# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0633LAB***
***7-Jul-11***

| **Sample ID** | | | S-104<br>@ 86-87'<br>ML | S-104<br>@ 97-98'<br>ML | S-109<br>@ 30-31'<br>CL | S-109<br>@ 53-54'<br>CL | S-109<br>@ 65-66'<br>ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,520 | 1,320 | 1,480 | 1,440 | 1,640 |
| saturated | | ohm-cm | 352 | 220 | 1,480 | 1,200 | 1,160 |
| **pH** | | | 3.7 | 5.1 | 6.7 | 7.1 | 7.0 |
| **Electrical Conductivity** | | mS/cm | 2.22 | 3.21 | 0.07 | 0.06 | 0.10 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 935 | 843 | 24 | 24 | 37 |
| magnesium | $Mg^{2+}$ | mg/kg | 644 | 848 | 7.6 | 7.8 | 11 |
| sodium | $Na^{1+}$ | mg/kg | 585 | 1,561 | 64 | 46 | 58 |
| potassium | $K^{1+}$ | mg/kg | 195 | 278 | 2.4 | 6.7 | 6.6 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | ND | 43 | 76 | 73 | 82 |
| fluoride | $F^{1-}$ | mg/kg | 10 | ND | 4.0 | 4.3 | 4.1 |
| chloride | $Cl^{1-}$ | mg/kg | 109 | 634 | 15 | 8.8 | 17 |
| sulfate | $SO_4^{2-}$ | mg/kg | 6,721 | 7,926 | 53 | 49 | 84 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND | 2.0 | 2.7 | 2.0 |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 76 | 98 | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | ND | ND | ND | 1.6 | ND |
| sulfide | $S^{2-}$ | qual | Trace | Trace | na | na | na |
| Redox | | mV | -37 | -46 | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

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***7-Jul-11***

| **Sample ID** | | | S-109<br>@ 77-78'<br>ML | S-109<br>@ 92-93'<br>ML | S-113<br>@ 98.5-99.5'<br>CL-ML | S-113<br>@ 114.3-115.3'<br>CL | S-114<br>@ 27-28'<br>SM |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 4,200 | 2,440 | 2,200 | 1,840 | 312,000 |
| saturated | | ohm-cm | 2,520 | 2,400 | 1,480 | 1,120 | 22,400 |
| **pH** | | | 7.2 | 4.0 | 6.9 | 7.3 | 7.7 |
| **Electrical Conductivity** | | mS/cm | 0.06 | 0.08 | 0.04 | 0.06 | 0.03 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 27 | 31 | 21 | 43 | 27 |
| magnesium | $Mg^{2+}$ | mg/kg | 7.6 | 9.2 | 6.4 | 10 | 5.6 |
| sodium | $Na^{1+}$ | mg/kg | 41 | 46 | 34 | 40 | 14 |
| potassium | $K^{1+}$ | mg/kg | 5.6 | 5.8 | 7.9 | 17 | 6.9 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 61 | 70 | 49 | 92 | 52 |
| fluoride | $F^{1-}$ | mg/kg | 4.7 | 2.6 | 4.4 | 3.4 | 0.9 |
| chloride | $Cl^{1-}$ | mg/kg | 12 | 20 | 13 | 3.7 | 3.4 |
| sulfate | $SO_4^{2-}$ | mg/kg | 56 | 79 | 26 | 27 | 20 |
| phosphate | $PO_4^{3-}$ | mg/kg | 2.0 | 1.6 | 3.1 | 4.7 | 2.1 |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 0.8 | ND | 1.0 | ND | ND |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

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***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0633LAB***
***7-Jul-11***

| **Sample ID** | | | S-114<br>@ 49-50'<br>CL | S-114<br>@ 61-62'<br>CL/ML | S-114<br>@ 83-84'<br>ML | S-115<br>@19-20'<br>ML | S-115<br>@ 39-40'<br>SM |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,680 | 2,600 | 1,840 | 1,880 | 128,000 |
| saturated | | ohm-cm | 1,680 | 1,880 | 1,160 | 1,600 | 5,600 |
| **pH** | | | 7.3 | 7.3 | 7.6 | 7.1 | 7.2 |
| **Electrical Conductivity** | | mS/cm | 0.09 | 0.07 | 0.20 | 0.06 | 0.05 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 45 | 34 | 92 | 38 | 22 |
| magnesium | $Mg^{2+}$ | mg/kg | 11 | 7.4 | 18 | 21 | 6.4 |
| sodium | $Na^{1+}$ | mg/kg | 54 | 43 | 72 | 91 | 64 |
| potassium | $K^{1+}$ | mg/kg | 10 | 11 | 24 | 3.4 | 3.1 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | 9.0 | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 64 | 49 | 265 | 73 | 64 |
| fluoride | $F^{1-}$ | mg/kg | 3.4 | 4.5 | 6.3 | 12 | 5.7 |
| chloride | $Cl^{1-}$ | mg/kg | 22 | 13 | 9.2 | 3.8 | 3.1 |
| sulfate | $SO_4^{2-}$ | mg/kg | 83 | 72 | 94 | 14 | 19 |
| phosphate | $PO_4^{3-}$ | mg/kg | 3.1 | 2.9 | 1.4 | 19 | 15 |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 3.3 | 2.4 | 3.9 | ND | ND |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0633LAB***
***7-Jul-11***

| **Sample ID** | | | S-115<br>@ 68-69'<br>ML | S-115<br>@ 96-97'<br>ML | S-115<br>@ 116-117'<br>ML | S-118<br>@ 75-76'<br>SP/SM with<br>tar | S-118<br>@ 89-90'<br>ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 2,840 | 3,760 | 4,400 | 4,400,000 | 3,400 |
| saturated | | ohm-cm | 1,280 | 1,880 | 1,760 | na* | 212 |
| **pH** | | | 7.3 | 7.3 | 7.4 | na* | 7.1 |
| **Electrical** | | | | | | na* | |
| **Conductivity** | | mS/cm | 0.07 | 0.08 | 0.07 | na* | 3.37 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 38 | 35 | 35 | na* | 783 |
| magnesium | $Mg^{2+}$ | mg/kg | 11 | 13 | 12 | na* | 343 |
| sodium | $Na^{1+}$ | mg/kg | 41 | 44 | 35 | na* | 2,634 |
| potassium | $K^{1+}$ | mg/kg | 6.0 | 11 | 13 | na* | 170 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | na* | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 73 | 128 | 64 | na* | 442 |
| fluoride | $F^{1-}$ | mg/kg | 3.5 | 4.4 | 4.2 | na* | ND |
| chloride | $Cl^{1-}$ | mg/kg | 11 | 16 | 8.3 | na* | 2,958 |
| sulfate | $SO_4^{2-}$ | mg/kg | 47 | 85 | 68 | na* | 4,155 |
| phosphate | $PO_4^{3-}$ | mg/kg | 2.4 | 1.8 | 1.7 | na* | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | na* | 49 |
| nitrate | $NO_3^{1-}$ | mg/kg | 1.4 | 2.7 | 1.1 | na* | ND |
| sulfide | $S^{2-}$ | qual | na | na | na | na* | na |
| Redox | | mV | na | na | na | na* | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
na *= Tar sample was hydrophobic. Therefore aqueous extraction of chemical content was incomplete.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0633LAB***
***7-Jul-11***

| **Sample ID** | | | S-118<br>@ 99-100'<br>ML |
|---|---|---|---|
| **Resistivity** | | **Units** | |
| as-received | | ohm-cm | 3,240 |
| saturated | | ohm-cm | 192 |
| **pH** | | | 7.0 |
| **Electrical Conductivity** | | mS/cm | 2.24 |
| **Chemical Analyses** | | | |
| **Cations** | | | |
| calcium | $Ca^{2+}$ | mg/kg | 192 |
| magnesium | $Mg^{2+}$ | mg/kg | 163 |
| sodium | $Na^{1+}$ | mg/kg | 2,151 |
| potassium | $K^{1+}$ | mg/kg | 156 |
| **Anions** | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 323 |
| fluoride | $F^{1-}$ | mg/kg | ND |
| chloride | $Cl^{1-}$ | mg/kg | 2,168 |
| sulfate | $SO_4^{2-}$ | mg/kg | 2,096 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND |
| **Other Tests** | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 47 |
| nitrate | $NO_3^{1-}$ | mg/kg | ND |
| sulfide | $S^{2-}$ | qual | na |
| Redox | | mV | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
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***Your #4953-10-1561, HDR|Schiff #11-0647LAB***
***8-Jul-11***

| **Sample ID** | | | G-102<br>@ 25.5'<br>CL | G-104<br>@ 10.5'<br>CL | G-104<br>@ 40.5'<br>CL/ML | G-104<br>@ 86'<br>ML | G-108<br>@ 65.5'<br>Sandy ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 2,000 | 2,320 | 9,200 | 1,160 | 680 |
| saturated | | ohm-cm | 1,400 | 560 | 1,200 | 420 | 480 |
| **pH** | | | 7.3 | 7.4 | 8.0 | 7.5 | 4.0 |
| **Electrical Conductivity** | | mS/cm | 0.08 | 0.24 | 0.23 | 2.03 | 2.19 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 23 | 28 | 89 | 1,089 | 1,353 |
| magnesium | $Mg^{2+}$ | mg/kg | 11 | 14 | 20 | 418 | 547 |
| sodium | $Na^{1+}$ | mg/kg | 75 | 219 | 117 | 753 | 256 |
| potassium | $K^{1+}$ | mg/kg | 5.6 | 2.1 | 31 | 147 | 88 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | 9.0 | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 85 | 125 | 242 | 232 | ND |
| fluoride | $F^{1-}$ | mg/kg | 3.7 | 2.7 | 1.6 | 1.7 | 18 |
| chloride | $Cl^{1-}$ | mg/kg | 14 | 217 | 34 | 142 | 64 |
| sulfate | $SO_4^{2-}$ | mg/kg | 87 | 78 | 208 | 5,333 | 6,599 |
| phosphate | $PO_4^{3-}$ | mg/kg | 2.5 | 2.9 | ND | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | 4.1 | 46 | 34 |
| nitrate | $NO_3^{1-}$ | mg/kg | 0.5 | 1.2 | 0.5 | ND | ND |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
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***MACTEC Engineering, Inc.***
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***8-Jul-11***

| **Sample ID** | | | G-109 @ 105.5' ML | G-109 @ 125' Clayey ML | G-111 @ 50' SM/Sandy ML | G-111 @70' SP-SM | G-111 @ 90' Clayey ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 560 | 560 | 1,640 | 2,800 | 1,160 |
| saturated | | ohm-cm | 208 | 156 | 1,480 | 2,160 | 280 |
| **pH** | | | 7.1 | 4.6 | 7.7 | 7.7 | 3.2 |
| **Electrical Conductivity** | | mS/cm | 2.52 | 3.39 | 0.18 | 0.14 | 2.38 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 341 | 425 | 62 | 55 | 927 |
| magnesium | $Mg^{2+}$ | mg/kg | 149 | 324 | 23 | 18 | 658 |
| sodium | $Na^{1+}$ | mg/kg | 2,281 | 3,022 | 89 | 57 | 856 |
| potassium | $K^{1+}$ | mg/kg | 228 | 268 | 20 | 13 | 13 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 403 | 61 | 299 | 119 | ND |
| fluoride | $F^{1-}$ | mg/kg | ND | ND | 2.6 | 1.4 | 20 |
| chloride | $Cl^{1-}$ | mg/kg | 1,503 | 2,384 | 20 | 18 | 241 |
| sulfate | $SO_4^{2-}$ | mg/kg | 3,616 | 5,440 | 146 | 167 | 6,915 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND | ND | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 59 | 99 | 5.5 | 1.6 | 69 |
| nitrate | $NO_3^{1-}$ | mg/kg | ND | ND | 0.5 | 11 | 21 |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
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***MACTEC Engineering, Inc.***
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***8-Jul-11***

| **Sample ID** | | | G-112 @ 10' SM | G-112 @ 25' CL | G-112 @ 45' Sandy CL | G-112 @ 75' SP-SM/SM | G-112 @ 105' ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 2,720 | 1,280 | 2,920 | 3,000 | 570 |
| saturated | | ohm-cm | 1,640 | 1,000 | 1,520 | 2,120 | 244 |
| **pH** | | | 7.2 | 7.4 | 7.8 | 7.8 | 7.4 |
| **Electrical Conductivity** | | mS/cm | 0.21 | 0.20 | 0.16 | 0.15 | 3.03 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 51 | 69 | 71 | 77 | 1,170 |
| magnesium | $Mg^{2+}$ | mg/kg | 20 | 20 | 20 | 15 | 428 |
| sodium | $Na^{1+}$ | mg/kg | 157 | 121 | 81 | 62 | 1,794 |
| potassium | $K^{1+}$ | mg/kg | 4.6 | 7.9 | 13 | 14 | 241 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | 21 | 18 | 9.0 | 9.0 | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 169 | 217 | 231 | 119 | 464 |
| fluoride | $F^{1-}$ | mg/kg | 1.8 | 3.6 | 1.5 | 1.2 | ND |
| chloride | $Cl^{1-}$ | mg/kg | 69 | 19 | 15 | 11 | 888 |
| sulfate | $SO_4^{2-}$ | mg/kg | 165 | 161 | 107 | 204 | 6,509 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND | 0.7 | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | 1.3 | 69 |
| nitrate | $NO_3^{1-}$ | mg/kg | 20 | 5.5 | 5.6 | 3.5 | 13 |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
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***8-Jul-11***

| **Sample ID** | | | G-123<br>@ 41'<br>Tar Sand | G-123<br>@ 47'<br>Tar Sand | G-123<br>@ 63'<br>Tar Sand | G-124<br>@ 35'<br>CL w/Tar | G-124<br>@ 55'<br>SP w/Tar |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,680,000 | 18,400 | 3,240,000 | 10,400 | 4,400,000 |
| saturated | | ohm-cm | 13,200 | 2,680 | 3,640 | 1,200 | 8,000 |
| **pH** | | | 4.9 | 5.5 | 7.0 | 7.5 | 3.3 |
| **Electrical Conductivity** | | mS/cm | 0.11 | 0.11 | 0.43 | 0.27 | 0.49 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 45 | 38 | 196 | 67 | 240 |
| magnesium | $Mg^{2+}$ | mg/kg | 33 | 30 | 42 | 59 | 119 |
| sodium | $Na^{1+}$ | mg/kg | 13 | 34 | 174 | 113 | 55 |
| potassium | $K^{1+}$ | mg/kg | 0.9 | 1.9 | 6.9 | 13 | 7.3 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | ND | 12 | 15 | 64 | ND |
| fluoride | $F^{1-}$ | mg/kg | ND | ND | ND | 0.9 | 2.8 |
| chloride | $Cl^{1-}$ | mg/kg | 1.2 | 5.2 | 49 | 6.5 | 4.4 |
| sulfate | $SO_4^{2-}$ | mg/kg | 244 | 230 | 833 | 544 | 1,183 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND | ND | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 0.9 | 0.9 | 6.8 | 4.2 | 4.8 |
| nitrate | $NO_3^{1-}$ | mg/kg | 5.0 | 0.8 | ND | 6.5 | 1.4 |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

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***MACTEC Engineering, Inc.***
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***8-Jul-11***

| **Sample ID** | | | G-125<br>@ 56'<br>Clayey ML | G-125<br>@ 68.5'<br>SM | G-125<br>@ 86'<br>SP | G-136<br>@ 65'<br>CL/CL-CH | G-136<br>@ 105'<br>SM |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,640 | 1,280 | 1,080 | 1,640 | 3,920 |
| saturated | | ohm-cm | 720 | 1,120 | 392 | 960 | 3,440 |
| **pH** | | | 7.6 | 7.8 | 2.1 | 7.4 | 7.8 |
| **Electrical Conductivity** | | mS/cm | 0.38 | 0.26 | 2.40 | 0.25 | 0.10 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | Ca2+ | mg/kg | 125 | 52 | 1,589 | 83 | 43 |
| magnesium | Mg2+ | mg/kg | 30 | 13 | 343 | 29 | 12 |
| sodium | Na1+ | mg/kg | 213 | 183 | 24 | 121 | 52 |
| potassium | K1+ | mg/kg | 39 | 15 | 5.2 | 28 | 7.3 |
| **Anions** | | | | | | | |
| carbonate | CO32- | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | HCO31 | mg/kg | 223 | 317 | ND | 390 | 113 |
| fluoride | F1- | mg/kg | 2.7 | 2.5 | 22 | 6.8 | 1.7 |
| chloride | Cl1- | mg/kg | 8.8 | 15 | 12 | 27 | 23 |
| sulfate | SO42- | mg/kg | 667 | 249 | 8,074 | 157 | 82 |
| phosphate | PO43- | mg/kg | ND | 0.5 | ND | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | NH41+ | mg/kg | 7.2 | 6.5 | 4.4 | 1.6 | ND |
| nitrate | NO31- | mg/kg | 0.6 | 4.2 | ND | 0.6 | 2.3 |
| sulfide | S2- | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0647LAB***
***8-Jul-11***

| **Sample ID** | | | G-142<br>@ 50.5'<br>CL-ML | G-142<br>@ 70.5'<br>Gravelly CL | G-143<br>@ 20.5'<br>CL w/Gravel | G-143<br>@ 40.5'<br>SP/SW | G-143<br>@ 80.5'<br>Sandy ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,320 | 5,200 | 6,000 | 144,000 | 2,480 |
| saturated | | ohm-cm | 880 | 1,520 | 2,600 | 4,040 | 1,600 |
| **pH** | | | 7.6 | 7.8 | 7.6 | 7.8 | 7.4 |
| **Electrical Conductivity** | | mS/cm | 0.24 | 0.21 | 0.07 | 0.08 | 0.10 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | Ca2+ | mg/kg | 95 | 102 | 24 | 29 | 43 |
| magnesium | Mg2+ | mg/kg | 30 | 25 | 5.6 | 9.2 | 15 |
| sodium | Na1+ | mg/kg | 91 | 74 | 74 | 53 | 51 |
| potassium | K1+ | mg/kg | 39 | 26 | 2.6 | 5.4 | 6.8 |
| **Anions** | | | | | | | |
| carbonate | CO32- | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | HCO31 | mg/kg | 125 | 195 | 67 | 37 | 49 |
| fluoride | F1- | mg/kg | 1.8 | 1.5 | 5.1 | 2.3 | 3.3 |
| chloride | Cl1- | mg/kg | 15 | 23 | 8.4 | 9.2 | 21 |
| sulfate | SO42- | mg/kg | 405 | 297 | 59 | 104 | 119 |
| phosphate | PO43- | mg/kg | ND | ND | 8.6 | 1.8 | 2.6 |
| **Other Tests** | | | | | | | |
| ammonium | NH41+ | mg/kg | 1.8 | ND | ND | ND | ND |
| nitrate | NO31- | mg/kg | 2.1 | 11 | 41 | 18 | 3.3 |
| sulfide | S2- | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

*MACTEC Engineering, Inc.*
*Westside Extension*
*Your #4953-10-1561, HDR|Schiff #11-0647LAB*
*8-Jul-11*

| **Sample ID** | | | G-146<br>@ 66'<br>CL-ML<br>w/Sand | G-146<br>@ 78.5'<br>Clayey ML | G-166<br>@ 57'<br>CL/CL-CH | S-103A<br>@ 86-87'<br>ML | S-103A<br>@ 111-112'<br>ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,280 | 4,800 | 1,360 | 1,360 | 1,160 |
| saturated | | ohm-cm | 1,120 | 1,840 | 1,040 | 408 | 244 |
| **pH** | | | 7.3 | 7.0 | 6.5 | 6.9 | 5.0 |
| **Electrical Conductivity** | | mS/cm | 0.11 | 0.09 | 0.09 | 1.20 | 2.39 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | Ca2+ | mg/kg | 45 | 39 | 32 | 164 | 481 |
| magnesium | Mg2+ | mg/kg | 13 | 11 | 10 | 106 | 320 |
| sodium | Na1+ | mg/kg | 69 | 51 | 73 | 827 | 1,748 |
| potassium | K1+ | mg/kg | 7.8 | 13 | 10 | 168 | 321 |
| **Anions** | | | | | | | |
| carbonate | CO32- | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | HCO31 | mg/kg | 79 | 79 | 67 | 201 | ND |
| fluoride | F1- | mg/kg | 3.7 | 3.1 | 7.4 | ND | ND |
| chloride | Cl1- | mg/kg | 19 | 11 | 23 | 349 | 599 |
| sulfate | SO42- | mg/kg | 134 | 94 | 79 | 1,637 | 5,384 |
| phosphate | PO43- | mg/kg | 2.5 | 2.1 | 5.6 | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | NH41+ | mg/kg | ND | ND | ND | 62 | 107 |
| nitrate | NO31- | mg/kg | 2.8 | 1.1 | 6.0 | 0.7 | 105 |
| sulfide | S2- | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0674LAB***
***14-Jul-11***

| **Sample ID** | | | G-101<br>@ 33.5'<br>CL | G-101<br>@ 43.5'<br>CL-ML | G-101<br>@ 63.5'<br>SP-SM | G-114<br>@ 33.5'<br>CL | G-114<br>@ 53.5'<br>ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,280 | 1,520 | 1,280 | 1,520 | 1,160 |
| saturated | | ohm-cm | 720 | 600 | 920 | 1,080 | 1,040 |
| **pH** | | | 8.2 | 8.2 | 7.1 | 7.8 | 8.3 |
| **Electrical Conductivity** | | mS/cm | 0.22 | 0.37 | 0.32 | 0.17 | 0.19 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 48 | 110 | 73 | 55 | 67 |
| magnesium | $Mg^{2+}$ | mg/kg | 20 | 53 | 29 | 15 | 15 |
| sodium | $Na^{1+}$ | mg/kg | 136 | 148 | 180 | 103 | 101 |
| potassium | $K^{1+}$ | mg/kg | 20 | 40 | 26 | 7.8 | 26 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | 18 | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 250 | 143 | 12 | 217 | 271 |
| fluoride | $F^{1-}$ | mg/kg | 1.5 | 1.3 | 1.1 | 2.1 | 1.7 |
| chloride | $Cl^{1-}$ | mg/kg | 15 | 20 | 71 | 20 | 2.4 |
| sulfate | $SO_4^{2-}$ | mg/kg | 251 | 664 | 557 | 94 | 171 |
| phosphate | $PO_4^{3-}$ | mg/kg | 0.6 | ND | 3.4 | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 1.7 | 4.9 | 1.7 | ND | 0.9 |
| nitrate | $NO_3^{1-}$ | mg/kg | 0.9 | 0.6 | 5.4 | 3.9 | 3.5 |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0674LAB***
***14-Jul-11***

| **Sample ID** | | | G-114<br>@ 77.5'<br>SP-SM | G-114<br>@ 89'<br>ML | G-114<br>@ 100.5'<br>CL-ML | G-139<br>@ 60'<br>CL | G-139<br>@ 70'<br>CL |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 3,200 | 1,240 | 880 | 1,800 | 2,600 |
| saturated | | ohm-cm | 1,760 | 332 | 248 | 1,800 | 1,880 |
| **pH** | | | 7.9 | 5.2 | 5.9 | 7.6 | 7.7 |
| **Electrical Conductivity** | | mS/cm | 0.18 | 2.35 | 2.40 | 0.11 | 0.13 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 59 | 730 | 629 | 60 | 61 |
| magnesium | $Mg^{2+}$ | mg/kg | 14 | 571 | 493 | 13 | 16 |
| sodium | $Na^{1+}$ | mg/kg | 81 | 935 | 1,427 | 65 | 70 |
| potassium | $K^{1+}$ | mg/kg | 21 | 196 | 217 | 6.5 | 11 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | 12 | 9.0 |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 104 | 40 | 58 | 229 | 279 |
| fluoride | $F^{1-}$ | mg/kg | 1.0 | 3.9 | 0.7 | 3.0 | 2.5 |
| chloride | $Cl^{1-}$ | mg/kg | 13 | 285 | 625 | 5.0 | 3.4 |
| sulfate | $SO_4^{2-}$ | mg/kg | 256 | 5,751 | 5,688 | 17 | 14 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND | ND | 1.5 | 1.7 |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 1.1 | 742 | 74 | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 21 | ND | 3.5 | ND | ND |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0674LAB***
***14-Jul-11***

