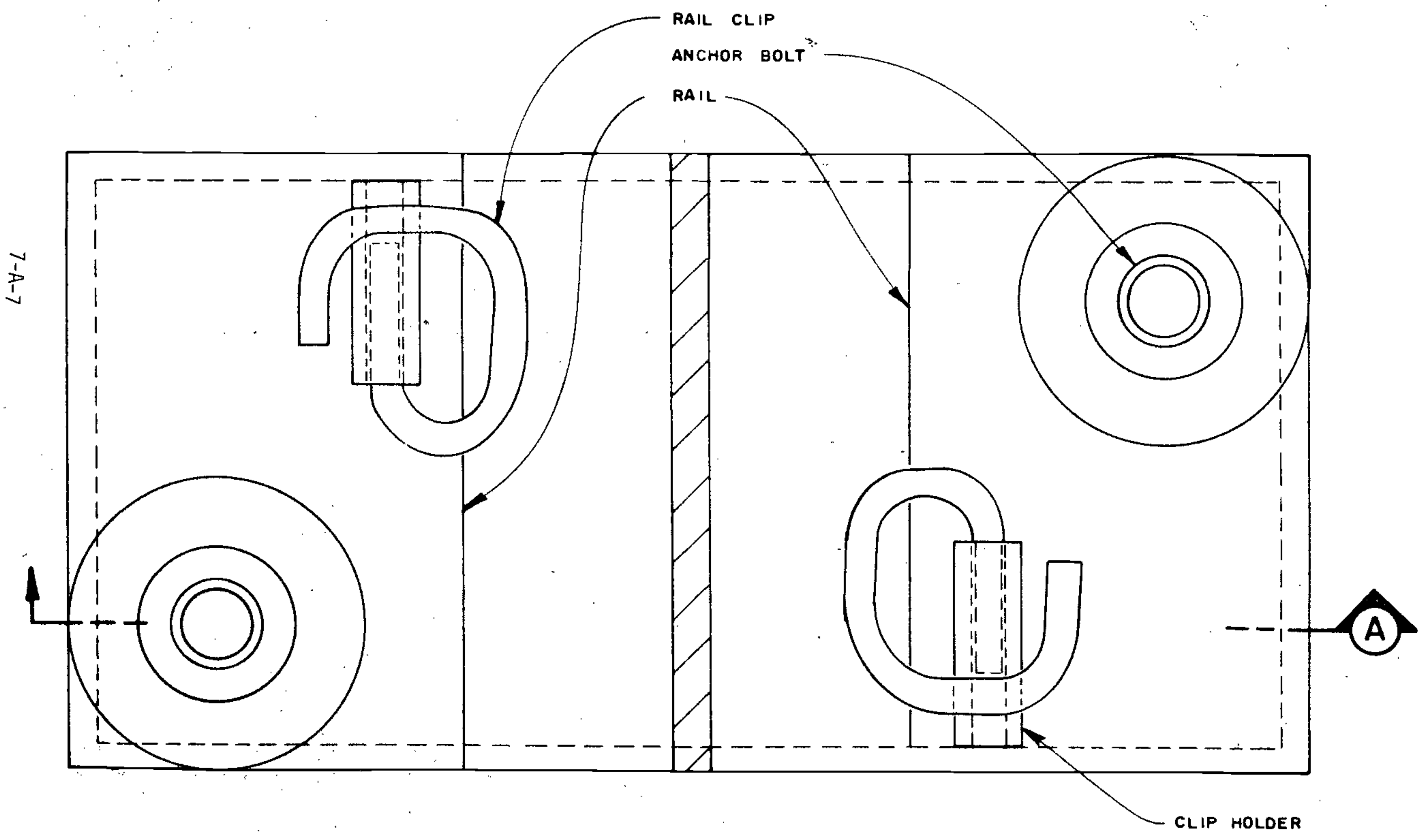
PRECAST CONCRETE TUNNEL LINER



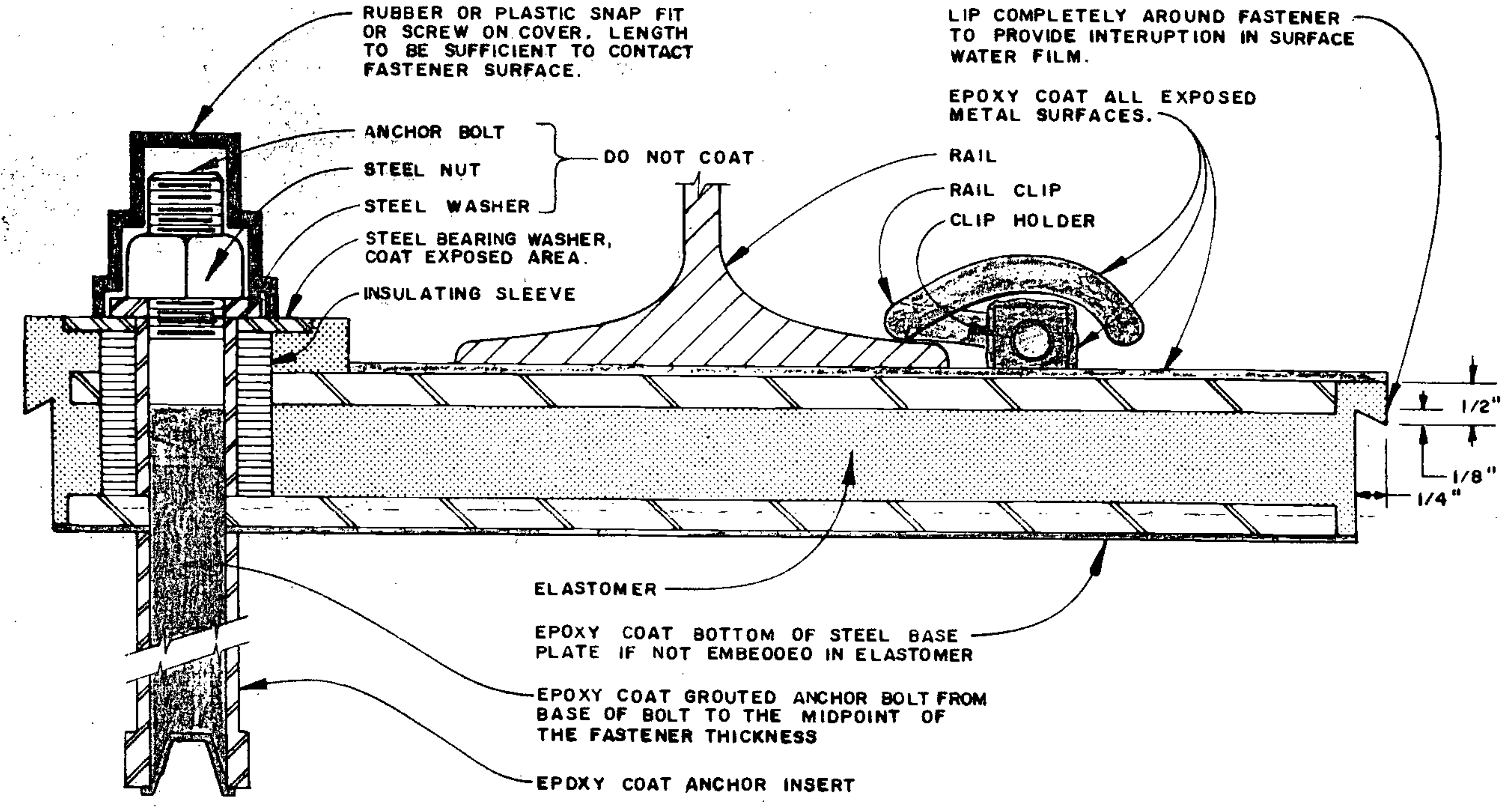




TUNNEL TEST ELECTRODE ARRANGEMENT

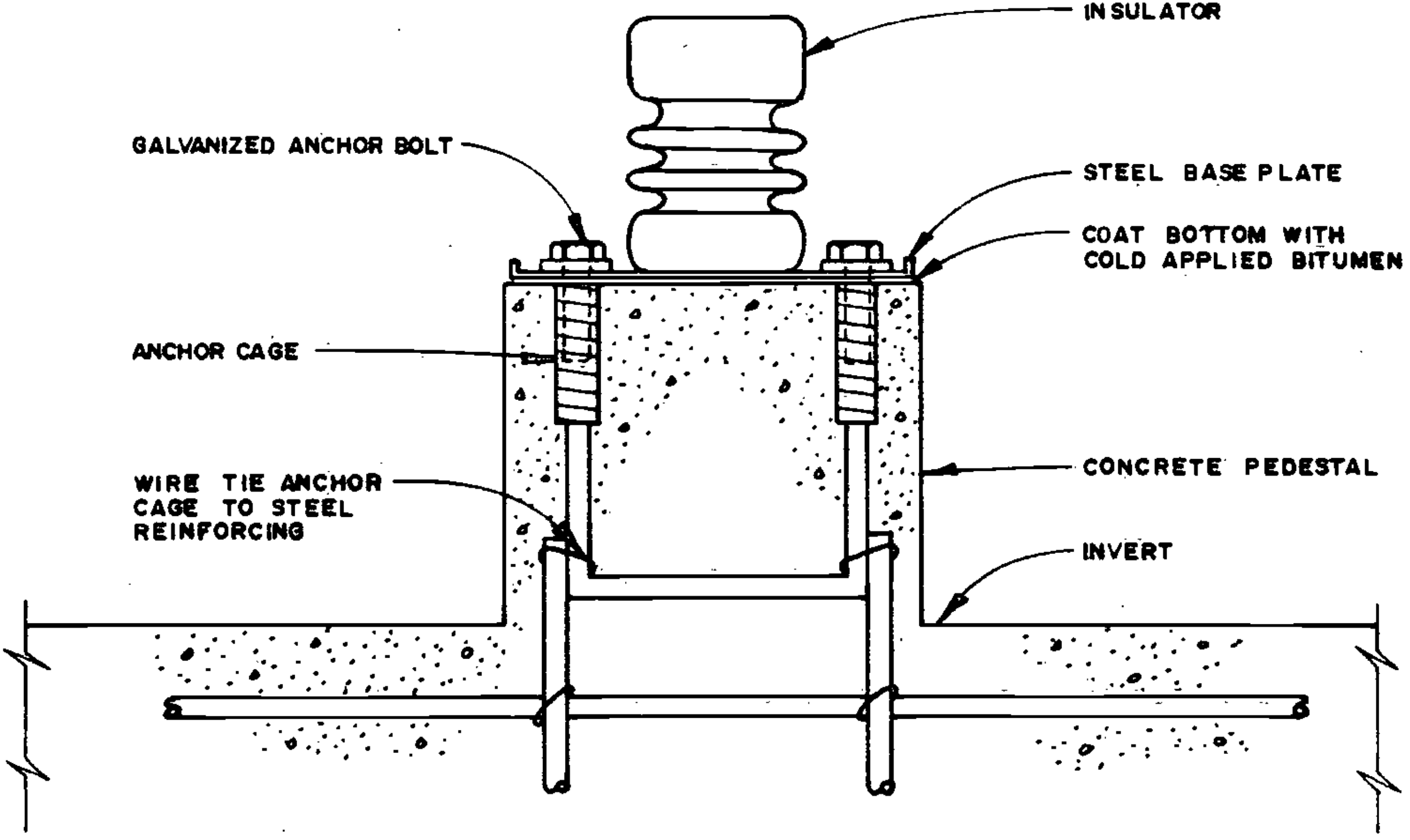


PLAN

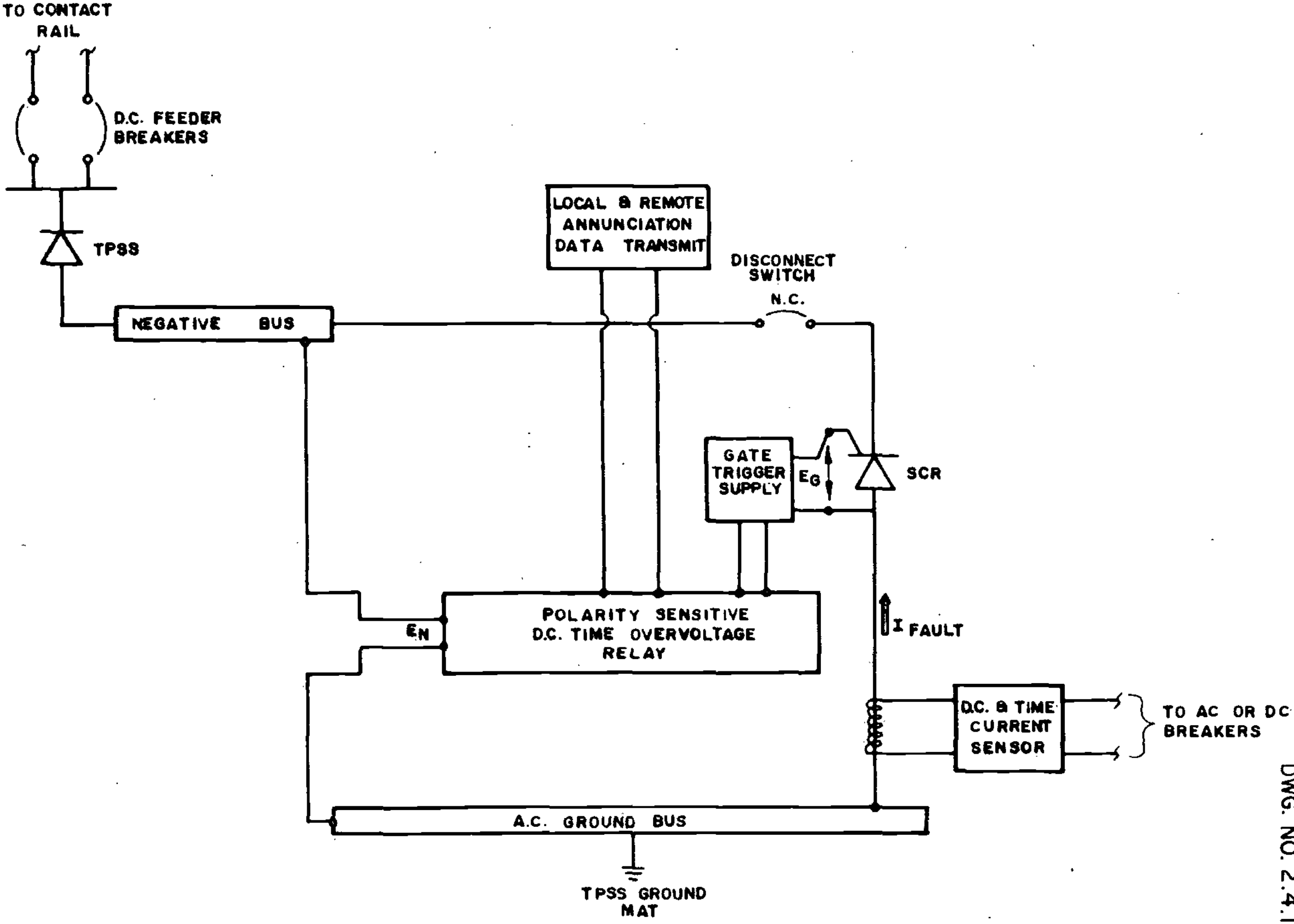


SECTION A

TYPICAL DIRECT FIXATION INSULATING RAIL FASTENER



TYPICAL PEDESTAL FOR CONTACT RAIL INSULATOR



DWG. NO. 2.4.1.

PROTECTION AGAINST EXCESSIVE NEGATIVE SYSTEM-TO-EARTH POTENTIALS

(TYPICAL EACH TPSS)

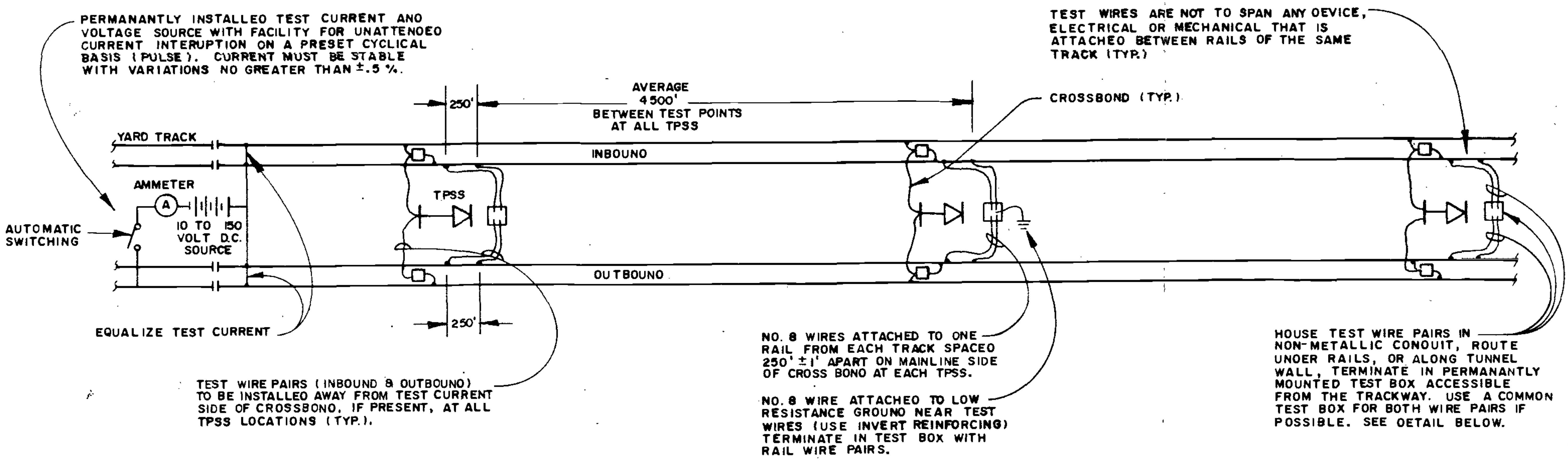
GENERAL OPERATING CONDITIONS

NEGATIVE SYSTEM POTENTIAL

- 75 VOLTS $\le E_N \le$ + 75 VOLTS	No Action: SCRs remain unfired, non-conducting, negative isolated.
- 80 VOLTS $< E_N <$ - 75 VOLTS FOR $t > 5$ SECONDS	Local and remote annunciation of excessive voltage; SCRs remain unfired, non-conducting; alert system personnel to system abnormality, not causing unsafe potentials. Negative isolated.
$E_N \le$ - 80 VOLTS $t > 1$ SECOND (FAULT CONDITION; POSITIVE TO EARTH)	SCR activated; negative system potential reduced to safe level>-80 volts. Additional SCRs at other TPSS may be activated as fault current increases and E_N again approaches - 80 volts. Local and remote annunciation. Additional action contingent upon magnitude of I_{Fault}.

DWG. NO. 2.4.1a

DWG. NO. 2.4.2.


PERMANANTLY INSTALLED TEST CURRENT AND VOLTAGE SOURCE WITH FACILITY FOR UNATTENDED CURRENT INTERUPTION ON A PRESET CYCLICAL BASIS (PULSE). CURRENT MUST BE STABLE WITH VARIATIONS NO GREATER THAN ±.5 %.

TEST WIRES ARE NOT TO SPAN ANY DEVICE, ELECTRICAL OR MECHANICAL THAT IS ATTACHED BETWEEN RAILS OF THE SAME TRACK (TYP.)

AVERAGE 4500' BETWEEN TEST POINTS AT ALL TPSS

CROSSBOND (TYP.)

EQUALIZE TEST CURRENT

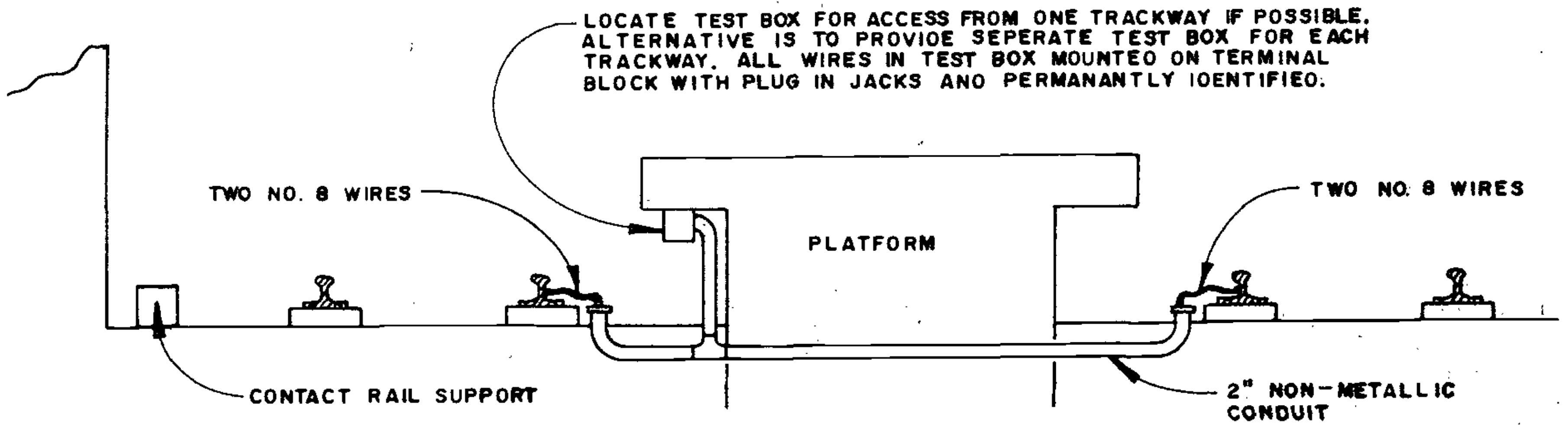
TEST WIRE PAIRS (INBOUND & OUTBOUND) TO BE INSTALLED AWAY FROM TEST CURRENT SIDE OF CROSSBOND, IF PRESENT, AT ALL TPSS LOCATIONS (TYP.).

NO. 8 WIRES ATTACHED TO ONE RAIL FROM EACH TRACK SPACED 250' ± 1' APART ON MAINLINE SIDE OF CROSS BOND AT EACH TPSS.

NO. 8 WIRE ATTACHED TO LOW RESISTANCE GROUND NEAR TEST WIRES (USE INVERT REINFORCING) TERMINATE IN TEST BOX WITH RAIL WIRE PAIRS.

HOUSE TEST WIRE PAIRS IN NON-METALLIC CONDUIT, ROUTE UNDER RAILS, OR ALONG TUNNEL WALL, TERMINATE IN PERMANANTLY MOUNTED TEST BOX ACCESSIBLE FROM THE TRACKWAY. USE A COMMON TEST BOX FOR BOTH WIRE PAIRS IF POSSIBLE. SEE DETAIL BELOW.

PLAN


LOCATE TEST BOX FOR ACCESS FROM ONE TRACKWAY IF POSSIBLE. ALTERNATIVE IS TO PROVIDE SEPERATE TEST BOX FOR EACH TRACKWAY. ALL WIRES IN TEST BOX MOUNTED ON TERMINAL BLOCK WITH PLUG IN JACKS AND PERMANANTLY IDENTIFIED.

NOTE: POSSIBLE TEST BOX LOCATION & WIRE ROUTING. OTHER OPTIONS AVAILABLE DEPENDING ON ACTUAL ARRANGEMENT AT END OF PLATFORM OR WITHIN TUNNELS.

DETAIL

TASK 7

STRAY CURRENT CONTROL RECOMMENDATIONS

Table of Contents

SECTION	DESCRIPTION	PAGE
1.	INTRODUCTION	7-1
2.	RECOMMENDATIONS	7-2
2.1	Tunnel Construction	7-2
2.2	Trackwork Construction	7-4
2.3	Traction Power System	7-6
2.4	Systemwide Testing and Monitoring . .	7-7
2.5	Utilities	7-10
2.6	Yard and Shop Area	7-11
3.	DISCUSSION	7-13
Appendix A	Rail Fastener Resistance Test Procedures	7-A-1

LIST OF DRAWINGS AND FIGURES

NUMBER	DESCRIPTION	
Figure 1	Fault Resistance vs. Fault Current and Negative System Potential	7-A-4
2.1.4	Typical Stray Current Measuring Test Facility	7-A-5
2.1.6	Tunnel Test Electrode Arrangement	7-A-6
2.2.2	Typical Direct Fixation Insulating Rail Fastener	7-A-7
2.3.1	Typical Pedestal For Contact Rail Insulator	7-A-8
2.4.1	Protection Against Excessive Negative System-to-Earth Potentials	7-A-9
2.4.1a	General Operating Conditions For Above	7-A-10
2.4.2	Track-to-Earth Resistance Measurement Scheme	7-A-11

1. INTRODUCTION

The Task 5 report, Analysis of Stray Earth Currents, together with the memorandums "Meeting on Stray Current Analysis" and the supplemental "Response to Comments from P.M. Burgess, Kaiser Engineers on the Task 5 Report" has formed the basis for the recommendations presented herewith for the control of stray earth current.

The Task 5 report pointed out that the most effective method of minimizing the detrimental effects of stray earth currents is through the control of stray currents at the source. The report presented the following combination of factors which would result in minimum levels of stray earth currents:

- Traction power substation spacing.
- Conductance within the positive and negative power distribution circuits.
- Electrical isolation of both the positive and negative circuits from ground.

Considering these factors, the stray current analysis was conducted for several sets of conditions. Since the substation spacing and the conductance of the positive and negative systems is fairly well defined, the primary variation in stray earth currents was analyzed for variations in the effectiveness of the electrical isolation of the system. The analysis pointed out what level of resistance would be required to limit the leakage of current from the rails so that extensive mitigative measures would not be required for area utilities and transit facilities.

The analysis showed that a track-to-earth resistance of 1,500 ohms per 1,000 feet of track (2 rails) would limit the stray current and earth potential levels to those which would not create significant detrimental effects (maximum current of 0.1 ampere per 1,000 feet of system or maximum potential gradient of 0.050 volt at 1,000 feet from the system.

The recommendations as presented are based on the results of the above mentioned report and supplemental documents together with certain stated conditions which have already been determined for the construction of the system.

The recommendations are directed primarily to maintaining a high level of track-to-earth resistance for the mainline track system with the maintenance yard electrically isolated from the mainline track. Under these conditions, minimal amounts of supplemental corrosion control measures for the underground tunnel construction and utilities will be required. As a result of establishing a high resistance track system, we have also made recommendations directed towards maintaining safe DC potential levels on the negative system.

2. RECOMMENDATIONS

2.1 Tunnel Construction

2.1.1 General

Control of corrosive stray earth currents associated with operation of the underground portion of the transit system can best be attained by maintaining a high electrical resistance between the negative system (principally running rails) and ground. This high resistance, 1,500 ohms per 1,000 feet of track (2 rails) may be obtained by the use of insulating rail fasteners, maintaining a relatively dry tunnel and ensuring no inadvertent connections to grounded structures. The term dry tunnel does not necessarily mean a tunnel absolutely free of water invasion and/or accumulation. A tunnel may be considered dry when the influx of water is limited to a low level of accumulation (to be determined as gallons/day/ surface area). The water influx shall not be from above the spring line and shall not drop or run directly on the rails and/or rail appurtenances. The volume of water must be limited to the extent that it does not attain a level higher than one-inch below the top surface of the rail fastener grout pad(s). The amount of water influx/accumulation shall be limited to a level which will preclude the existence of a high level of humidity in the tunnel.