| **Sample ID** | | | G-139<br>@ 80'<br>CL | G-189<br>@ 10'<br>ML | G-189<br>@ 40'<br>SW | G-189<br>@ 70'<br>ML | G-189<br>@ 100'<br>CL |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,920 | 1,760 | 28,400 | 2,280 | 1,720 |
| saturated | | ohm-cm | 1,920 | 1,760 | 4,800 | 2,280 | 1,400 |
| **pH** | | | 7.9 | 7.6 | 7.6 | 7.3 | 7.2 |
| **Electrical Conductivity** | | mS/cm | 0.14 | 0.06 | 0.04 | 0.04 | 0.05 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 67 | 49 | 20 | 22 | 30 |
| magnesium | $Mg^{2+}$ | mg/kg | 15 | 7.8 | 6.2 | 5.5 | 6.8 |
| sodium | $Na^{1+}$ | mg/kg | 70 | 29 | 33 | 32 | 35 |
| potassium | $K^{1+}$ | mg/kg | 10 | 3.5 | 3.2 | 46 | 10 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | 12 | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 263 | 143 | 70 | 46 | 67 |
| fluoride | $F^{1-}$ | mg/kg | 0.9 | 2.5 | 2.8 | 2.5 | 3.4 |
| chloride | $Cl^{1-}$ | mg/kg | 10 | 1.7 | 6.3 | 11 | 5.6 |
| sulfate | $SO_4^{2-}$ | mg/kg | 36 | 14 | 19 | 33 | 54 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | 3.6 | 4.7 | 2.0 | 2.1 |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | ND | 10 | 22 | 2.5 | 2.7 |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0674LAB***
***14-Jul-11***

| **Sample ID** | | | G-191 @ 15-16.5' SP | G-191 @ 45-46.5' SP-SM | G-191 @ 95-96' CL-ML |
|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | |
| as-received | | ohm-cm | 5,200 | 13,200 | 880 |
| saturated | | ohm-cm | 3,680 | 5,200 | 880 |
| **pH** | | | 7.8 | 7.7 | 7.6 |
| **Electrical Conductivity** | | mS/cm | 0.10 | 0.05 | 0.12 |
| **Chemical Analyses** | | | | | |
| **Cations** | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 69 | 19 | 48 |
| magnesium | $Mg^{2+}$ | mg/kg | 11 | 3.7 | 11 |
| sodium | $Na^{1+}$ | mg/kg | 36 | 45 | 61 |
| potassium | $K^{1+}$ | mg/kg | 12 | 2.3 | 11 |
| **Anions** | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 229 | 55 | 140 |
| fluoride | $F^{1-}$ | mg/kg | 2.3 | 3.5 | 4.6 |
| chloride | $Cl^{1-}$ | mg/kg | 2.2 | 5.0 | 11 |
| sulfate | $SO_4^{2-}$ | mg/kg | 45 | 6.1 | 103 |
| phosphate | $PO_4^{3-}$ | mg/kg | 4.1 | 3.6 | 3.0 |
| **Other Tests** | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 28 | 22 | 3.9 |
| sulfide | $S^{2-}$ | qual | na | na | na |
| Redox | | mV | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0673LAB***
***14-Jul-11***

| **Sample ID** | | | G-113<br>@ 25.5'<br>CL | G-113<br>@ 45.5'<br>ML | G-113<br>@ 75.5'<br>SM | G-113<br>@ 85.5'<br>CL | G-128<br>@ 25.5'<br>CL-ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 8,800 | 1,880 | 2,680 | 840 | 1,880 |
| saturated | | ohm-cm | 1,720 | 1,200 | 800 | 400 | 1,760 |
| **pH** | | | 6.9 | 7.5 | 4.2 | 5.5 | 7.4 |
| **Electrical Conductivity** | | mS/cm | 0.04 | 0.16 | 1.13 | 1.85 | 0.15 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 22 | 70 | 774 | 740 | 38 |
| magnesium | $Mg^{2+}$ | mg/kg | 8.2 | 17 | 233 | 461 | 17 |
| sodium | $Na^{1+}$ | mg/kg | 40 | 78 | 83 | 755 | 123 |
| potassium | $K^{1+}$ | mg/kg | 3.1 | 25 | 28 | 159 | 7.1 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | 12 | ND | ND | 23 |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 88 | 224 | ND | ND | 192 |
| fluoride | $F^{1-}$ | mg/kg | 2.1 | 1.6 | 5.1 | 2.1 | 2.7 |
| chloride | $Cl^{1-}$ | mg/kg | 6.9 | 23 | 20 | 258 | 20 |
| sulfate | $SO_4^{2-}$ | mg/kg | 14 | 101 | 2,301 | 3,147 | 50 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND | ND | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | 5.0 | 8.0 | 61 | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | ND | 2.5 | 5.2 | 0.5 | ND |
| sulfide | $S^{2-}$ | qual | na | na | Trace | na | na |
| Redox | | mV | na | na | 10 | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0673LAB***
***14-Jul-11***

| **Sample ID** | | | G-128<br>@ 50.5'<br>SC | G-128<br>@ 80.5'<br>CL | G-129<br>@ 20'<br>CL | G-129<br>@ 40'<br>ML | G-129<br>@ 70'<br>ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,360 | 680 | 2,120 | 3,200 | 1,520 |
| saturated | | ohm-cm | 1,240 | 520 | 1,160 | 560 | 840 |
| **pH** | | | 7.9 | 7.6 | 7.8 | 7.9 | 7.8 |
| **Electrical Conductivity** | | mS/cm | 0.21 | 0.58 | 0.19 | 0.25 | 0.25 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 46 | 212 | 45 | 63 | 70 |
| magnesium | $Mg^{2+}$ | mg/kg | 28 | 111 | 22 | 33 | 39 |
| sodium | $Na^{1+}$ | mg/kg | 135 | 214 | 130 | 145 | 114 |
| potassium | $K^{1+}$ | mg/kg | 13 | 47 | 8.8 | 32 | 22 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | 21 | 9.0 | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 183 | 262 | 229 | 220 | 159 |
| fluoride | $F^{1-}$ | mg/kg | 1.7 | 2.0 | 4.3 | 2.5 | 0.9 |
| chloride | $Cl^{1-}$ | mg/kg | 9.4 | 11 | 56 | 27 | 67 |
| sulfate | $SO_4^{2-}$ | mg/kg | 316 | 1,120 | 47 | 274 | 329 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND | ND | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 2.3 | 6.2 | ND | 1.2 | 2.6 |
| nitrate | $NO_3^{1-}$ | mg/kg | 4.1 | 2.0 | 0.7 | 0.8 | 13 |
| sulfide | $S^{2-}$ | qual | Positive | Trace | na | na | na |
| Redox | | mV | -108 | -97 | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0673LAB***
***14-Jul-11***

| **Sample ID** | | | G-129<br>@ 83.5'<br>CL | G-129<br>@ 100'<br>CL | G-186<br>@ 30.5'<br>CL | G-186<br>@ 75.5'<br>CL-ML | G-186<br>@ 85.5<br>CL |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 680 | 1,360 | 2,920 | 2,880 | 1,640 |
| saturated | | ohm-cm | 560 | 600 | 2,480 | 1,480 | 1,120 |
| **pH** | | | 7.8 | 7.8 | 7.9 | 7.7 | 7.7 |
| **Electrical Conductivity** | | mS/cm | 0.50 | 0.61 | 0.09 | 0.13 | 0.12 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 197 | 247 | 64 | 70 | 65 |
| magnesium | $Mg^{2+}$ | mg/kg | 87 | 134 | 11 | 16 | 15 |
| sodium | $Na^{1+}$ | mg/kg | 144 | 136 | 28 | 51 | 51 |
| potassium | $K^{1+}$ | mg/kg | 47 | 47 | 7.1 | 13 | 10 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | 12 | 9.0 | 9.0 |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 259 | 262 | 169 | 215 | 178 |
| fluoride | $F^{1-}$ | mg/kg | 1.8 | 1.2 | 1.7 | 4.6 | 0.8 |
| chloride | $Cl^{1-}$ | mg/kg | 78 | 50 | 2.1 | 3.5 | 7.0 |
| sulfate | $SO_4^{2-}$ | mg/kg | 807 | 1,104 | 24 | 51 | 62 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND | 3.3 | 2.1 | 2.0 |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 2.5 | 10 | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 4.5 | 2.6 | 0.8 | 1.9 | 1.6 |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

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*Corrosion Control and Condition Assessment (C3A) Department*

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0699LAB***
***20-Jul-11***

| **Sample ID** | | | G-110 @ 80.5' Clayey Siltstone | G-110 @ 90.5' Clayey Siltstone | G-110 @ 100.5' Clayey Siltstone | G-110 @ 110.5' Clayey Siltstone | G-135 @ 62' CL |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 960 | 760 | 600 | 480 | 1,120 |
| saturated | | ohm-cm | 480 | 368 | 216 | 228 | 1,120 |
| **pH** | | | 7.7 | 7.6 | 3.1 | 3.9 | 7.7 |
| **Electrical Conductivity** | | mS/cm | 1.33 | 1.39 | 2.77 | 2.52 | 0.18 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 538 | 330 | 628 | 407 | 54 |
| magnesium | $Mg^{2+}$ | mg/kg | 212 | 144 | 629 | 344 | 22 |
| sodium | $Na^{1+}$ | mg/kg | 664 | 950 | 1,844 | 1,976 | 97 |
| potassium | $K^{1+}$ | mg/kg | 101 | 147 | 194 | 266 | 18 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | 9.0 |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 381 | 314 | ND | 15 | 168 |
| fluoride | $F^{1-}$ | mg/kg | 1.6 | 0.8 | 14 | 2.8 | 8.8 |
| chloride | $Cl^{1-}$ | mg/kg | 197 | 399 | 724 | 901 | 33 |
| sulfate | $SO_4^{2-}$ | mg/kg | 2,183 | 2,055 | 7,712 | 5,313 | 50 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND | ND | ND | 0.7 |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 20 | 41 | 96 | 81 | 1.9 |
| nitrate | $NO_3^{1-}$ | mg/kg | 2.9 | 30 | 401 | ND | 1.1 |
| sulfide | $S^{2-}$ | qual | Positive | Positive | Positive | Positive | Negative |
| Redox | | mV | -106 | -44 | -86 | -98 | -21 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0699LAB***
***20-Jul-11***

| **Sample ID** | | | G-135 @ 86' CL | G-135 @ 92' SW | G-144 @ 10.5' CL-ML | G-144 @ 30.5' CL-ML | G-144 @ 50.5' Sandy CL |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 6,000 | 11,600 | 960 | 1,560 | 1,480 |
| saturated | | ohm-cm | 2,800 | 4,400 | 960 | 1,560 | 1,360 |
| **pH** | | | 8.1 | 7.8 | 7.6 | 7.6 | 7.5 |
| **Electrical Conductivity** | | mS/cm | 0.09 | 0.08 | 0.13 | 0.04 | 0.06 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 43 | 42 | 79 | 25 | 28 |
| magnesium | $Mg^{2+}$ | mg/kg | 15 | 12 | 17 | 7.5 | 8.3 |
| sodium | $Na^{1+}$ | mg/kg | 49 | 43 | 57 | 42 | 48 |
| potassium | $K^{1+}$ | mg/kg | 6.3 | 7.0 | 7.7 | 2.4 | 4.9 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 195 | 156 | 345 | 79 | 67 |
| fluoride | $F^{1-}$ | mg/kg | 3.9 | 2.1 | 5.6 | 5.1 | 4.0 |
| chloride | $Cl^{1-}$ | mg/kg | 13 | 23 | 2.0 | 6.8 | 13 |
| sulfate | $SO_4^{2-}$ | mg/kg | 35 | 62 | 33 | 12 | 56 |
| phosphate | $PO_4^{3-}$ | mg/kg | 3.1 | 1.7 | 3.8 | 6.3 | 2.5 |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | 1.1 | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | ND | 1.0 | 25 | 13 | 0.9 |
| sulfide | $S^{2-}$ | qual | Negative | Negative | Negative | Negative | Negative |
| Redox | | mV | 22 | 37 | 18 | 63 | 38 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0699LAB***
***20-Jul-11***

| **Sample ID** | | | G-144 | G-144 | G-144 | G-145 | G-145 |
|---|---|---|---|---|---|---|---|
| | | | @ 60.5' | @ 80.5' | @ 100.5' | @ 31.5' | @ 61.5' |
| | | | Sandy CL | CL | SC | Sandy CL | Sandy CL |
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,360 | 1,720 | 9,600 | 1,680 | 3,040 |
| saturated | | ohm-cm | 1,360 | 1,160 | 2,440 | 1,680 | 1,840 |
| **pH** | | | 7.5 | 7.5 | 7.6 | 7.7 | 7.8 |
| **Electrical Conductivity** | | mS/cm | 0.06 | 0.06 | 0.05 | 0.05 | 0.09 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 33 | 30 | 23 | 24 | 36 |
| magnesium | $Mg^{2+}$ | mg/kg | 10 | 9.0 | 6.8 | 6.3 | 0.5 |
| sodium | $Na^{1+}$ | mg/kg | 51 | 44 | 39 | 44 | 67 |
| potassium | $K^{1+}$ | mg/kg | 5.5 | 4.7 | 6.2 | 3.8 | 6.8 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 67 | 58 | 43 | 95 | 140 |
| fluoride | $F^{1-}$ | mg/kg | 4.5 | 5.3 | 2.0 | 2.3 | 3.1 |
| chloride | $Cl^{1-}$ | mg/kg | 15 | 13 | 11 | 8.4 | 13 |
| sulfate | $SO_4^{2-}$ | mg/kg | 62 | 49 | 46 | 12 | 57 |
| phosphate | $PO_4^{3-}$ | mg/kg | 3.1 | ND | 2.6 | 6.3 | 2.8 |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 0.5 | 2.1 | 1.5 | 20 | 3.2 |
| sulfide | $S^{2-}$ | qual | Negative | Negative | Negative | Negative | Negative |
| Redox | | mV | 60 | 31 | 56 | 80 | 57 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0699LAB***
***20-Jul-11***

| **Sample ID** | | | G-145<br>@ 95.5'<br>SM w/gravel | G-145<br>@ 115.5'<br>Sandy CL | G-148<br>@ 80.5'<br>Sandy<br>ML/SW | G-148<br>@ 90.5'<br>SM | G-148<br>@ 110.5'<br>CL-ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 5,600 | 1,000 | 1,680 | 2,040 | 1,160 |
| saturated | | ohm-cm | 2,840 | 1,000 | 1,680 | 1,920 | 1,160 |
| **pH** | | | 7.8 | 8.3 | 8.0 | 7.7 | 7.8 |
| **Electrical Conductivity** | | mS/cm | 0.06 | 0.15 | 0.07 | 0.07 | 0.07 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 22 | 65 | 28 | 29 | 32 |
| magnesium | $Mg^{2+}$ | mg/kg | 6.4 | 15 | 8.7 | 9.1 | 9.2 |
| sodium | $Na^{1+}$ | mg/kg | 42 | 75 | 46 | 44 | 51 |
| potassium | $K^{1+}$ | mg/kg | 3.8 | 22 | 3.8 | 5.0 | 7.0 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 58 | 253 | 67 | 52 | 125 |
| fluoride | $F^{1-}$ | mg/kg | 3.1 | 5.1 | 3.2 | 3.1 | 4.9 |
| chloride | $Cl^{1-}$ | mg/kg | 15 | 10 | 18 | 17 | 4.5 |
| sulfate | $SO_4^{2-}$ | mg/kg | 50 | 122 | 65 | 68 | 43 |
| phosphate | $PO_4^{3-}$ | mg/kg | 2.9 | 2.0 | 2.9 | 2.8 | 5.1 |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 1.9 | ND | 2.9 | 1.9 | 0.9 |
| sulfide | $S^{2-}$ | qual | Negative | Negative | Negative | Negative | Negative |
| Redox | | mV | 66 | 28 | 43 | 99 | 47 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0699LAB***
***20-Jul-11***

| **Sample ID** | | | G-148<br>@ 120.5'<br>SC | G-200 Alt<br>@ 70.5'<br>Sandy CL | G-200 Alt<br>@ 80.5'<br>SC | G-200 Alt<br>@ 90.5'<br>CL/ML | G-200 Alt<br>@ 100.5'<br>Sandy CL |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 4,800 | 2,200 | 3,880 | 1,760 | 1,760 |
| saturated | | ohm-cm | 1,440 | 2,200 | 3,400 | 1,760 | 640 |
| **pH** | | | 7.7 | 8.1 | 8.1 | 8.1 | 8.5 |
| **Electrical Conductivity** | | mS/cm | 0.11 | 0.09 | 0.09 | 0.18 | 0.31 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 63 | 67 | 58 | 92 | 156 |
| magnesium | $Mg^{2+}$ | mg/kg | 12 | 11 | 12 | 19 | 37 |
| sodium | $Na^{1+}$ | mg/kg | 69 | 46 | 43 | 70 | 104 |
| potassium | $K^{1+}$ | mg/kg | 13 | 5.6 | 13 | 24 | 52 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | 18 | 18 | 12 | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 259 | 160 | 160 | 302 | 290 |
| fluoride | $F^{1-}$ | mg/kg | 3.6 | 4.7 | 2.7 | 4.8 | 3.9 |
| chloride | $Cl^{1-}$ | mg/kg | 3.4 | 6.3 | 3.8 | 5.3 | 4.7 |
| sulfate | $SO_4^{2-}$ | mg/kg | 66 | 26 | 17 | 65 | 504 |
| phosphate | $PO_4^{3-}$ | mg/kg | 2.0 | ND | 1.9 | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND | 0.6 |
| nitrate | $NO_3^{1-}$ | mg/kg | ND | 1.8 | 0.7 | 0.7 | ND |
| sulfide | $S^{2-}$ | qual | Negative | Negative | Negative | Negative | Positive |
| Redox | | mV | 20 | 28 | 9 | 43 | -163 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1: soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0699LAB***
***20-Jul-11***

| **Sample ID** | | | G-203 | G-203 | G-203 | G-204 | G-204 |
|---|---|---|---|---|---|---|---|
| | | | @ 30' | @ 45.5' | @ 80.5' | @ 10' | @ 40' |
| | | | ML | SM | SM | ML | ML |
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 4,800 | 800 | 5,200 | 2,600 | 1,360 |
| saturated | | ohm-cm | 1,720 | 760 | 3,360 | 2,400 | 960 |
| **pH** | | | 8.0 | 7.5 | 8.0 | 7.4 | 7.1 |
| **Electrical Conductivity** | | mS/cm | 0.16 | 0.27 | 0.06 | 0.05 | 0.22 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 25 | 41 | 19 | 18 | 44 |
| magnesium | $Mg^{2+}$ | mg/kg | 8.7 | 21 | 7.2 | 9.1 | 26 |
| sodium | $Na^{1+}$ | mg/kg | 139 | 222 | 44 | 69 | 136 |
| potassium | $K^{1+}$ | mg/kg | 3.6 | 7.4 | 4.8 | 1.8 | 9.1 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 107 | 52 | 58 | 70 | 40 |
| fluoride | $F^{1-}$ | mg/kg | 7.8 | 3.3 | 2.7 | 12 | 3.7 |
| chloride | $Cl^{1-}$ | mg/kg | 43 | 242 | 16 | 2.1 | 115 |
| sulfate | $SO_4^{2-}$ | mg/kg | 150 | 250 | 50 | 7.3 | 264 |
| phosphate | $PO_4^{3-}$ | mg/kg | 6.6 | ND | 1.6 | 31 | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | ND | ND | 0.7 | ND | ND |
| sulfide | $S^{2-}$ | qual | Negative | Negative | Negative | Negative | Negative |
| Redox | | mV | 35 | 105 | 60 | 131 | 119 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1: soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0699LAB***
***20-Jul-11***

| **Sample ID** | | | G-204<br>@ 80'<br>CL | G-204<br>@ 100'<br>ML/CL | G-205<br>@ 35.5'<br>ML | G-205<br>@ 50'<br>ML | G-205<br>@ 95.5'<br>ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,400 | 1,880 | 840 | 12,000 | 1,560 |
| saturated | | ohm-cm | 1,400 | 1,880 | 760 | 3,560 | 1,560 |
| **pH** | | | 7.9 | 7.0 | 6.9 | 7.7 | 7.5 |
| **Electrical Conductivity** | | mS/cm | 0.08 | 0.09 | 0.34 | 0.07 | 0.07 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 36 | 33 | 41 | 19 | 30 |
| magnesium | $Mg^{2+}$ | mg/kg | 13 | 14 | 17 | 4.6 | 11 |
| sodium | $Na^{1+}$ | mg/kg | 41 | 46 | 304 | 66 | 39 |
| potassium | $K^{1+}$ | mg/kg | 12 | 14 | 5.3 | 3.3 | 12 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 67 | 46 | 49 | 43 | 46 |
| fluoride | $F^{1-}$ | mg/kg | 5.0 | 4.9 | 5.1 | 3.4 | 4.8 |
| chloride | $Cl^{1-}$ | mg/kg | 16 | 24 | 75 | 43 | 15 |
| sulfate | $SO_4^{2-}$ | mg/kg | 81 | 103 | 559 | 28 | 73 |
| phosphate | $PO_4^{3-}$ | mg/kg | 1.3 | 1.3 | 4.0 | 4.3 | 2.1 |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 3.3 | 1.4 | ND | ND | 1.8 |
| sulfide | $S^{2-}$ | qual | Negative | Negative | Negative | Negative | Negative |
| Redox | | mV | 92 | 93 | 69 | 74 | 72 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1: soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

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# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0750LAB***
***29-Jul-11***

| **Sample ID** | | | G-116<br>@ 35'<br>CL-ML | G-137<br>@ 61'<br>CL | G-137<br>@ 73'<br>CH | G-137<br>@ 85'<br>CL | G-137<br>@ 103'<br>CH |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 960 | 1,680 | 1,120 | 2,560 | 1,800 |
| saturated | | ohm-cm | 880 | 1,680 | 1,120 | 1,800 | 1,440 |
| **pH** | | | 8.2 | 8.3 | 8.5 | 8.4 | 8.2 |
| **Electrical Conductivity** | | mS/cm | 0.27 | 0.14 | 0.15 | 0.13 | 0.11 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 91 | 71 | 50 | 49 | 41 |
| magnesium | $Mg^{2+}$ | mg/kg | 40 | 22 | 22 | 26 | 23 |
| sodium | $Na^{1+}$ | mg/kg | 121 | 71 | 95 | 81 | 72 |
| potassium | $K^{1+}$ | mg/kg | 33 | 10 | 2.3 | 7.4 | 11 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | 6.0 | 9.0 | 30 | 18 | 9.0 |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 208 | 247 | 247 | 249 | 224 |
| fluoride | $F^{1-}$ | mg/kg | 3.5 | 5.4 | 7.0 | 5.3 | 3.8 |
| chloride | $Cl^{1-}$ | mg/kg | 11 | 20 | 16 | 3.4 | 2.9 |
| sulfate | $SO_4^{2-}$ | mg/kg | 377 | 41 | 31 | 22 | 18 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | 4.0 | ND | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 7.8 | ND | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 1.0 | ND | 0.5 | ND | ND |
| sulfide | $S^{2-}$ | qual | Trace | Trace | Trace | Negative | Negative |
| Redox | | mV | -33 | 35 | -71 | 46 | 58 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0750LAB***
***29-Jul-11***

| **Sample ID** | | | G-138<br>@ 70.5'<br>CL | G-138<br>@ 80.5'<br>CH |
|---|---|---|---|---|
| **Resistivity** | | **Units** | | |
| as-received | | ohm-cm | 11,200 | 2,040 |
| saturated | | ohm-cm | 1,560 | 1,800 |
| **pH** | | | 8.3 | 8.2 |
| **Electrical Conductivity** | | mS/cm | 0.17 | 0.13 |
| **Chemical Analyses** | | | | |
| **Cations** | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 55 | 56 |
| magnesium | $Mg^{2+}$ | mg/kg | 20 | 21 |
| sodium | $Na^{1+}$ | mg/kg | 87 | 79 |
| potassium | $K^{1+}$ | mg/kg | 24 | 6.3 |
| **Anions** | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | 21 | 15 |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 252 | 254 |
| fluoride | $F^{1-}$ | mg/kg | 6.4 | 4.8 |
| chloride | $Cl^{1-}$ | mg/kg | 3.1 | 3.0 |
| sulfate | $SO_4^{2-}$ | mg/kg | 8.0 | 18 |
| phosphate | $PO_4^{3-}$ | mg/kg | 1.7 | 2.4 |
| **Other Tests** | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 2.5 | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 0.5 | ND |
| sulfide | $S^{2-}$ | qual | Negative | Trace |
| Redox | | mV | 3.6 | 54 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