2.1.2 Precast Concrete Segmented Ring Tunnel Lining

a. No special effort is required to establish positive electrical continuity of reinforcing within segments or between segments provided that a high resistance between the negative system and ground is attained.

b. No special effort is required to ensure electrical isolation of reinforcing within segments or between segments.

c. Concrete for tunnel liner segments shall meet the following criteria:

(1) Sulfate resistant Type V cement.

(2) Maximum of 200 ppm chloride concentration in mixing water.

(3) Maximum water/cement ratio of .37 by weight in conjunction with the use of an air entrainment admixture resulting in a maximum air content of 6 percent by volume to establish a low permeability concrete.

(4) If admixtures or aggregates containing chlorides are used, the total concentration of chlorides from water, admixture and aggregates shall be determined and submitted for District approval prior to use.

(5) Concrete cover over segment steel reinforcing shall be a minimum of 2-inches on the external surface.

d. External surface of segments shall have a protective coating of coal tar epoxy.

e. Internal surfaces of the concrete ring segments do not require protective coating.

2.1.3 Concrete Invert Construction

a. Steel reinforcement in the invert shall be installed by standard construction methods (wire tied) with no special effort to establish electrical continuity or electrical isolation. Steel reinforcement shall be so placed under the running rails that the installation of rail anchor bolts and/or anchor bolt inserts do not contact the steel reinforcing.

b. No protective coating is required between the precast segment ring sections and the invert concrete or on the exposed surface of the invert concrete.

c. Concrete for invert construction shall be made with mixing water containing less than 200 ppm chlorides, and shall have a minimum 2-inch cover over the top layer of steel reinforcing.

2.1.4 Steel Tunnel Liner In Selected Areas Of Potential Gas And/Or Oil Contamination Of The Tunnel

a. The surface of the steel liner exposed in the interior of the tunnel shall have a protective coating for the prevention of atmospheric corrosion. A coating system such as inorganic zinc with an epoxy top coat will be adequate. If coated prior to placing in tunnel, coating damage from welding shall be repaired such that it is equal to the existing coating.

b. Cement grout to be placed between the steel liner and pre-cast segment rings shall be made with sulfate resistant Type II cement.

c. Install facilities for measuring the magnitude of stray current collected on the steel liner. The facilities shall be installed only on tunnel liners having a length in excess of 2,000 feet. The test facility shall consist of two 12-inch lengths of No. 8 stranded, THW insulated copper wire exothermically welded to the steel liner with a spacing of 300 feet between wires and with the wire pairs at 2,000 foot intervals. The wires shall be located at a convenient height for access on the safety walk side of the tunnel and terminated in suitable junction boxes attached to the liner, see enclosed drawing No. 2.1.4.

2.1.5 Passenger Stations

No special stray current corrosion control measures are required in the station areas other than the use of sulfate resistant concrete as recommended for the precast concrete tunnel liner segments (2.1.2.C). No special measures are required to establish electrical continuity or electrical isolation of steel reinforcing. No special insulation measures are required for the platforms provided they are constructed with a paver tile - grout surface.

2.1.6 Systemwide Tunnel Stray Current Test And Monitoring Facilities

a. Test electrodes shall be installed through the tunnel walls into the earth at approximate 1,000 foot intervals. The electrodes shall be placed in the wall most removed from the adjacent tunnel at an elevation below the top of the tunnel invert. The electrodes may be installed through grout tubes in precast concrete segments or through holes drilled through the steel tunnel liner and precast segments. The steel electrodes shall have a minimum 4-inches of bare steel in contact with earth. The electrodes shall be electrically insulated from the tunnel structure. Test wires shall be connected to the electrodes and segment steel reinforcing or steel tunnel liner depending upon the location of the electrode. The test wires shall be terminated in a test box mounted on the wall on the the safety walk side of the tunnel. The enclosed Drawing No. 2.1.6. shows the general arrangement for electrode installation.

2.2 Trackwork Construction

Measures recommended below are required to establish and maintain an in-service track-to-earth resistance of 1,500 ohms per 1,000 feet (two rails) for main line track system.

2.2.1 Grout Pads For Direct Fixation Rail Fasteners

a. Grout pads shall be constructed of epoxy/polymer modified concrete having a maximum water absorption of 2.0% by weight (ASTM-C140).

b. Top surface of grout pads shall have an elevation above the surface of the invert which will limit the accumulation of water to a maximum level of 1-inch below the top of the grout pad.

c. Grout pads may be constructed individually for each rail fastener or of sufficient length to support several rail fasteners. Drainage channels shall be constructed in the long grout pads to prevent excessive accumulation of water adjacent to the pads.

2.2.2 Direct Fixation Rail Fasteners For Use On Mainline Track

a. Anchor bolts and/or anchor bolt inserts shall have a protective coating of epoxy applied by fluidized bed method.

b. Anchor bolts and/or inserts shall have a minimum separation of one-half inch from grout pad reinforcement and shall not be in metallic contact with steel reinforcing in the grout pad and/or the invert.

c. Direct fixation fasteners, as illustrated in Drawing No. 2.2.2, shall be so constructed that there will be no direct low resistance metallic path between the steel running rail and ground. The following is required to achieve this:

(1) The fastener shall consist of a steel plate(s) embedded in an elastomer material having a resistivity on the order of 10^{14} ohm-centimeters dry, 10^{12} ohm-centimeters after long term water immersion and have a voltage rating to withstand the anticipated maximum voltage.

(2) Preferred arrangement of fastener construction is by a single steel support plate embedded in elastomer on four sides and bottom (no steel plate in direct contact with grout pad).

(3) If two steel plates are used, the bottom plate must be coated with elastomer or epoxy to prevent contact between metal and grout pad.

(4) Install a removable plastic or rubber cap to cover exposed anchor bolt, nut and steel washer.

(6) Fastener shall be constructed free of voids and recesses which will retain and/or make difficult the cleaning of conductive material which will degrade the electrical insulating characteristics of the fastener. The elastomer lip around the top edge of the fastener shall be constructed so that moisture will not form a continuous film from the top surface of the fastener to the grout pad.

d. Fastener assembly as recommended above shall be tested in accordance with the test procedures set forth in Appendix A to ensure that a minimum resistance 10 megohms (dry) is obtained.

2.2.3 Special Trackwork

Track shall be installed on insulating fasteners modified from the above tangent track fastener or on different fasteners all of which meet the above stated resistance criteria that the fastener shall have a minimum resistance of 10 megohms (dry).

2.3 Traction Power System

2.3.1 Positive System

a. Electrically connect the anchor cage for the contact rail insulator base plate anchor bolts to the reinforcing in the insulator support pedestal by bare wire ties as shown on the attached Drawing No. 2.3.1.

b. Coat bottom of bare metal base plate for contact rail insulator with cold-applied bitumen.

c. The contact rail shall have a minimum resistance to earth of 10 megohms per 1,000 feet of rail (individual insulators shall have a dry resistance in excess of 1,000 megohms).

2.3.2 Negative System

a. Inbound and outbound tracks shall be crossbonded as follows for stray current control purposes. Additional crossbonding for train control and/or traction power loss considerations will not materially change stray current conditions.

(1) Install a crossbond at every passenger station or within 100 feet of the end of the platform.

(2) Install a crossbond at every traction power substation. (Normal negative return cable installation will serve this purpose).

(3) Where a substation, with a crossbond, is within 500 feet of the end of a station platform, no additional crossbonding is required at the passenger station.

(4) Where a substation, with a crossbond, is more than 500 feet from the end of a station platform, an additional crossbond is required within 100 feet of the end of the platform away from the substation.

(5) The combination of items 1) through 4) should result in an approximate average spacing between crossbonds of 1 mile or less. The proposed installation of substations between Hollywood Bowl and Universal City and between Universal City and Lankershim will provide adequate crossbonding for these track sections.

(6) An intermediate crossbond should be installed midway between the Fairfax/Santa Monica Station and the Sunset/ La Brea Station, approximate station 661+12.

b. Train control, communication and/or other ancillary systems when connected to the track system shall not reduce the track-to-earth resistance to a level less than 1,500 ohms per 1,000 feet (2 rails).

2.3.3 Substations

a. Space shall be dedicated in close proximity to the negative bus/switchgear assembly in the traction power substation for possible future stray current test facilities. If space is not available in the immediate vicinity of the negative bus, an open conduit shall be installed between the available dedicated space and the negative bus.

b. Access shall be provided to the negative bus for possible future stray current testing by utilities. The access shall consist of a reserved 2-inch conduit in the AC service duct bank extending from ground level into the substation. The conduit shall be capped, with no wire(s) installed, and identified for future stray current testing.

2.4 Systemwide Testing and Monitoring

2.4.1 Negative System Potentials

a. Provide facilities necessary to continuously monitor and record negative system-to-earth potentials at selected locations throughout the transit system. The major features and purpose of this item are as follows:

(1) Establish base line conditions for normal revenue operations and test train simulations.

(2) Establish patterns and magnitudes of negative system-to-earth potentials during simulated abnormal operating conditions through use of variable resistance negative system-to-earth contacts.

(3) Review negative system potentials periodically either by manual review of recording charts or more frequently through data transmission to a central control facility.

(4) Information will be used to alert operations personnel of the need for maintenance or other corrective action on the negative system.

(5) Monitoring can be established through use of continuous recording voltmeters permanently installed at a minimum of seven locations throughout the system. Suggested locations are:

- Union Station TPSS
- 5th and Hill Passenger Station
- Wilshire and Normandie Passenger Station
- Wilshire and La Brea TPSS
- Fairfax and Santa Monica TPSS
- Intermediate TPSS at Approximate Station 875+00
- Lankershim (North Hollywood) TPSS

(6) Recording voltmeters are to be single channel potentiometric servo motor operated with a fixed span of ±100 volts center zero, .5 second full scale response time. Chart drive to be ½-inch per hour with several faster speeds selectable, up to a maximum of approximately 1-inch per minute.

b. Establish a method whereby abnormally large negative system-to-earth potentials can be detected, annunciated, and reduced to a level that will not present a hazard to passengers and SCRTD personnel who may come in contact with the negative system. Our concept of the detection system consists of the following major subsystems at each TPSS as illustrated on Drawing No. 2.4.1. and 2.4.1a. It must be emphasized that the proposed detection scheme described below and shown on Drawing 2.4.1 is presented as a conceptual approach only. It serves to illustrate what must be considered relative to systemwide safety in the event of excessive DC potentials on the negative system. Systems engineering personnel should review this matter carefully to determine the feasibility of the proposed arrangement and whether or not other protective relaying schemes would be more appropriate.

(1) Silicon control rectifiers (SCR or Thyristor) installed between the negative bus and the station ground mat. SCR's to be rated at 1,500 amperes with a reverse

and/or blocking voltage of 800 volts minimum (preliminary values, must be reviewed in detail). The dv/dt rating of the SCR must be reviewed in conjunction with the rate of rise of negative system potentials caused by normal load currents (i.e. train operations) to ensure that normal operating dv/dt characteristics for the negative system do not cause inadvertent SCR activation. Manufacturers' literature cite maximum dv/dt ratings of 200 to 300 volts/usec for SCR's which if exceeded will cause the SCR to conduct even if not triggered.

(2) Potential detection and SCR triggering devices and circuits that will activate the SCR's when the negative system-to-earth potential exceeds a preset and predetermined level (preliminary value of ±80 volts with respect to ground has been established, but will require further evaluation and review by SCRTD personnel).

(3) Installation of a current sensor in the ground connection (between SCR and negative bus) interfaced with AC or DC breakers to deenergize substations adjacent to faults or otherwise indicate and isolate the cause of the excessive voltage. The sensor must be capable of detecting a minimum current flow of 500 amperes (preliminary value, to be reviewed in detail).

2.4.2 Track-To-Earth Resistances

a. Provide facilities, test equipment and personnel to periodically measure negative system-to-earth resistance and relative distribution of test current flow. The test measuring arrangement should consist of the following major subsystems as illustrated on Drawing No. 2.4.2.

(1) Installation of current measuring test points at each traction power substation (approximately 16 locations).

(2) Each test point to consist of two No. 8, THW insulated stranded copper wires attached to one rail of each track spaced 250 feet apart. Test point locations must be interfaced with crossbond locations such that test wire pairs do not span a crossbond and each pair from different tracks are on the same side of the crossbond.

(3) Test wires to be routed to a permanently installed test box positioned for ease of access by maintenance personnel. Test wire pairs from each track should be housed in a common box if possible and appropriately identified.

(4) Installation of a stepped DC voltage source (10 to 150 volt) with a current rating of 100 amperes, associated

voltmeter and ammeter, test wires and current interruption facilities (either automatic or manual) to provide test current for measurement of track resistances.

b. The general concept of track resistance testing would include consideration of the following procedural items and system requirements.

    (1) Tests must be conducted when there is no load on the mainline system, including auxiliary loads for stored vehicles. This may require that tests be conducted during non-operational periods of the system.

    (2) Automatic grounding systems based on rail-to-earth potential such as that proposed in 2.4.1.b must be disconnected prior to testing.

    (3) Maintenance or operations personnel would be required to activate or set-up the test voltage source between track and a low resistance ground. (Across the mainline/yard interface is a suggested location).

    (4) Maintenance or operations personnel would be required to measure the change in potential at each test wire pair from the rails along the system caused by test current interruption. (Consideration should be given to automating this task through proposed data transmission systems if available).

    (5) Results generated from these tests would yield individual track section resistances and thus indicate the need for remedial action.

2.5 Utilities

2.5.1 SCRTD Facilities

a. Non-pressure drain pipe embedded in the invert should be non-metallic. If metallic pipe must be used, no special corrosion control measures will be required.

b. Metallic drainage discharge piping and water and fire piping exposed in the interior of the transit structure do not require special corrosion control measures. However, where piping penetrates the structure walls to connect to outside underground utilities, the following corrosion control measures shall be instituted:

    (1) Install piping through the structure wall in a watertight electrically insulating sleeve.

    (2) Electrically insulate the interior piping from the piping connected to the exterior utility just inside

the structure wall by the use of a pipeline insulating flange, coupling or union.

c. Underground metallic structures outside the transit structure shall be prepared for stray current testing. This preparation would consist of structures being made electrically continuous by the bonding of mechanical joints and test facilities being installed at the tie-in to existing structures and at other appropriate locations.

2.5.2 Facilities Of Other Than SCRTD Ownership

a. Along Mainline

No specific action will be required by SCRTD. However, test/monitoring facilities should be installed at the discretion of the owner at appropriate locations on replacements and/or relocated structures. Additional corrosion control measures may also be installed by the owners in conformance with their corrosion control programs.

b. Yard Area

Utilities and pipelines in the vicinity of the yard should be reviewed in detail to determine the need for test stations and other facilities to test for stray current effects upon system activation.

2.6 Yard And Shop Area

2.6.1 Yard

a. The mainline track system, both positive and negative, should be electrically separated at the mainline/yard train control interface. (Note: other considerations may require that this separation point be moved somewhat).

(1) This electrical separation point will provide the interface between mainline automatic train control and the yard train control system.

(2) Electrical separation to be achieved by a non-bridgeable gap in the positive system (contact rail) and rail insulating joints in the running rails.

(3) An automatic remote controlled interlock shall be provided for both positive and negative switch arrangements to electrically connect yard to mainline during abnormal situations.

(4) Vehicle couplers shall provide electrical continuity between vehicles to accommodate a minimum 100 ampere flow.

b. Yard track should be of standard timber tie and ballast construction with no intentional ground connections. All interconnects between yard track and railroad track shall be electrically insulated.

c. Yard traction power substation shall contain provisions for stray current mitigation drainage from both yard facilities and outside utilities.

d. Underground Utilities And Structures Within The Yard

   (1) Fire and potable water systems shall be of non-metallic piping, if acceptable. The use of non-metallic pipe must be reviewed from a mechanical standpoint to determine acceptability. If piping must be metallic, it must be made electrically continuous with provisions for the drainage of stray currents and possibly cathodic protection (to be determined).

   (2) Drainage piping shall be non-metallic and/or concrete and will require no special corrosion control measures.

   (3) Conduit shall be non-metallic.

   (4) Fencing shall be made electrically continuous.

2.6.2 Shop

a. Shop shall be electrically separated in both the positive and negative power circuits from the yard facilities.

   (1) Insulate yard rails from all shop rails which will be grounded inside and/or outside the shop.

   (2) Provide separate DC power supply for shop service.

b. Grounding

   (1) Steel reinforcing in shop structure shall be electrically connected to shop rails, all of which shall be grounded.

   (2) Metallic piping within the rebar grid shall be electrically connected to the reinforcing or grounded rails.

   (3) Metallic conduit shall be grounded.

2.6.3 Other

a. Hydraulic lifts and/or elevators having part of their assembly embedded in earth shall be prepared for the control of stray current by insulation from earth and cathodic protection.

b. Use non-metallic piping wherever possible.

3. DISCUSSION

As stated in the introduction, the Task 5 Stray Current Analysis showed that the most effective means of controlling stray earth currents was to minimize their discharge into the earth. This can best be achieved by maintaining a high resistance to earth of both the positive and negative systems.

On the basis of an effective track-to-earth resistance of 1,500 ohms per 1,000 feet of track (two rails), stray current discharged from the rails would be limited to less than 0.1 ampere per 1,000 feet of track. Stray current of this level will not create significant detrimental effects on underground structures. Thus recommendations have been directed toward obtaining and maintaining a high track-to-earth resistance.

In view of the anticipated low level of stray earth current, no special measures are recommended to establish electrical continuity or electrical isolation of steelwork (reinforcing) associated with the tunnel/station construction. However, the installation of test facilities is recommended to provide some means for long term monitoring of the effects on tunnel structures.

Test facilities have been recommended to measure the magnitude of stray current which may be collected on the steel tunnel liners in areas of possible petroleum contamination. This data will be useful in determining the effectiveness of the track resistance and also in evaluating the condition of the steel liner.

Test facilities have also been recommended (test electrodes through the tunnel walls into earth) to provide a means for evaluating the magnitude and effects of stray current on the tunnel structure. The electrodes will provide stable, permanent earth references for measuring these effects. The periodic recording of the voltages occurring between the tunnel structure and earth will provide an insight into the magnitude of stray current effects and their changes over an extended time period.

The recommendations relative to mainline trackwork are directed toward obtaining the most effective electrical insulation possible between the running rails and ground. Thus rather specific measures such as high resistant grout pads and very tightly controlled specifications for direct fixation insulating rail fasteners have been recommended to achieve this goal. Establishing a well insulated track system eliminates the need for extensive electrical bonding of the structural reinforcing at a considerable expense.

This also reduces the long term expense for stray current mitigation measures.

The recommendations relative to the direct fixation rail fasteners are not made with the intent to design the unit but to point out areas in the fastener construction where attention is required to ensure that long-term effective electrical insulation is achieved. Thus with improved electrical insulation, more effective long term service and stray current control can be expected.

The recommendations relative to the traction power system are directed primarily to the prevention of stray current leakage to earth. The crossbonding between tracks as recommended will be adequate from a stray current control standpoint. Additional bonding for traction power purposes will not have significant effect on stray current conditions.

Based on the anticipated low level of stray earth currents, no recommendations are presented for the installation of specific stray current drainage facilities at traction power substations. The need, if any, for such facilities can best be determined by stray current studies conducted after energizing of the transit system. The connection of utilities or other grounded structures to the transit negative system is to be only on a last resort basis.

Underground utilities associated with SCRTD facilities will be limited in number and extent. Stray current corrosion control recommendations are limited to establishing electrical continuity on buried metallic structures and insulating them from the building structures and outside utilities. No specific recommendations are made regarding utility structures of other than SCRTD ownership. Owners of adjacent structures and utilities should consider installing test and monitoring facilities to assist in future evaluation studies. Additional corrosion control measures may be installed by the owners at their discretion.

Stray current control recommendations for the yard and maintenance shop are presented in some detail since this large concentration timber tie and ballast track could create significant stray current effects on surrounding underground structures. The electrical separation of the mainline system, both positive and negative, from the yard system is of primary importance in reducing stray current effects in the yard area. Experience with other transit systems has shown that upon insulating the yard track system from the mainline track system, stray current effects on nearby utilities have been reduced from unacceptable magnitudes to levels which did not require special corrosion control measures.

Another approach to reducing the level of stray currents associated with yard track is to install the yard track on insulated rail fasteners. The use of insulated rail fasteners for yard track is extremely costly and difficult to achieve because of the large amount of special trackwork. Although no special insulating rail fasteners are recommended for yard track, the track system should not be intentionally connected to ground. Low resistance ground connections could result in localized large magnitudes of stray current as the result of train movement within the yard. Shop tracks, which must be grounded for safety reasons, must be electrically isolated from the remainder of the yard tracks and have their own independent power source. This is so that the small levels of stray current interchanged with earth will be localized and will not extend a significant distance from the shop building.

Recommendations presented under Systemwide Test and Monitoring (Recommendation 2.4) are directed towards two major items, namely safety (hazardous DC potentials) and overall maintenance and monitoring of track-to-earth resistance and potentials. Both items require attention, first to assure a safe transit system and second to assure effective stray current control is maintained once established. The need for the recommended action and/or measures is a direct result of establishing a well insulated negative return system.

The first item to be addressed is essentially a safety related matter. Under normal operations, passengers and SCRTD personnel will contact the negative system and ground. This contact will occur through the vehicle, directly to the running rails, or other parts of the negative system and earth (i.e. platforms, inverts, walkways, etc.). Normal operations will result in negative system potentials no greater than 78 volts with respect to ground (above ground potential). While there has been no definitive study of safe DC potentials for the transit industry, work conducted by Dalziel(1) has indicated the following safe potential levels based on "let-go" currents under extreme low body resistance conditions, of 2,000 ohms. We have added an additional 200 ohms to account for the resistance to earth of the contact area, platforms, invert, walkway, etc., based on wet concrete resistivity.

Table I

Men 136 volts DC at 62 ma	R = 2,200 ohms
Women 90 volts DC at 41 ma	R = 2,200 ohms
Children 68 volts DC at 31 ma	R = 2,200 ohms

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(1) "Let-Go Currents and Voltages", C.F. Dalziel and F.P. Massoglia: Transactions IEEE Vol. 75, No. 11, May 1956, pps. 49-56.

These values are the total voltage drop across individual and earth (i.e. platform, invert walkway, etc). Therefore, the voltage across the individual will be somewhat less than that cited, approximately 90% of the value listed. This yields a minimum safe DC level of 76 volts. As stated, normal system potentials will not exceed this value to any significant degree resulting in safe operations, especially when consideration is given to the fact that more realistic individual body resistances will range from 5,000 to 10,000 ohms. Negative system potentials above 80 volts (above or below ground potential) can be considered as unsafe and, therefore, require immediate action relative to the removal of the condition that caused the excessive potential.

One major abnormal operating condition that can cause negative system potentials to earth of 80 volts or greater is a positive-to-earth fault, that because of the resistance of the negative system will be limited to not more than 100 amperes and thus will remain undetected by conventional means.

When there is a positive-to-earth fault, the fault current will cause the entire negative system to be depressed in potential with respect to ground. Since a zero resistance positive-to-earth fault in conjunction with an 8.0 ohm negative-to-earth resistance (95,000 feet of double track at 750 ohms/1000') will result in a fault current of only 100 amperes it will in all likelihood remain undetected. However, the negative system will be depressed with respect to ground potential to 795 volts. Figure 1 shows the relationship between fault resistance, fault current and negative system potential using a simplistic model. While this model neglects such considerations as TPSS regulation and longitudinal resistance of positive and negative circuits, it serves to illustrate that relatively low level fault currents can result in significant negative system-to-earth potentials. Review of the information shown on Figure 1 shows negative system-to-earth potentials in excess of 80 volts will occur for fault resistances less than 72 ohms and fault currents of 10 to 100 amperes. Normally, proposed protective devices and circuits will not activate at these low current levels.

There are other abnormal operating conditions that could result in excessive DC potentials that will not be reduced by the proposed scheme. These conditions include loss of a TPSS or a high resistant positive-to-negative fault. In these instances, especially when there is a TPSS outage, certain operational constraints must be considered. The most important being the avoidance of simultaneous starting of two trains at one location, such that the total load current exceeds that required for a single train with normal acceleration.

Given the possible occurrence of a positive-to-earth fault, we have recommended that the SCRTD consider installation of a detection/protective scheme that will reduce excessive negative system potentials and in some instances remove the source of the fault current. The proposed arrangement is based on use of a silicon controlled rectifier connected between the negative bus and ground at each traction power substation. The underlying principle is to ground the negative system, in a controlled fashion, when the potential exceeds some predetermined value. The general operating characteristics and principles are as follows:

- Monitor the potential between the negative bus and ground at each TPSS through a time/over voltage relay (polarity sensitive DC device).

- If the potential should exceed some preset level (80 volts suggested) the SCR would be triggered depending upon the polarity of the over-voltage.

- When the SCR has been activated, there will be local and remote annunciation of the condition.

- The detection circuit switches to current sensing after the SCR is triggered (see Drawing 2.4.1). Additional action at this stage will be dependent upon the magnitude of the fault current. If above some predetermined level, AC or DC breakers will be opened; if below this level, for a specified time period, secondary annunciation would be completed.

We must emphasize that the proposed detection scheme discussed above and shown on Drawing 2.4.1 is presented as a conceptual approach only. It serves to illustrate what must be considered relative to systemwide safety in the event of excessive DC potentials on the negative system. These would be caused by abnormal conditions in conjunction with a well insulated (as opposed to grounded) track system. Systems engineering personnel should review this matter carefully to determine the feasibility of the proposed arrangement and whether or not other protective relaying schemes can be used.

The second major item addressed under Systemwide Test and Monitoring (Recommendation 2.4) is concerned with establishing "built-in" provisions to monitor and test the principal elements of stray current control for the Metro system. These elements concern negative system to earth potentials and track-to-earth resistance.

In regard to negative system-to-earth potentials, we have recommended installation of permanent strip chart recording voltmeters at seven locations throughout the system. The locations chosen are at five traction power substations and two passenger stations where there are no substations present. The basis for this recommendation is to provide baseline conditions for negative system potential and thus establish a means of alerting operations personnel to changes in potential (through chart review) that may indicate loss of effective stray current control caused by long term deterioration of track insulation. The recommendations also include provisions to simulate the loss of effective track insulation and the impact on systemwide negative potentials-to-earth. This simulation will be accomplished through variable resistance grounding of the negative system at several locations throughout the system.

We envision that the recording charts would be reviewed frequently during initial system start-up and revenue operations, perhaps weekly or more frequently. Once baseline conditions have been established, recording chart review could be done less frequently depending on results being obtained.

The other major aspect of systemwide testing consists of providing permanent facilities that will allow for the periodic measurement of track-to-earth resistances throughout the system. The rationale here is that track resistances would be measured at some predetermined frequency, perhaps monthly unless the previously discussed potential monitors indicate a loss of effective isolation. In this instance, track resistance measurements would be made as necessary to determine if the problem is localized or wide-spread. The major components required for the track resistance measurement arrangement proposed consist of permanently installed test wires attached to one rail of each track at approximately 16 locations throughout the system and a test current/voltage source with automatic unattended cycling. The test current source would be used to impress a current between track and ground (yard track for example). This current, in conjunction with the test voltage, would establish the overall track-to-earth resistance. In addition, the test wire pairs would be used to measure the percentage of current returning from each track section thus establishing a systemwide distribution of track resistances indicating particular areas that may require further review.

There are several important aspects of the proposed arrangement that must be emphasized.

- The measurements must be made when there is no load on the mainline negative system. Any load would show up on the reading at a test wire pair making it difficult to measure the amount of test current present.

- Measurements at test wire pairs would most likely be made by one or more individuals using portable voltmeters. Therefore, testing time and test facility access become critical if tests are to be made during the non-operational periods of the system.

For this reason, we have suggested that rail test facilities be made accessible from one trackway allowing one or more individuals to ride the trackway, stopping at the test facilities to make the measurements and then proceeding to the next test location. The actual procedures, vehicle requirements and method of data acquisition will require detailed study. The arrangement has been presented for SCRTD consideration of an important maintenance and monitoring aspect of stray current corrosion control.

Appendix A

Rail Fastener Resistance Test Procedures

1. General

The primary measure for the control of stray earth currents on SCRTD Metro Rail Project will be effective electrical insulation of the negative system (primarily running rails) from ground. A resistance value of 1,500 ohms per 1,000 feet of track (two rails) has been recommended as an effective value. Certain recommendations relative to construction of insulating rail fasteners have been included in the Task 7, Stray Current Control Recommendations Report. This Appendix presents detailed test procedures for evaluating the effectiveness of the electrical resistance qualities of the fasteners.

2. The electrical resistance of the elastomer material proposed for use in the rail fasteners shall be determined in accordance with ASTM Specification D257-78, "DC Resistance or Conductance of Insulating Materials". The resistivity shall be stated as a minimum of 10^{12} ohm-cm. The resistance of the fastener elastomeric material to water absorption shall be determined in accordance with ASTM D570-77, "Water Absorption of Plastics". The elastomeric material should show an increase in weight of less than 0.1 percent when exposed to water. The resistivity measurements should be repeated on the elastomer after the water resistance absorption tests.

3. Electrical Resistance Tests On The Completed And Assembled Rail Insulating Device

The following testing procedure should be considered for testing the complete rail fasteners. The test should be conducted on a minimum of six fasteners, some of which should have been subjected to mechanical tests which could result in a degrading of the electrical insulating properties, by resulting in cracked or otherwise damaged insulating components.

3.1 The insulated rail fastening device including a short length (18-inches) of 115-pound rail and rail clips shall be assembled on a polymer modified grout pad on a concrete test block simulating invert concrete. Six units should be so assembled. The rail section lengths shall be greater than the width of the concrete blocks (a minimum of 1.5 feet). The concrete blocks shall be placed upright in a bare (uncoated) metal trough with a minimum clearance of 4-inches between the walls of the trough and the other blocks, if more than one block is positioned in one trough. The trough shall be leveled and water poured into the trough taking care to ensure the fastener components are not wetted. The water may be tap water. Water shall be placed in the trough to fill it to approximately 1-inch below the top of the grout pad, measured at the center of the rail. The water shall be maintained at this level for the duration of the tests.

3.2 Immediately upon filling the trough, the resistance shall be measured between each of the six rail assemblies and the metal trough using a 500 volt "Meggar" Insulator Tester as manufactured by James J. Biddle Co., Philadelphia, PA, or equal. The measurements shall be repeated three times a day scheduled for a minimum of three days or until the resistance stabilizes for a period of three consecutive measurements (±5%). The rail fasteners shall have not less than 10 megohm insulation resistance between any rail and the metal trough under these conditions.

3.3 The fasteners shall be subjected to a fine mist spray for one hour's time which will provide the water at a rate of 1-inch per hour for the area covered. The water used shall have a resistivity within the 10,000 to 20,000 ohm-cm range and a temperature in the 60° to 80°F range. (The water accumulation within the trough shall not be allowed to exceed the stated level of 1-inch below the top of the block). Within five minutes of stopping the spray, the resistance of each fastener shall be measured in accordance with the previously established procedure. The resistance measurements shall be repeated three times at 15 minute intervals. The general environmental condition during this period shall be within the range of 60°F to 80°F and a relative humidity of 70 to 90%. The electrical resistance of the fasteners during these tests shall not be less than 400,000 ohms.

3.4 The fasteners shall be subjected to heat lamps placed directly above the fasteners to dry them. The positioning of the lamps and the heating intensity shall be adjusted to ensure the rail and fastener components do not exceed 110°F. The resistance of the fasteners shall be measured at regular intervals (starting at ½ hour intervals for a minimum of five measurements) until the resistance returns to the original dry minimum of 10 megohms, which must be restored within a maximum of 10 hours. At no time shall the fasteners be wiped, brushed or in any way cleaned of any residue which may collect during these tests.

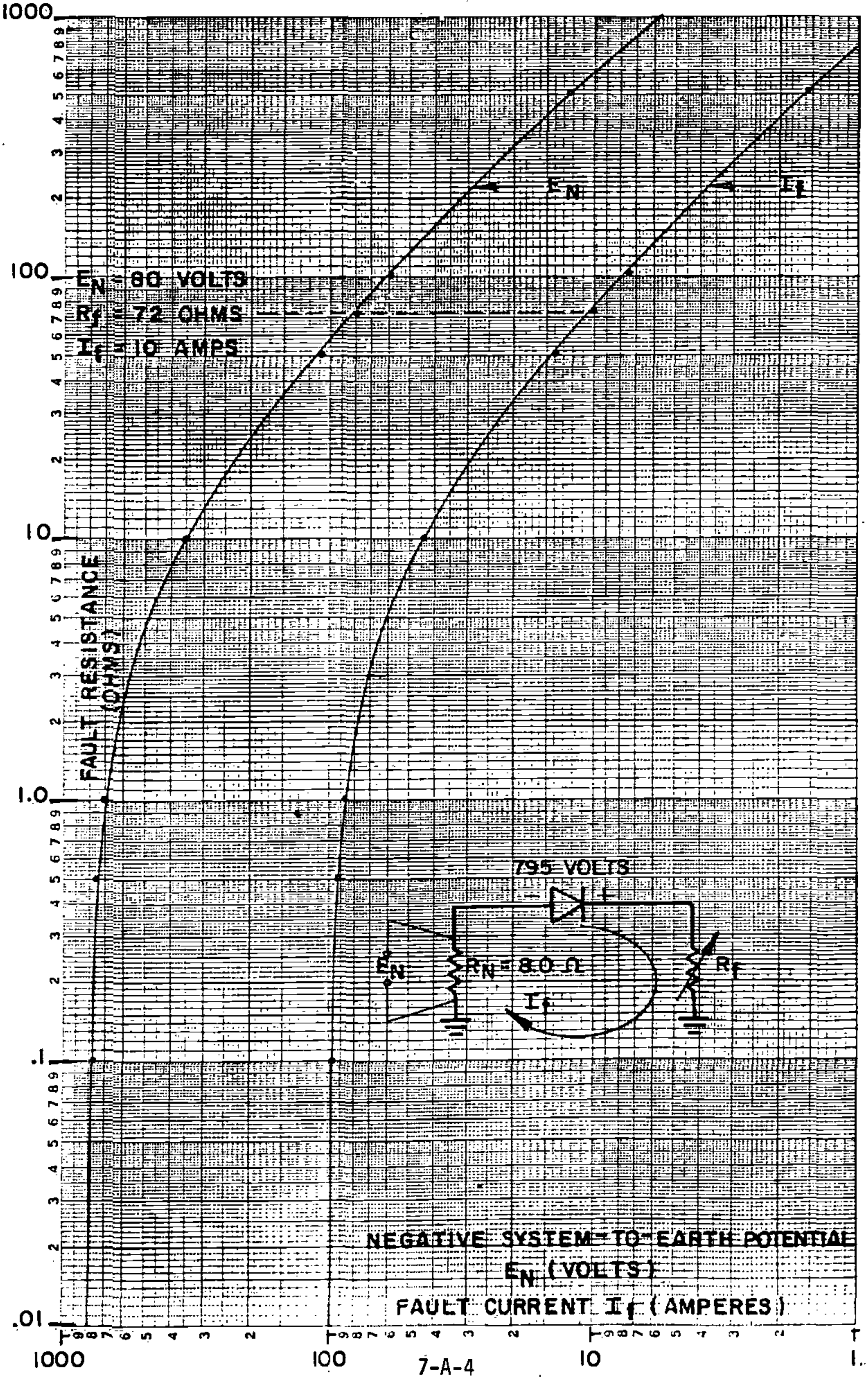
3.5 The tests described in 3.3 and 3.4 shall be repeated three times on the same fasteners without cleaning or disturbing the test conditions in any manner.

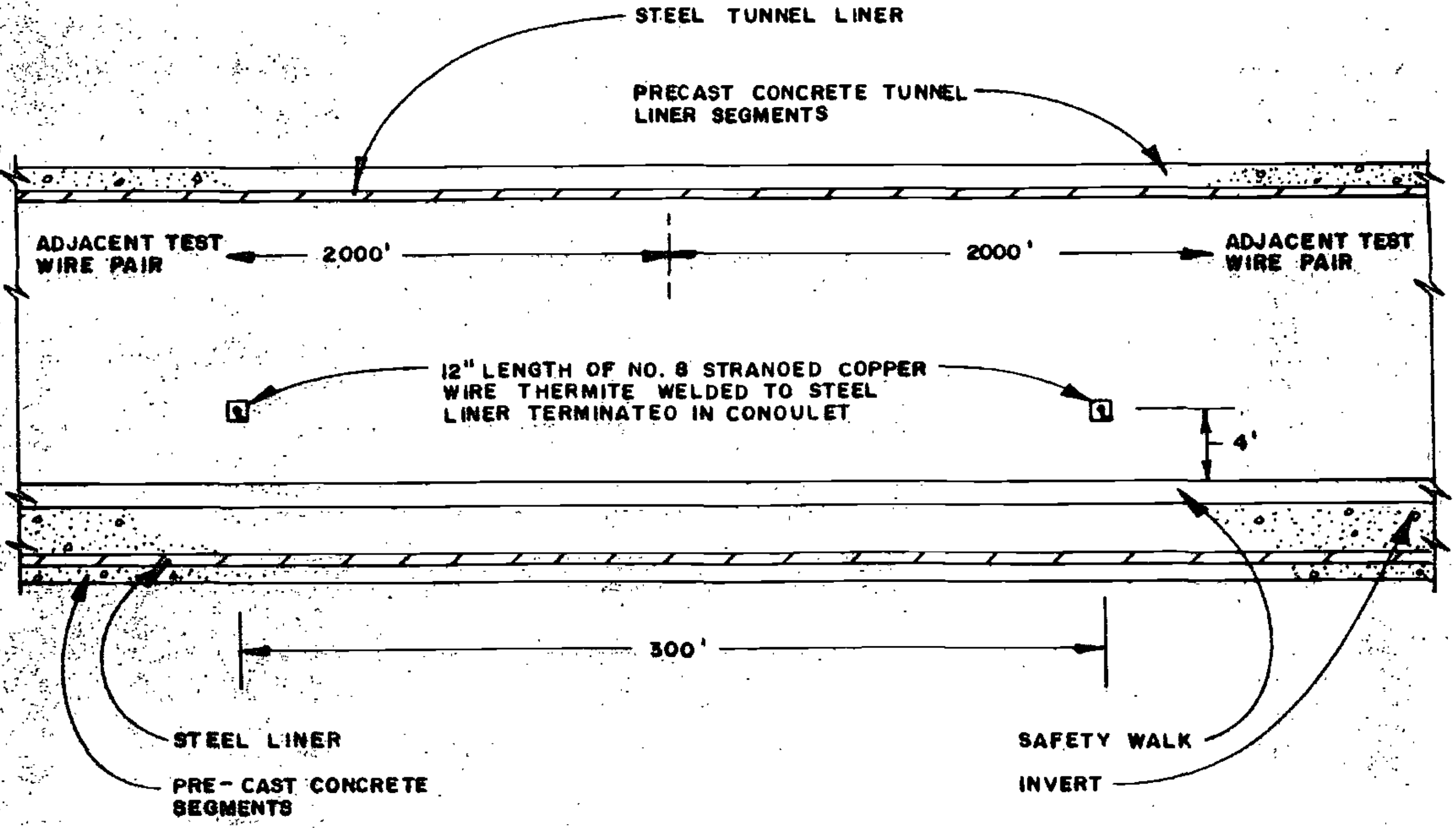
3.6 Acceptance shall consist of obtaining the resistance values stated under the conditions and time constraints noted.

4. The test procedure requirements, as stated, will require some consideration by the manufacturer relative to the electrical leakage paths such as undercutting the edges of the insulating components (primarily the elastomer material) to interrupt the electrical path from moisture accumulation on a smooth surface. Also the elimination and/or sealing of crevices or openings in the fastener which would permit the accumulation of dirt, rail filings and moisture should be thoroughly investigated. Experience and analysis indicates that the recommended measures are practical and will result in a definite improvement in the electrical resistance characteristics of these fasteners at little extra cost. This extra testing is well justified for the SCRTD Metro System since the control of stray earth currents is being predicated on maintaining a high degree of track-to-earth resistance.