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# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering, Inc.***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0765LAB***
***1-Aug-11***

| **Sample ID** | | | G-187<br>@ 40.5'<br>SM | G-187<br>@ 60.5'<br>ML | G-187<br>@ 70.5'<br>ML | G-187<br>@ 100.5'<br>CL |
|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | |
| as-received | | ohm-cm | 18,800 | 300 | 2,560 | 2,040 |
| saturated | | ohm-cm | 5,200 | 2,920 | 1,720 | 1,520 |
| **pH** | | | 7.8 | 7.3 | 7.0 | 6.6 |
| **Electrical Conductivity** | | mS/cm | 0.04 | 0.04 | 0.05 | 0.05 |
| **Chemical Analyses** | | | | | | |
| **Cations** | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 22 | 23 | 23 | 31 |
| magnesium | $Mg^{2+}$ | mg/kg | 6.2 | 5.1 | 7.0 | 10 |
| sodium | $Na^{1+}$ | mg/kg | 54 | 53 | 48 | 43 |
| potassium | $K^{1+}$ | mg/kg | 1.8 | 3.4 | 6.5 | 9.2 |
| **Anions** | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 52 | 46 | 34 | 55 |
| fluoride | $F^{1-}$ | mg/kg | 5.3 | 3.6 | 5.4 | 7.2 |
| chloride | $Cl^{1-}$ | mg/kg | 11 | 14 | 32 | 31 |
| sulfate | $SO_4^{2-}$ | mg/kg | 20 | 27 | 11 | 10 |
| phosphate | $PO_4^{3-}$ | mg/kg | 11 | 11 | 6.6 | 3.0 |
| **Other Tests** | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | ND | 9.0 | 4.0 | 5.4 |
| sulfide | $S^{2-}$ | qual | Positive | Trace | Trace | Trace |
| Redox | | mV | 34 | 104 | 76 | 133 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

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# Table 1 - Laboratory Tests on Soil Samples

***MACTEC Engineering***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0784LAB***
***5-Aug-11***

| **Sample ID** | | | G-119<br>@ 70.5'<br>ML | G-119<br>@ 90.5'<br>ML/CL | G-119<br>@ 100.5'<br>ML | G-121<br>@ 75.5'<br>ML/CL | G-121<br>@ 85.5'<br>ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 4,800 | 4,400 | 4,280 | 6,000 | 11,600 |
| saturated | | ohm-cm | 356 | 4,400 | 520 | 2,040 | 2,240 |
| **pH** | | | 7.0 | 6.1 | 4.3 | 7.4 | 3.9 |
| **Electrical Conductivity** | | mS/cm | 2.29 | 2.93 | 2.69 | 2.22 | 1.85 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 253 | 216 | 169 | 609 | 83 |
| magnesium | $Mg^{2+}$ | mg/kg | 203 | 406 | 338 | 133 | 74 |
| sodium | $Na^{1+}$ | mg/kg | 2,125 | 2,574 | 2,414 | 1,867 | 1,692 |
| potassium | $K^{1+}$ | mg/kg | 164 | 192 | 188 | 130 | 126 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 177 | 140 | 49 | 250 | 24 |
| fluoride | $F^{1-}$ | mg/kg | ND | ND | ND | ND | 3.1 |
| chloride | $Cl^{1-}$ | mg/kg | 1,998 | 2,444 | 2,198 | 1,274 | 942 |
| sulfate | $SO_4^{2-}$ | mg/kg | 2,667 | 3,892 | 3,508 | 3,590 | 2,149 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND | ND | ND | 3.8 |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 85 | 98 | 100 | 59 | 67 |
| nitrate | $NO_3^{1-}$ | mg/kg | ND | ND | ND | ND | ND |
| sulfide | $S^{2-}$ | qual | Negative | Negative | Negative | Trace | Negative |
| Redox | | mV | -23 | 1.3 | 28 | -40 | 64 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***AMEC E & I***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0793LAB***
***8-Aug-11***

| **Sample ID** | | | G-190<br>@ 20-21.5'<br>ML | G-190<br>@ 50'<br>ML | G-190<br>@ 70'<br>ML/SM | G-190<br>@ 80'<br>ML | G-199<br>@ 31-32.5'<br>SP-SM<br>w/gravel |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,560 | 2,200 | 1,400 | 1,360 | 10,000 |
| saturated | | ohm-cm | 1,000 | 2,040 | 1,400 | 1,360 | 6,400 |
| **pH** | | | 7.9 | 7.8 | 8.0 | 8.0 | 8.2 |
| **Electrical Conductivity** | | mS/cm | 0.17 | 0.06 | 0.11 | 0.13 | 0.05 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 90 | 35 | 65 | 96 | 21 |
| magnesium | $Mg^{2+}$ | mg/kg | 19 | 8.7 | 16 | 17 | 4.7 |
| sodium | $Na^{1+}$ | mg/kg | 68 | 45 | 48 | 48 | 49 |
| potassium | $K^{1+}$ | mg/kg | 6.3 | 4.3 | 8.7 | 8.9 | 4.6 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | 9.0 | 18 | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 223 | 58 | 156 | 194 | 64 |
| fluoride | $F^{1-}$ | mg/kg | 4.1 | 3.6 | 4.0 | 6.1 | 1.8 |
| chloride | $Cl^{1-}$ | mg/kg | 3.9 | 18 | 11 | 6.7 | 3.2 |
| sulfate | $SO_4^{2-}$ | mg/kg | 9.2 | 57 | 52 | 80 | 53 |
| phosphate | $PO_4^{3-}$ | mg/kg | 1.8 | 2.1 | 1.4 | 1.7 | 3.0 |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 176 | 6.7 | 6.1 | 5.6 | 1.7 |
| sulfide | $S^{2-}$ | qual | Negative | Negative | Negative | Negative | Negative |
| Redox | | mV | 68 | 47 | 2 | 56 | 50 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***AMEC E & I***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0793LAB***
***8-Aug-11***

| **Sample ID** | | | G-199 @ 80-81.5' SM | G-206 @ 35-36.5' SM | G-206 @ 55-56.5' CL Sandy Clay | G-206 @ 75-76.5' CL Sandy Clay | G-206 @ 85-86.5' Sandy Siltstone |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 2,800 | 1,560 | 560 | 1,080 | 800 |
| saturated | | ohm-cm | 2,720 | 1,120 | 560 | 440 | 312 |
| **pH** | | | 7.8 | 8.1 | 8.4 | 4.3 | 3.9 |
| **Electrical Conductivity** | | mS/cm | 0.03 | 0.18 | 0.28 | 1.73 | 2.19 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 19 | 69 | 97 | 757 | 546 |
| magnesium | $Mg^{2+}$ | mg/kg | 4.6 | 25 | 39 | 467 | 621 |
| sodium | $Na^{1+}$ | mg/kg | 3.8 | 119 | 131 | 499 | 927 |
| potassium | $K^{1+}$ | mg/kg | 4.5 | 23 | 24 | 86 | 147 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | 21 | 6.0 | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 37 | 263 | 130 | ND | ND |
| fluoride | $F^{1-}$ | mg/kg | 1.7 | 2.1 | 1.1 | 4.2 | 7.3 |
| chloride | $Cl^{1-}$ | mg/kg | 7.2 | 13 | 21 | 96 | 210 |
| sulfate | $SO_4^{2-}$ | mg/kg | 22 | 99 | 455 | 3,068 | 5,799 |
| phosphate | $PO_4^{3-}$ | mg/kg | 2.0 | ND | ND | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | 2.4 | 44 | 77 |
| nitrate | $NO_3^{1-}$ | mg/kg | 7.5 | ND | 3.0 | ND | 32 |
| sulfide | $S^{2-}$ | qual | Negative | Negative | Trace | Positive | Positive |
| Redox | | mV | 53 | 16 | -8 | -22 | 134 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***AMEC E & I***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0793LAB***
***8-Aug-11***

| **Sample ID** | | | G-207 @ 75-76.5' Sandy Siltstone |
|---|---|---|---|
| **Resistivity** | | **Units** | |
| as-received | | ohm-cm | 600 |
| saturated | | ohm-cm | 312 |
| **pH** | | | 3.3 |
| **Electrical Conductivity** | | mS/cm | 1.98 |
| **Chemical Analyses** | | | |
| **Cations** | | | |
| calcium | $Ca^{2+}$ | mg/kg | 442 |
| magnesium | $Mg^{2+}$ | mg/kg | 391 |
| sodium | $Na^{1+}$ | mg/kg | 948 |
| potassium | $K^{1+}$ | mg/kg | 85 |
| **Anions** | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | ND |
| fluoride | $F^{1-}$ | mg/kg | 6.8 |
| chloride | $Cl^{1-}$ | mg/kg | 222 |
| sulfate | $SO_4^{2-}$ | mg/kg | 3,192 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND |
| **Other Tests** | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 65 |
| nitrate | $NO_3^{1-}$ | mg/kg | ND |
| sulfide | $S^{2-}$ | qual | Positive |
| Redox | | mV | 143 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

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*Corrosion Control and Condition Assessment (C3A) Department*

# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Extension***
***Your #4953-10-1561, HDR|Schiff #11-0948LAB***
***15-Sep-11***

| **Sample ID** | | | G-141<br>@ 55'<br>CL | G-141<br>@ 65'<br>CL | G-141<br>@ 80.5'<br>Sandy CL |
|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | |
| as-received | | ohm-cm | 5,200 | 1,480 | 1,760 |
| saturated | | ohm-cm | 1,280 | 1,320 | 1,120 |
| **pH** | | | 7.4 | 7.8 | 8.0 |
| **Electrical Conductivity** | | mS/cm | 0.11 | 0.16 | 0.15 |
| **Chemical Analyses** | | | | | |
| **Cations** | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 41 | 83 | 56 |
| magnesium | $Mg^{2+}$ | mg/kg | 13 | 20 | 15 |
| sodium | $Na^{1+}$ | mg/kg | 66 | 83 | 78 |
| potassium | $K^{1+}$ | mg/kg | 21 | 23 | 29 |
| **Anions** | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | 6.0 | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 110 | 323 | 183 |
| fluoride | $F^{1-}$ | mg/kg | ND | 1.1 | 2.4 |
| chloride | $Cl^{1-}$ | mg/kg | 13 | 6.0 | 38 |
| sulfate | $SO_4^{2-}$ | mg/kg | 132 | 48 | 132 |
| phosphate | $PO_4^{3-}$ | mg/kg | 0.5 | ND | ND |
| **Other Tests** | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 4.5 | 2.9 | 3.9 |
| nitrate | $NO_3^{1-}$ | mg/kg | 0.5 | 1.8 | ND |
| sulfide | $S^{2-}$ | qual | Positive | Positive | Positive |
| Redox | | mV | -71 | -115 | -65 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# FIGURES F-10.63.1 THROUGH F-10.63.18 SOIL CORROSIVITY EVALUATION FOR WILSHIRE/LA BREA STATION

# SOIL CORROSIVITY EVALUATION

*for the*

# WESTSIDE SUBWAY EXTENSION

# WILSHIRE/LA BREA STATION

in

LOS ANGELES, CA

prepared for

AMEC E&I
5628 East Slauson Avenue
Los Angeles, CA  90040

Project No.: 4953-10-1561

PROJECT MANAGER: MR. MARTY HUDSON

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**HDR ENGINEERING, INC.**
*Consulting Corrosion Engineers*
431 West Baseline Road
Claremont, California 91711

HDR|SCHIFF #172549

October 18, 2011

## EXECUTIVE SUMMARY

The Westside Subway Extension is a proposed extension of the Metro Purple Line subway westward from the Wilshire/Western Station to the Veterans Administration West Los Angeles Hospital. Wilshire/La Brea station is one of the eight stations planned for the project. The station will be approximately 1,000 feet long and about 75 to 80 feet below ground surface.

Laboratory tests on the provided soil samples provided by AMEC E&I have been completed. Ten of the samples were selected for analysis. This soil is classified as severely corrosive to ferrous metals, aggressive to copper, very severe for sulfate attack on concrete, aggressive with respect to exposure of reinforcing steel to the migration of chloride, and aggressive with respect to exposure of concrete to acid attack.

A dielectrically coated steel pipeline for this route should also have bonded joints and test stations. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

Cathodically protect and provide corrosion monitoring for hydraulic elevators and associated components as required for compliance with Title 23 as necessary.

A dielectrically coated ductile iron pipe would also be a suitable choice. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

A polyvinyl chloride (PVC) pipe would also be a suitable choice. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating.

Type V cement should be used for concrete structures. Chloride levels were measured at levels where additional protective measures are required for concrete, including increased cover, admixtures, or other modifications of design. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system. Concrete structures and pipe should be protected from acid attack

Due to the soils at this site, post-tensioned slabs should be protected in accordance with soil considered aggressive (corrosive).

## TABLE OF CONTENTS

## INTRODUCTION

The existing subway system is owned and operated by Los Angeles County Metropolitan Transportation Authority (MTA) and provides public transportation throughout the City of Los Angeles, and surrounding areas.

The Westside Subway Extension is a proposed extension of the Metro Purple Line subway westward from the Wilshire/Western Station to the Veterans Administration West Los Angeles Hospital. In the Century City area, two alternative alignments are considered; one with a station along Santa Monica Boulevard, and one with a station along Constellation Boulevard. The proposed subway alignment is about 9 miles long. The depth to tunnel invert varies along the alignment from 40 to 160 feet below grade. The subway will consist of heavy rail transit operated in a twin tunnel configuration with eight new passenger stations, with two options in Century City.

Wilshire/La Brea station is one of the eight stations planned for the project. The station will be approximately 1,000 feet long and about 75 to 80 feet below ground surface. Ground water was encountered at depths of about 10 to 30 feet below ground surface. The station will include walls below grade, utility piping, hydraulic elevator systems, concrete structures and post-tensioning systems.

An analysis of soil corrosivity along the route of the Metro rail alignment was requested. Laboratory tests on the provided soil samples provided by AMEC E&I have been completed. Ten of the samples were selected for analysis. HDR Engineering, Inc. (HDR|Schiff) assumes that the samples selected are representative of the most corrosive soils at the site.

The scope of this study is limited to a determination of soil corrosivity and general corrosion control recommendations for materials planned for construction. HDR|Schiff understands shoring piles will be used only temporarily during construction and will not be considered in this study. If steel piles are considered for use as permanent structures in the future, HDR|Schiff will be glad to perform Romanoff similitude analysis for metal loss and determine estimated corrosion rates.

## LABORATORY TESTS ON SOIL SAMPLES

The electrical resistivity of each of the ten samples was measured in a soil box per ASTM G187 in its as-received condition and again after saturation with distilled water. Resistivities are at about their lowest value when the soil is saturated. The pH of the saturated samples was measured per ASTM G 51. A 5:1 water:soil extract from each sample was chemically analyzed for the major soluble salts commonly found in soil per ASTM D4327, D6919, and D513. Test results are shown in Table 1 in the Appendix to this report.

## SOIL CORROSIVITY

A major factor in determining soil corrosivity is electrical resistivity. The electrical resistivity of a soil is a measure of its resistance to the flow of electrical current. Corrosion of buried metal is an electrochemical process in which the amount of metal loss due to corrosion is directly proportional to the flow of electrical current (DC) from the metal into the soil. Corrosion currents, following Ohm's Law, are inversely proportional to soil resistivity. Lower electrical resistivities result from higher moisture and soluble salt contents and indicate corrosive soil.

A correlation between electrical resistivity and corrosivity toward ferrous metals is (Romanoff, 1989):

| Soil Resistivity in ohm-centimeters | Corrosivity Category |
|---|---|
| Greater than 10,000 | Mildly Corrosive |
| 2,001 to 10,000 | Moderately Corrosive |
| 1,001 to 2,000 | Corrosive |
| 0 to 1,000 | Severely Corrosive |

Other soil characteristics that may influence corrosivity towards metals are pH, soluble salt content, soil types, aeration, anaerobic conditions, and site drainage.

Electrical resistivities were in the moderately to severely corrosive categories with as-received moisture. When saturated, the resistivities were in the moderately to severely corrosive categories.

Soil pH values varied from 5.2 to 8.3. This range is strongly acidic to moderately alkaline (Romanoff, 1989). Total acidity is assumed to be high enough to warrant concern of acid attack on concrete. Soil with a pH less than 5.5 is considered aggressive to copper.

The soluble salt content of the samples ranged from low to very high.

The soluble salt content was very high in the samples from borings G-112 @ 105’ and G-114 @ 89’ and 100.5’ and less in the others. Chloride and sulfate salts were the predominant constituents. Chloride is particularly corrosive to ferrous metals, and in the higher concentrations measured in the soil samples, chloride can overcome the corrosion inhibiting effect of concrete on reinforcing steel. High concentrations of sulfate, as was measured in the soil samples, can react with components in concrete to cause degradation and reduced strength in a mechanism known as sulfate attack.

Nitrate was detected in low concentrations. The ammonium concentration was high enough to be deleterious to copper.

Tests were not made for sulfide and negative oxidation-reduction (redox) potential because these samples did not exhibit characteristics typically associated with anaerobic conditions.

The variation in soil types can create differential-aeration corrosion cells that would affect all metals.

This soil is classified as severely corrosive to ferrous metals, aggressive to copper, very severe for sulfate attack on concrete, aggressive with respect to exposure of reinforcing steel to the migration of chloride, and aggressive with respect to exposure of concrete to acid attack.

Heavy rail transit systems can present a multitude of DC stray current issues. These issues can affect not only the system of concern, but also other metallic utilities or structures proximal to rails, and DC substations if the proper mitigation practices are not followed. Stray current can increase corrosion rates above what would be expected from the chemical characteristics alone.

## CONCLUSIONS

This soil is classified as severely corrosive to ferrous metals, aggressive to copper, very severe for sulfate attack on concrete, aggressive with respect to exposure of reinforcing steel to the migration of chloride, and aggressive with respect to exposure of concrete to acid attack.

A dielectrically coated steel pipeline for this route should also have bonded joints and test stations. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

Cathodically protect and provide corrosion monitoring for hydraulic elevators and associated components as required for compliance with Title 23 as necessary.

A dielectrically coated ductile iron pipe would also be a suitable choice. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

A polyvinyl chloride (PVC) pipe would also be a suitable choice. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating.

Type V cement should be used for concrete structures. Chloride levels were measured at levels where additional protective measures are required for concrete, including increased cover, admixtures, or other modifications of design. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system. Concrete structures and pipe should be protected from acid attack.

Due to the soils at this site, post-tensioned slabs should be protected in accordance with soil considered aggressive (corrosive).

Due to the nature and magnitude of the project and the long design service life requirements, tolerance for corrosion on all project components is low. Based on the need for high reliability and the corrosivity considerations discussed above, it is clear that corrosion protection must be provided for the components exposed to the environment discussed with consideration given to the level of risk and practicality.

# RECOMMENDATIONS

## DC Stray Current

A study of the impact of the DC powered heavy rail system was not detailed as part of the scope work in this project. It is recommended that the client pursue such a study in order to take the necessary precautions to avoid the deleterious effects known to result from DC stray current.

## Steel Pipe

Implement *all* the following measures.

1. Underground steel pipe with rubber gasketed, mechanical, grooved end, or other nonconductive type joints should be bonded for electrical continuity. For pipe diameters less 18 inches use two joint bonds. For pipe diameters greater than or equal to 18 inches use three joint bonds. Electrical continuity is necessary for corrosion monitoring and cathodic protection.

2. Install corrosion monitoring test stations to facilitate corrosion monitoring and the application of cathodic protection:
    a. Two or four-wire test stations at each end of the pipeline depending on how the pipe terminates.
    b. Four-wire test stations at all buried insulating joints.
    c. Four-wire test stations at each end of all casings.
    d. Two-wire test stations at other locations as necessary so the interval between test stations does not exceed 1,200 feet.

    Where 4-wire test stations are required, use wires of difference size or insulation color for identification. Each wire should be independently welded or pin-brazed to the pipe.

3. To prevent dissimilar metal corrosion cells and to facilitate the application of cathodic protection, electrically isolate each buried steel pipeline per NACE Standard SP0286 from:
    a. Pumping plants.
    b. Reservoirs.
    c. Flow meters.
    d. Motorized operated valves.
    e. Dissimilar metals.
    f. Dissimilarly coated piping (cement-mortar vs. dielectric).
    g. Above ground steel pipe.
    h. All existing piping.

    Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

4. Prevent contact between the steel pipe and concrete and/or reinforcing steel, such as at wall penetrations and thrust blocks, with such items as plastic sleeves, rubber seals, or 20 mil plastic tape.

5. Apply a suitable dielectric coating intended for underground use such as:
   a. Polyurethane per AWWA C222 *or*
   b. Extruded polyethylene per AWWA C215 *or*
   c. A tape coating system per AWWA C214 *or*
   d. Hot applied coal tar enamel per AWWA C203 *or*
   e. Fusion bonded epoxy per AWWA C213.

6. Buried steel and iron pipe, fittings, and valves in appurtenances, such as air valves and blowoffs, should be coated with a material listed above or with coal-tar epoxy, wax tape, moldable sealant, or equivalent. If copper is used, electrically insulate it from the steel with an insulating joint or with a dielectric union.

7. Apply cathodic protection to steel piping as per NACE Standard SP0169.

8. To insure that corrosion control is properly designed, preliminary construction drawings should be reviewed by a qualified corrosion engineer.

9. After the pipeline is backfilled, but before the construction contract is completed, the pipeline should be tested to insure that the joint bonds are intact and test stations properly installed. Also, native pipe-to-soil potentials should be measured and recorded. These data will be useful in determining if pipeline conditions change in the future.

10. Pipe-to-soil potentials should be measured biennially to determine if conditions on the pipeline are changing.

## Hydraulic Elevator

Implement *all* the following measures:

1. Coat hydraulic elevator cylinders as described above for steel pipe, item #5 that is resistant to petroleum products (hydraulic fluid).
2. Electrically insulate each cylinder from building metals by installing dielectric material between the piston platen and car, insulating the bolts, and installing an insulated joint in the oil line.
3. Place each cylinder in a non-metallic casing with a plastic watertight seal at the bottom. Fill the annulus with a dry sand with a minimum resistivity of 25,000 ohm-centimeters, a pH of between 6.5 and 7.5 and a maximum chloride content of 200 ppm.
4. A removable moisture-proof sealing lid installed on the top of the casing prior to installation of the cylinder. The top of the casing shall be permanently sealed against moisture intrusion after installation of the cylinder.