FIGURE 1

S.C.R.T.D. / LOS ANGELES



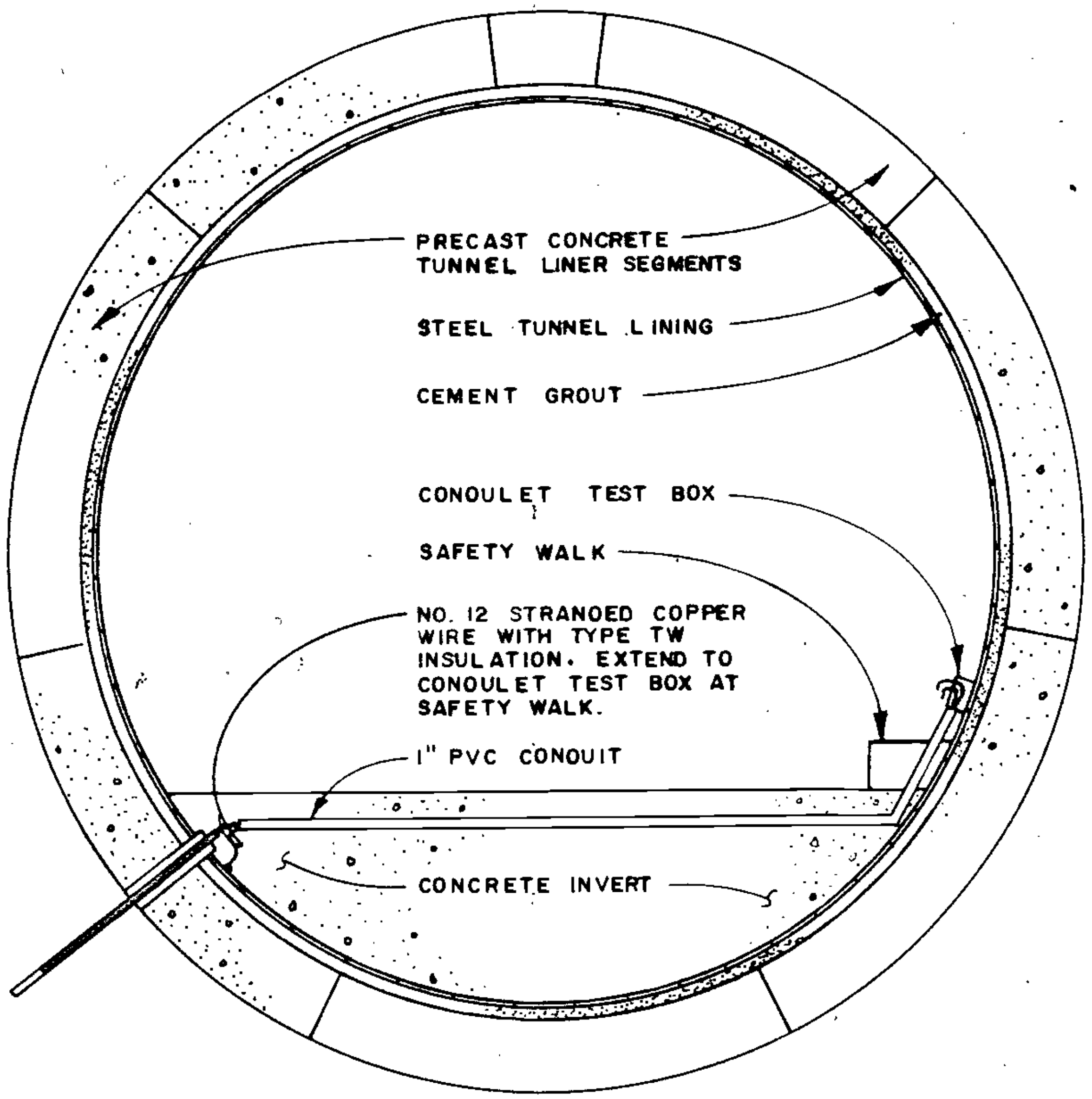


NOTE: TEST FACILITIES AT 2000' INTERVALS

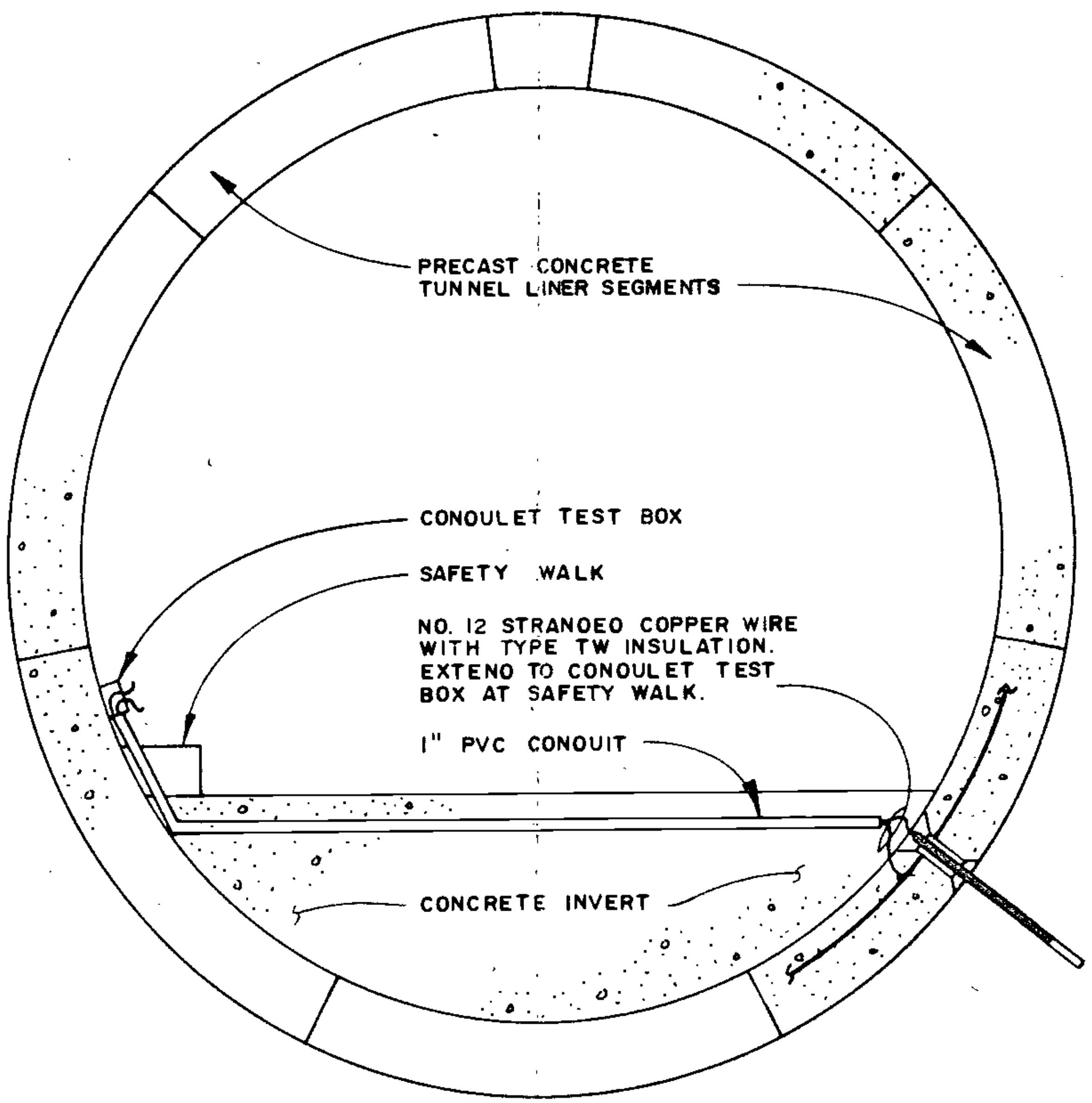
TYPICAL STRAY CURRENT MEASURING TEST FACILITY

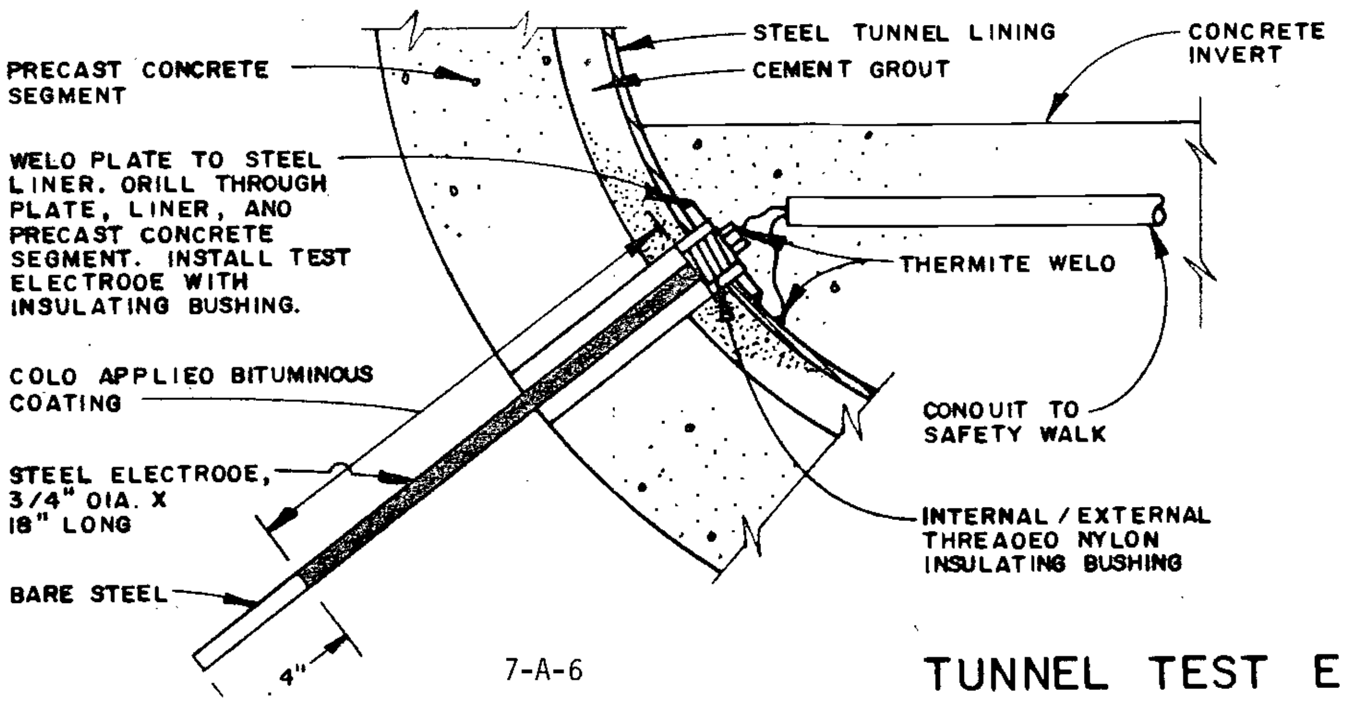
DWG. NO. 2.1.4

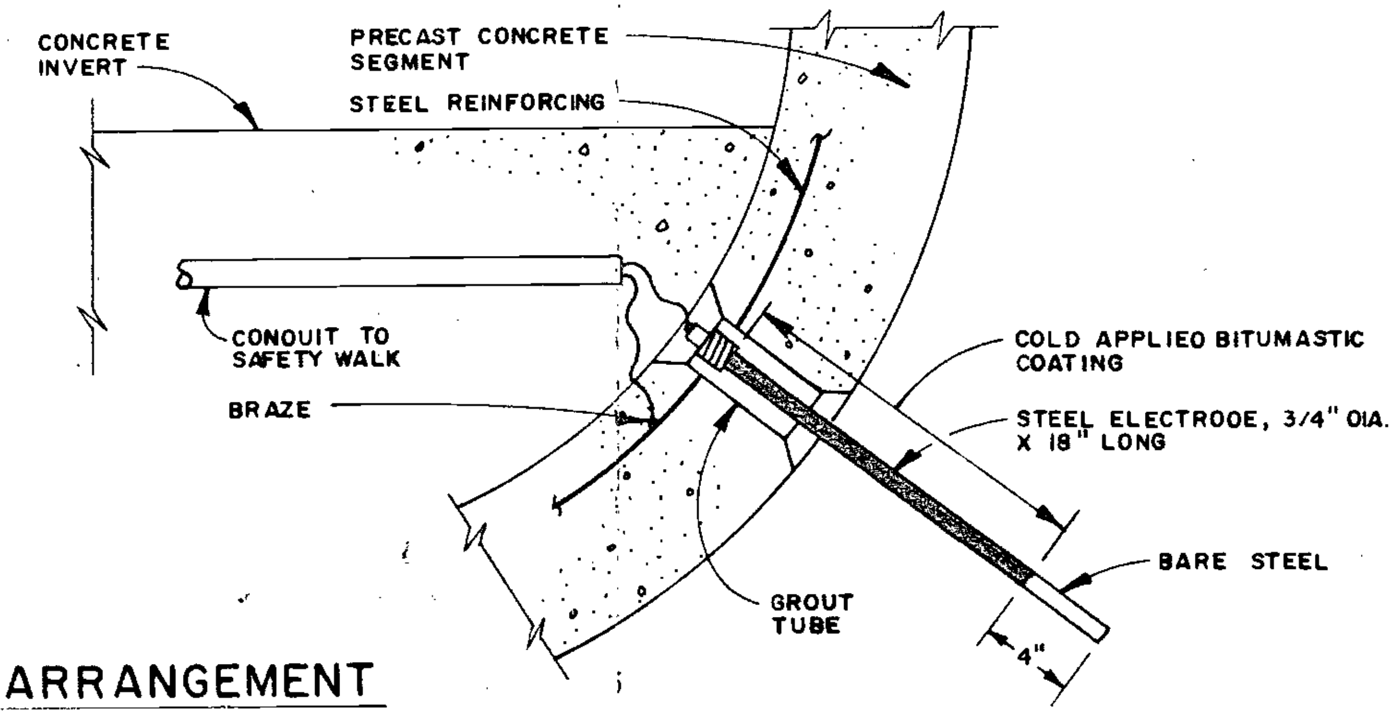
STEEL LINED TUNNEL



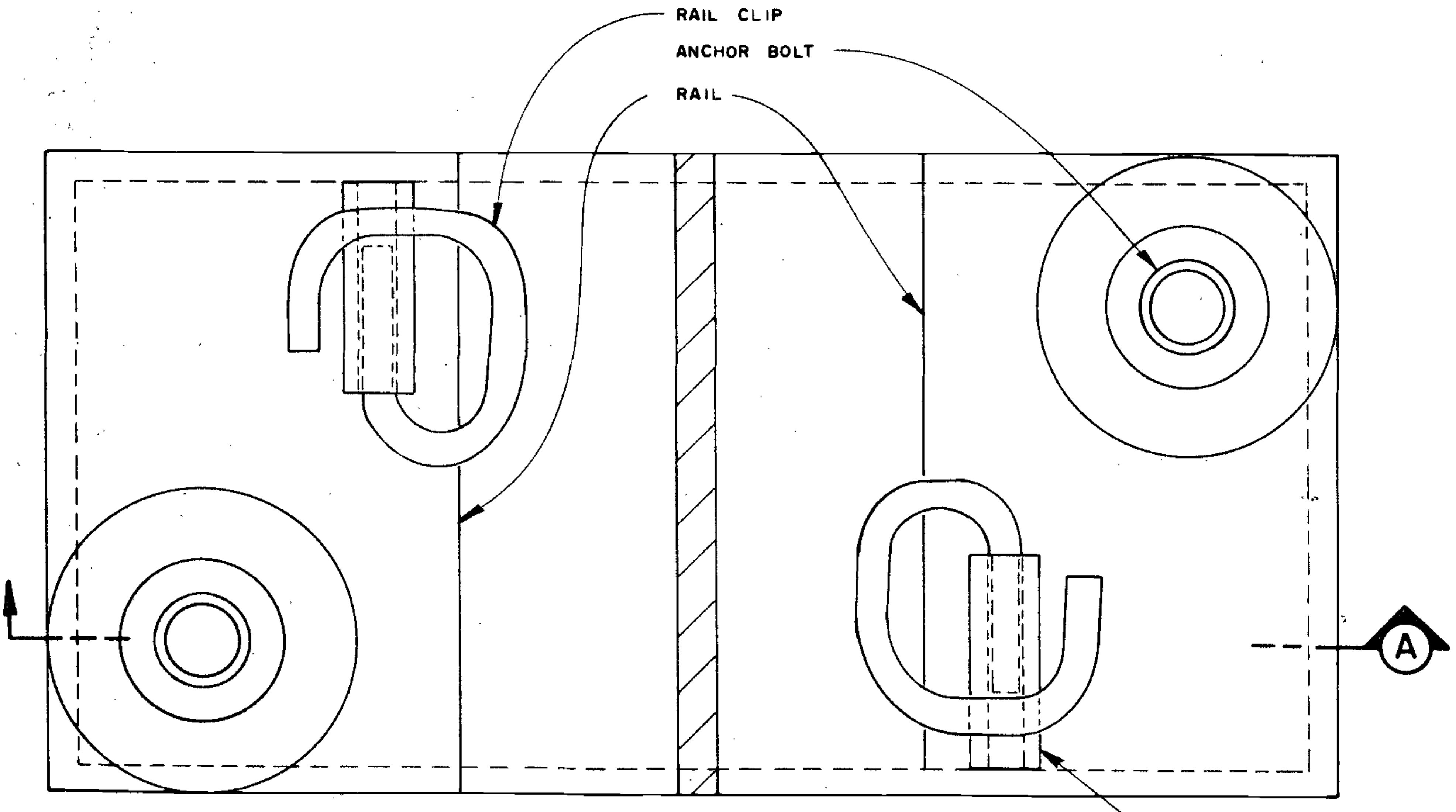
PRECAST CONCRETE TUNNEL LINER



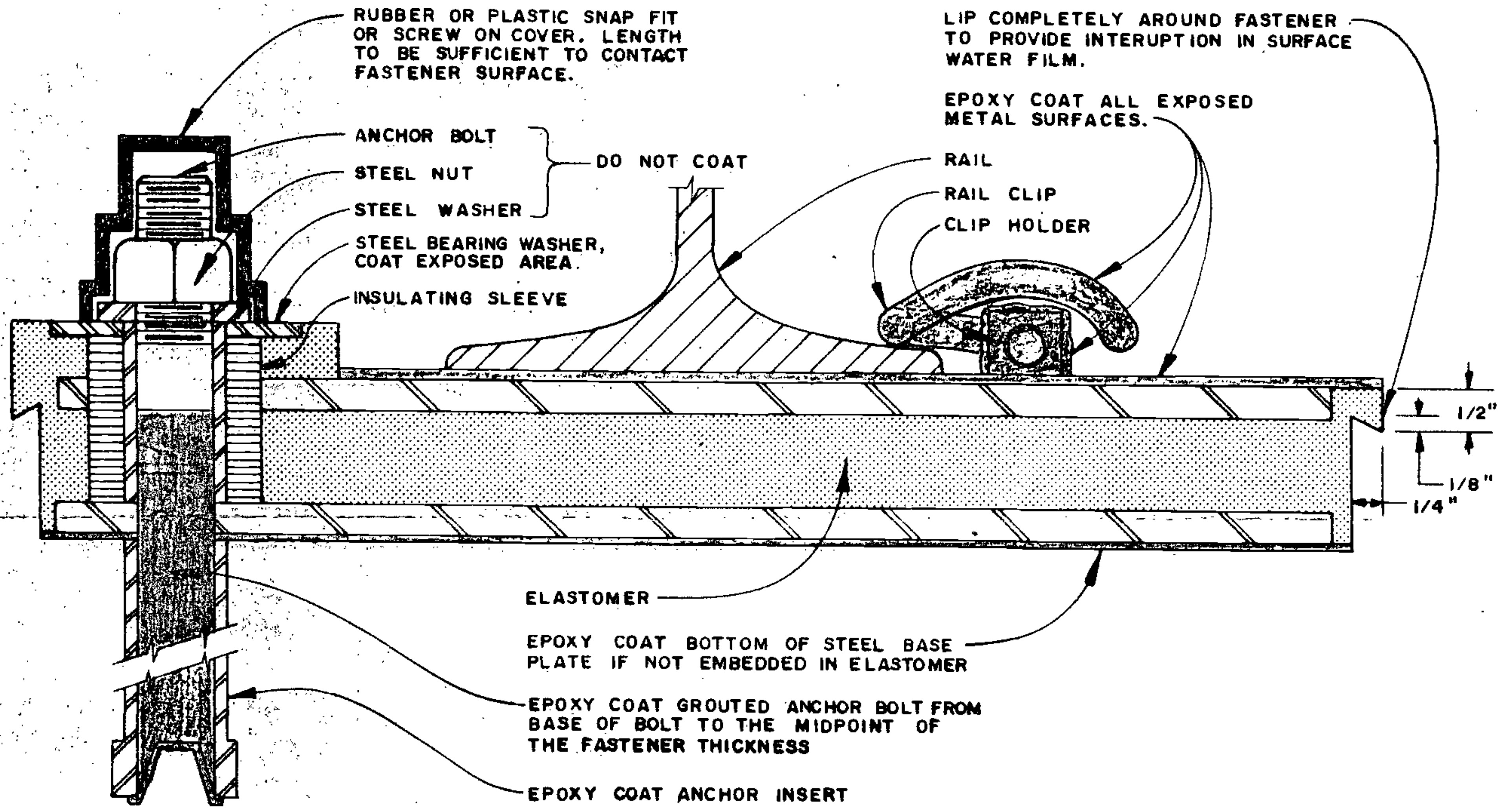




TUNNEL TEST ELECTRODE ARRANGEMENT



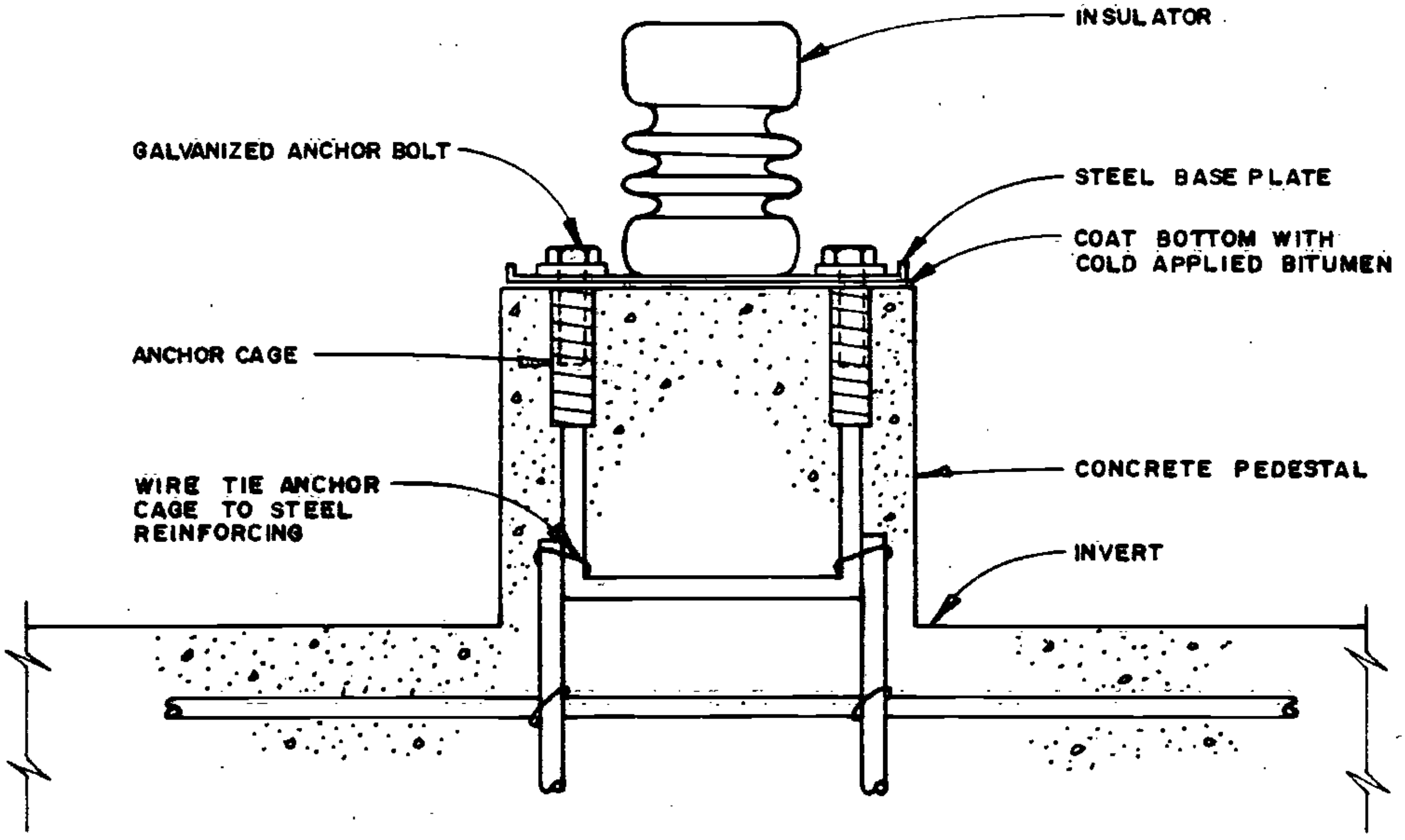
PLAN



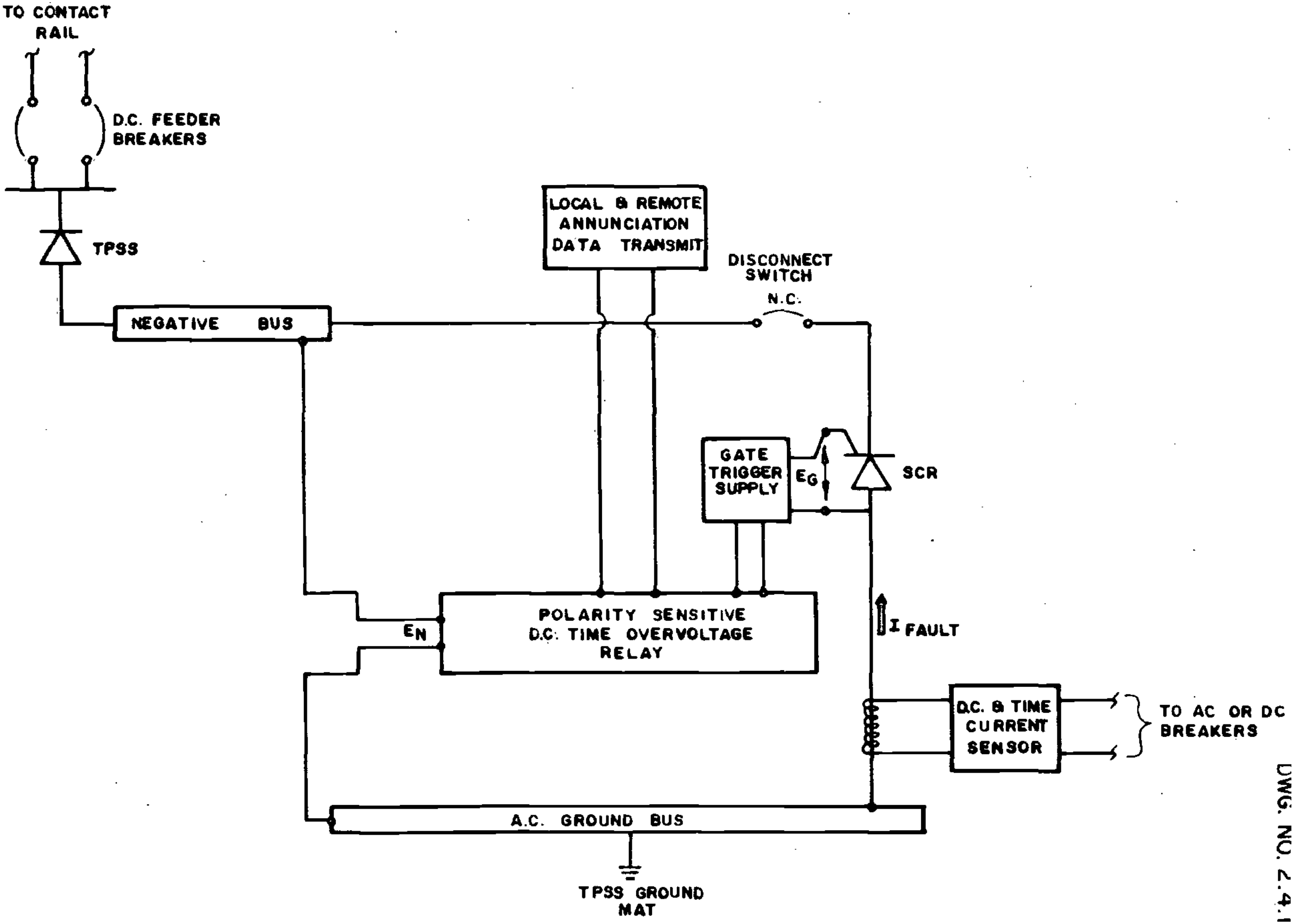
SECTION A

TYPICAL DIRECT FIXATION INSULATING RAIL FASTENER

DWG. NO. 2.2.2



TYPICAL PEDESTAL FOR CONTACT RAIL INSULATOR



DWG. NO. 2.4.1.

PROTECTION AGAINST EXCESSIVE NEGATIVE SYSTEM-TO-EARTH POTENTIALS

(TYPICAL EACH TPSS)

GENERAL OPERATING CONDITIONS

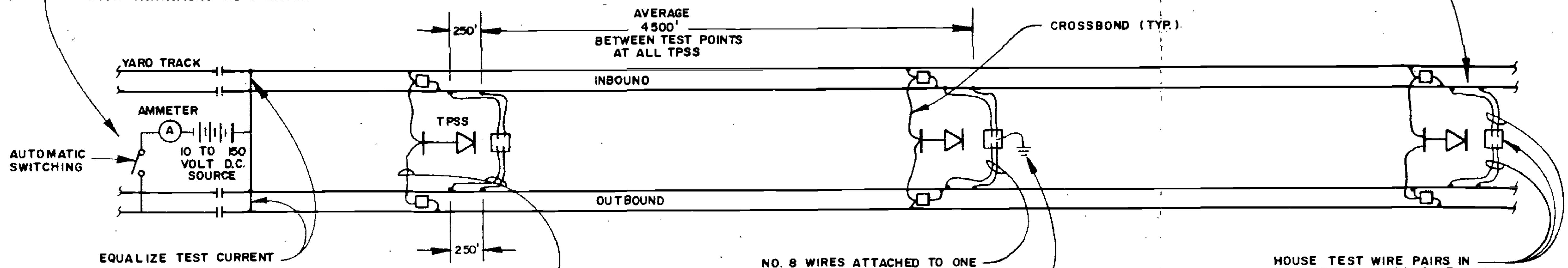
NEGATIVE SYSTEM POTENTIAL

$-75 \text{ VOLTS} \leq E_N \leq +75 \text{ VOLTS}$	No Action: SCRs remain unfired, non-conducting, negative isolated.
$-80 \text{ VOLTS} < E_N < -75 \text{ VOLTS}$ FOR $t > 5$ SECONDS	Local and remote annunciation of excessive voltage; SCRs remain unfired, non-conducting; alert system personnel to system abnormality, not causing unsafe potentials. Negative isolated.
$E_N \leq -80 \text{ VOLTS}$ $t > 1$ SECOND	SCR activated; negative system potential reduced to safe level >-80 volts. Additional SCRs at other TPSS may be activated as fault current increases and E_N again approaches - 80 volts.
(FAULT CONDITION; POSITIVE TO EARTH)	Local and remote annunciation. Additional action contingent upon magnitude of I_{Fault}.

DWG. NO. 2.4.1a

PERMANANTLY INSTALLED TEST CURRENT AND VOLTAGE SOURCE WITH FACILITY FOR UNATTENDED CURRENT INTERUPTION ON A PRESET CYCLICAL BASIS (PULSE). CURRENT MUST BE STABLE WITH VARIATIONS NO GREATER THAN ±.5 %.

TEST WIRES ARE NOT TO SPAN ANY DEVICE, ELECTRICAL OR MECHANICAL THAT IS ATTACHED BETWEEN RAILS OF THE SAME TRACK (TYP.)



TEST WIRE PAIRS (INBOUND & OUTBOUND) TO BE INSTALLED AWAY FROM TEST CURRENT SIDE OF CROSSBOND, IF PRESENT, AT ALL TPSS LOCATIONS (TYP.).

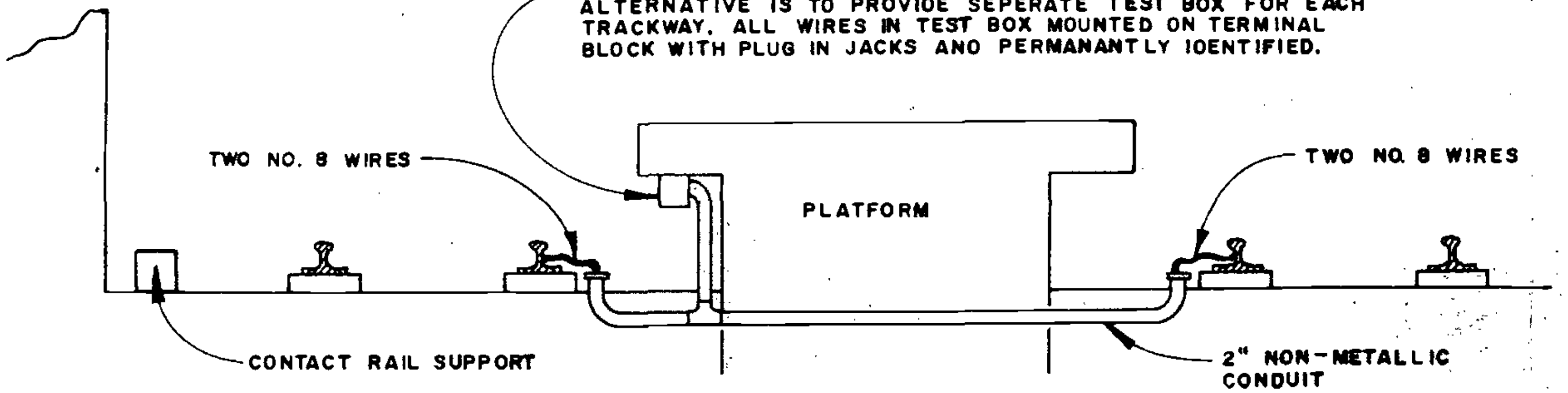
NO. 8 WIRES ATTACHED TO ONE RAIL FROM EACH TRACK SPACED 250' ± 1' APART ON MAINLINE SIDE OF CROSS BOND AT EACH TPSS.

NO. 8 WIRE ATTACHED TO LOW RESISTANCE GROUND NEAR TEST WIRES (USE INVERT REINFORCING) TERMINATE IN TEST BOX WITH RAIL WIRE PAIRS.

HOUSE TEST WIRE PAIRS IN NON-METALLIC CONDUIT, ROUTE UNDER RAILS, OR ALONG TUNNEL WALL, TERMINATE IN PERMANANTLY MOUNTED TEST BOX ACCESSIBLE FROM THE TRACKWAY. USE A COMMON TEST BOX FOR BOTH WIRE PAIRS IF POSSIBLE. SEE DETAIL BELOW.

PLAN

LOCATE TEST BOX FOR ACCESS FROM ONE TRACKWAY IF POSSIBLE. ALTERNATIVE IS TO PROVIDE SEPERATE TEST BOX FOR EACH TRACKWAY. ALL WIRES IN TEST BOX MOUNTED ON TERMINAL BLOCK WITH PLUG IN JACKS AND PERMANANTLY IDENTIFIED.



NOTE: POSSIBLE TEST BOX LOCATION & WIRE ROUTING. OTHER OPTIONS AVAILABLE DEPENDING ON ACTUAL ARRANGEMENT AT END OF PLATFORM OR WITHIN TUNNELS.

DETAIL

TASK 8

CORROSION CONTROL DESIGN CRITERIA AND SPECIFICATIONS

Table of Contents

Page

IV-5.1 General 1
IV-5.1.1 Scope 1
IV-5.1.2 Applicable Documents 2
IV-5.1.3 System Interfaces 5

IV-5.2 Stray Current Corrosion Control . . 6
IV-5.2.1 General 6
IV-5.2.2 Traction Power and Distribution . . 7
IV-5.2.3 Vehicle Storage and Maintenance Facilities 9
IV-5.2.4 Tunnel and Track Support Structures . 11
IV-5.2.5 Utility Structures 13
IV-5.2.6 Testing and Monitoring 17

IV-5.3 Underground Corrosion Control . . . 20
IV-5.3.1 General 20
IV-5.3.2 Concrete and Reinforced Concrete Structures 21
IV-5.3.3 Piping and Conduits 23
IV-5.3.4 Hydraulic Elevator Cylinders . . . 27
IV-5.3.5 Non-SCRTD Owned Facilities . . . 28
IV-5.3.6 Corrosion Control Components and Subsystems 28
IV-5.3.7 Testing 32

IV-5.4 Atmospheric Corrosion Control . . . 32
IV-5.4.1 General 32
IV-5.4.2 Above Grade Metals and Coatings . . 33
IV-5.4.3 Below Grade Metals and Coatings . . 35
IV-5.4.4 Transit Vehicles 40
IV-5.4.5 Design and Mechanical Requirements . . 41

Appendix A Revisions And/Or Additions To SCRTD Guide Specifications

- I. Concrete A-1
- II. Piping and Conduits A-3
- II.1 Pressure Piping A-3
- II.2 Gravity Flow Piping A-4
- II.3 Electrical Conduits A-5

Appendix B Standard Corrosion Control Specifications

- Part 1. General B-1
- Part 2. Products and Materials . . . B-1
- Part 3. Execution B-10

Appendix C-1 Fiberglass Reinforced Plastic (FRP) Casing - Elevators
Part 1. General C-1
Part 2. Products C-1
Part 3. Execution C-2

Appendix C-2 Elevator Cathodic Protection System

Part 1. General C-1
Part 2. Products C-1
Part 3. Execution C-2

Appendix D Specifications for Direct Fixation Insulating Rail Fastener

Part 1. General D-1
Part 2. Materials D-1
Part 3. Anchorage Assembly D-5
Part 4. Electrical Tests D-7

IV-5.1* General

This section describes design criteria for the control of external corrosion for the facilities and structures included in the SCRTD Metro Rail Project. Corrosion control criteria have been established to reduce, or eliminate, material degradation and deterioration to such a degree that the following objectives will be realized.

A. To realize the design life of SCRTD Metro Rail facilities by avoiding premature failure caused by corrosion.

B. To minimize annual operating and maintenance costs associated with material deterioration.

C. To ensure continuity and safety of operations by reducing or eliminating corrosion caused failures of SCRTD Metro Rail facilities and subsystems.

D. To minimize detrimental effects to SCRTD facilities, and to facilities belonging to others, caused by stray earth currents generated by operation of a DC powered rail return transit system.

IV-5.1.1 Scope

Corrosion control design will include specific requirements for each of the following major categories:

A. Stray current corrosion control.

B. Underground (or soil) corrosion control.

C. Atmospheric corrosion control.

Certain SCRTD facilities may require design features from one or more of these categories to achieve maximum service life.

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* This numbering system has been used throughout this Task in order to conform with the SCRTD design criteria numbering system, Volume IV, Section 5.

IV-5.1.2 Applicable Documents

The need for corrosion control, and corrosion control system design shall conform to the SCRTD corrosion control reports listed below, wherever applicable.

A. Soil Corrosion Study - SCRTD Metro Rail Project (WBS 12AAH, Task 4)

B. Analysis of Stray Earth Currents for SCRTD Metro Rail Project (WBS 12AAH, Task 5)

C. Atmospheric Corrosion - SCRTD Metro Rail Project (WBS 12AAH, Task 6)

D. Stray Current Control Recommendations - SCRTD Metro Rail Project (WBS 12AAH, Task 7)

E. Codes, Regulations and Industry Practices - SCRTD Metro Rail Project, Corrosion Control (WBS 12AAH, Task 2)

Corrosion control design shall conform to the following regulations, codes and laws as well as all applicable local or city laws, codes or statutes.

A. U.S. Department of Transportation, Regulations for the Transportation of Natural (or other) Gas by Pipeline, Parts 191 and 192, Title 49

B. U.S. Department of Transportation, Regulations for the Transportation of Liquids by Pipeline, Part 195, Title 49

C. Uniform Fire Code

D. National Fire Protection Association, Flammable and Combustible Liquids Code

E. California Pipeline Safety Act of 1981, Assembly Bill 911

The following standards, recommended practices, guidelines and specifications are referenced in this document and in the previous SCRTD reports referenced above. Adherence to these publications is required to the extent indicated by the reference thereto.

American Association of State Highway and Transportation Officials:

AASHTO M224-68 (R-1974)	Protective Coatings for Portland Cement

AASHTO M190-78	Bituminous-Coated Corrugated Metal Culvert Pipe and Pipe Arches
AASHTO M218-77	Zinc-Coated (Galvanized) Iron or Steel Sheets for Culverts and Underdrains
AASHTO M263-77	Cast Iron Soil Pipe and Fittings

American Society for Testing and Materials (ASTM):

ASTM A36-81a	Structural Steel
ASTM A53-81a	Pipe, Steel Black and Hot-Dipped, Zinc Coated Welded and Seamless
ASTM A74-81	Cast Iron Soil Pipe and Fittings
ASTM A90-81	Weight of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles
ASTM A135-79	Electric-Resistance-Welded Steel Pipe
ASTM B-3-74 (1980)	Soft or Annealed Copper Wire
ASTM B418-80	Cast and Wrought Galvanic Zinc Anodes For Use in Saline Electrolytes
ASTM C150-81	Portland Cement
ASTM D229-77	Rigid Sheet and Plate Materials Used for Electrical Insulation
ASTM D257-78	Resistance or Conductance of Insulating Materials
ASTM D518-61 (R-1974)	Rubber Deterioration-Surface Cracking
ASTM D570-81	Water Absorption of Plastics
ASTM D638-82	Tensile Properties of Plastic
ASTM D789-81	Nylon Injection Molding and Extrusion Materials

ASTM D1149-81	Rubber Deterioration-Surface Ozone Cracking in a Chamber
ASTM D1248-81a	Polyethylene Plastic Molding and Extrusion Materials
ASTM D2240-81	Rubber Property-Durometer Hardness
ASTM D2897-81	Reinforced and Filled Nylon Injection Molding and Extrusion Materials
ASTM D2992-71(R-1977)	Hydrostatic Design Basis for Reinforced Thermosetting Resin Pipe and Fittings
ASTM D2996-81	Filament-Wound Reinforced Thermosetting Resin Pipe
ASTM D3963-81	Epoxy-Coated Reinforcing Steel
ASTM E-11-81	Wire-Cloth Sieves for Testing Purposes

American Water Works Association (AWWA):

AWWA 203-78	Coal-Tar Protective Coatings and Linings for Steel Water Pipelines - Enamel and Tape-Hot Applied
AWWA C-900-81	Polyvinyl Chloride (PVC) Pressure Pipe, 4 Inches Through 12 Inches for Water

Department of Defense (DOD):

DOD-P-23236A (SH),	Paint Coating Systems, Steel Ship Tank, Type 1 (1979) Fuel and Salt Water Ballast

National Association of Corrosion Engineers (NACE):

NACE RP-01-69 (R-1983)	Control of External Corrosion on Underground or Submerged Metallic Piping Systems
NACE RP-02-74	High Voltage Electrical Inspection of Pipeline Coatings Prior to Installation

National Electrical Manufacturers Association (NEMA):

MR20-1958 (R-1976)	Semiconductors, Rectifiers, Cathodic Protection Units

Steel Structure Painting Council (SSPC):

SP-1	Solvent Cleaning
SP-5	White Metal Blast Cleaning

IV-5.1.3 System Interfaces

Corrosion control design shall interface with design criteria from the following systems.

Volume II - Civil/Structural

Civil

II-1.7.6	Trackway Drainage
II-1.7.7	Undertrack Structures
II-1.8	Trackwork
II-1.9	Utilities
II-1.10	Drainage

Structural

II-2.4	Underground Structures
II-2.8	Reinforced and Prestressed Concrete
II-2.12	Miscellaneous Structures
II-2.13	Plumbing
II-2.14	Drainage
II-2.15	Fire Protection

Yard

II-3.7	Yard Facilities
II-3.10	Shops
II-3.12	Test Track

Volume III - Stations

III-10	Heating, Ventilation and Air Conditioning
III-13	Materials/Finishes
III-14	Power
III-15.7	Drainage
III-20	Train Control

Volume IV - Mechanical/Electrical

HVAC

IV-1.11	Chilled, Condenser and Hot Water Distribution Piping
IV-1.17	Corrosion Control (subject to review)

Plumbing

IV-2	Plumbing (entire section)

Auxiliary Electrical Systems

IV-4.13	Materials
IV-4.19	Grounding
IV-4.22	Corrosion Control (subject to review)

Elevators/Escalators

IV-6.5	Elevator Criteria

Miscellaneous

IV-8 Miscellaneous Mechanical/Electrical Subsystems

Volume V - Subsystems

Passenger Vehicle

V-1.4	General Design Criteria
V-1.5	General
V-1.6	Trucks and Suspension (under frame)

Automatic Train Control

V-2.3	Functional Requirements
V-2.4	General Design Criteria
V-2.6	Wayside Apparatus
V-2.9	Yard ATC Apparatus
V-2.10	Test Track ATC Apparatus
V-2.11	Maintenance and Test Provisions

Traction Power

V-4 Traction Power and Distribution (entire section)

IV-5.2 Stray Current Corrosion Control

IV-5.2.1 General

The concept of stray current control is to control (reduce or limit) the level of stray earth currents at the source (transit system), rather than trying to mitigate the effects of uncontrolled stray earth currents on SCRTD facilities and other underground structures. All systems and subsystems (principally traction power and distribution) shall be constructed to meet the following general criteria.

- Maximum stray earth current generated by normal system operations of 0.10 ampere per 1,000 feet of system.
- An electrically ungrounded system, with no direct or indirect connections to earth, relative to the positive and negative power distribution circuits.

IV-5.2.2 Traction Power and Distribution (Mainline)

Traction power and distribution circuits shall be designed to meet the following stray current control criteria for each of the major subsystems indicated.

IV-5.2.2.1 Substations

A. The transit system shall have sufficient traction power substations, spaced at proper intervals, to maintain track-to-earth potentials at levels which will be safe for both workmen and patrons, and will not create unreasonable requirements for stray current control. Normal system operations shall result in track-to-earth potentials within the range of -80 to +80 volts.

B. Traction power substations must not be used to provide power to both the Metro Rail line and surface streetcar (LRV) lines should they be constructed in the future. Connections between power systems for these different type transit systems are not permitted, except possibly under emergency conditions and only when the positive circuit between substations is connected as a temporary measure.

C. An allocated wall space shall be provided within substations, in close proximity to the negative bus or an extension thereof, for future stray current test facilities. An open conduit shall be provided between the dedicated wall space and negative bus if required.

D. Electrical access shall be provided to the negative bus for future stray current testing by the utility operators. Access shall be made available through ground level facilities, with appropriate conduits routed to the negative bus for future test wire installation.

IV-5.2.2.2 Positive Distribution System

A. The positive distribution system shall have a minimum in-service resistance-to-earth of 10 million ohms per 1,000 feet of contact rail. Individual contact rail insulators shall have an in-service resistance in excess of 1,000 megohms.

B. The positive distribution system shall be operated as an electrically continuous bus with no breaks, except possibly for emergency or fault conditions. (This does not apply to the intentional electrical segregation of yard and mainline traction power distribution systems; see 5.2.3).

C. Contact rail support pedestal reinforcing steel shall be electrically connected to contact rail support anchor bolts and to invert reinforcing steel to ensure a metallic path for possible low level leakage currents.

D. There shall be a coating or gasket installed between the contact rail metallic support plates and the surface of the concrete support pedestals to prevent the direct interchange of leakage current between the support plate and the concrete.

IV-5.2.2.3 Negative Distribution System

A. The negative power distribution system (principally running rails) must be insulated from earth with no direct metallic connections to ground or other structures which are not insulated from earth and/or which could be damaged from stray current corrosion.

B. The negative distribution system shall have a reasonably maintainable, minimum in-service resistance-to-earth of 1,500 ohms per 1,000 feet of track (2 rails). Assembled rail fixation or fastening devices, complete with grout pad, shall have a minimum resistance of 10 megohms dry and 400,000 ohms after one hour exposure to a fine mist spray with a delivery rate of 1-inch of water per hour.

C. Negative system-to-earth resistance shall be uniformly distributed over all mainline track such that any definable section does not have a resistance value less than 90% of the minimum value of 1,500 ohms per 1,000 feet of track (2 rails).

D. Ancillary systems, train control devices, communication devices, or other facilities that are connected to the negative system shall have a composite effect resulting in no more than a 2% reduction of the stated minimum criteria value for negative system resistance.

E. Inbound and outbound tracks shall be crossbonded at all traction power substations and passenger stations. The final arrangement shall result in crossbonds within 500 feet of station platforms and an approximate average maximum spacing of one mile. (These criteria are the minimum for stray current control only; additional crossbonding may be required for traction power efficiency considerations, additional cross-bonding will not adversely affect the stray current control provisions).

IV-5.2.3 Vehicle Storage and Maintenance Facilities

IV-5.2.3.1 Yard

A. The yard positive and negative power distribution networks shall be electrically isolated from the mainline traction power system at the yard/mainline train control interface, or other suitable location.

B. The separate transformer rectifier unit, electrically isolated from the mainline traction power system required for the yard, must include provisions for emergency interconnection to the mainline power system.

C. Yard traction power substation shall include provisions for stray current drainage of both yard and outside structures. Minimum provisions are to include:

- Dedicated wall space in close proximity to the negative bus, with internal conduit routing to the bus.

- Access to the dedicated wall space from one of more conduits terminated outside the yard substation area, with manhole access, near structures that may require drainage.

D. Yard track shall be designed and constructed to insure a reasonable level of insulation from earth without the need for special insulating rail fastening devices. Yard track shall meet the following minimum criteria.

- No intentional connections from track, or other parts of the negative system, to ground or to other low earth resistance facilities.
- Electrical insulation of all interconnects to existing railroad track.
- Use of high resistivity, well drained ballast material to reduce the build-up of moisture around the ties.
- A minimum of 1-inch clearance between the ballast material and all metallic surfaces (top, bottom and sides) of the rail and of those metallic track components in electrical contact with the rail; i.e. tie plates, spikes, anchors, switch machine components, cable clamps, train control bonds, power bonds, etc.

E. Cross-bonding of the negative power rail within the yard shall be done to maximize the conductance of the negative return and thus minimize the track-to-earth potential produced by operations within the yard.

- All dead-ended tracks shall have the negative power rail crossbonded to other tracks within ten feet of the end of the track.
- The negative feeder cables shall have appropriately insulated sheaths and be installed in non-metallic ducts (except for risers).
- Crossbonding/negative feeder cables shall have a main cable run (possibly several cables) with taps to power rail(s) as opposed to long individual cables connected to a single rail.

IV-5.2.3.2 Maintenance Shop

A. Shop traction power shall be provided by a separate dedicated DC power supply electrically segregated in both the positive and negative circuits from the yard traction power system.

B. Shop track shall be electrically grounded to the shop building and shop grounding system to reduce potentials between the track and building components for safety considerations. All such grounded track shall be electrically insulated from yard track just off the shop building apron by the use of rail insulating joints (IJ's). Actual locations of IJ's must be interfaced with shop traction power distribution and with vehicle operations within the shop area. This is required to ensure that parked vehicles will not electrically short the shop to the yard for periods of time greater than the maximum required to move a vehicle in or out of the shop.

IV-5.2.4 Tunnel and Trackway Support Structures

IV-5.2.4.1 General

Stray current control criteria for tunnel and trackway support facilities require a minimum negative system-to-earth resistance of 1,500 ohms per 1,000 feet of track. As such, failure to meet criteria established in 5.2.1 through 5.2.3 will invalidate the criteria in this section and could lead to extensive stray current problems on tunnel structures and foreign utilities.

IV-5.2.4.2 Tunnel

A. Tunnel construction shall result in the following maximum water infiltration and accumulation:

- Water infiltration shall not be from above the spring line and shall not drop onto or run directly onto the rails and/or rail appurtenances. (Rails refers to both the contact rail and the running rails). In those areas where, because of special sealing problems, this criteria cannot be met, it will be necessary to provide special provisions for application of protective coating to the rails and appurtenances, other than the wheel or shoe contact areas.

- Water accumulation shall be limited, through proper drainage, such that it does not attain a level higher than 1-inch below the top surface of the rail fastener grout pad or other support device. (Note: It is not intended that this should be a common occurrence but only an occasional possibility).

- Water infiltration shall be limited to a level which will result in a maximum humidity within the tunnel of 60% during normal revenue operations.

- Special precaution must be taken to ensure that those appurtenances (switch operating rods, power cable clamps, etc.) which extend beneath the bottom rail flange do not contact water or other conductive materials which may accumulate on the tunnel invert.

B. Given the fact that rail-to-earth resistance is maintained at 1,500 ohm/1,000', there are no special or minimum stray current control criteria for precast concrete segmented rings, steel tunnel liners, concrete track inverts, or passenger stations except as required for testing and monitoring (see 5.2.6).

IV-5.2.4.3 Track Support Facilities

A. Grout pads for rail fastener support and leveling shall be constructed of epoxy or polymer modified concrete having a maximum water absorption of 2.0% by weight as determined by ASTM-C-140.

B. Top surface of grout pads shall have an elevation above the surface of the invert that will limit water accumulation to a maximum height of 1-inch below the top of the pad. (It must be noted that although this situation is acceptable on a limited basis, the water drainage system within the subway should not be designed for this level of water as a normal situation).

C. Drainage channels shall be constructed through grout pads, when pads are constructed of such a length that they will support several rail fasteners.

IV-5.2.5 Utility Structures

IV-5.2.5.1 SCRTD Facilities - Mainline

A. There are no special stray current control criteria for metallic pressure or non-pressure piping exposed within the tunnel structure or embedded in the invert.

B. All metallic pressure piping that penetrates the tunnel or station walls to connect to outside buried piping shall be electrically insulated from the outside piping and from the watertight wall sleeve. Electrical insulation of interior piping from outside piping shall be made just inside the tunnel or station wall through the use of an appropriate insulating fitting (see 5.3.6.2 for criteria regarding these fittings and devices).

C. All metallic non-pressure piping that passes through a concrete/soil interface shall be coated for a distance of 6-inches on each side of the interface. Coating shall be a bituminous mastic meeting criteria set forth in 5.3.6.5.

D. All underground buried metallic piping systems outside of the transit structure shall be made electrically continuous by installing AWG #4, 7 stranded copper wires across all mechanical joints. Wires are to be exothermically welded to the pipe in accordance with the following:

Pipe Diameter (D in inches)	No. of Wires per Mechanical Joint
12 or less	2
16 or greater	3

E. All electrically continuous piping shall have permanent test stations installed. Test stations shall consist of two AWG #8 stranded copper wires exothermically welded to the pipe and a third wire welded to a 6-inch length of #6 reinforcing steel (electrode) positioned 12-inches below the pipe. All wires are to be housed in an accessible test box or handhole. Test stations shall be installed at the following locations and noted on as-built drawings:

- At each tie-in to the existing outside utility facility.
- At 150 foot intervals along the piping.
- At each point of exit from the tunnel or station structure.

F. The installation of buried pipes at other than normal utility depths should be avoided. Piping entering a station should penetrate the structure/earth wall at normal utility depths and then proceed within the structure to the depth required through vent shafts, utility chases or other vertical passageways.

IV-5.2.5.2 SCRTD Facilities - Yard

A. All underground pressure and non-pressure piping and conduits installed within the yard area shall be non-metallic if mechanically acceptable.

B. All underground metallic pressure piping (if used) within the yard area shall meet the criteria listed below to reduce the effect of stray earth currents caused by yard operations and to allow for mitigation of any stray current effects that may occur.

- Electrical continuity by installing AWG #4, 7 stranded copper wires across all mechanical joints and couplings. Criteria for continuity shall be the same as that set forth in 5.2.5.1.D.
- Electrical insulation from interconnecting piping and other structures, including metallic casings that may be used when the pipe crosses under tracks. Insulation shall be achieved through the use of an appropriate insulating fitting (see 5.3.6.2 for criteria regarding these devices). Electrical segregation of the pipe into discrete insulated sections may be required to facilitate stray current control. Electrical segregation will be achieved through the use of appropriate insulating couplings (see 5.3.6.2). The need for electrical

segregation will be determined on an individual structure basis by corrosion engineers at early review of yard plans.

- Application of a protective coating with a minimum in-service resistivity of 10^{10} ohm-centimeters to all external surfaces that will contact soils (see 5.3.6.5 for criteria regarding pipeline coatings).

- Provisions for stray current drainage consisting of an AWG #4/0 cable(s) housed in conduit(s) routed from the piping to the drainage area in the yard traction power substation. (Specific routing(s) and point(s) of attachment to the piping to be determined during design.)

- Installation of test stations at all insulated connections and at 150 foot intervals along the pipe. Test stations shall be as described in 5.3.3.1.A.

C. All metallic fencing surrounding the yard perimeter shall be made electrically continuous.

IV-5.2.5.3 SCRTD Facilities Shop

A. All steel reinforcing, structural steel members and rails within the shop building shall be electrically connected to each other through a common grounding grid. Criteria to be used for the number of connections, size of wires used and grounding grid configurations shall include the following.

- A sufficiently low impedance that ground faults or normal operations do not build up voltages in excess of limits established for equipment and personnel.

B. All metallic pressure piping within the shop building or perimeter of the shop steel reinforcing grid shall include the following.

- Electrical insulation from interconnecting pressure piping located outside the shop building (or perimeter of reinforcing grid) through use of an appropriate insulating fitting located just inside the building (see 5.3.6.2 for criteria regarding these devices).

- Electrical insulation from watertight wall sleeves, when used, through the use of appropriate concentric support insulating devices (see 5.3.6.2 for criteria regarding these devices).

- Electrical connection to the building grounding network (5.2.5.3.A) at sufficient locations, using copper wires of sufficient size such that there will be no more than a negligible potential difference between the piping and grounding network during fault or normal operating conditions.

C. All metallic non-pressure piping (drain lines) and electrical conduits within the shop building or perimeter of the shop steel reinforcing grid shall include the following.

- Application of a bituminous mastic coating to the external surface of pipe or conduit where it passes through a concrete/soil interface. Coating shall be applied for a distance of 6-inches on each side of the interface (see 5.3.6.5 for criteria regarding coating).

- Electrical connection to the building grounding network (5.2.5.3.A) at sufficient locations using copper wires of sufficient size such that there will negligible potential difference between the piping or conduit and the grounding network during fault conditions or normal operations.

IV-5.2.5.4 Facilities of Other Than SCRTD Ownership

A. Non-SCRTD owned facilities along the mainline portion of the system do not have any stray current control requirements except as may be established by individual owners/operators.

B. All non-SCRTD owned facilities adjacent to the yard area must be reviewed to determine the need for test facilities and possible stray current corrosion mitigation.

IV-5.2.6 Testing and Monitoring

IV-5.2.6.1 General

Facilities to allow for electrical measurements, test procedures, acceptance criteria and other pertinent provisions, must be included with design to ensure, check and evaluate the stray current control measures at the time of construction and at the time of the start of revenue operations. Facilities must also be included to monitor conditions in the future to ensure the proper level of stray current control is maintained, and detect those conditions which require further investigation.

IV-5.2.6.2 Traction Power and Distribution

A. Permanent test/measuring facilities shall be installed on each track at all traction power substation locations to allow for the periodic measurement of negative system-to-earth resistance characteristics. Test facilities are to consist of the following:

- A pair of insulated (600 volt, Type THW) AWG #8, 7 stranded copper wires exothermically welded to the adjacent rails from each track at each TPSS. Individual wires from a pair are to be spaced 250 feet (±1 foot) apart.

- Test wire pairs shall not span any electrical or mechanical device installed between rails of one track or between tracks, such as impedance bonds, rail insulating joints or other train control devices.

- Test wire pairs from each track must be installed on the outbound side of the crossbond between tracks and/or connection to the negative bus of traction power substations.

- A single AWG #8 insulated 7 strand copper wire shall be attached to a low resistance ground (such as invert reinforcing steel or a driven ground rod) at the midpoint between individual wires of a test wire pair.

- All five wires (two test pairs and one ground wire) must be housed in non-metallic conduit(s), embedded in the invert, routed to, and terminating in a suitable metallic test box accessible from the trackway.

B. Permanent test/measuring facilities shall be installed at the interface between mainline track and yard track, or at another suitable location. Test facilities are to consist of the following:

- A permanently installed stepped DC voltage source (10 to 150 volts) with a current rating up to 100 amperes and provisions for unattended interruption on a selectable cyclical basis. Source must be stable, with variations no greater than ±.5%.

- Test voltage source must include suitable voltmeter, ammeter, wiring and other facilities to allow for connection between the mainline track (positive side of source) and a suitable earth contact (negative side of source) such as yard track (preferred earth contact).

C. Permanent potential monitor recorders shall be installed at a minimum of seven locations to monitor and record negative system-to-earth potentials caused by operations. Suggested locations for monitor recorders are:

Union Station TPSS

5th and Hill Passenger Station

Wilshire and Normandie Passenger Station

Wilshire and La Brea TPSS

Fairfax and Santa Monica TPSS

Intermediate TPSS at Approximate Station 875+00

Lankershim (North Hollywood) TPSS

- Recording DC voltmeters are to be single channel potentiometric servo motor operated with a fixed span of ±100 volts (center zero). Response time shall be .5 second full scale. Chart drive to be .5-inch per hour with a minimum of four faster speeds selectable up to a maximum rate of 1-inch per minute.

D. Facilities shall be installed at each traction power substation to automatically ground the negative system during the occurrence of unsafe DC potentials created by a positive system-to-earth fault. The facilities must be capable of automatically removing the ground connection upon removal of the cause of the excessive potential. Automatic grounding facilities shall not activate when negative system potentials are less than 80 volts to earth. The automatic grounding facilities shall operate in accordance with the following criteria.

Negative System Potential-to-Earth (E_N)*	Operating Criteria
-75 E_N	No grounding - system isolated from earth
-80 E_N -75 volts (for t 5 seconds) . .	No grounding - local and remote annunciation of condition
E_N -80 volts . . .	System grounded to reduce E_N potential. Additional action dependent upon magnitude of fault current.

* Polarity indicated is with positive of voltmeter connected to negative system.

IV-5.2.6.3 Tunnel and Trackway Support Structures

A. Permanent test facilities for stray current monitoring shall be installed on steel tunnel liners with a length in excess of 2,000 feet. Test facilities shall consist of a pair of AWG #8 insulated copper wires exothermically welded to the liner with individual wires from a pair spaced at 300 feet. Wire pairs shall be installed 1,000 feet from the end of the steel liner and at 2,000 foot intervals thereafter. Test wires shall be accessible from the safety walkway within the tunnel, and housed in a permanently mounted metallic test box.

B. Permanent test reference electrodes for stray current monitoring shall be installed through the wall of each tunnel at 1,000 foot intervals (exclusive of station structures) in the wall most removed from the adjacent tunnel. The reference electrode shall be at an elevation below the top of the invert and extend through the wall terminating one foot outside the tunnel with a minimum of 4-inches of bare metal in contact with the earth outside the tunnel. All portions of the electrode shall be electrically insulated from the tunnel structure. Permanent test wires shall be attached to the electrodes and a segment of steel reinforcing within the precast segment ring, or steel liner if present. Test wires shall be housed in a suitable test box accessible from the safety walkway within the tunnel.

IV-5.3 Corrosion Control for Buried Structures

IV-5.3.1 General

Corrosion control criteria for below grade, buried facilities is dependent upon the following:

- Material of construction (use of aluminum or aluminum alloys for direct burial shall not be permitted).
- Location within transit route.
- Accessibility of the structure after installation.
- Maintenance requirements.

Criteria have been established for concrete and metallic facilities anticipated to be included in the Metro Rail Project and are directed primarily towards reducing or eliminating corrosion caused by acidic and high chloride and sulfate concentration waters and soils. Individual facilities must be reviewed to determine the need for, and extent of possible additional requirements, not established by these criteria.

IV-5.3.2 Concrete and Reinforced Concrete Structures

IV-5.3.2.1 Precast Segmented Liner Panels

Concrete used for this item shall include the following to provide protection against corrosive ground waters and soils.

A. Sulfate resistant Type V Portland cement.

B. Maximum water/cement ratio of .37 by weight in conjunction with the use of an air entrainment admixture resulting in a maximum air content of 6% by volume to establish a low permeability concrete to prevent absorption of ground waters high in chloride concentrations. Final mix parameters must be reviewed to insure required concrete strengths are achieved (reference ACI 211.1).

C. Maximum of 200 ppm chloride concentration in mixing water. If admixtures or aggregates containing chlorides are used, the total concentration of chlorides in water, admixture and aggregates shall be determined and submitted for District approval prior to use.

D. Application of a coal-tar epoxy protective coating, with a minimum resistivity of 10^{10} ohm-centimeters, to the external surfaces. Coating shall be applied in strict accordance with the manufacturers recommended practices but shall have not less than 10 mils dry film thickness per coat, with a minimum of two coats required. Coating to withstand exposure to a pH of 3 to 10 and anticipated construction handling such that no more than 5% of the surface area per panel requires repair. Other materials may be used provided they have a performance record equal to or surpassing that of coal-tar epoxies for the intended use.

E. Minimum 2-inches concrete cover over steel reinforcing on the external surface of the panel.

IV-5.3.2.2 Cast-In-Place Concrete/Reinforced Concrete

Concrete used for structures that will contact soils (i.e. outside station walls, vent shafts or similar structures) shall include the following to provide protection against corrosive ground waters and soils.

A. Sulfate resistant Type V Portland cement for all structures south and east of Wilshire and Fairfax passenger station, inclusive.

B. Sulfate resistant Type II Portland cement for all structures north and west of Wilshire and Fairfax passenger station.

C. Maximum water/cement ratio of .40 by weight in conjunction with the use of an air entrainment admixture resulting in a maximum air content of 5.5% (max. aggregate size of 1.5-inches) by volume to establish a low permeability concrete. Final mix parameters must be reviewed to insure required concrete strengths are achieved (reference ACI 211.1).

D. Maximum 200 ppm chloride concentration in mixing water. If admixtures or aggregates containing chlorides are used, the total concentration of chlorides in water, admixture and aggregates shall be determined and submitted for District approval prior to use.

E. Minimum 2-inches concrete cover on the soil side of all steel reinforcement when the concrete is poured within a form or a minimum 3-inches cover when the concrete is poured directly against soils.

F. Application of a protective coating to the exterior surfaces (soil contacting surfaces) south and east of Wilshire and Fairfax passenger stations and other areas where soils and/or ground waters have a pH less than or equal to 5.0 or a chloride concentration greater than or equal to 350 ppm. Need for coating shall be determined by testing for these parameters or as indicated in the Soil Corrosion Study Report (see IV-5.1.2. Applicable Documents).

G. Protective coatings used for protection of concrete from soil corrosion shall be either coal-tar epoxy or other material with an equivalent performance record for the intended service and pH conditions noted. Coating shall be applied in strict accordance with the manufacturers recommended practices but shall have not less than 10 mils dry film thickness per coat, with a minimum of two coats required.

IV-5.3.2.3 Concrete/Reinforced Concrete Not in Contact With Soils

The only corrosion control criteria for concrete that does not come into contact with soils or ground waters is a maximum of 200 ppm chloride concentration in mixing water. Items in this category would include precast tunnel invert, grout between steel liners and precast panels, interior station walls and other similar structures. If admixtures or aggregates containing chlorides are used, the total concentration of chlorides in water, admixture and aggregates shall be determined and submitted for District approval prior to use.

IV-5.3.3 Piping and Conduits

IV-5.3.3.1 Pressure Piping

A. All underground, buried cast iron, ductile iron and steel pressure piping shall meet the following minimum criteria.

   - External surfaces to have a protective coating with a minimum in-service resistivity 10^{10} ohm-cm. Thickness of coating shall be determined by the recommended practices of the coating manufacturer and experience with the coating system to the degree that additional thickness, beyond what is normally employed may be required. The final thickness will be strictly dependent upon the specific coating used (see 5.3.6.5).

   - Electrical insulation from interconnecting piping and other structures through use of non-metallic pipe inserts, insulating flanges, couplings, or unions (see 5.3.6.2).

   - Electrical continuity through the installation of insulated copper wires across all mechanical joints (except those intended to be insulators) for which electrical continuity cannot be assured (see 5.3.6.1).