5. Provide permanent test facilities and apply cathodic protection to hydraulic cylinders as per NACE Standard SP0169.
6. The elevator oil line should be placed above ground if possible but, if underground, should be protected by one of the following corrosion control options:

   **OPTION 1**

   a. Provide a bonded dielectric coating.
   b. Electrically isolate the pipeline.
   c. Apply cathodic protection to steel piping as per NACE Standard SP0169.

   **OPTION 2**

   a. Place the oil line in a PVC casing pipe with solvent-welded joints to prevent contact with soil and soil moisture.

7. If Steel underground storage tanks are used, cathodic protection and corrosion control requirements shall comply with Title 23.

## Reinforced Concrete Pipe (Non-Pressurized)

Implement *all* the following measures.

1. To prevent dissimilar metal corrosion cells electrically isolate the storm drain per NACE Standard SP0286 from all structures and facilities.

   Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

2. Prevent contact between the steel pipe and concrete and/or reinforcing steel, such as at wall penetrations and thrust blocks, with such items as plastic sleeves, rubber seals, or 20 mil plastic tape.

3. Buried steel and iron pipe and fittings in appurtenances should be cement-mortar coated or concrete or cement slurry encased where possible. Otherwise, they should be wrapped with wax tape per AWWA Standard C-217

4. To insure that corrosion control is properly designed, preliminary construction drawings should be reviewed by a qualified corrosion engineer.

5. Apply a suitable dielectric waterproofing coating intended for underground use. This coating is to be compatible with and applied over the concrete/cement-mortar.

## Iron Pipe

Implement *all* the following measures:

1. To prevent dissimilar metal corrosion cells and to facilitate the application of cathodic protection, electrically isolate each buried iron pipeline per NACE Standard SP0286 from:
    a. Pumping plants.
    b. Reservoirs.
    c. Flow meters.
    d. Motorized operated valves.
    e. Dissimilar metals.
    f. Dissimilarly coated piping (cement-mortar vs. dielectric).
    g. Above ground steel pipe.
    h. All existing piping.

    Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

2. Bond all nonconductive type joints for electrical continuity. Electrical continuity is necessary for corrosion monitoring and cathodic protection. For pipe diameters less 18 inches use two joint bonds. For pipe diameters greater than or equal to 18 inches use three joint bonds. Electrical continuity is necessary for corrosion monitoring and cathodic protection.

3. Install corrosion monitoring test stations to facilitate corrosion monitoring and the application of cathodic protection:
    a. Two or four-wire test stations at each end of the pipeline depending on how the pipe terminates.
    b. Four-wire test stations at all buried insulating joints.
    c. Four-wire test stations at each end of all casings.
    d. Two-wire test stations at other locations as necessary so the interval between test stations does not exceed 1,200 feet.

    Where 4-wire test stations are required, use wires of difference size or insulation color for identification. Each wire should be independently welded or pin-brazed to the pipe.

4. Use iron pipe, fittings, and valves in appurtenances to the extent possible to avoid creating dissimilar metal corrosion cells. Steel appurtenances such as bolts should be coated with wax tape. If copper is used, electrically isolate it from the iron.

5. Prevent contact between iron and concrete including reinforcing steel, using such items as plastic sleeves, rubber seals, two layers of 8 mil thick polyethylene plastic, or 20 mil plastic tape.

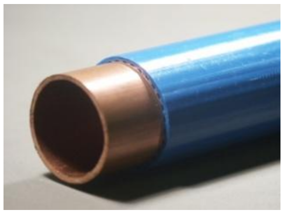
6. Apply a suitable coating intended for underground use such as:
    a. Epoxy coating; *or*
    b. Polyurethane; *or*
    c. Wax tape.

    NOTE: The thin factory-applied asphaltic coating applied to ductile iron pipe for transportation and aesthetic purposes does not constitute a corrosion control coating.

7. Apply cathodic protection to cast and ductile iron piping as per NACE Standard SP0169.

### Copper Pipe

Protect buried copper pipe by *one* of the following measures:



1. Installation of a factory-coated copper pipe with a minimum 25-mil thickness such as Kamco's Aqua Shield™, Mueller's Streamline Protec™, or equal. The coating must be continuous with no cuts or defects.

2. Installation of 12-mil polyethylene pipe wrapping tape with butyl rubber mastic over a suitable primer. Protect wrapped copper tubing by applying cathodic protection per NACE Standard SP0169.

### Polyvinyl Chloride (PVC) Pipe

1. No special measures are required to protect PVC.

2. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating such as wax tape per AWWA C217, plastic pipe wrapping tape, coal tar epoxy, polyurethane, or equivalent.

3. Install electrically insulated joints in iron riser connections to above grade metallic piping.

4. Use iron pipe, fittings, and valves in appurtenances, such as air valves and blowoffs, to the extent possible to avoid creating dissimilar metal corrosion cells. Steel appurtenances such as bolts should be coated as described above. If copper is used, electrically isolate it from the iron.

### All Pipe

1. On all pipes, appurtenances, and fittings not protected by cathodic protection or encased in concrete, coat pipe specials such as valves, bolts, flange joints, joint harnesses, and flexible couplings with wax tape per AWWA C217 after assembly.

2. Where metallic pipelines penetrate concrete structures such as building floors, vault walls, and thrust blocks use plastic sleeves, rubber seals, or other dielectric material to prevent pipe contact with the concrete and reinforcing steel.

## Concrete Structures

The concrete mix design should provide the least permeable and mostly crack-free matrix to reduce penetration of aggressive ions and oxygen into the concrete. The concrete mixture should be designed to help protect the steel adequately from corrosion. Factors in concrete mix design that can reduce the permeability of the concrete include lowering the water-to-cement ratio by either increasing the cement content or decreasing water content. Finely divided materials such as fly ash, granulated blast furnace slag, silica fume, and other pozzolans can further reduce permeability of the concrete.

In addition, aggregates having water-soluble chloride ions on their surfaces, or even within their particles, can cause corrosion problems. If enough surface-borne chlorides are present, a portion will not be bound within the solid "paste" phase during hydration of the cement. Most of the chlorides released from the interior of an aggregate particle after the first few hours of hydration will not be bound at all. Unbound chloride ions can cause passivity breakdown of the steel created by the alkaline cement.

The following standards contain important guidelines for the maximum concentration of chloride, sulfate and carbonate ions on the mixing water and admixture:

- Portland Cement Association PCA Publication E B.001, Design and Control of Concrete mixtures
- American Concrete Institute ACI 318, Building Code Requirements for Reinforced Concrete Structures
- American Concrete Institute ACI 222, Corrosion of Metals in Concrete

Nevertheless, there are certain steps that can be taken to enhance the protective properties of the concrete. The most important factor is keeping the cement content high enough to maintain a pH of 12.5 or greater.

1. Protect concrete structures and pipe from sulfate attack in soil with a severe sulfate concentration, between 0.20 and 2.0 percent. Use Type V cement, a maximum water/cement ratio of 0.45, and minimum strength of 4500 psi per applicable code.
2. Chloride levels were measured at levels where additional protective measures may be required for concrete, including increased cover, admixtures, or other modifications of design based on the Metro Rail Design Criteria. Possible measures are presented below.
    a. Protective Concrete - A concrete mix designed to protect embedded steel and iron that should be based on the following parameters: 1) a chloride content of 900 ppm in the soil; 2) the desired service life; and 3) concrete cover. A protective concrete mix may include a corrosion inhibitor admixture and/or silica fume admixture.

    b. Waterproof Concrete - Waterproofing for concrete could be a gravel capillary break under the concrete, a waterproof membrane, and/or a liquid applied waterproof barrier coating such as Grace PrePrufe® Products. Visqueen, similar rolled barriers, or bentonite-based membranes are not viable waterproofing systems, from a corrosion standpoint.
    c. Coat Embedded Metal - A coating for embedded steel and iron could be an epoxy coating applied to the metal. Purple fusion bonded epoxy (FBE) (ASTM A934) intended for prefabricated reinforcing steel reinforcing steel is suitable. The green flexible FBE (ASTM A775) is not recommended.
    d. Cathodic Protection - Cathodic protection is most practical for pipelines and must be designed for each application. The amount of cathodic protection current needed can be minimized by coating the steel or iron.

3. Due to the high ground water table encountered at this site, cyclical or continual wetting may be an issue. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system.

4. Concrete structures and pipe should be protected from acid attack because soil with a pH ≤ 5.5 and assumed total acidity ≥ 250 mmol $H^{1+}$/kg (AWWA 1995) was found on-site. Concrete can be protected by preventing contact with the moisture in acidic soil. Contact can be prevented with an impermeable, waterproof, acid resistant barrier coating such as Grace PrePrufe Products®. ®.

## Post Tensioning Slabs: Unbonded Single-Stranded Tendons and Anchors

1. Soil is considered an aggressive environment for post-tensioning strands and anchors. Therefore, due to the soils found on-site, protect post-tensioning strands and anchors against corrosion in this aggressive (corrosive) environment. Implement *all* the following measures: (ACI 2001)(PTI 2006)(PTI 2000)
    a. Completely encapsulate the tendon and anchor with polyethylene to create a watertight seal.
    b. All components exposed to the job site should be protected within one working day after their exposure during installation.
    c. Ensure the minimum concrete cover over the tendon tail is 1-inch, or greater if required by the applicable building code.
    d. Caps and sleeves should be installed within one working day after the cutting of the tendon tails and acceptance of the elongation records by the engineer.
    e. Inspect the following to ensure the encapsulated system is completely watertight:
        i. Sheathing: Verify that all damaged areas, including pin-holes, are repaired.
        ii. Stressing tails: After removal, ensure they are cut to a length for proper installation of P/T coating filled end caps.

    iii. End caps: Ensure proper installation before patching the pocket former recesses.
    iv. Patching: Ensure the patch is of an approved material and mix design, and installed void-free.

f. Limit the access of direct runoff onto the anchorage area by designing proper drainage.

g. Provide at least 2 inches of space between finish grade and the anchorage area, or more if required by applicable building codes.

## CLOSURE

Our services have been performed with the usual thoroughness and competence of the engineering profession. No other warranty or representation, either expressed or implied, is included or intended.

Please call if you have any questions.

Respectfully Submitted,
HDR ENGINEERING, INC.

REGISTERED PROFESSIONAL ENGINEER
STEVEN R FOX
No. CR 1137
Exp. 3-31-13
CORROSION
STATE OF CALIFORNIA

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11-1050SCS-RPT_Wilshire-LaBrea_IB_rev00

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# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-09-0472, SA #09-0628SCSP***
***13-Aug-09***

| **Sample ID** | | | G-3<br>@ 40' |
|---|---|---|---|
| **Resistivity** | | **Units** | |
| as-received | | ohm-cm | 6,000 |
| saturated | | ohm-cm | 900 |
| **pH** | | | 8.4 |
| **Electrical Conductivity** | | mS/cm | 0.21 |
| **Chemical Analyses** | | | |
| **Cations** | | | |
| calcium | $Ca^{2+}$ | mg/kg | 102 |
| magnesium | $Mg^{2+}$ | mg/kg | 26 |
| sodium | $Na^{1+}$ | mg/kg | 92 |
| potassium | $K^{1+}$ | mg/kg | 27 |
| **Anions** | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 207 |
| flouride | $F^{1-}$ | mg/kg | 8.3 |
| chloride | $Cl^{1-}$ | mg/kg | 11 |
| sulfate | $SO_4^{2-}$ | mg/kg | 263 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND |
| **Other Tests** | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 0.9 |
| nitrate | $NO_3^{1-}$ | mg/kg | ND |
| sulfide | $S^{2-}$ | qual | na |
| Redox | | mV | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

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# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0647LAB***
***8-Jul-11***

| **Sample ID** | | | G-112 @ 10' SM | G-112 @ 25' CL | G-112 @ 45' Sandy CL | G-112 @ 75' SP-SM/SM | G-112 @ 105' ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 2,720 | 1,280 | 2,920 | 3,000 | 570 |
| saturated | | ohm-cm | 1,640 | 1,000 | 1,520 | 2,120 | 244 |
| **pH** | | | 7.2 | 7.4 | 7.8 | 7.8 | 7.4 |
| **Electrical Conductivity** | | mS/cm | 0.21 | 0.20 | 0.16 | 0.15 | 3.03 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 51 | 69 | 71 | 77 | 1,170 |
| magnesium | $Mg^{2+}$ | mg/kg | 20 | 20 | 20 | 15 | 428 |
| sodium | $Na^{1+}$ | mg/kg | 157 | 121 | 81 | 62 | 1,794 |
| potassium | $K^{1+}$ | mg/kg | 4.6 | 7.9 | 13 | 14 | 241 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | 21 | 18 | 9.0 | 9.0 | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 169 | 217 | 231 | 119 | 464 |
| fluoride | $F^{1-}$ | mg/kg | 1.8 | 3.6 | 1.5 | 1.2 | ND |
| chloride | $Cl^{1-}$ | mg/kg | 69 | 19 | 15 | 11 | 888 |
| sulfate | $SO_4^{2-}$ | mg/kg | 165 | 161 | 107 | 204 | 6,509 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND | 0.7 | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | 1.3 | 69 |
| nitrate | $NO_3^{1-}$ | mg/kg | 20 | 5.5 | 5.6 | 3.5 | 13 |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

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# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0674LAB***
***14-Jul-11***

| **Sample ID** | | | G-114<br>@ 33.5'<br>CL | G-114<br>@ 53.5'<br>ML | G-114<br>@ 77.5'<br>SP-SM | G-114<br>@ 89'<br>ML | G-114<br>@ 100.5'<br>CL-ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,520 | 1,160 | 3,200 | 1,240 | 880 |
| saturated | | ohm-cm | 1,080 | 1,040 | 1,760 | 332 | 248 |
| **pH** | | | 7.8 | 8.3 | 7.9 | 5.2 | 5.9 |
| **Electrical Conductivity** | | mS/cm | 0.17 | 0.19 | 0.18 | 2.35 | 2.40 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 55 | 67 | 59 | 730 | 629 |
| magnesium | $Mg^{2+}$ | mg/kg | 15 | 15 | 14 | 571 | 493 |
| sodium | $Na^{1+}$ | mg/kg | 103 | 101 | 81 | 935 | 1,427 |
| potassium | $K^{1+}$ | mg/kg | 7.8 | 26 | 21 | 196.0 | 217 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | 18 | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 217 | 271 | 104 | 40 | 58 |
| fluoride | $F^{1-}$ | mg/kg | 2.1 | 1.7 | 1.0 | 3.9 | 0.7 |
| chloride | $Cl^{1-}$ | mg/kg | 20 | 2.4 | 13 | 285 | 625.0 |
| sulfate | $SO_4^{2-}$ | mg/kg | 94 | 171 | 256 | 5,751 | 5,688 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND | ND | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | 0.9 | 1.1 | 742 | 74 |
| nitrate | $NO_3^{1-}$ | mg/kg | 3.9 | 3.5 | 21 | ND | 3.5 |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# FIGURES F-10.64.1 THROUGH F-10.64.19 SOIL CORROSIVITY EVALUATION FOR WILSHIRE/FAIRFAX STATION

# SOIL CORROSIVITY EVALUATION

*for the*

# WESTSIDE SUBWAY EXTENSION

# WILSHIRE/FAIRFAX STATION

in

LOS ANGELES, CA

prepared for

AMEC E&I
5628 East Slauson Avenue
Los Angeles, CA 90040

Project No.: 4953-10-1561

PROJECT MANAGER: MR. MARTY HUDSON

prepared by

**HDR ENGINEERING, INC.**
*Consulting Corrosion Engineers*
431 West Baseline Road
Claremont, California 91711

HDR|SCHIFF #172549

October 18, 2011

# EXECUTIVE SUMMARY

The Westside Subway Extension is a proposed extension of the Metro Purple Line subway westward from the Wilshire/Western Station to the Veterans Administration West Los Angeles Hospital. Wilshire/Fairfax station is one of the eight stations planned for the project. The station will be approximately 860 feet long and about 60 to 70 feet below ground surface.

Laboratory tests on the provided soil samples provided by AMEC E&I have been completed. Thirteen of the samples were selected for analysis. This soil is classified as severely corrosive to ferrous metals, aggressive to copper, very severe for sulfate attack on concrete, aggressive with respect to exposure of reinforcing steel to the migration of chloride based on the Metro Rail Design Criteria, and aggressive with respect to exposure of concrete to acid attack.

A dielectrically coated steel pipeline for this route should also have bonded joints and test stations. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

Cathodically protect and provide corrosion monitoring for hydraulic elevators and associated components as required for compliance with Title 23 as necessary.

A dielectrically coated ductile iron pipe would also be a suitable choice. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

A polyvinyl chloride (PVC) pipe would also be a suitable choice. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating.

Type V cement plus pozzolan should be used for concrete structures. Chloride levels were measured at levels where additional protective measures are required for concrete, including increased cover, admixtures, or other modifications of design base on the Metro Rail Design Criteria. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system. Concrete structures and pipe should be protected from acid attack.

Due to the soils at this site, post-tensioned slabs should be protected in accordance with soil considered aggressive (corrosive).

# Table of Contents

## INTRODUCTION

The existing subway system is owned and operated by Los Angeles County Metropolitan Transportation Authority (MTA) and provides public transportation throughout the City of Los Angeles, and surrounding areas.

The Westside Subway Extension is a proposed extension of the Metro Purple Line subway westward from the Wilshire/Western Station to the Veterans Administration West Los Angeles Hospital. In the Century City area, two alternative alignments are considered; one with a station along Santa Monica Boulevard, and one with a station along Constellation Boulevard. The proposed subway alignment is about 9 miles long. The depth to tunnel invert varies along the alignment from 40 to 160 feet below grade. The subway will consist of heavy rail transit operated in a twin tunnel configuration with eight new passenger stations, with two options in Century City.

Wilshire/Fairfax station is one of the eight stations planned for the project. The station will be approximately 860 feet long and about 60 to 70 feet below ground surface. Ground water was encountered at depths of about 15 to 45 feet below ground surface. The station will include walls below grade, utility piping, hydraulic elevator systems, concrete structures and post-tensioning systems.

An analysis of soil corrosivity along the route of the Metro rail alignment was requested. Laboratory tests on the provided soil samples provided by AMEC E&I have been completed. Thirteen of the samples were selected for analysis. HDR Engineering, Inc. (HDR|Schiff) assumes that the samples selected are representative of the most corrosive soils at the site.

The scope of this study is limited to a determination of soil corrosivity and general corrosion control recommendations for materials planned for construction. HDR|Schiff understands shoring piles will be used only temporarily during construction and will not be considered in this study. If steel piles are considered for use as permanent structures in the future, HDR|Schiff will be glad to perform Romanoff similitude analysis for metal loss and determine estimated corrosion rates.

## LABORATORY TESTS ON SOIL SAMPLES

The electrical resistivity of each of the 13 samples was measured in a soil box per ASTM G187 in its as-received condition and again after saturation with distilled water. Resistivities are at about their lowest value when the soil is saturated. The pH of the saturated samples was measured per ASTM G 51. A 5:1 water:soil extract from each sample was chemically analyzed for the major soluble salts commonly found in soil per ASTM D4327, D6919, and D513. Test results are shown in Table 1 in the Appendix to this report.

## SOIL CORROSIVITY

A major factor in determining soil corrosivity is electrical resistivity. The electrical resistivity of a soil is a measure of its resistance to the flow of electrical current. Corrosion of buried metal is an electrochemical process in which the amount of metal loss due to corrosion is directly proportional to the flow of electrical current (DC) from the metal into the soil. Corrosion currents, following Ohm's Law, are inversely proportional to soil resistivity. Lower electrical resistivities result from higher moisture and soluble salt contents and indicate corrosive soil.

A correlation between electrical resistivity and corrosivity toward ferrous metals is (Romanoff, 1989):

| Soil Resistivity in ohm-centimeters | Corrosivity Category |
|---|---|
| Greater than 10,000 | Mildly Corrosive |
| 2,001 to 10,000 | Moderately Corrosive |
| 1,001 to 2,000 | Corrosive |
| 0 to 1,000 | Severely Corrosive |

Other soil characteristics that may influence corrosivity towards metals are pH, soluble salt content, soil types, aeration, anaerobic conditions, and site drainage.

Electrical resistivities were in the mildly corrosive to corrosive categories with as-received moisture. When saturated, the resistivities were in the mildly to severely corrosive categories. The resistivities dropped considerably with added moisture because the samples were dry as-received. The wide variations in soil resistivity can create concentration type corrosion cells that increase corrosion rates above what would be expected from the chemical characteristics alone.

Soil pH values varied from 2.6 to 7.7. This range is extremely acidic to mildly alkaline (Romanoff, 1989). Total acidity is assumed to be high enough to warrant concern of acid attack on concrete.

The soluble salt content of the samples ranged from low to very high.

The soluble salt content was very high in the samples from borings S-106 @ 23-24’ and G-6 @ 70’ and less in the others. Chloride and sulfate salts were the predominant constituents. Chloride is particularly corrosive to ferrous metals, and in the higher concentrations measured in the soil samples, chloride can overcome the corrosion inhibiting effect of concrete on reinforcing steel. High concentrations of sulfate, as was measured in the soil samples, can react with components in concrete to cause degradation and reduced strength in a mechanism known as sulfate attack.

Nitrate was detected in low concentrations. The ammonium concentration was high enough to be deleterious to copper.

Some of the samples were tested for sulfides as they exhibited characteristics typically associated with anaerobic conditions. Sulfide, which is aggressive to copper and ferrous metals, showed no reaction in a qualitative test. The positive and negative redox potentials measured in the samples from S-106 @ 23-24’, 33-34’, 47-48’, 61-62’, 77-78’, 91-92’ and 108-109’ indicate oxidizing conditions in which anaerobic, sulfide-producing bacteria are inactive.

The variation in soil types can create differential-aeration corrosion cells that would affect all metals.

This soil is classified as severely corrosive to ferrous metals, aggressive to copper, very severe for sulfate attack on concrete, aggressive with respect to exposure of reinforcing steel to the migration of chloride based on the Metro Rail Design Criteria, and aggressive with respect to exposure of concrete to acid attack.

Heavy rail transit systems can present a multitude of DC stray current issues. These issues can affect not only the system of concern, but also other metallic utilities or structures proximal to rails, and DC substations if the proper mitigation practices are not followed. Stray current can increase corrosion rates above what would be expected from the chemical characteristics alone.

## CONCLUSIONS

This soil is classified as severely corrosive to ferrous metals, aggressive to copper, very severe for sulfate attack on concrete, aggressive with respect to exposure of reinforcing steel to the migration of chloride based on the Metro Rail Design Criteria, and aggressive with respect to exposure of concrete to acid attack.

Tar was found within the soil samples used for analysis of the Wilshire/Fairfax station. Chemical constituents were found to be more aggressive at this site in comparison to the other sites.

A dielectrically coated steel pipeline for this route should also have bonded joints and test stations. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

Cathodically protect and provide corrosion monitoring for hydraulic elevators and associated components as required for compliance with Title 23 as necessary.

A dielectrically coated ductile iron pipe would also be a suitable choice. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

A polyvinyl chloride (PVC) pipe would also be a suitable choice. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating.

Type V cement plus pozzolan should be used for concrete structures. Chloride levels were measured at levels where additional protective measures are required for concrete, including increased cover, admixtures, or other modifications of design base on the Metro Rail Design Criteria. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system. Concrete structures and pipe should be protected from acid attack.

Due to the soils at this site, post-tensioned slabs should be protected in accordance with soil considered aggressive (corrosive).

Due to the nature and magnitude of the project and the long design service life requirements, tolerance for corrosion on all project components is low. Based on the need for high reliability and the corrosivity considerations discussed above, it is clear that corrosion protection must be provided for the components exposed to the environment discussed with consideration given to the level of risk and practicality.

## RECOMMENDATIONS

### DC Stray Current

A study of the impact of the DC powered heavy rail system was not detailed as part of the scope work in this project. It is recommended that the client pursue such a study in order to take the necessary precautions to avoid the deleterious effects known to result from DC stray current.

### Steel Pipe

Implement *all* the following measures.

1. Underground steel pipe with rubber gasketed, mechanical, grooved end, or other nonconductive type joints should be bonded for electrical continuity. For pipe diameters less 18 inches use two joint bonds. For pipe diameters greater than or equal to 18 inches use three joint bonds. Electrical continuity is necessary for corrosion monitoring and cathodic protection.

2. Install corrosion monitoring test stations to facilitate corrosion monitoring and the application of cathodic protection:
   a. Two or four-wire test stations at each end of the pipeline depending on how the pipe terminates.
   b. Four-wire test stations at all buried insulating joints.
   c. Four-wire test stations at each end of all casings.
   d. Two-wire test stations at other locations as necessary so the interval between test stations does not exceed 1,200 feet.

   Where 4-wire test stations are required, use wires of difference size or insulation color for identification. Each wire should be independently welded or pin-brazed to the pipe.

3. To prevent dissimilar metal corrosion cells and to facilitate the application of cathodic protection, electrically isolate each buried steel pipeline per NACE Standard SP0286 from:
    a. Pumping plants.
    b. Reservoirs.
    c. Flow meters.
    d. Motorized operated valves.
    e. Dissimilar metals.
    f. Dissimilarly coated piping (cement-mortar vs. dielectric).
    g. Above ground steel pipe.
    h. All existing piping.

    Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

4. Prevent contact between the steel pipe and concrete and/or reinforcing steel, such as at wall penetrations and thrust blocks, with such items as plastic sleeves, rubber seals, or 20 mil plastic tape.

5. Apply a suitable dielectric coating intended for underground use such as:
    a. Polyurethane per AWWA C222 *or*
    b. Extruded polyethylene per AWWA C215 *or*
    c. A tape coating system per AWWA C214 *or*
    d. Hot applied coal tar enamel per AWWA C203 *or*
    e. Fusion bonded epoxy per AWWA C213.

6. Buried steel and iron pipe, fittings, and valves in appurtenances, such as air valves and blowoffs, should be coated with a material listed above or with coal-tar epoxy, wax tape, moldable sealant, or equivalent. If copper is used, electrically insulate it from the steel with an insulating joint or with a dielectric union.

7. Apply cathodic protection to steel piping as per NACE Standard SP0169.

8. To insure that corrosion control is properly designed, preliminary construction drawings should be reviewed by a qualified corrosion engineer.

9. After the pipeline is backfilled, but before the construction contract is completed, the pipeline should be tested to insure that the joint bonds are intact and test stations properly installed. Also, native pipe-to-soil potentials should be measured and recorded. These data will be useful in determining if pipeline conditions change in the future.

10. Pipe-to-soil potentials should be measured biennially to determine if conditions on the pipeline are changing.

## Hydraulic Elevator

Implement *all* the following measures:

1. Coat hydraulic elevator cylinders as described above for steel pipe, item #5a -#5e5 that is resistant to petroleum products (hydraulic fluid).
2. Electrically insulate each cylinder from building metals by installing dielectric material between the piston platen and car, insulating the bolts, and installing an insulated joint in the oil line.
3. Place each cylinder in a non-metallic casing with a plastic watertight seal at the bottom. Fill the annulus with dry sand with a minimum resistivity of 25,000 ohm-centimeters, a pH of between 6.5 and 7.5 and a maximum chloride content of 200 ppm.
4. A removable moisture-proof sealing lid installed on the top of the casing prior to installation of the cylinder. The top of the casing shall be permanently sealed against moisture intrusion after installation of the cylinder.
5. Apply cathodic protection to hydraulic cylinders as per NACE Standard SP0169.
6. The elevator oil line should be placed above ground if possible but, if underground, should be protected by one of the following corrosion control options:

   **OPTION 1**

   a. Provide a bonded dielectric coating.
   b. Electrically isolate the pipeline.
   c. Apply cathodic protection to steel piping as per NACE Standard SP0169.

   **OPTION 2**

   a. Place the oil line in a PVC casing pipe with solvent-welded joints to prevent contact with soil and soil moisture.

7. If Steel underground storage tanks are used, cathodic protection and corrosion control requirements shall comply with Title 23.

## Reinforced Concrete Pipe (Non-Pressurized)

Implement *all* the following measures.

1. To prevent dissimilar metal corrosion cells electrically isolate the storm drain per NACE Standard SP0286 from all structures and facilities.

   Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

2. Prevent contact between the steel pipe and concrete and/or reinforcing steel, such as at wall penetrations and thrust blocks, with such items as plastic sleeves, rubber seals, or 20 mil plastic tape.

3. Buried steel and iron pipe and fittings in appurtenances should be cement-mortar coated or concrete or cement slurry encased where possible. Otherwise, they should be wrapped with wax tape per AWWA Standard C-217

4. To insure that corrosion control is properly designed, preliminary construction drawings should be reviewed by a qualified corrosion engineer.

5. Apply a suitable dielectric waterproofing coating intended for underground use. This coating is to be compatible with and applied over the concrete/cement-mortar.

## Iron Pipe

Implement *all* the following measures:

1. To prevent dissimilar metal corrosion cells and to facilitate the application of cathodic protection, electrically isolate each buried iron pipeline per NACE Standard SP0286 from:
   a. Pumping plants.
   b. Reservoirs.
   c. Flow meters.
   d. Motorized operated valves.
   e. Dissimilar metals.
   f. Dissimilarly coated piping (cement-mortar vs. dielectric).
   g. Above ground steel pipe.
   h. All existing piping.

   Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

2. Bond all nonconductive type joints for electrical continuity. Electrical continuity is necessary for corrosion monitoring and cathodic protection. For pipe diameters less 18 inches use two joint bonds. For pipe diameters greater than or equal to 18 inches use three joint bonds. Electrical continuity is necessary for corrosion monitoring and cathodic protection.

3. Install corrosion monitoring test stations to facilitate corrosion monitoring and the application of cathodic protection:
   a. Two or four-wire test stations at each end of the pipeline depending on how the pipe terminates.
   b. Four-wire test stations at all buried insulating joints.
   c. Four-wire test stations at each end of all casings.
   d. Two-wire test stations at other locations as necessary so the interval between test stations does not exceed 1,200 feet.

Where 4-wire test stations are required, use wires of difference size or insulation color for identification. Each wire should be independently welded or pin-brazed to the pipe.

4. Use iron pipe, fittings, and valves in appurtenances to the extent possible to avoid creating dissimilar metal corrosion cells. Steel appurtenances such as bolts should be coated with wax tape. If copper is used, electrically isolate it from the iron.

5. Prevent contact between iron and concrete including reinforcing steel, using such items as plastic sleeves, rubber seals, two layers of 8 mil thick polyethylene plastic, or 20 mil plastic tape.

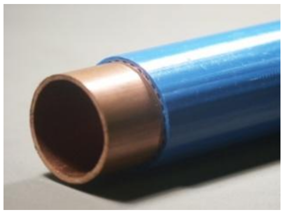
6. Apply a suitable coating intended for underground use such as:
   a. Epoxy coating; *or*
   b. Polyurethane; *or*
   c. Wax tape.

   NOTE: The thin factory-applied asphaltic coating applied to ductile iron pipe for transportation and aesthetic purposes does not constitute a corrosion control coating.

7. Apply cathodic protection to cast and ductile iron piping as per NACE Standard SP0169.

## Copper Pipe

Protect buried copper pipe by *one* of the following measures:



1. Installation of a factory-coated copper pipe with a minimum 25-mil thickness such as Kamco's Aqua Shield™, Mueller's Streamline Protec™, or equal. The coating must be continuous with no cuts or defects.

2. Installation of 12-mil polyethylene pipe wrapping tape with butyl rubber mastic over a suitable primer. Protect wrapped copper tubing by applying cathodic protection per NACE Standard SP0169.

## Polyvinyl Chloride (PVC) Pipe

1. No special measures are required to protect PVC.

2. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating such as wax tape per AWWA C217, plastic pipe wrapping tape, coal tar epoxy, polyurethane, or equivalent.

3. Install electrically insulated joints in iron riser connections to above grade metallic piping.

4. Use iron pipe, fittings, and valves in appurtenances, such as air valves and blowoffs, to the extent possible to avoid creating dissimilar metal corrosion cells. Steel appurtenances such as

bolts should be coated as described above. If copper is used, electrically isolate it from the iron.

## All Pipe

1. On all pipes, appurtenances, and fittings not protected by cathodic protection or encased in concrete, coat pipe specials such as valves, bolts, flange joints, joint harnesses, and flexible couplings with wax tape per AWWA C217 after assembly.

2. Where metallic pipelines penetrate concrete structures such as building floors, vault walls, and thrust blocks use plastic sleeves, rubber seals, or other dielectric material to prevent pipe contact with the concrete and reinforcing steel.

## Concrete Structures

The concrete mix design should provide the least permeable and mostly crack-free matrix to reduce penetration of aggressive ions and oxygen into the concrete. The concrete mixture should be designed to help protect the steel adequately from corrosion. Factors in concrete mix design that can reduce the permeability of the concrete include lowering the water-to-cement ratio by either increasing the cement content or decreasing water content. Finely divided materials such as fly ash, granulated blast furnace slag, silica fume, and other pozzolans can further reduce permeability of the concrete.

In addition, aggregates having water-soluble chloride ions on their surfaces, or even within their particles, can cause corrosion problems. If enough surface-borne chlorides are present, a portion will not be bound within the solid “paste” phase during hydration of the cement. Most of the chlorides released from the interior of an aggregate particle after the first few hours of hydration will not be bound at all. Unbound chloride ions can cause passivity breakdown of the steel created by the alkaline cement.

The following standards contain important guidelines for the maximum concentration of chloride, sulfate and carbonate ions on the mixing water and admixture:

- Portland Cement Association PCA Publication E B.001, Design and Control of Concrete mixtures
- American Concrete Institute ACI 318, Building Code Requirements for Reinforced Concrete Structures
- American Concrete Institute ACI 222, Corrosion of Metals in Concrete

Nevertheless, there are certain steps that can be taken to enhance the protective properties of the concrete. The most important factor is keeping the cement content high enough to maintain a pH of 12.5 or greater.

1. Protect concrete structures and pipe from sulfate attack in soil with a very severe sulfate concentration, over 2.0 percent. Use Type V cement plus pozzolan, a maximum water/cement ratio of 0.45, and minimum strength of 4500 psi per applicable code.

2. Chloride levels were measured at levels where additional protective measures may be required for concrete, including increased cover, admixtures, or other modifications of design based on the Metro Rail Design Criteria. Possible measures are presented below.
    a. Protective Concrete - A concrete mix designed to protect embedded steel and iron that should be based on the following parameters: 1) a chloride content of 270 ppm in the soil; 2) the desired service life; and 3) concrete cover. A protective concrete mix may include a corrosion inhibitor admixture and/or silica fume admixture.
    b. Waterproof Concrete - Waterproofing for concrete could be a gravel capillary break under the concrete, a waterproof membrane, and/or a liquid applied waterproof barrier coating such as Grace PrePrufe Products®. Visqueen, similar rolled barriers, or bentonite-based membranes are not viable waterproofing systems, from a corrosion standpoint.
    c. Coat Embedded Metal - A coating for embedded steel and iron could be an epoxy coating applied to the metal. Purple fusion bonded epoxy (FBE) (ASTM A934) intended for prefabricated reinforcing steel reinforcing steel is suitable. The green flexible FBE (ASTM A775) is not recommended.
    d. Cathodic Protection - Cathodic protection is most practical for pipelines and must be designed for each application. The amount of cathodic protection current needed can be minimized by coating the steel or iron.

3. Due to the high ground water table encountered at this site, cyclical or continual wetting may be an issue. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system.

4. Concrete structures and pipe should be protected from acid attack because soil with a pH ≤ 5.5 and assumed total acidity ≥ 250 mmol $H^{1+}$/kg (AWWA 1995) was found on-site. Concrete can be protected by preventing contact with the moisture in acidic soil. Contact can be prevented with an impermeable, waterproof, acid resistant barrier coating such as Grace PrePrufe Products®.

## Post Tensioning Slabs: Unbonded Single-Stranded Tendons and Anchors

1. Soil is considered an aggressive environment for post-tensioning strands and anchors. Therefore, due to the soils found on-site, protect post-tensioning strands and anchors against corrosion in this aggressive (corrosive) environment. Implement *all* the following measures: (ACI 2001)(PTI 2006)(PTI 2000)
    a. Completely encapsulate the tendon and anchor with polyethylene to create a watertight seal.
    b. All components exposed to the job site should be protected within one working day after their exposure during installation.
    c. Ensure the minimum concrete cover over the tendon tail is 1-inch, or greater if required by the applicable building code.

d. Caps and sleeves should be installed within one working day after the cutting of the tendon tails and acceptance of the elongation records by the engineer.

e. Inspect the following to ensure the encapsulated system is completely watertight:

    i. Sheathing: Verify that all damaged areas, including pin-holes, are repaired.

    ii. Stressing tails: After removal, ensure they are cut to a length for proper installation of P/T coating filled end caps.

    iii. End caps: Ensure proper installation before patching the pocket former recesses.

    iv. Patching: Ensure the patch is of an approved material and mix design, and installed void-free.

f. Limit the access of direct runoff onto the anchorage area by designing proper drainage.

g. Provide at least 2 inches of space between finish grade and the anchorage area, or more if required by applicable building codes.

## CLOSURE

Our services have been performed with the usual thoroughness and competence of the engineering profession. No other warranty or representation, either expressed or implied, is included or intended.

Please call if you have any questions.

Respectfully Submitted,
HDR ENGINEERING, INC.

REGISTERED PROFESSIONAL ENGINEER
STEVEN R FOX
No. CR 1137
Exp. 3-31-13
CORROSION
STATE OF CALIFORNIA

Ian Budner
EIT Corrosion Technician

Steven R. Fox, P.E.
Vice President

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Romanoff, M. (1989). Underground Corrosion, National Bureau of Standards (NBS) Circular 579. Houston, TX, United States of America: Reprinted by NACE.

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# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-09-0472, SA #09-0628SCSP***
***13-Aug-09***

| **Sample ID** | | | G-5<br>@ 20' | G-5<br>@ 30' | G-6<br>@ 70'<br>ML | G-7<br>@ 20' | G-7<br>@ 40' |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 5,600 | 3,680 | 18,000 | 2,640 | 1,300 |
| saturated | | ohm-cm | 880 | 520 | 600 | 760 | 840 |
| **pH** | | | 8.2 | 6.8 | 7.3 | 6.7 | 7.8 |
| **Electrical Conductivity** | | mS/cm | 0.42 | 0.84 | 1.16 | 0.10 | 0.22 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 75 | 180 | 361 | 37 | 72 |
| magnesium | $Mg^{2+}$ | mg/kg | 66 | 186 | 180 | 21 | 40 |
| sodium | $Na^{1+}$ | mg/kg | 308 | 508 | 557 | 96 | 157 |
| potassium | $K^{1+}$ | mg/kg | 22 | 16 | 75 | 6.1 | 16 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 634 | 235 | 217 | 122 | 369 |
| flouride | $F^{1-}$ | mg/kg | 3.9 | 1.9 | 1.4 | 12.9 | 1.9 |
| chloride | $Cl^{1-}$ | mg/kg | 23 | 46 | 264 | 15 | 26 |
| sulfate | $SO_4^{2-}$ | mg/kg | 362 | 1,600 | 1,810 | 74 | 173 |
| phosphate | $PO_4^{3-}$ | mg/kg | 1.0 | ND | ND | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 4.3 | 5.1 | 32 | ND | 3.5 |
| nitrate | $NO_3^{1-}$ | mg/kg | 1.2 | ND | ND | 1.5 | 1.9 |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

HDR | SCHIFF
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*Corrosion Control and Condition Assessment (C3A) Department*

# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0647LAB***
***8-Jul-11***

| **Sample ID** | | | G-123 @ 41' Tar Sand | G-123 @ 47' Tar Sand | G-123 @ 63' Tar Sand | G-124 @ 35' CL w/Tar | G-124 @ 55' SP w/Tar |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,680,000 | 18,400 | 3,240,000 | 10,400 | 4,400,000 |
| saturated | | ohm-cm | 13,200 | 2,680 | 3,640 | 1,200 | 8,000 |
| **pH** | | | 4.9 | 5.5 | 7.0 | 7.5 | 3.3 |
| **Electrical Conductivity** | | mS/cm | 0.11 | 0.11 | 0.43 | 0.27 | 0.49 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 45 | 38 | 196 | 67 | 240 |
| magnesium | $Mg^{2+}$ | mg/kg | 33 | 30 | 42 | 59 | 119 |
| sodium | $Na^{1+}$ | mg/kg | 13 | 34 | 174 | 113 | 55 |
| potassium | $K^{1+}$ | mg/kg | 0.9 | 1.9 | 6.9 | 13 | 7.3 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | ND | 12 | 15 | 64 | ND |
| fluoride | $F^{1-}$ | mg/kg | ND | ND | ND | 0.9 | 2.8 |
| chloride | $Cl^{1-}$ | mg/kg | 1.2 | 5.2 | 49 | 6.5 | 4.4 |
| sulfate | $SO_4^{2-}$ | mg/kg | 244 | 230 | 833 | 544 | 1,183 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND | ND | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 0.9 | 0.9 | 6.8 | 4.2 | 4.8 |
| nitrate | $NO_3^{1-}$ | mg/kg | 5.0 | 0.8 | ND | 6.5 | 1.4 |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0815LAB***
***12-Aug-11***

| **Sample ID** | | | S-106<br>@ 23-24'<br>ML w/Tar | S-106<br>@ 33-34'<br>ML w/Tar | S-106<br>@ 47-48'<br>SM w/Tar | S-106<br>@ 61-62'<br>SM w/Tar | S-106<br>@ 77-78'<br>SM w/Tar |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 3,240 | 1,520 | 18,400 | 392,000 | 560,000 |
| saturated | | ohm-cm | 560 | 920 | 2,760 | 26,400 | 14,400 |
| **pH** | | | 3.4 | 7.4 | 7.7 | 6.4 | 3.3 |
| **Electrical Conductivity** | | mS/cm | 2.53 | 0.33 | 0.05 | 0.04 | 0.06 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 1,755 | 56 | 14 | 20 | 22 |
| magnesium | $Mg^{2+}$ | mg/kg | 922 | 60 | 17 | 12 | 6.9 |
| sodium | $Na^{1+}$ | mg/kg | 293 | 165 | 28 | 18 | 29 |
| potassium | $K^{1+}$ | mg/kg | 12 | 18 | 3.2 | 2.9 | ND |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | ND | 162 | 18 | 15 | ND |
| fluoride | $F^{1-}$ | mg/kg | ND | ND | ND | ND | ND |
| chloride | $Cl^{1-}$ | mg/kg | 8.1 | 7.4 | 3.3 | 3.0 | 6.9 |
| sulfate | $SO_4^{2-}$ | mg/kg | 8,790 | 580 | 81 | 83 | 111 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND | ND | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 14 | 7.0 | 2.2 | 1.3 | 2.7 |
| nitrate | $NO_3^{1-}$ | mg/kg | ND | ND | ND | ND | ND |
| sulfide | $S^{2-}$ | qual | Negative | Negative | Negative | Negative | Negative |
| Redox | | mV | 141 | -19 | -67 | -14 | 43 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0815LAB***
***12-Aug-11***

| **Sample ID** | | | S-106<br>@ 91-92'<br>ML w/Tar | S-106<br>108-109'<br>ML w/Tar |
|---|---|---|---|---|
| **Resistivity** | | **Units** | | |
| as-received | | ohm-cm | 4,400,000 | 31,200 |
| saturated | | ohm-cm | 20,000 | 2,560 |
| **pH** | | | 2.6 | 3.0 |
| **Electrical Conductivity** | | mS/cm | 0.07 | 0.30 |
| **Chemical Analyses** | | | | |
| **Cations** | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 25 | 63 |
| magnesium | $Mg^{2+}$ | mg/kg | 7.0 | 25 |
| sodium | $Na^{1+}$ | mg/kg | 19 | 157 |
| potassium | $K^{1+}$ | mg/kg | ND | ND |
| **Anions** | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | ND | ND |
| fluoride | $F^{1-}$ | mg/kg | ND | ND |
| chloride | $Cl^{1-}$ | mg/kg | 6.0 | 90 |
| sulfate | $SO_4^{2-}$ | mg/kg | 142 | 530 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND |
| **Other Tests** | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 2.8 | 4.5 |
| nitrate | $NO_3^{1-}$ | mg/kg | ND | ND |
| sulfide | $S^{2-}$ | qual | Negative | Negative |
| Redox | | mV | 125 | -13 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# FIGURES F-10.65.1 THROUGH F-10.65.19 SOIL CORROSIVITY EVALUATION FOR WILSHIRE/LA CIENEGA STATION

# SOIL CORROSIVITY EVALUATION

*for the*

# WESTSIDE SUBWAY EXTENSION

# WILSHIRE/LA CIENEGA STATION

in

LOS ANGELES, CA

prepared for

AMEC E&I
5628 East Slauson Avenue
Los Angeles, CA 90040

Project No.: 4953-10-1561

PROJECT MANAGER: MR. MARTY HUDSON

prepared by

**HDR ENGINEERING, INC.**
*Consulting Corrosion Engineers*
431 West Baseline Road
Claremont, California 91711

HDR|SCHIFF #172549

October 18, 2011

## EXECUTIVE SUMMARY

The Westside Subway Extension is a proposed extension of the Metro Purple Line subway westward from the Wilshire/Western Station to the Veterans Administration West Los Angeles Hospital. Wilshire/La Cienega station is one of the eight stations planned for the project. The station will be approximately 1,000 feet long and about 60 to 70 feet below ground surface.

Laboratory tests on the provided soil samples provided by AMEC E&I have been completed. 18 of the samples were selected for analysis. This soil is classified as severely corrosive to ferrous metals, aggressive to copper, moderate for sulfate attack on concrete, and could subject metal to microbial induced corrosion.

A dielectrically coated steel pipeline for this route should also have bonded joints and test stations. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

Cathodically protect and provide corrosion monitoring for hydraulic elevators and associated components as required for compliance with Title 23 as necessary.

A dielectrically coated ductile iron pipe would also be a suitable choice. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

A polyvinyl chloride (PVC) pipe would also be a suitable choice. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating.

Type II cement should be used for concrete structures. Standard concrete cover over reinforcing steel may be used. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system.

Due to the soils at this site, post-tensioned slabs should be protected in accordance with soil considered aggressive (corrosive).

## TABLE OF CONTENTS

## INTRODUCTION

The existing subway system is owned and operated by Los Angeles County Metropolitan Transportation Authority (MTA) and provides public transportation throughout the City of Los Angeles, and surrounding areas.

The Westside Subway Extension is a proposed extension of the Metro Purple Line subway westward from the Wilshire/Western Station to the Veterans Administration West Los Angeles Hospital. In the Century City area, two alternative alignments are considered; one with a station along Santa Monica Boulevard, and one with a station along Constellation Boulevard. The proposed subway alignment is about 9 miles long. The depth to tunnel invert varies along the alignment from 40 to 160 feet below grade. The subway will consist of heavy rail transit operated in a twin tunnel configuration with eight new passenger stations, with two options in Century City.