- Electrical access to piping through test stations installed at all insulated connections and along the piping at 150 foot intervals. Test stations to consist of two AWG #8 insulated stranded copper wires exothermically welded to the pipe and a separate AWG #8 insulated stranded copper wire welded or brazed to a 6-inch length of #6 reinforcing steel located 12-inches below the pipe. All three wires are to be housed in a permanent accessible at-grade metallic box or handhole. An additional pair of AWG #8 wires shall be attached to the existing piping at all insulated connections.

- Cathodic protection of the piping through either impressed current or sacrificial anode systems (see 5.3.6.3 and 5.3.6.4).

B. Copper Pipe

Buried copper piping shall have an insulating union installed just inside the station or structure wall. Additional corrosion control criteria must be determined for each installation on an individual basis taking into account local soil characteristics and the piping to which the copper connects. Design of corrosion control systems shall be accomplished on an individual installation basis.

C. Reinforced/Prestressed Concrete Pipe

Criteria for this general category of pipe shall be:

- A protective coal-tar coating applied to the exterior surfaces to provide an electrical and waterproof barrier between the soil and pipe. Minimum in-service resistivity of the coating to be 10^{10} ohm-centimeters. Coating shall be applied in accordance with manufacturers recommended practices, but shall have not less than 10 mils dry film thickness per coat with a minimum of two coats required. Other coatings with an equivalent performance record for the intended service are acceptable.

- Water/cement ratios of .30 by weight for the core concrete and .25 for the outer mortar coating to establish a low permeability concrete. These values represent the preferred levels for water cement ratios, however, industry practices may result in significant increases and wide variations to these levels. A maximum water/cement ratio of .6 by weight in accordance with AWWA C-300-82 will not be permitted.

- Maximum of 200 ppm chloride concentration in mixing water for concrete used in core fabrication and outer mortar coating.

- Use of sulfate resistant cement as follows: Type II for soil sulfate concentrations less than or equal to 2,000 ppm or ground water concentrations less than or equal to 1,000 ppm. Type V for soil sulfate concentrations greater than 2,000 ppm or ground water concentrations greater than 1,000 ppm. Sulfate concentrations shall be determined through actual testing of the local soils and/or ground waters at the proposed pipe locations, or as set forth in Geotechnical Consultant reports or the Soil Corrosion Study Report (WBS 12AAH Task 4).

IV-5.3.3.2 Gravity Flow Piping (Non-Pressured)

Gravity fed piping for water drainage systems should be non-metallic if mechanical considerations and soil conditions are suitable. If metallic piping is used it shall meet the following criteria.

A. Corrugated Steel

- Galvanizing, both interior and exterior, to a combined minimum thickness of 2.0 oz. per square foot of coated surface (interior and exterior).

- Protective coating, with a minimum resistivity of 10^{10} ohm-centimeters on both the internal and external surfaces. Coating to be a hot-applied asphalt based material with a minimum dry film thickness of 50 mils and an established performance record for the intended service. Polymeric coatings, such as PVC, if used must be applied to a minimum dry film thickness of 10 mils.

B. Cast Iron and Ductile Iron

All piping in this category shall have an internal mortar lining and an application of bituminous seal coating to both the internal mortar lining and external surfaces. All piping directly buried in soils shall have an additional application of protective coating to the external surfaces. This coating shall consist of a cold-applied polyethylene backed mastic tape (minimum 45 mils total thickness) requiring a primer for application or polyethylene encasement conforming to AWWA Standard C105. Tape system shall have an established performance record for the intended service.

C. Reinforced Concrete Pipe

- Water/cement ratios of .30 by weight for the core concrete and .25 for the outer mortar coating to establish a low permeability concrete. These values represent the preferred levels for water cement ratios, however, industry practices may result in significant increases and wide variations to these levels. A maximum water/cement ratio of .6 by weight in accordance with AWWA C-300-82 will not be permitted.

- Maximum of 200 ppm chloride concentration in mixing water for concrete used in core fabrication and outer mortar coating.

- Use of sulfate resistant cement as follows: Type II for soil sulfate concentrations less than or equal to 2,000 ppm or ground water concentrations less than or equal to 1,000 ppm. Type V for soil sulfate concentrations greater than 2,000 ppm or ground water concentrations greater than 1,000 ppm. Sulfate concentrations shall be determined through actual testing of the local soils and/or ground water at the proposed pipe locations, or as set forth in Geotechnical Consultant reports or the Soil Corrosion Study Report (WBS 12AAH Task 4).

- Application of a bituminous seal coating to the internal and external surfaces of all pipe in this category. Seal coat to have an established performance record for the intended service.

IV-5.3.3.3 Electrical Conduits

Electrical conduits for below grade (buried) use shall be non-metallic (PVC, fiberglass, or similar material) if possible. If metallic conduits must be used, they shall meet the following minimum criteria:

- Galvanized steel with a PVC topcoat (or other acceptable coating) for direct burial, including couplings and fittings.
- Galvanized steel with a minimum of 3-inches concrete cover on soil sides within duct banks.
- Electrical continuity must be assured for all metallic conduits.

IV-5.3.4 Hydraulic Elevator Cylinders

Steel hydraulic elevator cylinders shall meet the following minimum criteria.

- An external protective coal-tar epoxy coating with a minimum in-service resistivity of 10^{10} ohm-centimeters and be resistant to deterioration from petroleum products (hydraulic fluid). Coating shall be applied in strict accordance with manufacturers recommended practices but shall have not less than 10 mils dry film thickness per coat, with two coats required.
- An outer concentric fiberglass reinforced plastic (FRP) casing supplemented with an outer steel casing with the space between casings filled with plaster sand.
- Silica sand fill between the cylinder and FRP casing. Sand fill shall have a minimum resistivity of 25,000 ohm-centimeters (as measured when sand is 100% saturated with distilled water), a pH between 7 and 7.5 and a maximum chloride and sulfate ion concentration less than 100 ppm for each.

- Cathodic protection through the use of sacrificial anodes installed in the sand fill.
- Test facilities on cylinder, anodes and earth reference to permit evaluation and activation of the protection system.

IV-5.3.5 Non-SCRTD Owned Facilities

Corrosion control requirements for underground facilities to be constructed as part of this project and owned/operated by others shall be the responsibility of the individual owners.

IV-5.3.6 Corrosion Control Components and Subsystems

IV-5.3.6.1 Electrical Continuity For Piping

A. Electrical continuity shall be established by exothermically welding two or more AWG #4 insulated, stranded copper wires (maximum of 18-inches in length) between or across the pipe joint or coupling that must be made continuous in accordance with the following criteria.

Pipe Diameter (D in inches)	Number of Bond Wires
12" or less	2
16" or more	3

B. Wires used to provide electrical continuity shall be seven stranded copper 98.9 percent International Annealed Copper Standard conductivity. All wire shall have 600 volt Type THW insulation.

IV-5.3.6.2 Electrical Insulation For Piping

A. Electrical insulation for piping shall be achieved through the use of non-metallic inserts, preassembled insulating flanges, couplings, insulating unions, or concentric support insulating spacers where applicable.

B. Insulating devices shall have a minimum resistance of 10 megohms prior to installation and shall have mechanical specifications equivalent to the structure in which it is installed. Insulating devices shall have sufficient resistance after insertion into the piping such that a maximum of 2% of a test current applied across the device flows through the insulator, including flow through conductive fluids if present.

C. All insulating devices (except complete non-metallic units) shall be coated with coal tar epoxy internally for a distance on each side of the insulator equal to two times the diameter of the pipe in which it is used.

D. All insulating devices (except non-metallic units) buried in soils shall be encased in a hot-applied protective coating (such as asphalt) to provide a minimum coverage of 1-inch around all components. Protective coating to be equal to or superior to coating applied to piping and must be compatible with such coating.

E. All insulating devices installed in chambers or otherwise exposed to partial immersion or high humidity shall have a protective coating applied to a minimum thickness of 10 mils over all components.

IV-5.3.6.3 Cathodic Protection Rectifier Units

A. Units shall consist of a transformer, silicon or selenium full wave bridge rectifier, instrument wiring, terminal board, internal circuit breaker, DC output ammeter and voltmeter suitably mounted in a cabinet or other appropriate enclosure.

B. Units shall be sized for the specific installation, but must meet the following minimum criteria:

- Input voltage 60 Hz, 120/240 volt single phase. Output voltage; rated DC to 10% overload adjustable in a minimum of ten equal steps.

IV-5.3.6.4 Anodes

A. Sacrificial Anodes

- Anodes to consist of a galvanized steel strip core bonded to a magnesium alloy. Core to extend the full length of the anode. Anode to be either ribbon or casting of specified weight and shape. Anodes with prepackaged backfill shall consist of a cloth sack containing a specially prepared backfill mix to provide a stable electrical contact between the anode and the soil. Connecting wires shall be single strand AWG #12 copper, with THW insulation, soldered to the steel core strip and sealed against moisture penetration.

B. Impressed Current Anodes

- Anodes shall be high silicon, chrominum bearing iron with a minimum of 14% silicon and 4% chromium. Anodes shall be tubular with copper wire attached inside the center of the anode using a precast lead connection and encapsulated to prevent moisture penetration. Maximum resistance of anode-to-wire connection shall be .005 ohm. Copper wires used for connection to anodes shall include the following.

- Seven strand copper wire sized as necessary for the specific anode. Copper to be 98.9 percent International Annealed Copper Standard conductivity.

- Wire insulation shall be high molecular weight polyethylene minimum 7/64-inch thick. Halar or kynar insulation may be used where deterioration caused by chlorine generated by the anode operation is possible.

IV-5.3.6.5 Pipeline Coatings

A. Protective coatings for underground corrosion control shall have a minimum resistivity of 10^{10} ohm-centimeters, in service. Coating thickness and application shall be determined by the recommended practices of the coating manufacturer and experience with the coating system to the degree that additional thickness, beyond what is normally employed may be required. The final thickness will be dependent upon the specific coating used.

B. Coatings shall have mechanical characteristics capable of withstanding reasonable abuse during installation and earth stresses after installation for the design life of the piping coated. Coatings shall have an established performance record for the intended service and resistance to deterioration from soils with a pH between 3 to 10 or other contaminants that may be present.

C. Generic coatings suitable for use on pipelines that will be buried are listed below. Thicknesses shown represent minimums, however, manufacturers recommendations must be followed when they will result in a coating thickness greater than those shown.

- <u>Extruded polyethylene/butyl base system</u>
  Butyl rubber, hot applied in two layers, minimum 10 mils dry film thickness per layer.
  Polyethylene applied in a minimum of three layers, minimum dry film thickness of 12 mils per layer.

- <u>Coal-tar enamels (hot applied)</u>

  Minimum thickness of 32 mils per coat with a minimum of three coats required. Coating must be supplemented with a fiberglass wrap to provide mechanical strength. A suitable primer must be applied to all bare metal surfaces to be coated (reference AWWA C-203).

- <u>Coal-tar epoxies (two component systems)</u>

  Minimum 10 mils dry film thickness per coat, with a minimum of two coats required. The need for a primer is dependent upon the specific coating used since some coal-tar epoxies are self-priming.

- <u>Asphalt enamels (hot applied)</u>

  Thickness and other criteria for asphalt enamels shall be the same as that specified for coal-tar enamels.

- <u>Polyethylene backed butyl mastic adhesive tapes (cold applied)</u>

  Minimum 5 mil thick polyethylene backing; minimum 40 mil thick mastic adhesive layer. Tape coating systems must be the type that require the use of a primer for application, either to develop adhesion or as a surface preparation agent. All tape systems must be applied with a 50% overlap.

- Bituminous Mastics

  Minimum dry film thickness of 10 mils per coat with a minimum of two coats required. Preferred application method is through airless spray.

IV-5.3.7 Testing

IV-5.3.7.1 All underground corrosion control designs shall include provisions and facilities for testing to insure compliance with design specifications. Minimum testing criteria shall include:

- Electrical continuity.
- Electrical insulation.
- Coating effectiveness.

IV-5.3.7.2 All underground corrosion control systems shall include operational and activation tests to establish proper and effective functioning.

IV-5.4 Atmospheric Corrosion Control

IV-5.4.1 General

Criteria for atmospheric corrosion control are based on preservation of appearance and reduction of maintenance costs. Separate, but similar criteria are presented for each of three major areas, namely, above grade installations, facilities within the passenger stations and tunnel, and the transit vehicle. General systemwide criteria for all three areas include the following:

- Materials selection; choose materials with established performance records for the service intended and to avoid the occurrence of dissimilar metal couples.
- Sealants; use suitable sealants in crevices and material recesses to prevent the accumulation of moisture.
- Protective Coatings; use either barrier or sacrificial type coatings on most exposed metals to prevent exposure to the atmosphere and in some instances to provide cathodic protection.
- Design; proper design to avoid use of dissimilar metals and the occurrence of recesses or crevices that may trap moisture.

IV-5.4.2 Above Grade Metals and Coatings (those exposed to weather)

IV-5.4.2.1 Steels and Ferrous Alloys

A. Carbon steels, alloy steels, weathering steels, cast or ductile irons exposed to the atmosphere outside the tunnel area shall have a barrier and/or sacrificial type coating applied to all external surfaces.

B. Stainless Steels

Stainless steels used for above grade service shall meet the following minimum criteria.

- Series 200, 300, or chromium-molybdenum ferritic types (e.g. type 444) for exposed surfaces in unsheltered environments and where appearance is critical or a necessary consideration.
- Columbium/titanium stabilized grades, or extra low carbon grades when welding is required.
- Application of a protective coating (barrier type) only when appearance is critical.
- All stainless steel surfaces must be cleaned and passivated after fabrication.
- Restrict the use of ordinary series 400 stainless steels to sheltered areas or where appearance is not critical. (This restriction does not apply to the chromium - molybdenum ferritic types.)

IV-5.4.2.2 Aluminum and Aluminum Alloys

All aluminum and aluminum alloys used for above grade service (not buried) shall have a sealed hard anodized finish to minimize pitting corrosion (Finish A4X).

IV-5.4.2.3 Copper and Copper Alloys

All materials in this category shall have a barrier type coating applied only where the natural patina is not desired or where there will be intermittent contact with acid rain or fog.

IV-5.4.2.4 Magnesium Alloys

All materials in this category shall have a barrier type coating applied when long term appearance is critical.

IV-5.4.2.5 Coatings

Coatings used for above grade service on the metals specified below shall have an established performance record for the intended service and be compatible with the base metal to which they are applied.

A. Coatings for Steel and Ferrous Alloys

Primer and topcoat systems must be compatible and shall be supplied by the same manufacturer.

- Hot dip galvanizing, when used, shall be applied to a weight of 2 oz. per square foot on the exposed surface. Damage to galvanized areas shall be repaired with an inorganic zinc coating or flame sprayed zinc.
- Flame sprayed zinc shall be applied to a minimum thickness of 10 mils. A seal coat of vinyl or epoxy coating is required over flame sprayed zinc.
- Aluminum coatings when applied to steels shall be Type II with a minimum thickness of 2 mils.
- Flame sprayed aluminum, when applied to ferrous alloys shall have a minimum thickness of 10 mils and a top seal coat of vinyl or epoxy.
- Inorganic zinc, as a primer only, shall be applied to a minimum thickness of 2 mils and a maximum of 3 mils. A topcoat must be applied over inorganic zinc primers.
- Vinyls or epoxy topcoats must be applied over inorganic zinc primer, with an additional aliphatic polyurethane topcoat over epoxy where appearance is critical.

- Polyurethane coating shall be applied over an epoxy primer when appearance is critical.

- Fusion bonded epoxy, polyester, polyethylene or nylon can be used on ferrous materials for above grade service.

C. Coatings for Non-Ferrous Metals

Coatings used for non-ferrous metals for above grade service shall consist of compatible primer and topcoat, supplied by the same manufacturer.

- Wash primers shall be used on stainless steels, copper, and copper alloys and magnesium alloys. Aluminum alloys shall be anodized.

- Topcoats shall be applied over compatible primers. Topcoats shall consist of epoxy, where appearance is not critical, or with an additional topcoat of polyurethane for appearance.

- Fusion bonded epoxy, polyester, polyethylene, or nylon can be used and shall be applied by fluidized bed or electrostatic spray methods.

IV-5.4.3 Below Grade Metals and Coatings (Inside Tunnels and Stations)

IV-5.4.3.1 Steels and Ferrous Alloys

A. Carbon steels, alloy steels, weathering steels, cast or ductile irons throughout the tunnel and station areas, including those items which will be exposed to intermittent immersion or contact (splash) with seepage water, shall be coated using a sacrificial primer and heavy build barrier type topcoat (see IV-5.4.3.5.B). Carbon steel tunnel liners shall be coated with an inorganic zinc primer and a coal-tar epoxy topcoat system with an established performance record for the intended service.

B. Stainless Steels

Stainless steels to be used throughout the tunnel and station areas, including those exposed to intermittent contact with seepage waters, shall be the following:

- Series 300 were stains would be objectionable.
- Type 304, 316, 317, 444, Carpenter 20 or higher grade if contact with seepage water is expected.
- Do not coat those surfaces on which continuous contact or complete immersion in seepage water is anticipated.
- All stainless steels used for this service shall meet the criteria of 5.4.2.1.B when welding is required and all stainless shall be cleaned and passivated after fabrication.

IV-5.4.3.2 Aluminum and Aluminum Alloys

A. Anodized aluminum (finish A4X) exposed to seepage water shall have an application of a barrier type coating.

B. Aluminum alloys used in areas where water seepage is likely shall be resistant to acid chloride stress corrosion cracking. Suitable alloys include 2024-T8, 2219-T6, 2219-T8, 6061-T6, 7075-T73, 7075-T736.

IV-5.4.3.3 Copper and Copper Alloys

A. Where these metals will be exposed to seepage waters they shall be coated with a high performance barrier type coating.

B. Where discoloration of these materials would be objectionable, coat exposed areas with a heat cured or thermosetting lacquer.

C. Brass alloys with a zinc content greater than 15 percent shall not be used in areas where they will be exposed to seepage waters.

IV-5.4.3.4 Specific Hardware Items Used Inside Tunnels

A. Steel fastener arrangement used for securing precast tunnel liner panels must be reviewed in detail to determine the need for protective measures or specialized materials. Consideration must be given to the extreme moisture and high humidity that will exist within the tunnel when these items are installed, since such conditions will affect the selection of the specific measures employed, especially with regard to coatings.

B. <u>Electrical Equipment and Enclosures</u> (switch boxes, transformers, connection cabinets and similar facilities)

There are no special or minimum atmospheric corrosion control criteria for these facilities provided they are located in an air-conditioned environment. If such a location is not possible, the following criteria must be established for the conditions indicated.

1) No exposure to seepage waters anticipated.

   - Coat steel or ferrous surfaces with a sacrificial primer and a barrier topcoat .
   - Unsealed cabinets shall be internally heated to prevent condensation.
   - All non-oil immersed internal metallic components shall be coated with a barrier topcoat.
   - Use vapor phase inhibitors on all sealed cabinets and enclosures where the seal can be expected to be maintained.

2) Exposure to seepage waters anticipated.

   - Use non-metallic or stainless steel enclosures and fasteners wherever possible.
   - <u>Do not use</u> standard manufacturers finish or uncoated galvanized steel fittings.
   - Coat steel surfaces with a sacrificial primer and a barrier topcoat.
   - Cabinets shall be internally heated to prevent condensation.

- All non-oil immersed internal metallic components shall be coated with a barrier topcoat.

- Use vapor phase inhibitors on all sealed cabinets and enclosures where the seal can be expected to be maintained.

C. Exposed electrical conduits shall be aluminum with a sealed hard anodized finish (finish to be A4X). Conduits shall have a ¼-inch separation to concrete surfaces. Conduit fastener surfaces contacting concrete surfaces shall have a barrier coating.

D. Miscellaneous metallic items such as fire water piping, light fixtures, railings, fencing, step edges, signal fixtures, duct work, vents and vent shaft equipment shall include the following:

- Steel and ferrous alloys; application of a sacrificial primer and a barrier top coating where the item will be exposed to intermittent contact to seepage water; otherwise hot dip galvanizing or aluminizing of exposed surfaces is the only requirement.

- Aluminum; anodized with an additional application of a urethane or vinyl topcoat where the item will be exposed to intermittent contact to seepage water; otherwise a sealed hard anodized finish is the only requirement.

E. Pumps used for drainage water ejection systems shall have a barrier type coating applied to all exterior steel surfaces. Impellers and internal parts shall have nonmetallic linings suitable for the intended service.

IV-5.4.3.5 Coatings - Below Grade Service (In Tunnels and Stations)

A. General

Coatings for use on metals located in tunnel and station areas shall be either barrier type or sacrificial coatings with established performance records for the intended service. Prolonged exposure or complete immersion will require additional consideration and possibly different coating systems based on separate review of the specific item.

B. Barrier Type Coatings

These coatings shall consist of a primer and suitable topcoat, or a self priming topcoat. Coatings shall meet the following minimum criteria.

Steels (except stainless steels):

- Inorganic zinc primer with a minimum dry film thickness of 2 mils and a maximum of 3 mils and a two coat application of an epoxy topcoat, either coal-tar, polyamide, polyamine, or polyester.
- Where appearance is critical, supplement the above with a topcoat of polyurethane.
- Fusion bonded epoxy, polyester or nylon applied by fluidized bed or electrostatic spray can be used in lieu of the above.
- Cermet (fused aluminum-ceramic) can be used on steel components and fasteners when such facilities are not exposed to water seepage.

Non-ferrous Materials:

- Use a wash primer, epoxy primer and barrier topcoat.
- Aluminum shall be anodized.

C. Sacrificial Type Coatings

These coatings shall consist of a layer of metal applied to steel that will be anodic to the steel under presence of moisture. Coatings in this category shall meet the following minimum criteria.

- Hot-dip galvanizing (zinc) shall be applied to a minimum thickness of 2.0 oz. per square foot.
- Flame spray aluminum or zinc shall be applied to a minimum thickness of 10

mils. Seal this coating with an application of epoxy or vinyl and apply additional epoxy or vinyl intermediate and topcoats.

IV-5.4.4 Transit Vehicles

IV-5.4.4.1 These criteria are directed towards reducing vehicle maintenance and enhancing vehicle appearance by reducing the impact of seepage waters that may contact the vehicles.

IV-5.4.4.2 Outer Shell (Cladding Panels)

Stainless steels, if used, shall be series 200 or 300. Aluminum, if used, shall be series 5000 or 6000, shall be anodized and an application of a clear polyurethane sealer considered.

IV-5.4.4.3 Structure

A. Anodized aluminum and stainless steel structural components not exposed to the weather or seepage waters do not require coating or other minimal corrosion control criteria.

B. Stainless steel shall be Type 304, 316 or equivalent grade while aluminum shall be 5000 or 6000 series and anodized. Anodizing tends to reduce fatigue strength of aluminum and as such must be given consideration during design.

IV-5.4.4.4 Underframe Components

A. Steel shall be coated with an inorganic zinc primer and an epoxy topcoat or flame sprayed aluminum with an epoxy topcoat.

B. Aluminum shall be anodized and coated with an epoxy primer and a suitable topcoat.

IV-5.4.4.5 Fasteners

A. Riveted joints shall have drilled holes and elastic panel seals to prevent fretting.

B. Fasteners shall be aluminum or stainless steel as follows:

Materials to be Joined	Fastener Material Required
Aluminum to Aluminum	Aluminum or Series 300 stainless steel
300 series stainless to 300 series stainless	300 series stainless steel
Aluminum to 300 series stainless steel	300 series stainless steel

IV-5.4.5 Design and Mechanical Requirements

Facilities shall be constructed to eliminate crevices at joints and fasteners. Use a sealant at crevices if design modifications are not feasible. Bimetallic couples are to be avoided through design modification or by use of a dielectric material between dissimilar metals. Acceptable bimetallic couples, subject to engineering review include:

- Aluminum/stainless steel
- Stainless steel/carbon steel
- Aluminum/zinc (galvanizing)

Bimetallic couples that should be avoided through design modification or use of dielectric separators include:

- Aluminum/copper
- Copper/steel

APPENDIX A

Revisions and/or Additional to SCRTD Guide Specifications

The following comments and statements relative to corrosion control requirements for specific items shall be added to the appropriate subsections in the standard specification sections. Since a copy of the proposed specification index was not available, the statements are not keyed to specific specifications but are related to general items and/or categories which must be subsequently assigned to specific subsections. These statements, in some cases, will establish acceptable corrosion control specifications without any additional reference to other sections.

However, in many cases, these statements will indicate only that corrosion control measures are required and should be referred to specific subsections within the proposed Standard Corrosion Control Specification Section. The section designation and format for the Corrosion Control Specification shall be as determined by Southern California Rapid Transit District.

The Corrosion Control Design Criteria are very specific in their reference to measures required for corrosion control associated with the transit system yard installations. The criteria recommend substantial electrical bonding, insulation coating and cathodic protection for soil and stray current corrosion control on underground facilities. No special specifications have been prepared for the yard construction in that the various standard specifications sections together with the proposed Corrosion Control Specification section will provide adequate coverage for items associated with the yard.

I. Concrete

I.1 Concrete shall meet the following minimum standards:

A. Cast-In-Place in Contact With Soils

1) Maximum water/cement ratio .40 by weight.

2) Air entrainment admixture resulting in a maximum air content of 5.5% by volume (max. aggregate size of 1.5-inches).

3) Maximum 200 ppm chloride concentration in mixing water.

B. Precast Segmented Tunnel Liner Panels

1) Maximum water/cement ratio of .37 by weight.

2) Air entrainment admixture resulting in a maximum air content of 6% by volume.

3) Maximum 200 ppm chloride concentration in mixing water.

I.2 Portland cement: ASTM C 150 type as follows:

A. Sulfate resistant Type II - tunnel invert concrete; cement grout between steel tunnel liner and precast concrete tunnel lining segments; cast-in-place structures and shotcrete north and west of Wilshire and Fairfax passenger stations (sulphate resistant Type V may be substituted for Type II at the discretion of the engineer).

B. Sulfate resistant Type V - all tunnel liner segments; cast-in-place concrete in contact with earth south and east of Wilshire and Fairfax passenger stations.

I.3 Concrete Reinforcement

A. Concrete deposited directly against ground shall provide a minimum cover of 3-inches to the steel reinforcing.

B. Formed concrete shall provide a minimum cover of 2-inches to the steel reinforcing.

I.4 Precast Concrete Tunnel Liner Segments

A. Concrete shall be as stated in I.1.b and I.2 above.

B. Concrete shall provide a minimum cover of 2-inches to the segment steel reinforcing on the external side.

C. External surface of segment shall have a coal tar epoxy protective coating, minimum resistivity of 10^{10} ohm-centimeter, to withstand an exposure to pH 3 to 10. The coating shall conform to Department of Defense DOD-P- 23236A(SH) Type I or American Association of State Highway and Transportation Officials (AASHTO M224-68 (1974). Coating shall have not less than 10 mils dry film thickness per coat, with a minimum of two coats. Coating of equal or surpassing qualities may be used.

I.5 Concrete structures in contact with soil (station walls, vent shafts, etc.)

A. Shall meet specifications I.1.A and I.4.C above where soil/ground water has a pH less than 5.0 and/or chloride concentration in excess of 550 ppm. Exterior surface of concrete structure shall have protective coating as in I.4.C above.