Wilshire/La Cienega station is one of the eight stations planned for the project. The station will be approximately 1,000 feet long and about 60 to 70 feet below ground surface. Ground water was encountered at depths of about 20 to 30 feet below ground surface. The station will include walls below grade, utility piping, hydraulic elevator systems, concrete structures and post-tensioning systems.

An analysis of soil corrosivity along the route of the Metro rail alignment was requested. Laboratory tests on the provided soil samples provided by AMEC E&I have been completed. 18 of the samples were selected for analysis. HDR Engineering, Inc. (HDR|Schiff) assumes that the samples selected are representative of the most corrosive soils at the site.

The scope of this study is limited to a determination of soil corrosivity and general corrosion control recommendations for materials planned for construction. HDR|Schiff understands shoring piles will be used only temporarily during construction and will not be considered in this study. If steel piles are considered for use as permanent structures in the future, HDR|Schiff will be glad to perform Romanoff similitude analysis for metal loss and determine estimated corrosion rates.

## LABORATORY TESTS ON SOIL SAMPLES

The electrical resistivity of each of the 18 samples was measured in a soil box per ASTM G187 in its as-received condition and again after saturation with distilled water. Resistivities are at about their lowest value when the soil is saturated. The pH of the saturated samples was measured per ASTM G 51. A 5:1 water:soil extract from each sample was chemically analyzed for the major soluble salts commonly found in soil per ASTM D4327, D6919, and D513. Test results are shown in Table 1 in the Appendix to this report.

## SOIL CORROSIVITY

A major factor in determining soil corrosivity is electrical resistivity. The electrical resistivity of a soil is a measure of its resistance to the flow of electrical current. Corrosion of buried metal is an electrochemical process in which the amount of metal loss due to corrosion is directly proportional to the flow of electrical current (DC) from the metal into the soil. Corrosion currents, following Ohm's Law, are inversely proportional to soil resistivity. Lower electrical resistivities result from higher moisture and soluble salt contents and indicate corrosive soil.

A correlation between electrical resistivity and corrosivity toward ferrous metals is (Romanoff, 1989):

| Soil Resistivity in ohm-centimeters | Corrosivity Category |
|---|---|
| Greater than 10,000 | Mildly Corrosive |
| 2,001 to 10,000 | Moderately Corrosive |
| 1,001 to 2,000 | Corrosive |
| 0 to 1,000 | Severely Corrosive |

Other soil characteristics that may influence corrosivity towards metals are pH, soluble salt content, soil types, aeration, anaerobic conditions, and site drainage.

Electrical resistivities were in the moderately to severely categories with as-received moisture. When saturated, the resistivities were in the corrosive and severely corrosive categories.

Soil pH values varied from 7.4 to 8.2. This range is mildly to moderately alkaline (Romanoff, 1989). These values do not particularly increase soil corrosivity.

The soluble salt content of the samples ranged from low to high.

The soluble salt content was high in the samples from borings S-107 @ 102-103’, G-131 @ 90’, G-128 @ 80.5, and G-129 @ 83.5’ and less in the others. Sulfate salts were the predominant constituents. High concentrations of sulfate, as was measured in the soil samples, can react with components in concrete to cause degradation and reduced strength in a mechanism known as sulfate attack.

Nitrate was detected in low concentrations. The ammonium concentration was high enough to be deleterious to copper.

Sulfide, which is aggressive to copper and ferrous metals, was found to be present in a qualitative test performed on the samples from borings S-107 @ 121-122’ and G-128 @ 50.5’ and 80.5’. The negative redox potential measured on the sample indicates reducing conditions in which anaerobic, sulfide-producing bacteria are active.

The variation in soil types can create differential-aeration corrosion cells that would affect all metals.

This soil is classified as severely corrosive to ferrous metals, aggressive to copper, moderate for sulfate attack on concrete, and could subject metal to microbial induced corrosion.

Heavy rail transit systems can present a multitude of DC stray current issues. These issues can affect not only the system of concern, but also other metallic utilities or structures proximal to rails, and DC substations if the proper mitigation practices are not followed. Stray current can increase corrosion rates above what would be expected from the chemical characteristics alone.

## CONCLUSIONS

This soil is classified as severely corrosive to ferrous metals, aggressive to copper, moderate for sulfate attack on concrete, and could subject metal to microbial induced corrosion.

A dielectrically coated steel pipeline for this route should also have bonded joints and test stations. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

Cathodically protect and provide corrosion monitoring for hydraulic elevators and associated components as required for compliance with Title 23 as necessary.

A dielectrically coated ductile iron pipe would also be a suitable choice. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

A polyvinyl chloride (PVC) pipe would also be a suitable choice. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating.

Type II cement should be used for concrete structures. Standard concrete cover over reinforcing steel may be used. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system.

Due to the soils at this site, post-tensioned slabs should be protected in accordance with soil considered aggressive (corrosive).

Due to the nature and magnitude of the project and the long design service life requirements, tolerance for corrosion on all project components is low. Based on the need for high reliability and the corrosivity considerations discussed above, it is clear that corrosion protection must be provided for the components exposed to the environment discussed with consideration given to the level of risk and practicality.

## RECOMMENDATIONS

### DC Stray Current

A study of the impact of the DC powered heavy rail system was not detailed as part of the scope work in this project. It is recommended that the client pursue such a study in order to take the necessary precautions to avoid the deleterious effects known to result from DC stray current.

### Steel Pipe

Implement *all* the following measures.

1. Underground steel pipe with rubber gasketed, mechanical, grooved end, or other nonconductive type joints should be bonded for electrical continuity. For pipe diameters less 18 inches use two joint bonds. For pipe diameters greater than or equal to 18 inches use three joint bonds. Electrical continuity is necessary for corrosion monitoring and cathodic protection.

2. Install corrosion monitoring test stations to facilitate corrosion monitoring and the application of cathodic protection:
    a. Two or four-wire test stations at each end of the pipeline depending on how the pipe terminates.
    b. Four-wire test stations at all buried insulating joints.
    c. Four-wire test stations at each end of all casings.
    d. Two-wire test stations at other locations as necessary so the interval between test stations does not exceed 1,200 feet.

    Where 4-wire test stations are required, use wires of difference size or insulation color for identification. Each wire should be independently welded or pin-brazed to the pipe.

3. To prevent dissimilar metal corrosion cells and to facilitate the application of cathodic protection, electrically isolate each buried steel pipeline per NACE Standard SP0286 from:
    a. Pumping plants.
    b. Reservoirs.
    c. Flow meters.
    d. Motorized operated valves.
    e. Dissimilar metals.
    f. Dissimilarly coated piping (cement-mortar vs. dielectric).
    g. Above ground steel pipe.
    h. All existing piping.

    Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

4. Prevent contact between the steel pipe and concrete and/or reinforcing steel, such as at wall penetrations and thrust blocks, with such items as plastic sleeves, rubber seals, or 20 mil plastic tape.

5. Apply a suitable dielectric coating intended for underground use such as:
   a. Polyurethane per AWWA C222 *or*
   b. Extruded polyethylene per AWWA C215 *or*
   c. A tape coating system per AWWA C214 *or*
   d. Hot applied coal tar enamel per AWWA C203 *or*
   e. Fusion bonded epoxy per AWWA C213.

6. Buried steel and iron pipe, fittings, and valves in appurtenances, such as air valves and blowoffs, should be coated with a material listed above or with coal-tar epoxy, wax tape, moldable sealant, or equivalent. If copper is used, electrically insulate it from the steel with an insulating joint or with a dielectric union.

7. Apply cathodic protection to steel piping as per NACE Standard SP0169.

8. To insure that corrosion control is properly designed, preliminary construction drawings should be reviewed by a qualified corrosion engineer.

9. After the pipeline is backfilled, but before the construction contract is completed, the pipeline should be tested to insure that the joint bonds are intact and test stations properly installed. Also, native pipe-to-soil potentials should be measured and recorded. These data will be useful in determining if pipeline conditions change in the future.

10. Pipe-to-soil potentials should be measured biennially to determine if conditions on the pipeline are changing.

## Hydraulic Elevator

Implement *all* the following measures:

1. Coat hydraulic elevator cylinders as described above for steel pipe, item #5that is resistant to petroleum products (hydraulic fluid).
2. Electrically insulate each cylinder from building metals by installing dielectric material between the piston platen and car, insulating the bolts, and installing an insulated joint in the oil line.
3. Place each cylinder in a non-metallic casing with a plastic watertight seal at the bottom. Fill the annulus with dry sand with a minimum resistivity of 25,000 ohm-centimeters, a pH of between 6.5 and 7.5 and a maximum chloride content of 200 ppm.
4. A removable moisture-proof sealing lid installed on the top of the casing prior to installation of the cylinder. The top of the casing shall be permanently sealed against moisture intrusion after installation of the cylinder.
5. Apply cathodic protection to hydraulic cylinders as per NACE Standard SP0169.

6. The elevator oil line should be placed above ground if possible but, if underground, should be protected by one of the following corrosion control options:

   **OPTION 1**

   a. Provide a bonded dielectric coating.
   b. Electrically isolate the pipeline.
   c. Apply cathodic protection to steel piping as per NACE Standard SP0169.

   **OPTION 2**

   a. Place the oil line in a PVC casing pipe with solvent-welded joints to prevent contact with soil and soil moisture.

7. If steel underground storage tanks are used, cathodic protection and corrosion control requirements shall comply with Title 23.

### Reinforced Concrete Pipe

Implement *all* the following measures.

1. To prevent dissimilar metal corrosion cells electrically isolate the storm drain per NACE Standard SP0286 from all structures and facilities.

   Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

2. Prevent contact between the steel pipe and concrete and/or reinforcing steel, such as at wall penetrations and thrust blocks, with such items as plastic sleeves, rubber seals, or 20 mil plastic tape.

3. Buried steel and iron pipe and fittings in appurtenances should be cement-mortar coated or concrete or cement slurry encased where possible. Otherwise, they should be wrapped with wax tape per AWWA Standard C-217

4. To insure that corrosion control is properly designed, preliminary construction drawings should be reviewed by a qualified corrosion engineer.

5. Apply a suitable dielectric waterproofing coating intended for underground use. This coating is to be compatible with and applied over the concrete/cement-mortar.

### Iron Pipe

Implement *all* the following measures:

1. To prevent dissimilar metal corrosion cells and to facilitate the application of cathodic protection, electrically isolate each buried iron pipeline per NACE Standard SP0286 from:
   a. Pumping plants.

   b. Reservoirs.
   c. Flow meters.
   d. Motorized operated valves.
   e. Dissimilar metals.
   f. Dissimilarly coated piping (cement-mortar vs. dielectric).
   g. Above ground steel pipe.
   h. All existing piping.

   Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

2. Bond all nonconductive type joints for electrical continuity. Electrical continuity is necessary for corrosion monitoring and cathodic protection. For pipe diameters less 18 inches use two joint bonds. For pipe diameters greater than or equal to 18 inches use three joint bonds. Electrical continuity is necessary for corrosion monitoring and cathodic protection.

3. Install corrosion monitoring test stations to facilitate corrosion monitoring and the application of cathodic protection:
   a. Two or four-wire test stations at each end of the pipeline depending on how the pipe terminates.
   b. Four-wire test stations at all buried insulating joints.
   c. Four-wire test stations at each end of all casings.
   d. Two-wire test stations at other locations as necessary so the interval between test stations does not exceed 1,200 feet.

   Where 4-wire test stations are required, use wires of difference size or insulation color for identification. Each wire should be independently welded or pin-brazed to the pipe.

4. Use iron pipe, fittings, and valves in appurtenances to the extent possible to avoid creating dissimilar metal corrosion cells. Steel appurtenances such as bolts should be coated with wax tape. If copper is used, electrically isolate it from the iron.

5. Prevent contact between iron and concrete including reinforcing steel, using such items as plastic sleeves, rubber seals, two layers of 8 mil thick polyethylene plastic, or 20 mil plastic tape.

6. Apply a suitable coating intended for underground use such as:
   a. Epoxy coating; *or*
   b. Polyurethane; *or*
   c. Wax tape.

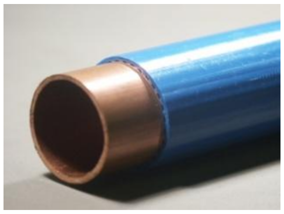
   NOTE: The thin factory-applied asphaltic coating applied to ductile iron pipe for transportation and aesthetic purposes does not constitute a corrosion control coating.

7. Apply cathodic protection to cast and ductile iron piping as per NACE Standard SP0169.

## Copper Pipe

Protect buried copper pipe by *one* of the following measures:

1. Installation of a factory-coated copper pipe with a minimum 25-mil thickness such as Kamco's Aqua Shield™, Mueller's Streamline Protec™, or equal. The coating must be continuous with no cuts or defects.



2. Installation of 12-mil polyethylene pipe wrapping tape with butyl rubber mastic over a suitable primer. Protect wrapped copper tubing by applying cathodic protection per NACE Standard SP0169.

## Polyvinyl Chloride (PVC) Pipe

1. No special measures are required to protect PVC.

2. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating such as wax tape per AWWA C217, plastic pipe wrapping tape, coal tar epoxy, polyurethane, or equivalent.

3. Install electrically insulated joints in iron riser connections to above grade metallic piping.

4. Use iron pipe, fittings, and valves in appurtenances, such as air valves and blowoffs, to the extent possible to avoid creating dissimilar metal corrosion cells. Steel appurtenances such as bolts should be coated as described above. If copper is used, electrically isolate it from the iron.

## All Pipe

1. On all pipes, appurtenances, and fittings not protected by cathodic protection or encased in concrete, coat pipe specials such as valves, bolts, flange joints, joint harnesses, and flexible couplings with wax tape per AWWA C217 after assembly.

2. Where metallic pipelines penetrate concrete structures such as building floors, vault walls, and thrust blocks use plastic sleeves, rubber seals, or other dielectric material to prevent pipe contact with the concrete and reinforcing steel.

## Concrete Structures

The concrete mix design should provide the least permeable and mostly crack-free matrix to reduce penetration of aggressive ions and oxygen into the concrete. The concrete mixture should be designed to help protect the steel adequately from corrosion. Factors in concrete mix design that can reduce the permeability of the concrete include lowering the water-to-cement ratio by either increasing the cement content or decreasing water content. Finely divided materials such as fly ash, granulated blast furnace slag, silica fume, and other pozzolans can further reduce permeability of the concrete.

In addition, aggregates having water-soluble chloride ions on their surfaces, or even within their particles, can cause corrosion problems. If enough surface-borne chlorides are present, a portion will not be bound within the solid "paste" phase during hydration of the cement. Most of the chlorides released from the interior of an aggregate particle after the first few hours of hydration will not be bound at all. Unbound chloride ions can cause passivity breakdown of the steel created by the alkaline cement.

The following standards contain important guidelines for the maximum concentration of chloride, sulfate and carbonate ions on the mixing water and admixture:

- Portland Cement Association PCA Publication E B.001, Design and Control of Concrete mixtures
- American Concrete Institute ACI 318, Building Code Requirements for Reinforced Concrete Structures
- American Concrete Institute ACI 222, Corrosion of Metals in Concrete

Nevertheless, there are certain steps that can be taken to enhance the protective properties of the concrete. The most important factor is keeping the cement content high enough to maintain a pH of 12.5 or greater.

1. From a corrosion standpoint, Type II cement should be used for concrete structures and pipe because the sulfate concentration is moderate, 0.10 to 0.20 percent.

2. Standard concrete cover over reinforcing steel may be used for concrete structures and pipe in contact with these soils due to the low chloride concentration found onsite.

3. Due to the high ground water table encountered at this site, cyclical or continual wetting may be an issue. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system.

## Post Tensioning Slabs: Unbonded Single-Stranded Tendons and Anchors

1. Soil is considered an aggressive environment for post-tensioning strands and anchors. Therefore, due to the soils found on-site, protect post-tensioning strands and anchors against corrosion in this aggressive (corrosive) environment. Implement *all* the following measures: (ACI 2001)(PTI 2006)(PTI 2000)
    a. Completely encapsulate the tendon and anchor with polyethylene to create a watertight seal.
    b. All components exposed to the job site should be protected within one working day after their exposure during installation.
    c. Ensure the minimum concrete cover over the tendon tail is 1-inch, or greater if required by the applicable building code.

d. Caps and sleeves should be installed within one working day after the cutting of the tendon tails and acceptance of the elongation records by the engineer.

e. Inspect the following to ensure the encapsulated system is completely watertight:
    i. Sheathing: Verify that all damaged areas, including pin-holes, are repaired.
    ii. Stressing tails: After removal, ensure they are cut to a length for proper installation of P/T coating filled end caps.
    iii. End caps: Ensure proper installation before patching the pocket former recesses.
    iv. Patching: Ensure the patch is of an approved material and mix design, and installed void-free.

f. Limit the access of direct runoff onto the anchorage area by designing proper drainage.

g. Provide at least 2 inches of space between finish grade and the anchorage area, or more if required by applicable building codes.

## CLOSURE

Our services have been performed with the usual thoroughness and competence of the engineering profession. No other warranty or representation, either expressed or implied, is included or intended.

Please call if you have any questions.

Respectfully Submitted,
HDR ENGINEERING, INC.

Ian Budner
EIT Corrosion Technician

REGISTERED PROFESSIONAL ENGINEER
STEVEN R FOX
No. CR 1137
Exp. 3-31-13
CORROSION
STATE OF CALIFORNIA

Steven R. Fox, P.E.
Vice President

11-1050SCS-RPT_Wilshire_LaCienega_IB_rev00

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Romanoff, M. (1989). Underground Corrosion, National Bureau of Standards (NBS) Circular 579. Houston, TX, United States of America: Reprinted by NACE.

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HDR | SCHIFF
www.hdrinc.com
*Corrosion Control and Condition Assessment (C3A) Department*

# Table 1 - Laboratory Tests on Soil Sample(s)

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0498LAB***
***31-May-11***

| **Sample ID** | | | S-107<br>@ 28-29'<br>CL | S-107<br>@ 42-43'<br>ML | S-107<br>@ 59-60'<br>ML/CL | S-107<br>@ 72-73'<br>CL | S-107<br>@ 85-86'<br>CL/ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,600 | 1,360 | 960 | 800 | 1,240 |
| saturated | | ohm-cm | 1,240 | 960 | 640 | 480 | 760 |
| **pH** | | | 8.1 | 7.9 | 8.1 | 8.0 | 7.9 |
| **Electrical Conductivity** | | mS/cm | 0.24 | 0.34 | 0.45 | 0.57 | 0.50 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 52 | 115 | 128 | 247 | 201 |
| magnesium | $Mg^{2+}$ | mg/kg | 21 | 51 | 51 | 95 | 90 |
| sodium | $Na^{1+}$ | mg/kg | 188 | 124 | 259 | 180 | 137 |
| potassium | $K^{1+}$ | mg/kg | 35 | 51 | 38 | 55 | 71 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | 24 | ND | 9.0 | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 275 | 305 | 176 | 458 | 354 |
| fluoride | $F^{1-}$ | mg/kg | 3.5 | 2.5 | 0.6 | ND | ND |
| chloride | $Cl^{1-}$ | mg/kg | 47 | 40 | 49 | 97 | 131 |
| sulfate | $SO_4^{2-}$ | mg/kg | 158 | 427 | 792 | 853 | 696 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | 0.9 | ND | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 2.7 | 4.6 | 7.9 | 10 | 8.8 |
| nitrate | $NO_3^{1-}$ | mg/kg | 1.0 | ND | 1.1 | 0.9 | 0.6 |
| sulfide | $S^{2-}$ | qual | Positive | Positive | Positive | Positive | Positive |
| Redox | | mV | -126 | -267 | -117 | -272 | -313 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Sample(s)

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0498LAB***
***31-May-11***

| **Sample ID** | | | S-107<br>@ 102-103'<br>ML | S-107<br>@ 121-122'<br>ML |
|---|---|---|---|---|
| **Resistivity** | | **Units** | | |
| as-received | | ohm-cm | 3,480 | 3,400 |
| saturated | | ohm-cm | 480 | 800 |
| **pH** | | | 8.0 | 8.2 |
| **Electrical Conductivity** | | mS/cm | 0.58 | 0.29 |
| **Chemical Analyses** | | | | |
| **Cations** | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 244 | 113 |
| magnesium | $Mg^{2+}$ | mg/kg | 102 | 43 |
| sodium | $Na^{1+}$ | mg/kg | 124 | 80 |
| potassium | $K^{1+}$ | mg/kg | 68 | 79 |
| **Anions** | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | 9.0 |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 354 | 245 |
| fluoride | $F^{1-}$ | mg/kg | 1.1 | 2.5 |
| chloride | $Cl^{1-}$ | mg/kg | 57 | 48 |
| sulfate | $SO_4^{2-}$ | mg/kg | 921 | 318 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND |
| **Other Tests** | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 12 | 3.3 |
| nitrate | $NO_3^{1-}$ | mg/kg | 1.1 | ND |
| sulfide | $S^{2-}$ | qual | na | Trace |
| Redox | | mV | na | -97 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0633LAB***
***7-Jul-11***

| **Sample ID** | | | G-131<br>@ 20'<br>ML | G-131<br>@ 90'<br>ML | G-132<br>@ 10'<br>CL |
|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | |
| as-received | | ohm-cm | 1,080 | 1,080 | 1,000 |
| saturated | | ohm-cm | 1,080 | 600 | 1,000 |
| **pH** | | | 8.1 | 8.1 | 8.0 |
| **Electrical Conductivity** | | mS/cm | 0.25 | 0.54 | 0.29 |
| **Chemical Analyses** | | | | | |
| **Cations** | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 60 | 208 | 62 |
| magnesium | $Mg^{2+}$ | mg/kg | 27 | 102 | 35 |
| sodium | $Na^{1+}$ | mg/kg | 198 | 121 | 185 |
| potassium | $K^{1+}$ | mg/kg | 12 | 78 | 7.8 |
| **Anions** | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | 27 | ND | 18 |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 389 | 153 | 387 |
| fluoride | $F^{1-}$ | mg/kg | 6.0 | 1.7 | 15 |
| chloride | $Cl^{1-}$ | mg/kg | 15 | 33 | 41 |
| sulfate | $SO_4^{2-}$ | mg/kg | 153 | 1,002 | 108 |
| phosphate | $PO_4^{3-}$ | mg/kg | 0.8 | ND | 0.6 |
| **Other Tests** | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | 9.4 | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 0.5 | 0.7 | 15 |
| sulfide | $S^{2-}$ | qual | na | na | na |
| Redox | | mV | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0673LAB***
***14-Jul-11***

| **Sample ID** | | | G-128 @ 25.5' CL-ML | G-128 @ 50.5' SC | G-128 @ 80.5' CL | G-129 @ 20' CL | G-129 @ 40' ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,880 | 1,360 | 680 | 2,120 | 3,200 |
| saturated | | ohm-cm | 1,760 | 1,240 | 520 | 1,160 | 560 |
| **pH** | | | 7.4 | 7.9 | 7.6 | 7.8 | 7.9 |
| **Electrical Conductivity** | | mS/cm | 0.15 | 0.21 | 0.58 | 0.19 | 0.25 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 38 | 46 | 212 | 45 | 63 |
| magnesium | $Mg^{2+}$ | mg/kg | 17 | 28 | 111 | 22 | 33 |
| sodium | $Na^{1+}$ | mg/kg | 123 | 135 | 214 | 130 | 145 |
| potassium | $K^{1+}$ | mg/kg | 7.1 | 13 | 47 | 8.8 | 31.9 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | 23 | ND | ND | 21 | 9.0 |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 192 | 183 | 262 | 229 | 220 |
| fluoride | $F^{1-}$ | mg/kg | 2.7 | 1.7 | 2.0 | 4.3 | 2.5 |
| chloride | $Cl^{1-}$ | mg/kg | 20 | 9.4 | 11 | 56 | 27 |
| sulfate | $SO_4^{2-}$ | mg/kg | 50 | 316 | 1,120 | 47 | 274 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND | ND | ND | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | 2.3 | 6.2 | ND | 1.2 |
| nitrate | $NO_3^{1-}$ | mg/kg | ND | 4.1 | 2.0 | 0.7 | 0.8 |
| sulfide | $S^{2-}$ | qual | na | Positive | Trace | na | na |
| Redox | | mV | na | -108 | -97 | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0673LAB***
***14-Jul-11***

| **Sample ID** | | | G-129 @ 70' ML | G-129 @ 83.5' CL | G-129 @ 100' CL |
|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | |
| as-received | | ohm-cm | 1,520 | 680 | 1,360 |
| saturated | | ohm-cm | 840 | 560 | 600 |
| **pH** | | | 7.8 | 7.8 | 7.8 |
| **Electrical Conductivity** | | mS/cm | 0.25 | 0.50 | 0.61 |
| **Chemical Analyses** | | | | | |
| **Cations** | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 70 | 197 | 247 |
| magnesium | $Mg^{2+}$ | mg/kg | 39 | 87 | 134 |
| sodium | $Na^{1+}$ | mg/kg | 114 | 144 | 136 |
| potassium | $K^{1+}$ | mg/kg | 22 | 47 | 47.0 |
| **Anions** | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 159 | 259 | 262 |
| fluoride | $F^{1-}$ | mg/kg | 0.9 | 1.8 | 1.2 |
| chloride | $Cl^{1-}$ | mg/kg | 67 | 78 | 50 |
| sulfate | $SO_4^{2-}$ | mg/kg | 329 | 807 | 1,104 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND | ND | ND |
| **Other Tests** | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 2.6 | 2.5 | 10 |
| nitrate | $NO_3^{1-}$ | mg/kg | 13 | 4.5 | 2.6 |
| sulfide | $S^{2-}$ | qual | na | na | na |
| Redox | | mV | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# FIGURES F-10.66.1 THROUGH F-10.66.18 SOIL CORROSIVITY EVALUATION FOR WILSHIRE/RODEO STATION

# SOIL CORROSIVITY EVALUATION

*for the*

# WESTSIDE SUBWAY EXTENSION

# WILSHIRE/RODEO STATION

in

LOS ANGELES, CA

prepared for

**AMEC E&I**
5628 East Slauson Avenue
Los Angeles, CA 90040

Project No.: 4953-10-1561

PROJECT MANAGER: MR. MARTY HUDSON

prepared by

**HDR ENGINEERING, INC.**
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Claremont, California 91711

HDR|SCHIFF #172549

October 18, 2011

## EXECUTIVE SUMMARY

The Westside Subway Extension is a proposed extension of the Metro Purple Line subway westward from the Wilshire/Western Station to the Veterans Administration West Los Angeles Hospital. Wilshire/Rodeo station is one of the eight stations planned for the project. The station will be approximately 1,050 feet long and about 70 to 80 feet below ground surface.