8. Shall meet specifications I.1.A and I.2.A above north and west of Wilshire and Fairfax passenger station and I.1.A and I.2.8 for south and east of Fairfax passenger station.

I.6 Concrete structures not in contact with earth and/or ground water shall meet specifications for standard concrete (Type I).

II. <u>Piping and Conduits</u>

II.1 Pressure Piping

II.1.1 Buried cast iron, ductile iron and steel piping

A. External surfaces shall have a protective coating as specified in Section ___ Corrosion Control Specifications 2.5.A-E.

B. All mechanical pipe joints and fittings shall be electrically bonded in accordance with Section ___ Corrosion Control Specifications 2.1.B, 2.2, and 3.2.

C. Piping shall be electrically insulated from interconnecting piping and other structures through the use of insulating sleeves and pipeline insulating devices as specified in Section ___ Corrosion Control Specifications 2.4.A and B.

D. Electrical access to the piping shall be provided by test stations installed in accordance with Section ___ Corrosion Control Specifications 2.0.A, 2.1, 2.2 and 3.7.

E. Cathodic protection of the piping shall be provided by impressed current or sacrificial anode systems as indicated. The system shall be as specified in Section ___ Corrosion Control Specifications 2.6, 2.7, 2.8 and 3.10.

II.1.2 Copper Pipe

A. Insulating coupling shall be installed just inside station or structure wall.

B. Additional corrosion control measures, if required, shall be determined on an individual location basis and shall be in accordance with Section ___ Corrosion Control Specification.

II.1.3 Reinforced/Prestressed Concrete Pipe

A. The preferred water/cement ratios for core concrete shall be .30 by weight and for mortar concrete shall be .25 by weight.

B. The maximum chloride concentration in mixing water shall be 200 ppm.

C. Portland cement shall be sulfate resistant of the following types:

1) Type II - sulfate concentration in soil less than 2,000 ppm or ground water concentration of less than 1,000 ppm.

2) Type V - sulfate concentration in soil in excess of 2,000 ppm or ground water concentration in excess of 1,000 ppm.

D. A protective coating of coal tar epoxy or equal shall be applied to the external surface of the pipe as in I.4.c and conform to DOD-P-23236A(SH) Type I or AASHTO M 224-68 (1974).

II.2 Gravity Flow (Non-Pressured) Piping

II.2.1 All metallic non-pressure piping passing through a concrete soil interface shall have a protective coating of cold-applied bitumen on the external surface for 6-inches each side of interface. Coating shall be one specified in Section ___ Corrosion Control Specification 2.5.

II.2.2 Corrugated Steel Pipe

A. Shall be galvanized to a combined thickness of 2.0 oz. per square foot of coated surface (interior and exterior) in accordance with AASHTO M 218-77.

B. Pipe shall have a protective coating of hot-applied, bituminous material on both internal and external surfaces with a minimum thickness of 50 mils in accordance with AASHTO M 190-78.

II.2.3 Cast Iron and Ductile Iron Pipe

A. Shall have an internal mortar lining with a bituminous seal coating applied to both the internal and external surfaces in accordance with AASHTO M 263-77, ASTM A 74-81.

B. Piping directly buried in soil shall have a supplemental coating of cold applied polyethylene backed mastic tape applied to the external surface with a minimum 45 mil thickness. Coating shall be in accordance with Section ___ Corrosion Control Specification 2.5.c.

II.2.4 Reinforced Concrete Pipe

A. Concrete shall be as in II.1.3 above.

B. A bituminous seal coating shall be applied to the external and internal surface of the pipe in accordance with AASHTO M 224-68 (1974) 3.5.

II.3 Electrical Conduits

II.3.1 Below Grade (Buried) Service

A. Non-metallic (PVC, fiberglass, etc.) where possible.

B. Direct burial - galvanized steel with PVC coating (or other coating), including couplings and fittings.

C. Duct bank - galvanized steel with 3-inch concrete cover on soil side.

D. Metallic conduit passing through a concrete/soil interface shall have a protective coating for 6-inches each side of the interface. Coating shall be PVC or one specified in Section ___ Corrosion Control Specification 2.5.

APPENDIX B

Standard Corrosion Control Specifications

Section (to be determined by SCRTD)
Corrosion Control

Part 1. General

1.1 Description - This work shall consist of furnishing and installing materials and systems specifically related to the control of underground corrosion resulting from soil and/or stray direct current. The need for such materials and installation shall be as set forth in other sections of these contract documents. This work shall include, but not necessarily be limited to, such items as electrical bonding, protective coatings, insulating devices and components, cathodic protection devices and corrosion control test stations.

1.2 Quality Assurance - Products used for corrosion control shall be obtained from manufacturers regularly engaged in the production of such products, and shall be certified as meeting all applicable tests and requirements.

1.3 Submittals

A. Shop Drawings - as prepared by the contractor.

B. Product Data - manufacturers installation instructions, including descriptions of required installation procedures, equipment, and precautions to be observed.

1.4 Measurement and Payment

A. Work covered by this section will not be measured or paid for separately, but will be included with the unit price bid for the specific facility requiring the corrosion control measures.

Part 2. Products and Materials

2.0 Test Station Housings

A. Curb Test Box - Acceptable Products

1. Type NM7 with locking lid, and 18-inch shaft length, as manufactured by CP Test Service, Valco, Inc., Harrison, NJ 07209 or equal.

2. Catalog No. TI45 as manufactured by Handley Industries, Inc., Jackson, MI 49204 or equal.

3. Catalog No. 1-RT as manufactured by Brooks Products, El Monte, CA 91734 or equal.

B. Above Grade Test Box - Subway

1. Enclosure: Wall mounted NEMA IV; internal dimensions 6-inches wide by 6-inches high by 4-inches deep or as shown on contract drawings, fabricated from 14 gauge hot dip galvanized steel.

2. Cover: Plain, hot dip galvanized steel with neoprene gasket. Cover to be screw mounted.

2.1 Wire and Cable

A. Conductors shall be soft annealed copper of the size specified and shall conform to ASTM B-3.

B. Cables sized number 8 and larger shall be seven (7) stranded copper, Class B, with 600 volt, THW insulation suitable for direct burial in wet and dry environments and conform to U.L. Standard 83.

C. Cables attached to impressed current anodes shall be seven (7) stranded copper, Class B, with 600 volt, high molecular weight polyethylene, halar or kynar insulation with 7/64-inches minimum thickness and conform to U.L. Standard 83.

D. Cables sized number 10 and smaller shall be either solid or stranded copper, with 600 volt THW insulation and conform to U.L. Standard 83.

2.2 Thermite Welding Equipment

A. Materials shall be either Erico Products, Inc. "Cadweld Process" or Continental Industries, Inc. "Thermoweld Process". Materials used shall be in accordance with the following:

Ductile or Cast Iron Surfaces: Use CAHBA or M-150 series welders sized as required for the specific surface, with special alloy XF-19 weld metal, amount as required for the specific conductor size.

Steel Surfaces: Use materials as recommended by the manufacturer regarding welder size and shape and weld metal size and alloying.

2.3 Brazing Materials

A. Two types of filler metal suitable for torch brazing of steel are silver alloys and copper zinc alloys. The Society of Automotive Engineers (SAE) designates the copper zinc alloys as containing 59% copper and 41% zinc.

B. Silver alloys shall consist of sheet brass with a layer of silver rolled on each side. Flow temperature shall be approximately 1,380°F.

2.4 Pipeline Insulating Devices

A. Insulating joints shall be constructed to provide an interruption in the electrical continuity of the pipeline and meet the mechanical requirements of installation. Components of the insulating joints to be buried shall be capable of withstanding the coating application temperature to which they will be exposed. Insulating joint unit shall have an effective electrical resistance of not less than ten megohms. Four basic types of pipeline insulating devices to be used are as follows:

1. Insulating flange assemblies shall consist of 1/8-inch thick phenolic washers and 1/32-inch to 1/16-inch thick phenolic bolt sleeves with a minimum dielectric strength of 500 volts/mil and a water absorption of one percent maximum (ASTM D 229); insulating gasket 1/8-inch thick with a minimum dielectric strength of 500 volts/mil and a maximum water absorption of one percent (ASTM D 229). Components shall withstand temperature to 400°F.

2. Factory encapsulated insulating joint utilizing epoxy fiberglass and epoxy resin insulating materials such as manufactured by PSI Industries, Burbank, CA or equal.

3. Insulating couplings utilizing a flexible rubber or plastic insulating material installed over pipe ends to be electrically separated.

4. PVC insulating insert, consisting of an 18-inch plain end length of PVC pipe in accordance with AWWA C-900-81.

5. Insulating unions as manufactured by Rockford- Eclipse Division, Rockford,

Illinois, Central Plastics Company, Shawnee, OK or equal.

B. Casing and Wall Penetration Insulators

1. Casing insulators shall be constructed to withstand the mechanical requirements of installation and shall maintain electrical isolation between the carrier pipe and the casing. If the carrier pipe has non-rigid mechanical or push-on joints, not less than two insulators shall be installed on each length of pipe. Insulators shall be as manufactured by either T.D. Williamson, PSI Products, Inc., F.H. Maloney Company or equal. Annulus between the outside diameter of the carrier pipe and the inside diameter of the casing shall be not less than 1-inch. For carrier pipe having joints which protrude from the outer wall of the pipe, the annulus between the inside diameter of the casing and the joints shall be not less than 1-inch.

2. Wall Insulators

Seals shall be modular mechanical type, consisting of interlocking synthetic rubber links shaped to continuously fill the annular space between the pipe and wall opening. Links shall be loosely assembled with bolts to form a continuous rubber belt around the pipe with a pressure plate under each bolt head and nut. After the seal assembly is positioned in the sleeve, tightening of the bolts shall cause the rubber sealing elements to expand and provide an absolutely watertight seal between the pipe and wall opening. The seal shall be constructed so as to provide electrical insulation between pipe and wall. Caulking or other types of mastic sealant or lead oakum joints are not acceptable. Manufacturer: Thunderline Corporation, Wayne, MI 48184, Distributor Calvin Jolly Associates, Pasadena, CA 91101 or equal.

2.5 Protective Coatings (Underground)

A. Cold-applied bitumen coating shall consist of bituminous resins, additives and fillers within an aromatic solvent system with volume resistivities in excess of 10^{12} ohm-cm, shall be of the "fast dry" type, and shall be either Royston Company's "Roskote A-938", Koppers Company's "Bitumastic

No. 50", or Utility Products Company's "Thick-N-Quick Mastic".

B. Extruded polyethylene, hot butyl based system consisting of a pure gum butyl rubber, tackifier, polybutylene vinyl acetate copolymer adhesive in conjunction with a plastic resin of medium density copolymer ethylene and butene-1. Resin shall meet ASTM D 1248-70a, Type II, Class C, Category 5. Suitable product manufactured by Bredero Price Company, Houston, TX or equal.

C. Cold-applied multi-layer polyethylene tape system shall consist of polyethylene backed butyl mastic adhesive tape. Polyethylene tape shall be minimum 5 mil thickness with 40 mil thick mastic adhesive layer. System must be type requiring a primer and be applied with 50% overlap. Systems as manufactured by Johns Manville Company (Engard), Royston Company (Greenline), and Polyken Pipeline Company are acceptable.

D. Coal-tar epoxy coating shall be a two component, chemically cured material conforming to DOD-P-23236A(SH), Type I, and shall be either Porter Coatings Company's "Tarset", Carbomastic Company's "No. 16HF", or Koppers Company's "Bitumastic 300-M".

E. Coal-tar enamel shall be of the hot-applied type conforming to the applicable portions of AWWA C203-78, Section 2, either Type I or Type II. Coal-tar primer shall conform to the characteristics specified within the applicable portions of AWWA C203-78, Section 2.

F. Asphalt enamel shall be hot applied specifically formulated for underground protection of pipe. The enamel shall have properties which fall within ±10 percent of the following:

Typical Properties of Pipe Coating

Test	Properties
Weight, lbs/gal at 60°F	9.95
Flash point, c.o.c., above °F	525
Softening point (R&B) °F	240
Penetration at 77°F, 100g/5 sec	8
Penetration at 32°F, 200g/60 sec	5
Penetration at 115°F, 50g/5 sec	14
Penetration at 150°F, 50g/5 sec	40 max.
Ash (mineral filler) % by weight	18-22
Settlement ratio, maximum	1.02
High temperature sag test @ 160°F,	

24 hours, inches	None
Low temperature crack test @ 20°F	None
Peel test, 60°F to 160°F	None
Break test @77°F, 1" Mandrill	None
Water absorption, 35 wks, % by weight, maximum	.9
Resistivity, ohm-cm, above	1x10^{16}
Voltage breakdown, volts per mil above	1,000

Asphalt primer shall be as specified by the manufacturer of the asphalt enamel. The continuous thickness shall be 3/32-inches with an allowable variation of ± 1/32-inches.

G. Galvanizing shall be hot dip to a minimum weight of 2.0 oz. per square foot of coated surface. Zinc coating weight shall be determined by test according to ASTM A90.

2.6 Cathodic protection rectifiers shall be of a type specifically made for this application. The units shall meet NEMA MR20-1958 (reaffirmed 1976) standards publications "Semiconductors Rectifiers, Cathodic Protection Units". The unit shall have the following features.

A. Selenium or silicon full-wave bridge rectification.

B. Single phase 60 hz. input with internal wiring arrangement for use with either 120 or 240 volt service and with internal circuit breaker.

C. The DC output shall be as determined for the specific application. The output shall be adjustable from 5% of rated output to full output in a minimum of 10 steps.

D. The unit shall have a continuous reading ammeter and voltmeter accurate to within 3% of full scale suitably mounted in cabinet or other enclosure.

E. The unit shall be oil-immersed or air-cooled as determined for the specific application with case and brackets suitable mounting. The unit shall be as manufactured by Good-All Electric, Inc., Ogallala, NE, Matcor, Inc. Doylestown, PA.

2.7 Anodes, impressed current type shall be high-silicon, chromium bearing iron type of size and shape as shown on the contract drawings with the following additional requirements.

A. Chemical Composition:

Element	Percent
Silicon	14.33
Chromium	4.50
Carbon	0.85
Manganese	0.65
Iron	Remainder

B. Physical Properties:

Tensile Strength	15,000 psi
Compressive Strength	100,000 psi
Brinell Hardness	520
Density	7.0 grams per cubic-centimeter
Melting Point	2,300°F
Specific Resistance	72 microhms per centimeter cube at 20°C
Coefficient of Expansion	7.33×10^{-6} per degree F from 32-212 F

C. Wire: Single conductor stranded copper, HMWPE, halar or kynar 7/64-inch thick insulated cable sized as shown, factory connected to the anode with connection sealed with cast epoxy resin encapsulation to prevent moisture penetration. Maximum resistance anode-to-wire connection shall be .005 ohm.

D. Anode packaged in 8-inch diameter and 8 feet long or 5-inch diameter and 6 feet long steel pipe, ASTM 53 Type E, Grade A as shown, ends crimped, to ½-inch interior grade plywood end seal, and containing compacted backfill of coke breeze of graded coal or recalcined petroleum coke with the following requirements.

1) Volume resistivity on dry basis 60 ohm-cm(Max.)
2) Chemical composition:

Material	Percent
Fixed Carbon	78.22-78.40
Ash	18.6 (Max.)
Moisture	9.5-14.7
Volatile Matter	3.00-3.14
Sulphur	1.2 (Max.)

3) Sieve Size:

Sieve Designation per ASTM E11	Passing Percent By Weight
1/2-inch	100
3/8-inch	85
No. 6	65

2.8 Anodes, Magnesium Sacrificial Type; shall be of bare ribbon 3/8 by 3/4-inch section or packaged anode, type and size as shown, with the following additional requirements.

A. Chemical composition for standard type anodes:

Element	Percent
Aluminum	5-7
Zinc	2-4
Silicon	0.3 (Max.)
Manganese	0.15 (Min.)
Copper	0.1 (Max.)
Iron	0.003 (Max.)
Nickel	0.003 (Max.)
Other metallic elements	0.3 (Max.)
Magnesium	Remainder

B. Chemical composition for high potential type anodes:

Element	Percent
Aluminum	0.01 (Max).
Manganese	0.5-0.8 (a minimum of 0.5 plus 60% of aluminum)
Copper	0.02 (Max.)
Iron	0.03 (Max.)
Nickel	0.001 (Max.)
Other metallic elements (Max.)	0.05 each
Magnesium	Remainder

C. Wire: Single conductor copper, insulated cable, sized as shown, factory connected to the anode with connection sealed with cast epoxy resin encapsulation.

D. Anode packaged in permeable cloth sack containing compacted backfill of mixture with the following requirements:

Material	Percent
Gypsum	75
Bentonite	20
Sodium Sulfate	5

2.9 Anodes, Zinc Sacrificial Type shall be ASTM B418-20, bare ribbon 5/8 by 7/8-inch section or packaged anode, type and size as shown, with the following additional requirements.

A. Lead wire: Single conductor insulated cable, sized as shown, factory connected to the anode with connection sealed with cast epoxy resin encapsulation.

B. Anode packaged in permeable cloth sack containing compacted backfill of mixture with the following requirements:

Material	Percent
Hydrated Gypsum	50
Bentonite	50

2.10 Separators - Insulating pads shall be placed between all metal pipeline which cross 12 inches or closer. Isolation shall be achieved as follows:

A. 3/16-inch "Kapco" Rock Shield

B. Non-metallic straps, i.e. Polyken Tape

C. Steel pipe one size larger than carrier pipe.

2.11 Pipe Test Electrode

A. Six-inch length of No. 6 reinforcing steel with AWG #8 stranded, insulated copper test wire exothermically welded or brazed to reinforcing bar.

2.12 Tunnel Test Electrode

A. Steel Rod: ASTM A36. Rod shall be of diameter and length shown and threaded one end to fit insulating bushing. Rod shall have a coal tar epoxy protective coating from base of threads to within 4-inches of external end of rod. Four inch end of rod shall be bare steel.

B. Insulating bushing shall be manufactured of polymerized plastic, ASTM D789 with tensile strength of not less than 2,300 psi determined in accordance with ASTM D638. Bushing shall be sized to fit grout tube and/or drilled hole in steel tunnel liner and shall be internally and externally threaded.

C. Test wires shall be AWG #12 stranded copper with 600 volt THW insulation.

Part 3. Execution

3.1 Welding For Corrosion Control Purposes

A. Welding Procedures. Connections between copper conductors and metallic piping, concrete reinforcement, and other metal components shall be made by either exothermic welding or brazing. Procedures, materials, and equipment for thermite welding shall be in accordance with manufacturer's printed welding recommendations accepted by the Engineer. Brazing shall conform to American Welding Society (AWS) standard practices; brazing is not allowed on natural gas distribution and transmission facilities.

B. Thermite Weld. For test station wires, and pipe joint bond wires, when the thermite weld has cooled and the slag removed, the weld will be tested by striking the weld with a two pound hammer around the weld and at an angle of 45 degrees to the surface while pulling on the wire. Defective welds shall be removed and replaced with new welds at no additional expense to the District.

3.2 Bonding of Underground Structures

A. Where indicated, piping or other buried structures which contain mechanical or other non-metallurgical joints shall be made electrically continuous by bonding. The bonding shall be achieved by the method shown for the specific structure with the number of bond wires required in accordance with the following:

Pipe Diameter (In Inches)	No. of Wires per Mechanical Joint
12" or less	2
16" or more	3

B. Piping which is specified to be electrically bonded for corrosion control purposes will be tested prior and subsequent to backfilling to verify continuity. Piping which will require this testing is that piping which has mechanical joints such as cast and ductile iron. Electrical resistance of the pipe will be measured in lengths for which the total length of pipe and the number of mechanical joints is known. The test station wires will be used as the electrical contact points to the pipe for these measurements to facilitate the repeating of the measurements subsequent to backfilling. Electrical resistance obtained will be compared with the calculated resistance for the section. The calculated resistance shall be based on the resistance per unit length of pipe. This is a function of the resistivity and the cross-sectional area of the metal conductor in the pipe wall, the length of pipe, the number of pipe joints, the resistance of the bond wires installed across the pipe joints, and the number of bond wires within the pipe length being measured. A variation of greater than 20 percent from the calculated resistance shall be subject to review and additional tests to determine the reason for the variation and the corrective measures required. Contractor shall assist the Engineer in the performance of these tests by providing electrical contacts or physical access to the pipe. The resistance value obtained prior to backfill will be used as the standard for comparison for the resistance values obtained subsequent to backfilling.

3.3 Insulating Devices in Piping

A. Insulating joints shall be installed at the locations specified. Those assembled joints and their components shall be stored in a manner which will ensure that they will be protected from the weather, water, dirt, and other foreign matter which could adversely affect their electrical insulating properties. Electrical properties of the insulating joint shall be verified to be not less than ten megohms when connected to the line on one side and with the other side suspended in such manner that it has, for all intents, an infinite resistance to earth. Upon completion of the pipeline construction, within reasonable distances from the insulating joint and with the line activated with the proposed fluid, the effective resistance of the insulating joint shall be verified by test.

B. Protective coating shall be applied to the internal surface of the pipe, if the pipe contains an electrically conductive fluid. The length of the internal coated surfaces shall be equal to two times the nominal pipe O.D. up to a maximum of 4 feet centered on the insulating flange. Protective coating shall be coal-tar epoxy for potable water and sewage type fluids. External surfaces of buried insulating joints shall be coated with hot-applied coal-tar enamel, using an expendable coating mold as indicated on the drawings. Insulating joints which are within pits, structures and other areas such that they would not be expected to be submerged within an electrically conductive medium, but which may be subject to substantial condensation moisture shall be constructed with an encapsulated type insulating joint. The insulating device shall permit the ready application of protective coating both internally and externally and shall be readily removable from the piping system. The joint shall have minimum 18-inch lengths of flanged pipe extending from each end. Protective coatings shall be applied in accordance with these specifications and the manufacturer's recommendations and in such manner that their continued effectiveness can be reasonably assured. Buried insulating joints and those otherwise inaccessible shall have test stations installed as specified.

C. Electrical insulation tests on insulating joints for pipelines will be executed either prior to insertion in the pipeline (if a preassembled unit) or immediately after insertion into the pipeline and prior to the application of protective coating. The electrical resistance of the insulating joint will be measured with the piping on one side of the joint being electrically insulated from earth. These measurements will be made with a relatively low voltage DC source (not to exceed 24 volts). The resistance shall be not less than ten megohms. A resistance value of less than ten megohm will be evaluated to determine the reason, and corrective action shall be taken to obtain the required minimum resistance. Subsequent to activation of the pipeline, electrical resistance tests will be conducted to evaluate the electrical leakage through the insulating joint. An indicated current leakage through the insulator of greater than three percent of the total test current impressed across the insulating joint shall be reason for corrective action, if so required by the Engineer.

D. PVC inserts, 18-inches in length sized the same as the nominal pipe diameter, shall be installed where indicated on the contract drawings. This item must be coupled into the piping system without use of any harnessing or tie rods that will bridge the insert resulting in a leakage path. Electrical tests are not required for this item.

3.4 Casing Insulation

A. Where indicated, high density polyethylene casing insulators shall be installed in the number required per manufacturer's recommendations and in such manner that their proper mechanical and electrical functions can be reasonably assured. Skids and other items for placing the pipe within the casing shall not be used unless there is a positive means of removing all of these items from within the casing and some means of verifying that they have been removed. After the pipe has been installed within the casing, and before the pipe has been connected to the remainder of the pipeline on either end, the effective resistance between the carrier pipe and the casing shall be measured. These tests will be conducted using a low voltage DC source (not to exceed 24 volts). Resistance shall be not less than 100,000 ohms for coated carrier pipe and not less than 1,000 ohms for uncoated carrier pipe. Test stations shall be installed on the casing and the carrier pipe as specified. Electrical continuity of the casing shall be obtained by bonding mechanical joints as specified. Resistance values less than those specified will be evaluated by the Engineer. Corrective action shall be taken if so required by the Engineer, at no additional expense to the District.

3.5 Wall Insulators

A. Where indicated, all pressure piping passing through an external structural wall, floor, or roof into a soil environment must be electrically insulated from the reinforced concrete wall. Insulators shall be installed in accordance with the manufacturer's instruction. Wall seal arrangement shall result in a positive watertight seal between pipe and wall for anticipated pressures.

3.6 Tunnel Test Electrodes

A. Electrodes shall be installed at approximate 1,000 foot intervals beginning 1,000 feet from east end of tunnel system or at locations shown on contract drawings.

B. Electrodes shall be installed below invert level, extending into earth from opposite exterior sides of each paralleling tunnel as shown on contract drawings.

C. Electrodes to be installed with insulating bushings in the manner indicated through grout tubes in precast concrete tunnel liner segments or through holes drilled through the steel lined precast concrete tunnel liner segments.

D. Test stations shall be installed as shown for each electrode.

3.7 Test Stations, Underground Pipe

A. Test stations shall be installed at the locations specified and at 150 feet intervals along the piping and in the manner indicated. Wires shall be attached to the pipe and the casing using the thermite welding process and in accordance with manufacturer's recommendations. Thermite weld shall be tested mechanically and electrically in accordance with these specifications. The wire shall be examined; broken and nicked strands and/or insulation shall be subject for rejection of the weld. Effectiveness of the test station wires will be verified before and after backfilling by measuring the electrical resistance of the combination of two wires connected to the same pipe section. The resistances will be measured from the test station terminal ends of the wires. The resistance values obtained will be compared with the calculated resistance of the test station wires based on the standard resistance for the size wire involved and the length of the test station wires. The resistance value measured prior to backfill, will be used for verification of measurements subsequent to backfilling.

B. Each weld, bared copper wire, and pipe surface surrounding the weld for not less than 4-inches, shall be coated. Type of coating shall be the same as exists on the piping, except that if the piping has no other coating, the coating shall be cold-applied bitumen. Wires shall be protected during backfilling operations, shall be terminated within a curb box, and shall have sufficient slack to extend not less than 12-inches above final grade. Upon establishing final grade, complete with paving or other finished surface, the boxes for the test stations shall be positioned to be accessible without excavation. Electrical integrity of the test station wires shall be verified at this time. Discrepancies found shall be corrected at no additional expense to the District.

3.8 Test Station/Tunnel Test Electrodes

A. Test stations shall be installed for each electrode in the manner indicated. Wires shall be attached to the electrode, reinforcing steel or steel tunnel liner by the thermite welding process or brazing in accordance with the manufacturer's recommendations. Weld area and bared copper wire shall be coated with cold-applied bitumen prior to concrete invert pour.

B. Test wires shall be extended through PVC conduit to test box mounted on tunnel wall with access from the safety walk without special equipment.

3.9 Test Stations, Current Measuring Steel Lined Tunnel

A. Test stations shall be installed in tunnel sections in which steel liner is electrically continuous for lengths in excess of 2,000 feet. Test station pairs shall be placed at 2,000 foot intervals as shown on the contract drawings.

B. Test station pairs shall consist of 12-inch lengths of AWG No. 8 copper wire thermite welded to the steel tunnel liner with 300 foot spacing between wires. Test stations shall be placed on safety walk side of tunnel and require no special equipment for access.

3.10 Protective Coating Underground Piping

A. Protective coatings shall be applied to utility piping and appurtenances at the locations indicated and in accordance with these specifications and the coating manufacturer's recommendations.

1. Hot-applied coal-tar enamel shall be applied in accordance with applicable portions of AWWA C203-78 and NACE Standard RP-02-74. Of particular importance in obtaining an effective coating of this type is insuring the pipe surface has been cleaned properly and that the primer has been allowed to dry properly, but is not dead prior to the application of the coating. After the hot enamel has been poured in the coating mold and hardened, the mold shall be refilled to compensate for the shrinkage. Backfilling of

the pipe in the vicinity of the coating mold shall not be done until the second pour of the coating has hardened and the coating has been accepted.

2. Cold-applied bitumen coating shall be applied through airless spray technique in accordance with manufacturer's recommendations regarding the cleanliness of the metal surface to be coated, the use of a primer, and the required drying time. After the coating has dried, it shall be tested for bond to the metal surface by attempting to pry the coating off with a flat blade instrument, such as a putty knife. Evidence of the coating peeling, as opposed to being removed in small pieces, shall be reason for rejection and subject to removal and complete recoating. Coating shall be subjected to a wet sponge, low voltage (max. of 100 volts) type fault detector test; detector shall be furnished by the Contractor and shall be in good working order. Faults shall be corrected to the satisfaction of the Engineer.

3. Coal-tar epoxy coatings shall be applied in accordance with the manufacturer's recommendations and these specifications. Evidences of improper bonding, as described under cold-applied bitumen type coatings, shall be grounds for rejection. Coating, when cured, will be tested with a low voltage fault detector; detector shall be furnished by the Contractor, and repairs shall be made, as required, to the satisfaction of the Engineer.

4. Extruded polyethylene coating systems and cold-applied polyethylene tape systems shall be installed in accordance with manufacturer's instructions regarding surface preparation, use of primers and application restrictions. These coating systems shall be used generally on straight non-irregular surfaces. Where irregular surfaces are to be coated, such as bell joints, fittings and/or bends, a cold-applied bitumen coating is to be used, unless specified otherwise. Extruded and tape polyethylene coatings shall be subject to a high voltage (17,000 volts max.) type detector test in accordance with NACE Standard RP-02-74. Detector shall be furnished by the Contractor. Faults shall be repaired to the satisfaction of the Engineer.

3.10 Cathodic Protection Anodes

A. Anodes of the externally or rectifier driven type shall be installed at the locations and the manner given on the contract drawings. Wires from the anodes shall be routed so as to prevent damage and mechanical stress on the insulation upon backfilling. Insulation on anode wires shall be inspected for damage and approved prior to backfilling. Anodes with damaged wire insulation shall be replaced at no expense to the District. Splicing of anode wires shall not be permitted without specific written approval of the Engineer. Installation shall conform to NACE Standard RP-01-69 (R-1983).

B. Sacrificial metal anodes of magnesium or zinc shall be installed at the locations and in the manner given on the contract drawings. Installation shall conform to NACE Standard RP-01-69 (R-1983).

   1. Wet packaged anode thoroughly before backfilling the hole.

   2. Use fine clay soil, free from stones and bricks, for backfilling (the use of select backfill will not be acceptable).

C. Install test boxes of type and at location shown.

D. Connect anode lead wires to header cable or in test boxes as shown.

APPENDIX C-1

Fiberglass Reinforced Plastic (FRP) Casing-Elevators

Division

Section (to be determined by SCRTD)

Part 1. General

1.1 Description - This work shall consist of furnishing and installing a fiberglass reinforced plastic casing as part of the elevator hydraulic cylinder cathodic protection requirements.

1.2 Other Requirements - Installation of anodes, coating of steel cylinder, test station and associated wiring are covered under Division ____ Section ____, Elevator Cathodic Protection System (Appendix C-2 enclosed).

Part 2. Products

2.1 Fiberglass Reinforced Pipe (FRP)

2.1.1 FRP shall be a minimum of 24-inches O.D. with 0.375-inch wall thickness and shall meet the requirements of ASTM D-2992 for static and cyclic pressure ratings for the size specified. FRP shall be manufactured by the filament winding process using isophthalic resin to impregnate continuous glass strands. Strands are wound at a 35.25 degree angle in accordance with ASTM D-2996.

2.1.2 The bottom and all joint fabrications of the FRP shall be permanently closed and sealed against any moisture intrusion with cover of same material and minimum equal thickness as the FRP in accordance with the manufacturer's published specifications and recommendations.

2.1.3 Provide a removable top cap of the same materials as specified above. Cap shall be temporarily sealed to FRP. The cap is for the protection of the FRP well and casing until the time of removal when elevator and hydraulic piston and cathodic protection system are installed.

2.1.4 Wall thickness of pipe, couplings and cap shall be designed to withstand the earth and/or hydrostatic pressure to which it will be exposed, but shall not be less than 0.375-

inch. The wall thickness shall be designed with a safety factor of five after installation of the elevator cylinder and sand fill. Test pressure shall be 125% of maximum anticipated external pressure. Calculations establishing wall thickness and test pressure to be furnished by FRP manufacturer for Engineer's approval.

2.2 Steel Outer Casing

2.2.1 Shall be a minimum 30-inch O.D. steel casing ASTM A-135 or API 5L, Grade B, 0.375-inch wall thickness with closed end.

2.2.2 Steel casing shall provide a well of sufficient depth to contain fiberglass casing and the elevator hydraulic cylinder.

2.2.3 Weld shear collar, as indicated, to casing both sides all around to form watertight seal.

Part 3. Execution

3.1 Steel Outer Casing Installation

3.1.1 Casing shall be installed so that FRP casing may be located within specified and indicated tolerances for position and plumbness.

3.1.2 Steel casing to be positioned so that shear collar will provide an adequate waterstop and there will be no metallic contact between casing and elevator pit reinforcing steel.

3.2 FRP Casing Installation

3.2.1 Install casing in as long lengths as possible and in accordance with manufacturer's recommendations and shop drawings as approved by the Engineer.

3.2.2 Casing sections shall be supported, joined, bonded, reinforced, wrapped and pressure grouted in the steel casing with non-shrink grout in accordance with manufacturer's recommendations and shop drawings as approved by the Engineer.

a. Field joint splices shall be of same materials as FRP and installed in such fashion, on the exterior and interior of casings, such as to not interfere with work of elevator or other Contractors and to prevent water intrusion. Splice materials total thickness on exterior of casing shall at least equal casing thickness.

3.2.3 Cut top of casings cleanly at elevation indicated or otherwise required, in a manner recommended and approved by the manufacturer.

3.2.4 Locate FRP casing within specified and indicated tolerances for position and plumbness.

3.2.5 Upon installation and plugging of FRP casing and shaft completion, cast remainder of elevator pit floor.

3.2.6 Slope non-shrink grout away from the fiberglass casing.

APPENDIX C-2

Elevator Cathodic Protection System

Division

Section (to be determined by SCRTD)

Part 1. General

1.1 Description - This work shall consist of furnishing and installing sacrificial ribbon anodes, coal-tar epoxy coating, test station and associated conduits and wiring to establish a cathodic protection system for an elevator steel hydraulic cylinder.

Part 2. Products

2.1 Magnesium ribbon shall be bare 3/8-inch by 3/4-inch section with a steel wire core. The magnesium alloy shall have the following composition.

Element	Percent
Aluminum	0.01
Manganese	0.05 to 0.08
Copper	0.02
Iron	0.03
Nickel	0.001
Other Metallic Elements	0.05 each
Magnesium	Remainder

The magnesium ribbon shall be as manufactured by Dow Chemical Company, Galvoline or an approved equal.

2.2 The test electrode shall be made from a No. 6 reinforcing bar approximately eight (8)-inches in length.

2.3 Test electrode wire shall be an AWG No. 12 stranded copper wire with 600 volt type THW insulation. It shall be of a length such that there will be 18-inches of slack in test box. Wire insulation shall be black in color.

2.4 Magnesium anode test wires shall be AWG No. 12, 600 volt type THW insulation, stranded copper wire, the test wires shall be long enough to connect into the test box. Wire insulation shall be white and red in color as shown.

2.5 Hydraulic cylinder test wire shall be AWG No. 8, 600 volt Type THW insulation, stranded copper wire, the test wire shall be long enough to connect into the test box. Wire insulation shall be black.

2.6 Junction Box

The test station box for termination of test leads from the cylinder, magnesium ribbons and test electrode shall be a NEMA 4 enclosure fabricated from 14 gauge galvanized steel, watertight, 12-inches wide by 12-inches high by 4-inches deep and lockable by padlock.

2.6.1 Seams shall be continuously welded with neither holes nor knockouts.

2.6.2 Doors shall be fully gasketed with neoprene, and shall have a three point (minimum) latching mechanism and a handle. Heavy gauge continuous type hinges shall secure the door to the box. The finish shall be satin gray enamel.

2.6.3 A five (5) point terminal block shall be installed in the test box.

2.7 Protective coating for corrosion control on the hydraulic cylinder shall be a coal-tar epoxy, two component, chemically cured material conforming to DOD-P-23236A(SH) Type 1, Class 2. Products suitable for application are: Bitumastic 300-M, Koppers Company; Carbomastic No. 16HFP, Carboline Company; Tarset, Porter Coatings Company or an approved equal.

2.8 Conduit shall be PVC coated steel, 3/4-inch diameter. Lengths of conduit shall be determined by the Engineer.

2.9 Sand for backfill around hydraulic cylinder shall be clean quartz sand with a resistivity of not less than 25,000 ohm-centimeters (as measured when sand is 100% saturated with distilled water), a pH between 7 and 7.5, and a maximum chloride and sulfate ion concentration less than 100 ppm for each.

Part 3. Execution

3.1 Application of Coal-Tar Epoxy

3.1.1 Coal-tar epoxy coating shall be in accordance with the manufacturer's recommendations. Shall have not less than 10 mils dry film thickness per coat with a minimum two coats required. The coal-tar epoxy must obtain an effective bond to the metal surface of the hydraulic cylinder. Surface of the hydraulic cylinder shall be prepared in accordance with coating manufacturer's recommendations. After the coating has cured, the coating shall be tested by attempting to pry the coating off with a flat blade instrument such as a putty knife. Any evidence of peeling shall be reason for rejection and subject to removal and complete recoating. The coating will be subjected to a wet sponge, low voltage, maximum of 100 volts, type fault detector. Faults shall be repaired.

3.2 Cathodic Protection System Installation

3.2.1 The two magnesium ribbons shall be bent in accordance with the contract drawings. The plastic PVC disc shall be placed over top the ribbons. The ribbon disc apparatus shall be placed in the FRP casing.

3.2.2 A red test wire shall be connected by screw thread connector to each end of one magnesium ribbon while two white test wires shall be connected in the same manner to the other magnesium ribbon as shown. Connections shall be coated with splicing compound and electrical tape.

3.2.3 The test electrode, with a black test wire, shall be installed in accordance with the contract drawings.

3.2.4 An AWG No. 8 stranded, copper wire shall be attached to the cylinder by exothermic weld.

3.2.5 All test wires shall be fed into the junction box and connected to the terminal block.

3.2.6 The electrical continuity of each magnesium ribbon shall be verified by measuring the electrical resistance using the test wires in the junction box. The measured resistance shall include the series resistance through one test station wire, through the ribbon and through the other test lead. The approximate resistance of this assembly shall be calculated using the lengths and resistances per unit lengths of the various components. The resistance values shall be determined prior and subsequent to backfilling. Any discrepancies greater than 10 percent between calculated and theoretical resistances shall be reviewed by the Authority or its designate.

3.2.7 The metallic conduits supporting the magnesium ribbon shall be raised at a rate equal to that of the casing filling with sand.

3.3 Electrical Testing and Acceptance

3.3.1 Electrical resistance tests shall be made prior to and subsequent to backfilling the casing to ensure the various components of the cathodic protection system are not in contact with each other.

APPENDIX D

Specifications for Direct Fixation Insulating Rail Fastener

The following comments and statements are to be added to the Design/Procurement Specifications for Direct Fixation Rail Fasteners. These specifications have been prepared to satisfy the stray current/corrosion control criteria established for the SCRTD Metro Rail Project, and as such are not intended to be complete fastener design specifications. The information contained herein must be subjected to careful review as the trackwork design and fastener procurement documents are being prepared to ensure that the corrosion/stray current control measures are integrated with the mechanical and other requirements of the fasteners.

Part 1. General

The direct fixation fasteners shall be constructed and installed so as to electrically insulate the rail from the trackbed, such that a resistance of 1,500 ohms per 1,000 feet of track (2 rails) can be reasonably maintained over the proposed service life of the fastener. This resistance value and other values stated as acceptance criteria throughout this specification are based on a fastener spacing of 30-inches.

Part 2. Materials

2.1 Elastomer

2.1.1 Elastomer shall be fabricated and compounded of a neoprene base, natural rubber, a blend of these two elastomers, or polyurethane. Polyurethane shall be a polyether base and shall include an ultraviolet light screening agent such as carbon black in its formulation.

2.1.2 Elastomer samples shall be tested for the following parameters and meet the acceptance criteria indicated.

2.1.2.1 Ozone Tests

a) Sample preparation in accordance with Procedure A of ASTM Designation D518, Surface Cracking Resistance of Stretched Rubber Components.

b) Testing in accordance with ASTM Designation D1149, Accelerated Ozone Cracking of

Vulcanized Rubber at a temperature of 40°C and at an ozone concentration of 50 pphm.

c) Acceptance Criteria: The elastomer shall not exhibit any cracking when examined in accordance with ASTM Designation D1149 at end of a 100 hour exposure. (Note: these test requirements are based on experience, the level of ozone anticipated must be reviewed to assure the stated requirements are adequate).

2.1.2.2 Electrical Resistivity and Water Absorption Tests

a) A sufficient number of samples shall be prepared (not less than ten) using material from the elastomer process that will be used to fabricate the fastener. The actual number of samples tested shall be determined by the elastomer manufacturer to establish a statistically representative population of possible variations in elastomer processing.

b) Samples shall be a minimum of 1/4-inch and a maximum of 1/2-inch thick, with other dimensions chosen to satisfy the requirements of ASTM Designations D257 and D570.

c) Determine dry volume resistivity and 24 hour immersion water absorption in accordance with ASTM Designations D257, DC Resistance or Conductance of Insulating Materials, and D570, Water Absorption of Plastics respectively.

d) Acceptance Criteria: Volume resistivity shall be a minimum of 10^{14} ohm-centimeters dry and short term water absorption shall be a maximum of .2% by weight.

e) All samples tested above shall be tested for long term water absorption and corresponding resistivity characteristics.

f) Immerse all samples in accordance with ASTM Designation D570, Water Absorption of Plastics following the procedures of section 6.4 Long Term Immersion, of this designation. Determine weight increase and resistivity for each sample after the first week of immersion and at two week intervals thereafter until the weight increase and decrease in resistivity per two week period, as shown by three consecutive testings, averages less than one percent of the total increase in weight and decrease in resistivity. At this point, the material will be considered as substantially saturated.

g) Towel dry substantially saturated samples and determine both water absorption and volume resistivity. These tests must be performed within 2 hours after completion of the saturation tests in f) above and without subjecting the sample to an environment which would result in accelerated drying.

h) Acceptance Criteria: Long term water immersion shall result in a minimum volume resistivity of 10^{12} ohm-centimeters and the long term water absorption shall not exceed 0.5%.

2.2 Anchorage Assembly and Threaded Elements

2.2.1 Anchor Bolts and Threaded Elements

All bolts and studs shall be plain carbon steel or high strength steel as necessary to meet mechanical requirements. All anchorage assembly items such as bolts, nuts, washers and other threaded items shall be fabricated from the same ferrous material to avoid the occurrence of bimetallic galvanic couples.

2.2.2 Coating Materials

Coating materials shall be 100 percent dry powder epoxy resin such as Scotch Kote Resin No. 203, manufactured by the Minnesota Mining and Manufacturing Company, Corvel Epoxy ECB-1363A manufactured by the Polymer Corporation, or approved equal meeting the requirements of ASTM Designation D3963 Annex A1, Epoxy Coated Reinforcing Steel, modified as necessary for application by electrostatic fluidized bed method.

2.2.3 Insulating Materials

Material used for dielectric insulating sleeves or protective bolt caps shall be a glass filled nylon in accordance with ASTM Designation D-2897, Reinforced and Filled Nylon Injection Molding and Extension Materials of specified type to meet anticipated compressive loads or other material with equivalent characteristics.

2.2.3.1 Electrical Resistivity Tests

a) Sample preparation and testing in accordance with ASTM Designation D257 DC Resistance or Conductance of Insulating Materials.

b) Acceptance Criteria: Volume resistivity shall be a minimum of 10^{12} ohm-centimeters.

2.2.3.2 Water Absorption Tests

a) Sample preparation and testing in accordance with ASTM Designation D570, Water Absorption of Plastics.

b) Acceptance Criteria: The insulating material shall have an increase in weight of not greater than 0.1 percent after 24 hours immersion.

Part 3. Fastener Construction

3.1 General

3.1.1 Fastener shall be free of voids and recesses which will retain and/or make difficult the cleaning of conductive material from the fastener which could degrade the electrical insulating characteristics of the fastener.

3.1.2 The fastener shall consist of a rail bearing assembly, anchorage assembly and rail hold down devices all of which must be constructed, fabricated, or assembled to provide a minimum in-service resistance of 1,500 ohms per 1,000 feet of track (2 rails).

3.2 Rail Bearing Assembly

3.2.1 Rail bearing plate shall be embedded in elastomer such that bottom and four edges are covered with the elastomeric material.

3.2.2 Secondary, bottom non-bearing plates, if used, shall be embedded in elastomer such that there is elastomer material separating rail bearing plate and secondary plate and elastomeric material covering all four edges and the bottom surface. The final arrangement shall have elastomeric material covering all surfaces of the secondary plate (non-bearing) such that the steel will not directly contact other metal.

3.2.3 Steel bearing washers for use in anchoring the fastener to the grout pad shall be encased in elastomer on all sides, except the top which shall remain uncovered to the extent required to allow for anchor bolt insertion, secondary washer and nut assembly.

3.2.4 Elastomer around the sides of the fastener shall be so formed that there will be an undercut elastomer overhanging lip on the four sides of the fastener, near the top, to prevent the formation of an electrically conductive moisture film between the top surface of the fastener and the grout pad surface.

3.2.5 The rail bearing assembly shall be fabricated with expansion recesses in the bottom to allow for expansion of the elastomer material when the fastener is under load. The recesses shall be sized and spaced such that there are no exposed steel surfaces and there is a minimum of 1/4-inch of elastomer over the bottom of the rail bearing plate.

3.3 Anchorage Assembly

Anchorage assembly shall be an integral part of the rail fastener and include an electrically insulating bolt sleeve, dielectric coating application to both anchor bolt and bolt insert, and an electrically insulating bolt cap.

3.3.1 Anchor Bolt and Anchor Bolt Inserts

These components shall be coated with an epoxy resin insulating coating applied by electrostatic fluidized bed method. Surface preparation and coating application shall be in accordance with the manufacturers recommendations and the general guidelines listed below. All surfaces of inserts and anchor bolts shall have a minimum coating thickness of 10 mils and a maximum thickness of 20 mils. A sufficient length of the threaded portion of the bolt shall remain uncoated to allow for positive anchoring of the rail fastener.

3.3.1.1 Degreasing to remove all oil, grease or other foreign matter by solvent, caustic degreasing or by steam cleaning shall be in accordance with Steel Structures Painting Council (SSPC) Specification SP 1.

3.3.1.2 Surface preparation shall be to white metal in accordance with SSPC Specification SP 5.

3.3.1.3 Preheating of the inserts shall be to a uniform temperature of not less than 325°F. Insert temperature shall be checked and recorded every hour. These records shall be submitted to the District with the production lot test results submitted in accordance with established procedures.

3.3.1.4 Dipping and movement of the inserts into a fluidized bed of proper temperature and density shall provide complete and uniform coverage of all surfaces except interior threads when provided.

3.3.1.5 Post curing shall be in an oven immediately following the coating application at a temperature between 400°F and 425°F for a time to ensure complete cure of the epoxy resin. Post cure oven temperature shall be recorded every hour. These records shall be submitted to the District with the production lot test results submitted in accordance with established procedures.

3.3.2 Electrical insulating sleeves shall be installed to prevent metallic contact between the rail bearing plate and those items which can be expected to have earth contacts such as anchor bolts, anchor bolt inserts and steel bottom plate (non-bearing), if used.

3.3.3 A removable, reusable cover shall be provided for the exposed anchor bolt, steel nut and steel washer. The cover shall be one piece, molded from a reinforced polymeric plastic and shall be threaded internally to match anchor bolt threads. The cover shall be sized and shaped such that when secured to the top several threads of the anchor bolt, steel washer and nut are completely encased within the cap. The cap shall be of sufficient length to fit over various lengths of exposed anchor bolt and still result in a compressed seal between the base of the cap and the top of the elastomer.

3.4 Rail Hold Down Devices

These devices shall be positioned such that they do not have metallic contact to anchor bolts or to ground. Hold down devices shall not provide openings or crevices which will permit excessive accumulation of moisture, dirt or debris.

Part 4. Electrical Tests

4.1 Anchor Bolts and Inserts

4.1.1 Epoxy coated anchor bolts and inserts shall be tested for coating thickness, hardness and imperfections in accordance with the following.

4.1.1.1 Thickness tests shall be performed at a sufficient number of locations on the sample to ensure the coating thickness is adequately defined. The measurements shall be made using a magnetic coating thickness gauge. Coating thickness shall be a minimum of 10 mils and a maximum of 20 mils to be considered as acceptable.

4.1.1.2 Visual inspection of the coated items shall be performed. Any item showing epoxy coating with runs, sags or chips will not be acceptable.

4.1.1.3 Epoxy coating shall have a hardness of not less than 85 nor greater than 90 Shore D when measured in accordance with ASTM Designation D2240, Rubber Property-Durometer Hardness.

4.1.1.4 Coated items shall be tested for imperfections using a low voltage spark type coating fault detector/electrode arrangement. Test voltage shall be between 50 and 100 volts DC. Any item that produces an indication of a coating fault when the electrode is passed over the coating shall be considered a failure.

4.1.2 The above tests shall be performed by the epoxy coating applicator and witnessed by the District's representative. The frequency of testing shall be in accordance with a sequential statistical quality control plan developed by the epoxy coating applicator and approved by the District. The plan shall ensure that the average defective rate of a batch shall not exceed two percent and that the maximum defective rate shall not exceed five percent. These defective rates shall be demonstrated at a 90 percent degree of confidence. The certified test results shall be submitted to the District in writing within seven days after the completion of each production lot.

4.2 Completed and Assembled Fasteners

4.2.1 General

The following tests shall be performed to determine the electrical resistance of the rail fastener. These tests shall be conducted on a minimum of six fully assembled fasteners each with an 18-inch length of 132 pound rail and installed on a concrete test block. A minimum of two of the six fasteners shall have been previously subjected to mechanical tests, which could possibly result in a degrading of the electrical insulating properties of the fastener because of the development of cracks, splits or separations that could result in areas where moisture could accumulate.

4.2.2 Applied Voltage Test

4.2.2.1 Procedure

a) Fully assembled rail fasteners as described in 4.2.1 shall be tested for electrical resistance.

b) Electrically ground both anchor bolts and apply 500 volts DC between the rail head and ground for three minutes. Measure the current flow to the nearest 0.1 microampere and calculate the resistance.

c) Release the fastener from the rail and test block and immerse the fastener in distilled water as follows:

- neoprene based elastomers: 70 hours at 100°C.

- Natural rubber and polyurethane based elastomers: 336 hours at 70°C.

d) After removal from the water immersion after the prescribed time interval, without drying, and with no portion of the fastener at a temperature less than 35°C, the fastener shall be reassembled on the test block complete with rail, and tested for electrical resistance.

e) Within 15 minutes after removal of the fastener from water immersion, and after assembly on the test block, ground both anchor bolts and apply 500 volts DC between the rail head and ground for three minutes. Actual current flow shall be measured and recorded to the nearest 0.1 microampere and the resistance calculated.

f) After procedures b) through e) have been completed, apply a 50 volt AC potential between the rail head and ground for three minutes of each increment of measurement for frequencies from 20 Hz to 10 kHz in increments of 20 Hz up to 100 Hz, 200 Hz up to 1,000 Hz and 2,000 Hz up to 10 kHz. The impedance after three minutes shall be measured with an accuracy of plus or minus two percent and recorded for each frequency.

4.2.2.2 Test Acceptance Criteria: The minimum resistance for 500 volts DC shall be 10 megohms when dry and 1.2 megohms when wet. The minimum impedance for and frequency between 20 Hz and 10 kHz with 50 volts AC shall be 10,000 ohms.

4.2.3 Resistance Tests Under Simulated Atmospheric Conditions

Rail fasteners including an 18-inch length of 132 pound rail shall be assembled on a concrete test block simulating the grout pad. Six units should be so assembled. The rail section lengths shall be greater than the width of the concrete blocks (a minimum of 1.0 foot).

4.2.3.1 Procedure

a) The concrete blocks shall be placed upright in a bare (uncoated) metal trough with a minimum clearance of 4-inches between the walls of the trough and the other blocks, if more than one block is positioned in one trough. The trough shall be leveled and water poured into the trough taking care to ensure the fastener components are not wetted. The water may be regular tap water. Water shall be placed in the trough to fill it to approximately 1-inch below the top of the concrete block measured at the center of the rail. The water shall be maintained at this level for the duration of the tests.

b) Immediately upon filling the trough, the resistance shall be measured between each of the six rail assemblies and the metal trough using a 500 volt "Meggar" Insulator Tester as manufactured by James J. Biddle Company, Philadelphia, PA or equal. The measurements shall be repeated three times a day scheduled for a minimun of three days or until the resistance stabilizes for a period of three consecutive measurments (±5%). The rail fasteners shall have not less than 10 megohm insulation resistance between any rail and the metal trough under these conditions.

c) The fasteners shall be subjected to an evenly distributed fine mist spray for one hour's time which will provide the water at a rate of 1-inch per hour for the area covered. The water used shall have a resistivity within the

10,000 to 20,000 ohm-centimeter range and a temperature in the 16°C to 27°C range. (The water accumulation within the trough shall not be allowed to exceed the stated level of 1-inch below the top of the grout pad). Within five minutes of stopping the spray, the resistance of each fastener shall be measured in accordance with the previously established procedure. The resistance measurements shall be repeated three times at 15 minute intervals. The general environmental condition during the resistance measurement period shall be within the range of 16°C to 27°C and a relative humidity of 70 to 90%. The electrical resistance of the fasteners during these tests shall not be less than 400,000 ohms.

d) The fasteners shall be subjected to heat lamps placed directly above the fasteners to dry them. The positioning of the lamps and the heating intensity shall be adjusted to ensure the rail and fastener components do not exceed 44°C. The resistance of the fasteners shall be measured at regular intervals (starting at ½ hour intervals for a minimum of five measurements) until the resistance returns to the original dry minimum of 10 megohms, which must be restored within a maximum time of 10 hours. At no time shall the fasteners be wiped, brushed or in any way cleaned of any residue which may collect during these tests.

e) The tests described in c) and d) shall be repeated three times on the same fasteners without cleaning or disturbing the test conditions in any manner.

4.2.3.2 Acceptance shall consist of obtaining the resistance values stated under the conditions and time constraints specified for each of the three tests described in sections 4.2.3.1.a and b, 4.2.3.1.c and 4.2.3.1.d.