Laboratory tests on the provided soil samples provided by AMEC E&I have been completed. 15 of the samples were selected for analysis. This soil is classified as severely corrosive to ferrous metals, aggressive to copper, and aggressive with respect to exposure of concrete to acid attack.

A dielectrically coated steel pipeline for this route should also have bonded joints and test stations. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

Cathodically protect and provide corrosion monitoring for hydraulic elevators and associated components as required for compliance with Title 23 as necessary.

A dielectrically coated ductile iron pipe would also be a suitable choice. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

A polyvinyl chloride (PVC) pipe would also be a suitable choice. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating.

Type II cement should be used for concrete structures. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system. Concrete structures and pipe should be protected from acid attack.

Due to the soils at this site, post-tensioned slabs should be protected in accordance with soil considered aggressive (corrosive).

## TABLE OF CONTENTS

## INTRODUCTION

The existing subway system is owned and operated by Los Angeles County Metropolitan Transportation Authority (MTA) and provides public transportation throughout the City of Los Angeles, and surrounding areas.

The Westside Subway Extension is a proposed extension of the Metro Purple Line subway westward from the Wilshire/Western Station to the Veterans Administration West Los Angeles Hospital. In the Century City area, two alternative alignments are considered; one with a station along Santa Monica Boulevard, and one with a station along Constellation Boulevard. The proposed subway alignment is about 9 miles long. The depth to tunnel invert varies along the alignment from 40 to 160 feet below grade. The subway will consist of heavy rail transit operated in a twin tunnel configuration with eight new passenger stations, with two options in Century City.

Wilshire/Rodeo station is one of the eight stations planned for the project. The station will be approximately 1,050 feet long and about 70 to 80 feet below ground surface. Ground water was encountered at depths of about 25 to 70 feet below ground surface. The station will include walls below grade, utility piping, hydraulic elevator systems, concrete structures and post-tensioning systems.

An analysis of soil corrosivity along the route of the Metro rail alignment was requested. Laboratory tests on the provided soil samples provided by AMEC E&I have been completed. 15 of the samples were selected for analysis. HDR Engineering, Inc. (HDR|Schiff) assumes that the samples selected are representative of the most corrosive soils at the site.

The scope of this study is limited to a determination of soil corrosivity and general corrosion control recommendations for materials planned for construction. HDR|Schiff understands shoring piles will be used only temporarily during construction and will not be considered in this study. If steel piles are considered for use as permanent structures in the future, HDR|Schiff will be glad to perform Romanoff similitude analysis for metal loss and determine estimated corrosion rates.

## LABORATORY TESTS ON SOIL SAMPLES

The electrical resistivity of each of the 15 samples was measured in a soil box per ASTM G187 in its as-received condition and again after saturation with distilled water. Resistivities are at about their lowest value when the soil is saturated. The pH of the saturated samples was measured per ASTM G 51. A 5:1 water:soil extract from each sample was chemically analyzed for the major soluble salts commonly found in soil per ASTM D4327, D6919, and D513. Test results are shown in Table 1 in the Appendix to this report.

## SOIL CORROSIVITY

A major factor in determining soil corrosivity is electrical resistivity. The electrical resistivity of a soil is a measure of its resistance to the flow of electrical current. Corrosion of buried metal is an electrochemical process in which the amount of metal loss due to corrosion is directly proportional to the flow of electrical current (DC) from the metal into the soil. Corrosion currents, following Ohm's Law, are inversely proportional to soil resistivity. Lower electrical resistivities result from higher moisture and soluble salt contents and indicate corrosive soil.

A correlation between electrical resistivity and corrosivity toward ferrous metals is (Romanoff, 1989):

| Soil Resistivity in ohm-centimeters | Corrosivity Category |
|---|---|
| Greater than 10,000 | Mildly Corrosive |
| 2,001 to 10,000 | Moderately Corrosive |
| 1,001 to 2,000 | Corrosive |
| 0 to 1,000 | Severely Corrosive |

Other soil characteristics that may influence corrosivity towards metals are pH, soluble salt content, soil types, aeration, anaerobic conditions, and site drainage.

Electrical resistivities were in the moderately to severely categories with as-received moisture. When saturated, the resistivities were in the moderately to severely corrosive categories. Some as-received resistivities were at or near their saturated values. The remaining resistivities dropped considerably with added moisture because the samples were dry as-received.

Soil pH values varied from 4.0 to 8.3. This range is extremely acidic to moderately alkaline (Romanoff, 1989). Total acidity is assumed to be high enough to warrant concern of acid attack on concrete. Soil with a pH less than 5.5 is considered aggressive to copper.

The soluble salt content of the samples was low.

Nitrate was detected in low concentrations.

Some of the samples were tested for sulfides as they exhibited characteristics typically associated with anaerobic conditions. Sulfide, which is aggressive to copper and ferrous metals, showed no reaction in a qualitative test. The positive redox potentials measured in all of the samples from borings G-144 and G-145 indicates oxidizing conditions in which anaerobic, sulfide-producing bacteria are inactive.

The variation in soil types can create differential-aeration corrosion cells that would affect all metals.

This soil is classified as severely corrosive to ferrous metals, aggressive to copper, and aggressive with respect to exposure of concrete to acid attack.

Heavy rail transit systems can present a multitude of DC stray current issues. These issues can affect not only the system of concern, but also other metallic utilities or structures proximal to rails, and DC substations if the proper mitigation practices are not followed. Stray current can increase corrosion rates above what would be expected from the chemical characteristics alone.

## CONCLUSIONS

This soil is classified as severely corrosive to ferrous metals, aggressive to copper, and aggressive with respect to exposure of concrete to acid attack.

A dielectrically coated steel pipeline for this route should also have bonded joints and test stations. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

Cathodically protect and provide corrosion monitoring for hydraulic elevators and associated components as required for compliance with Title 23 as necessary.

A dielectrically coated ductile iron pipe would also be a suitable choice. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

A polyvinyl chloride (PVC) pipe would also be a suitable choice. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating.

Type II cement may be used for concrete structures. Standard concrete cover over reinforcing steel may be used. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system.

Due to the soils at this site, post-tensioned slabs should be protected in accordance with soil considered aggressive (corrosive).

Due to the nature and magnitude of the project and the long design service life requirements, tolerance for corrosion on all project components is low. Based on the need for high reliability and the corrosivity considerations discussed above, it is clear that corrosion protection must be provided for the components exposed to the environment discussed with consideration given to the level of risk and practicality.

## RECOMMENDATIONS

### DC Stray Current

A study of the impact of the DC powered heavy rail system was not detailed as part of the scope work in this project. It is recommended that the client pursue such a study in order to take the necessary precautions to avoid the deleterious effects known to result from DC stray current.

## Steel Pipe

Implement *all* the following measures.

1. Underground steel pipe with rubber gasketed, mechanical, grooved end, or other nonconductive type joints should be bonded for electrical continuity. For pipe diameters less 18 inches use two joint bonds. For pipe diameters greater than or equal to 18 inches use three joint bonds. Electrical continuity is necessary for corrosion monitoring and cathodic protection.

2. Install corrosion monitoring test stations to facilitate corrosion monitoring and the application of cathodic protection:
   a. Two or four-wire test stations at each end of the pipeline depending on how the pipe terminates.
   b. Four-wire test stations at all buried insulating joints.
   c. Four-wire test stations at each end of all casings.
   d. Two-wire test stations at other locations as necessary so the interval between test stations does not exceed 1,200 feet.

   Where 4-wire test stations are required, use wires of difference size or insulation color for identification. Each wire should be independently welded or pin-brazed to the pipe.

3. To prevent dissimilar metal corrosion cells and to facilitate the application of cathodic protection, electrically isolate each buried steel pipeline per NACE Standard SP0286 from:
   a. Pumping plants.
   b. Reservoirs.
   c. Flow meters.
   d. Motorized operated valves.
   e. Dissimilar metals.
   f. Dissimilarly coated piping (cement-mortar vs. dielectric).
   g. Above ground steel pipe.
   h. All existing piping.

   Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

4. Prevent contact between the steel pipe and concrete and/or reinforcing steel, such as at wall penetrations and thrust blocks, with such items as plastic sleeves, rubber seals, or 20 mil plastic tape.

5. Apply a suitable dielectric coating intended for underground use such as:
   a. Polyurethane per AWWA C222 *or*
   b. Extruded polyethylene per AWWA C215 *or*
   c. A tape coating system per AWWA C214 *or*

   d. Hot applied coal tar enamel per AWWA C203 *or*
   e. Fusion bonded epoxy per AWWA C213.

6. Buried steel and iron pipe, fittings, and valves in appurtenances, such as air valves and blowoffs, should be coated with a material listed above or with coal-tar epoxy, wax tape, moldable sealant, or equivalent. If copper is used, electrically insulate it from the steel with an insulating joint or with a dielectric union.

7. Apply cathodic protection to steel piping as per NACE Standard SP0169.

8. To insure that corrosion control is properly designed, preliminary construction drawings should be reviewed by a qualified corrosion engineer.

9. After the pipeline is backfilled, but before the construction contract is completed, the pipeline should be tested to insure that the joint bonds are intact and test stations properly installed. Also, native pipe-to-soil potentials should be measured and recorded. These data will be useful in determining if pipeline conditions change in the future.

10. Pipe-to-soil potentials should be measured biennially to determine if conditions on the pipeline are changing.

## Hydraulic Elevator

Implement *all* the following measures:

1. Coat hydraulic elevator cylinders as described above for steel pipe, item #5a -#5e5 that is resistant to petroleum products (hydraulic fluid).
2. Electrically insulate each cylinder from building metals by installing dielectric material between the piston platen and car, insulating the bolts, and installing an insulated joint in the oil line.
3. Place each cylinder in a non-metallic casing with a plastic watertight seal at the bottom. Fill the annulus with dry sand with a minimum resistivity of 25,000 ohm-centimeters, a pH of between 6.5 and 7.5 and a maximum chloride content of 200 ppm.
4. A removable moisture-proof sealing lid installed on the top of the casing prior to installation of the cylinder. The top of the casing shall be permanently sealed against moisture intrusion after installation of the cylinder.
5. Apply cathodic protection to hydraulic cylinders as per NACE Standard SP0169.
6. The elevator oil line should be placed above ground if possible but, if underground, should be protected by one of the following corrosion control options:

   **OPTION 1**

   a. Provide a bonded dielectric coating.
   b. Electrically isolate the pipeline.
   c. Apply cathodic protection to steel piping as per NACE Standard SP0169.

**OPTION 2**

   a. Place the oil line in a PVC casing pipe with solvent-welded joints to prevent contact with soil and soil moisture.

7. If steel underground storage tanks are used, cathodic protection and corrosion control requirements shall comply with Title 23.

## Reinforced Concrete Pipe

Implement *all* the following measures.

1. To prevent dissimilar metal corrosion cells electrically isolate the storm drain per NACE Standard SP0286 from all structures and facilities.

   Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

2. Prevent contact between the steel pipe and concrete and/or reinforcing steel, such as at wall penetrations and thrust blocks, with such items as plastic sleeves, rubber seals, or 20 mil plastic tape.

3. Buried steel and iron pipe and fittings in appurtenances should be cement-mortar coated or concrete or cement slurry encased where possible. Otherwise, they should be wrapped with wax tape per AWWA Standard C-217

4. To insure that corrosion control is properly designed, preliminary construction drawings should be reviewed by a qualified corrosion engineer.

5. Apply a suitable dielectric waterproofing coating intended for underground use. This coating is to be compatible with and applied over the concrete/cement-mortar.

## Iron Pipe

Implement *all* the following measures:

1. To prevent dissimilar metal corrosion cells and to facilitate the application of cathodic protection, electrically isolate each buried iron pipeline per NACE Standard SP0286 from:
   a. Pumping plants.
   b. Reservoirs.
   c. Flow meters.
   d. Motorized operated valves.
   e. Dissimilar metals.
   f. Dissimilarly coated piping (cement-mortar vs. dielectric).
   g. Above ground steel pipe.
   h. All existing piping.

Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

2. Bond all nonconductive type joints for electrical continuity. Electrical continuity is necessary for corrosion monitoring and cathodic protection. For pipe diameters less 18 inches use two joint bonds. For pipe diameters greater than or equal to 18 inches use three joint bonds. Electrical continuity is necessary for corrosion monitoring and cathodic protection.

3. Install corrosion monitoring test stations to facilitate corrosion monitoring and the application of cathodic protection:
    a. Two or four-wire test stations at each end of the pipeline depending on how the pipe terminates.
    b. Four-wire test stations at all buried insulating joints.
    c. Four-wire test stations at each end of all casings.
    d. Two-wire test stations at other locations as necessary so the interval between test stations does not exceed 1,200 feet.

   Where 4-wire test stations are required, use wires of difference size or insulation color for identification. Each wire should be independently welded or pin-brazed to the pipe.

4. Use iron pipe, fittings, and valves in appurtenances to the extent possible to avoid creating dissimilar metal corrosion cells. Steel appurtenances such as bolts should be coated with wax tape. If copper is used, electrically isolate it from the iron.

5. Prevent contact between iron and concrete including reinforcing steel, using such items as plastic sleeves, rubber seals, two layers of 8 mil thick polyethylene plastic, or 20 mil plastic tape.

6. Apply a suitable coating intended for underground use such as:
    a. Epoxy coating; *or*
    b. Polyurethane; *or*
    c. Wax tape.

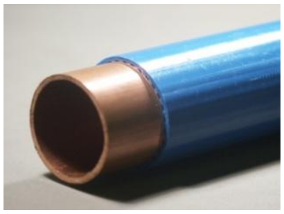
    NOTE: The thin factory-applied asphaltic coating applied to ductile iron pipe for transportation and aesthetic purposes does not constitute a corrosion control coating.

7. Apply cathodic protection to cast and ductile iron piping as per NACE Standard SP0169.

## Copper Pipe

Protect buried copper pipe by *one* of the following measures:

1. Installation of a factory-coated copper pipe with a minimum 25-mil thickness such as Kamco's Aqua Shield™, Mueller's Streamline Protec™, or equal. The coating must be continuous with no cuts or defects.



2. Installation of 12-mil polyethylene pipe wrapping tape with butyl rubber mastic over a suitable primer. Protect wrapped copper tubing by applying cathodic protection per NACE Standard SP0169.

### Polyvinyl Chloride (PVC) Pipe

1. No special measures are required to protect PVC.

2. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating such as wax tape per AWWA C217, plastic pipe wrapping tape, coal tar epoxy, polyurethane, or equivalent.

3. Install electrically insulated joints in iron riser connections to above grade metallic piping.

4. Use iron pipe, fittings, and valves in appurtenances, such as air valves and blowoffs, to the extent possible to avoid creating dissimilar metal corrosion cells. Steel appurtenances such as bolts should be coated as described above. If copper is used, electrically isolate it from the iron.

### All Pipe

1. On all pipes, appurtenances, and fittings not protected by cathodic protection or encased in concrete, coat pipe specials such as valves, bolts, flange joints, joint harnesses, and flexible couplings with wax tape per AWWA C217 after assembly.

2. Where metallic pipelines penetrate concrete structures such as building floors, vault walls, and thrust blocks use plastic sleeves, rubber seals, or other dielectric material to prevent pipe contact with the concrete and reinforcing steel.

### Concrete Structures

The concrete mix design should provide the least permeable and mostly crack-free matrix to reduce penetration of aggressive ions and oxygen into the concrete. The concrete mixture should be designed to help protect the steel adequately from corrosion. Factors in concrete mix design that can reduce the permeability of the concrete include lowering the water-to-cement ratio by either increasing the cement content or decreasing water content. Finely divided materials such as fly ash, granulated blast furnace slag, silica fume, and other pozzolans can further reduce permeability of the concrete.

In addition, aggregates having water-soluble chloride ions on their surfaces, or even within their particles, can cause corrosion problems. If enough surface-borne chlorides are present, a portion will not be bound within the solid “paste” phase during hydration of the cement. Most of the chlorides released from the interior of an aggregate particle after the first few hours of hydration will not be bound at all. Unbound chloride ions can cause passivity breakdown of the steel created by the alkaline cement.

The following standards contain important guidelines for the maximum concentration of chloride, sulfate and carbonate ions on the mixing water and admixture:

- Portland Cement Association PCA Publication E B.001, Design and Control of Concrete mixtures
- American Concrete Institute ACI 318, Building Code Requirements for Reinforced Concrete Structures
- American Concrete Institute ACI 222, Corrosion of Metals in Concrete

Nevertheless, there are certain steps that can be taken to enhance the protective properties of the concrete. The most important factor is keeping the cement content high enough to maintain a pH of 12.5 or greater.

1. From a corrosion standpoint, Type II cement may be used for concrete structures and pipe because the sulfate concentration is negligible, 0 to 0.1 percent.

2. Standard concrete cover over reinforcing steel may be used for concrete structures and pipe in contact with these soils due to the low chloride concentration found onsite.

3. Due to the high ground water table encountered at this site, cyclical or continual wetting may be an issue. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system.

4. Concrete structures and pipe should be protected from acid attack because soil with a pH ≤ 5.5 and assumed total acidity ≥ 250 mmol $H^{1+}$/kg (AWWA 1995) was found on-site. Concrete can be protected by preventing contact with the moisture in acidic soil. Contact can be prevented with an impermeable, waterproof, acid resistant barrier coating such as Grace PrePrufe Products®.

## Post Tensioning Slabs: Unbonded Single-Stranded Tendons and Anchors

1. Soil is considered an aggressive environment for post-tensioning strands and anchors. Therefore, due to the soils found on-site, protect post-tensioning strands and anchors against corrosion in this aggressive (corrosive) environment. Implement *all* the following measures: (ACI 2001)(PTI 2006)(PTI 2000)
    a. Completely encapsulate the tendon and anchor with polyethylene to create a watertight seal.
    b. All components exposed to the job site should be protected within one working day after their exposure during installation.
    c. Ensure the minimum concrete cover over the tendon tail is 1-inch, or greater if required by the applicable building code.
    d. Caps and sleeves should be installed within one working day after the cutting of the tendon tails and acceptance of the elongation records by the engineer.
    e. Inspect the following to ensure the encapsulated system is completely watertight:

    i. Sheathing: Verify that all damaged areas, including pin-holes, are repaired.
    ii. Stressing tails: After removal, ensure they are cut to a length for proper installation of P/T coating filled end caps.
    iii. End caps: Ensure proper installation before patching the pocket former recesses.
    iv. Patching: Ensure the patch is of an approved material and mix design, and installed void-free.

f. Limit the access of direct runoff onto the anchorage area by designing proper drainage.

g. Provide at least 2 inches of space between finish grade and the anchorage area, or more if required by applicable building codes.

## CLOSURE

Our services have been performed with the usual thoroughness and competence of the engineering profession. No other warranty or representation, either expressed or implied, is included or intended.

Please call if you have any questions.

Respectfully Submitted,
HDR ENGINEERING, INC.

Ian Budner
EIT Corrosion Technician

REGISTERED PROFESSIONAL ENGINEER
STEVEN R FOX
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Exp. 3-31-13
CORROSION
STATE OF CALIFORNIA

Steven R. Fox, P.E.
Vice President

11-1050SCS-RPT_Wilshire_Rodeo_IB_rev00

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# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-09-0472, SA #09-0628SCSP***
***13-Aug-09***

| **Sample ID** | | | G-11<br>@ 20' | G-11<br>@ 70' |
|---|---|---|---|---|
| **Resistivity** | | **Units** | | |
| as-received | | ohm-cm | 6,800 | 1,080 |
| saturated | | ohm-cm | 1,520 | 1,020 |
| **pH** | | | 7.7 | 7.8 |
| **Electrical Conductivity** | | mS/cm | 0.08 | 0.12 |
| **Chemical Analyses** | | | | |
| **Cations** | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 43 | 60 |
| magnesium | $Mg^{2+}$ | mg/kg | 12 | 19 |
| sodium | $Na^{1+}$ | mg/kg | 79 | 69 |
| potassium | $K^{1+}$ | mg/kg | 8.2 | 24 |
| **Anions** | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 189 | 189 |
| flouride | $F^{1-}$ | mg/kg | 1.9 | 1.5 |
| chloride | $Cl^{1-}$ | mg/kg | 3.4 | 18 |
| sulfate | $SO_4^{2-}$ | mg/kg | 37 | 79 |
| phosphate | $PO_4^{3-}$ | mg/kg | 4.7 | ND |
| **Other Tests** | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 0.8 | 2.0 |
| nitrate | $NO_3^{1-}$ | mg/kg | 1.4 | 1.6 |
| sulfide | $S^{2-}$ | qual | na | na |
| Redox | | mV | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

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# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0633LAB***
***7-Jul-11***

| **Sample ID** | | | S-109<br>@ 30-31'<br>CL | S-109<br>@ 53-54'<br>CL | S-109<br>@ 65-66'<br>ML | S-109<br>@ 77-78'<br>ML | S-109<br>@ 92-93'<br>ML |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,480 | 1,440 | 1,640 | 4,200 | 2,440 |
| saturated | | ohm-cm | 1,480 | 1,200 | 1,160 | 2,520 | 2,400 |
| **pH** | | | 6.7 | 7.1 | 7.0 | 7.2 | 4.0 |
| **Electrical Conductivity** | | mS/cm | 0.07 | 0.06 | 0.10 | 0.06 | 0.08 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 24 | 24 | 37 | 27 | 30.8 |
| magnesium | $Mg^{2+}$ | mg/kg | 7.6 | 7.8 | 11 | 7.6 | 9.2 |
| sodium | $Na^{1+}$ | mg/kg | 64 | 46 | 58 | 41 | 46 |
| potassium | $K^{1+}$ | mg/kg | 2.4 | 6.7 | 6.6 | 5.6 | 5.8 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 76 | 73 | 82 | 61 | 70 |
| fluoride | $F^{1-}$ | mg/kg | 4.0 | 4.3 | 4.1 | 4.7 | 2.6 |
| chloride | $Cl^{1-}$ | mg/kg | 15 | 8.8 | 17 | 12 | 20 |
| sulfate | $SO_4^{2-}$ | mg/kg | 53 | 49 | 84 | 56 | 79 |
| phosphate | $PO_4^{3-}$ | mg/kg | 2.0 | 2.7 | 2.0 | 2.0 | 1.6 |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | ND | 1.6 | ND | 0.8 | ND |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0699LAB***
***20-Jul-11***

| **Sample ID** | | | G-144<br>@ 10.5'<br>CL-ML | G-144<br>@ 30.5'<br>CL-ML | G-144<br>@ 50.5'<br>Sandy CL | G-144<br>@ 60.5'<br>Sandy CL | G-144<br>@ 80.5'<br>CL |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 960 | 1,560 | 1,480 | 1,360 | 1,720 |
| saturated | | ohm-cm | 960 | 1,560 | 1,360 | 1,360 | 1,160 |
| **pH** | | | 7.6 | 7.6 | 7.5 | 7.5 | 7.5 |
| **Electrical Conductivity** | | mS/cm | 0.13 | 0.04 | 0.06 | 0.06 | 0.06 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 79 | 25 | 28 | 33 | 30 |
| magnesium | $Mg^{2+}$ | mg/kg | 17 | 7.5 | 8.3 | 10 | 9.0 |
| sodium | $Na^{1+}$ | mg/kg | 57 | 42 | 48 | 51 | 44 |
| potassium | $K^{1+}$ | mg/kg | 7.7 | 2.4 | 4.9 | 5.5 | 4.7 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 345 | 79 | 67 | 67 | 58 |
| fluoride | $F^{1-}$ | mg/kg | 5.6 | 5.1 | 4.0 | 4.5 | 5.3 |
| chloride | $Cl^{1-}$ | mg/kg | 2.0 | 6.8 | 13 | 15 | 13 |
| sulfate | $SO_4^{2-}$ | mg/kg | 33 | 12 | 56 | 62 | 49 |
| phosphate | $PO_4^{3-}$ | mg/kg | 3.8 | 6.3 | 2.5 | 3.1 | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 25 | 13 | 0.9 | 0.5 | 2.1 |
| sulfide | $S^{2-}$ | qual | Negative | Negative | Negative | Negative | Negative |
| Redox | | mV | 18 | 63 | 38 | 60 | 31 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0699LAB***
***20-Jul-11***

| **Sample ID** | | | G-144 @ 100.5' SC | G-145 @ 31.5' Sandy CL | G-145 @ 61.5' Sandy CL | G-145 @ 95.5' SM w/gravel | G-145 @ 115.5' Sandy CL |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 9,600 | 1,680 | 3,040 | 5,600 | 1,000 |
| saturated | | ohm-cm | 2,440 | 1,680 | 1,840 | 2,840 | 1,000 |
| **pH** | | | 7.6 | 7.7 | 7.8 | 7.8 | 8.3 |
| **Electrical Conductivity** | | mS/cm | 0.05 | 0.05 | 0.09 | 0.06 | 0.15 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 23 | 24 | 36 | 22 | 65 |
| magnesium | $Mg^{2+}$ | mg/kg | 6.8 | 6.3 | 0.5 | 6.4 | 15 |
| sodium | $Na^{1+}$ | mg/kg | 39 | 44 | 67 | 42 | 75 |
| potassium | $K^{1+}$ | mg/kg | 6.2 | 3.8 | 6.8 | 3.8 | 22 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 43 | 95 | 140 | 58 | 253 |
| fluoride | $F^{1-}$ | mg/kg | 2.0 | 2.3 | 3.1 | 3.1 | 5.1 |
| chloride | $Cl^{1-}$ | mg/kg | 11 | 8.4 | 13 | 15 | 10 |
| sulfate | $SO_4^{2-}$ | mg/kg | 46 | 12 | 57 | 50 | 122 |
| phosphate | $PO_4^{3-}$ | mg/kg | 2.6 | 6.3 | 2.8 | 2.9 | 2.0 |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 1.5 | 20 | 3.2 | 1.9 | ND |
| sulfide | $S^{2-}$ | qual | Negative | Negative | Negative | Negative | Negative |
| Redox | | mV | 56 | 80 | 57 | 66 | 28 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# FIGURES F-10.67.1 THROUGH F-10.67.16 SOIL CORROSIVITY EVALUATION FOR CENTURY CITY CONSTELLATION STATION

# SOIL CORROSIVITY EVALUATION

*for the*

# WESTSIDE SUBWAY EXTENSION

# CENTURY CITY CONSTELLATION STATION

in

LOS ANGELES, CA

prepared for

AMEC E&I
5628 East Slauson Avenue
Los Angeles, CA 90040

Project No.: 4953-10-1561

PROJECT MANAGER: MR. MARTY HUDSON

prepared by

**HDR ENGINEERING, INC.**
*Consulting Corrosion Engineers*
431 West Baseline Road
Claremont, California 91711

HDR|SCHIFF #172549

October 18, 2011

## EXECUTIVE SUMMARY

The Westside Subway Extension is a proposed extension of the Metro Purple Line subway westward from the Wilshire/Western Station to the Veterans Administration West Los Angeles Hospital. Century City Constellation station is one of the eight stations planned for the project. The station will be approximately 980 feet long and about 85 to 95 feet below ground surface.

Laboratory tests on the soil samples provided by AMEC E&I have been completed. Six of the samples were selected for analysis. This soil is classified as severely corrosive to ferrous metals and aggressive to copper.

A dielectric coated steel pipeline for this route should also have bonded joints and test stations. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

Cathodically protect and provide corrosion monitoring for hydraulic elevators and associated components as required for compliance with Title 23.

A dielectric coated ductile iron pipe would also be a suitable choice. In addition, cathodic protection should be installed and applied concurrently with the pipeline. A polyethylene wrap may be used on non-pressurized iron pipe due to corrosive soils along portions of the route.

A polyvinyl chloride (PVC) pipe would also be a suitable choice. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating.

Type II cement may be used for concrete structures. Standard concrete cover over reinforcing steel may be used. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system.

Due to the soils at this site, post-tensioned slabs should be protected in accordance with soil considered aggressive (corrosive).

## Table of Contents

## INTRODUCTION

The existing subway system is owned and operated by Los Angeles County Metropolitan Transportation Authority (MTA) and provides public transportation throughout the City of Los Angeles, and surrounding areas.

The Westside Subway Extension is a proposed extension of the Metro Purple Line subway westward from the Wilshire/Western Station to the Veterans Administration West Los Angeles Hospital. In the Century City area, two alternative alignments are considered; one with a station along Santa Monica Boulevard, and one with a station along Constellation Boulevard. The proposed subway alignment is about 9 miles long. The depth to tunnel invert varies along the alignment from 40 to 160 feet below grade. The subway will consist of heavy rail transit operated in a twin tunnel configuration with eight new passenger stations, with two options in Century City.

Century City Constellation station is one of the eight stations planned for the project. The station will be approximately 980 feet long and about 85 to 95 feet below ground surface. Ground water was encountered at depths of about 35 to 50 feet below ground surface. The station will include walls below grade, utility piping, hydraulic elevator systems, concrete structures, and post-tensioning systems.

An analysis of soil corrosivity along the route of the Metro rail alignment was requested. Laboratory tests on the soil samples provided by AMEC E&I have been completed. Six of the samples were selected for analysis. HDR Engineering, Inc. (HDR|Schiff) assumes that the samples selected are representative of the most corrosive soils at the site.

The scope of this study is limited to a determination of soil corrosivity and general corrosion control recommendations for materials planned for construction. HDR|Schiff understands shoring piles will be used only temporarily during construction and will not be considered in this study. If steel piles are considered for use as permanent structures in the future, HDR|Schiff will be glad to perform Romanoff similitude analysis for metal loss and determine estimated corrosion rates.

## LABORATORY TESTS ON SOIL SAMPLES

The electrical resistivity of each of the six samples was measured in a soil box per ASTM G187 in its as-received condition and again after saturation with distilled water. Resistivities are at about their lowest value when the soil is saturated. The pH of the saturated samples was measured per ASTM G51. A 5:1 water:soil extract from each sample was chemically analyzed for the major soluble salts commonly found in soil per ASTM D4327, D6919, and D513. Test results are shown in Table 1 in the Appendix to this report.

## SOIL CORROSIVITY

A major factor in determining soil corrosivity is electrical resistivity. The electrical resistivity of a soil is a measure of its resistance to the flow of electrical current. Corrosion of buried metal is an electrochemical process in which the amount of metal loss due to corrosion is directly proportional to the flow of electrical current (DC) from the metal into the soil. Corrosion currents, following Ohm's Law, are inversely proportional to soil resistivity. Lower electrical resistivities result from higher moisture and soluble salt contents and indicate corrosive soil.

A correlation between electrical resistivity and corrosivity toward ferrous metals is (Romanoff, 1989):

| Soil Resistivity in ohm-centimeters | Corrosivity Category |
|---|---|
| Greater than 10,000 | Mildly Corrosive |
| 2,001 to 10,000 | Moderately Corrosive |
| 1,001 to 2,000 | Corrosive |
| 0 to 1,000 | Severely Corrosive |

Other soil characteristics that may influence corrosivity towards metals are pH, soluble salt content, soil types, aeration, anaerobic conditions, and site drainage.

Electrical resistivities were in the moderately corrosive and corrosive categories with as-received moisture. When saturated, the resistivities were in the moderately to severely corrosive categories. The resistivities dropped considerably with added moisture because the samples were dry as-received.

Soil pH values varied from 7.3 to 8.2. This range is neutral to moderately alkaline (Romanoff, 1989). These values do not particularly increase soil corrosivity.

The soluble salt content of the samples ranged from low to high.

Nitrate was detected in low concentrations. The ammonium concentration was high enough to be deleterious to copper.

Tests were not made for sulfide and negative oxidation-reduction (redox) potential because these samples did not exhibit characteristics typically associated with anaerobic conditions.

The variation in soil types can create differential-aeration corrosion cells that would affect all metals.

This soil is classified as severely corrosive to ferrous metals and aggressive to copper.

Heavy rail transit systems can present a multitude of DC stray current issues. These issues can affect not only the system of concern, but also other metallic utilities or structures proximal to rails, and DC substations if the proper mitigation practices are not followed. Stray current can increase corrosion

## CONCLUSIONS

This soil is classified as severely corrosive to ferrous metals and aggressive to copper.

A dielectrically coated steel pipeline for this route should also have bonded joints and test stations. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

Cathodically protect and provide corrosion monitoring for hydraulic elevators and associated components as required for compliance with Title 23.

A dielectrically coated ductile iron pipe would also be a suitable choice. In addition, cathodic protection should be installed and applied concurrently with the pipeline. A polyethylene wrap may be used on non-pressurized iron pipe due to corrosive soils along portions of the route.

A polyvinyl chloride (PVC) pipe would also be a suitable choice. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating.

Type II cement may be used for concrete structures. Standard concrete cover over reinforcing steel may be used. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system.

Due to the soils at this site, post-tensioned slabs should be protected in accordance with soil considered aggressive (corrosive).

Due to the nature and magnitude of the project and the long design service life requirements, tolerance for corrosion on all project components is low. Based on the need for high reliability and the corrosivity considerations discussed above, it is clear that corrosion protection must be provided for the components exposed to the environment discussed with consideration given to the level of risk and practicality.

## RECOMMENDATIONS

### DC Stray Current

A study of the impact of the DC powered heavy rail system was not detailed as part of the scope work in this project. It is recommended that the client pursue such a study in order to take the necessary precautions to avoid the deleterious effects known to result from DC stray current.

## Steel Pipe

Implement *all* the following measures.

1. Underground steel pipe with rubber gasketed, mechanical, grooved end, or other nonconductive type joints should be bonded for electrical continuity. For pipe diameters less 18 inches use two joint bonds. For pipe diameters greater than or equal to 18 inches use three joint bonds. Electrical continuity is necessary for corrosion monitoring and cathodic protection.

2. Install corrosion monitoring test stations to facilitate corrosion monitoring and the application of cathodic protection:
   a. Two or four-wire test stations at each end of the pipeline depending on how the pipe terminates.
   b. Four-wire test stations at all buried insulating joints.
   c. Four-wire test stations at each end of all casings.
   d. Two-wire test stations at other locations as necessary so the interval between test stations does not exceed 1,200 feet.

   Where 4-wire test stations are required, use wires of difference size or insulation color for identification. Each wire should be independently welded or pin-brazed to the pipe.

3. To prevent dissimilar metal corrosion cells and to facilitate the application of cathodic protection, electrically isolate each buried steel pipeline per NACE Standard SP0286 from:
   a. Pumping plants.
   b. Reservoirs.
   c. Flow meters.
   d. Motorized operated valves.
   e. Dissimilar metals.
   f. Dissimilarly coated piping (cement-mortar vs. dielectric).
   g. Above ground steel pipe.
   h. All existing piping.

   Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

4. Prevent contact between the steel pipe and concrete and/or reinforcing steel, such as at wall penetrations and thrust blocks, with such items as plastic sleeves, rubber seals, or 20 mil plastic tape.

5. Apply a suitable dielectric coating intended for underground use such as:
   a. Polyurethane per AWWA C222 *or*
   b. Extruded polyethylene per AWWA C215 *or*
   c. A tape coating system per AWWA C214 *or*

    d. Hot applied coal tar enamel per AWWA C203 *or*
    e. Fusion bonded epoxy per AWWA C213.

6. Buried steel and iron pipe, fittings, and valves in appurtenances, such as air valves and blowoffs, should be coated with a material listed above or with coal-tar epoxy, wax tape, moldable sealant, or equivalent. If copper is used, electrically insulate it from the steel with an insulating joint or with a dielectric union.

7. Apply cathodic protection to steel piping as per NACE Standard SP0169.

8. To insure that corrosion control is properly designed, preliminary construction drawings should be reviewed by a qualified corrosion engineer.

9. After the pipeline is backfilled, but before the construction contract is completed, the pipeline should be tested to insure that the joint bonds are intact and test stations properly installed. Also, native pipe-to-soil potentials should be measured and recorded. These data will be useful in determining if pipeline conditions change in the future.

10. Pipe-to-soil potentials should be measured biennially to determine if conditions on the pipeline are changing.

## Hydraulic Elevator

Implement *all* the following measures:

1. Coat hydraulic elevator cylinders as described above for steel pipe, item #5 that is resistant to petroleum products (hydraulic fluid).
2. Electrically insulate each cylinder from building metals by installing dielectric material between the piston platen and car, insulating the bolts, and installing an insulated joint in the oil line.
3. Place each cylinder in a non-metallic casing with a plastic watertight seal at the bottom. Fill the annulus with a dry sand with a minimum resistivity of 25,000 ohm-centimeters, a pH of between 6.5 and 7.5 and a maximum chloride content of 200 ppm.
4. A removable moisture-proof sealing lid installed on the top of the casing prior to installation of the cylinder. The top of the casing shall be permanently sealed against moisture intrusion after installation of the cylinder.
5. Provide permanent test facilities and apply cathodic protection to hydraulic cylinders as per NACE Standard SP0169.
6. The elevator oil line should be placed above ground if possible but, if underground, should be protected by one of the following corrosion control options:

   **OPTION 1**

    a. Provide a bonded dielectric coating.
    b. Electrically isolate the pipeline.
    c. Apply cathodic protection to steel piping as per NACE Standard SP0169.

**OPTION 2**

   a. Place the oil line in a PVC casing pipe with solvent-welded joints to prevent contact with soil and soil moisture.

7. If Steel underground storage tanks are used, cathodic protection and corrosion control requirements shall comply with Title 23.

## Reinforced Concrete Pipe

Implement *all* the following measures.

1. To prevent dissimilar metal corrosion cells electrically isolate the storm drain per NACE Standard SP0286 from all structures and facilities.

   Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

2. Prevent contact between the steel pipe and concrete and/or reinforcing steel, such as at wall penetrations and thrust blocks, with such items as plastic sleeves, rubber seals, or 20 mil plastic tape.

3. Buried steel and iron pipe and fittings in appurtenances should be cement-mortar coated or concrete or cement slurry encased where possible. Otherwise, they should be wrapped with wax tape per AWWA Standard C-217

4. To insure that corrosion control is properly designed, preliminary construction drawings should be reviewed by a qualified corrosion engineer.

5. Apply a suitable dielectric waterproofing coating intended for underground use. This coating is to be compatible with and applied over the concrete/cement-mortar.

## Iron Pipe

Implement *all* the following measures:

1. To prevent dissimilar metal corrosion cells and to facilitate the application of cathodic protection, electrically isolate each buried iron pipeline per NACE Standard SP0286 from:
   a. Pumping plants.
   b. Reservoirs.
   c. Flow meters.
   d. Motorized operated valves.
   e. Dissimilar metals.
   f. Dissimilarly coated piping (cement-mortar vs. dielectric).
   g. Above ground steel pipe.
   h. All existing piping.

Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

2. Bond all nonconductive type joints for electrical continuity. Electrical continuity is necessary for corrosion monitoring and cathodic protection. For pipe diameters less 18 inches use two joint bonds. For pipe diameters greater than or equal to 18 inches use three joint bonds. Electrical continuity is necessary for corrosion monitoring and cathodic protection.

3. Install corrosion monitoring test stations to facilitate corrosion monitoring and the application of cathodic protection:
    a. Two or four-wire test stations at each end of the pipeline depending on how the pipe terminates.
    b. Four-wire test stations at all buried insulating joints.
    c. Four-wire test stations at each end of all casings.
    d. Two-wire test stations at other locations as necessary so the interval between test stations does not exceed 1,200 feet.

    Where 4-wire test stations are required, use wires of difference size or insulation color for identification. Each wire should be independently welded or pin-brazed to the pipe.

4. Use iron pipe, fittings, and valves in appurtenances to the extent possible to avoid creating dissimilar metal corrosion cells. Steel appurtenances such as bolts should be coated with wax tape. If copper is used, electrically isolate it from the iron.

5. Prevent contact between iron and concrete including reinforcing steel, using such items as plastic sleeves, rubber seals, two layers of 8 mil thick polyethylene plastic, or 20 mil plastic tape.

6. Apply a suitable coating intended for underground use such as:
    a. Polyethylene encasement per AWWA C105; *or*
    b. Epoxy coating; *or*
    c. Polyurethane; *or*
    d. Wax tape.

    NOTE: The thin factory-applied asphaltic coating applied to ductile iron pipe for transportation and aesthetic purposes does not constitute a corrosion control coating.

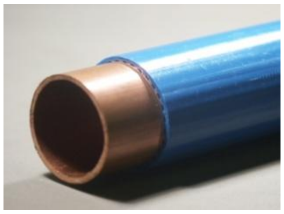
7. Apply cathodic protection to cast and ductile iron piping as per NACE Standard SP0169.

### Iron Pipe (Non-Pressurized)

1. Encase iron pipe, fittings, and valves in an 8 mil polyethylene wrap per AWWA Standard C105/ANSI 21.5.

## Copper Pipe

Protect buried copper pipe by *one* of the following measures:



1. Installation of a factory-coated copper pipe with a minimum 25-mil thickness such as Kamco's Aqua Shield™, Mueller's Streamline Protec™, or equal. The coating must be continuous with no cuts or defects.
2. Installation of 12-mil polyethylene pipe wrapping tape with butyl rubber mastic over a suitable primer. Protect wrapped copper tubing by applying cathodic protection per NACE Standard SP0169.

## Polyvinyl Chloride (PVC) Pipe

1. No special measures are required to protect PVC.
2. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating such as wax tape per AWWA C217, plastic pipe wrapping tape, coal tar epoxy, polyurethane, or equivalent.
3. Install electrically insulated joints in iron riser connections to above grade metallic piping.
4. Use iron pipe, fittings, and valves in appurtenances, such as air valves and blowoffs, to the extent possible to avoid creating dissimilar metal corrosion cells. Steel appurtenances such as bolts should be coated as described above. If copper is used, electrically isolate it from the iron.

## All Pipe

1. On all pipes, appurtenances, and fittings not protected by cathodic protection or encased in concrete, coat pipe specials such as valves, bolts, flange joints, joint harnesses, and flexible couplings with wax tape per AWWA C217 after assembly.
2. Where metallic pipelines penetrate concrete structures such as building floors, vault walls, and thrust blocks use plastic sleeves, rubber seals, or other dielectric material to prevent pipe contact with the concrete and reinforcing steel.

## Concrete Structures

The concrete mix design should provide the least permeable and mostly crack-free matrix to reduce penetration of aggressive ions and oxygen into the concrete.  The concrete mixture should be designed to help protect the steel adequately from corrosion. Factors in concrete mix design that can reduce the permeability of the concrete include lowering the water-to-cement ratio by either increasing the cement content or decreasing water content. Finely divided materials such as fly ash, granulated blast furnace slag, silica fume, and other pozzolons can further reduce permeability of the concrete.

In addition, aggregates having water-soluble chloride ions on their surfaces, or even within their particles, can cause corrosion problems. If enough surface-borne chlorides are present, a portion will not be bound within the solid "paste" phase during hydration of the cement. Most of the chlorides released from the interior of an aggregate particle after the first few hours of hydration will not be bound at all. Unbound chloride ions can cause passivity breakdown of the steel created by the alkaline cement.

The following standards contain important guidelines for the maximum concentration of chloride, sulfate and carbonate ions on the mixing water and admixture:

- Portland Cement Association PCA Publication E B.001, Design and Control of Concrete mixtures
- American Concrete Institute ACI 318, Building Code Requirements for Reinforced Concrete Structures
- American Concrete Institute ACI 222, Corrosion of Metals in Concrete

Nevertheless, there are certain steps that can be taken to enhance the protective properties of the concrete. The most important factor is keeping the cement content high enough to maintain a pH of 12.5 or greater.

1. From a corrosion standpoint, Type II cement may be used for concrete structures and pipe because the sulfate concentration is negligible, 0 to 0.1 percent.

2. Standard concrete cover over reinforcing steel may be used for concrete structures and pipe in contact with these soils due to the low chloride concentration found onsite.

3. Due to the high ground water table encountered at this site, cyclical or continual wetting may be an issue. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system.

## Post Tensioning Slabs: Unbonded Single-Stranded Tendons and Anchors

1. Soil is considered an aggressive environment for post-tensioning strands and anchors. Therefore, due to the soils found on-site, protect post-tensioning strands and anchors against corrosion in this aggressive (corrosive) environment. Implement *all* the following measures: (ACI 2001)(PTI 2006)(PTI 2000)
    a. Completely encapsulate the tendon and anchor with polyethylene to create a watertight seal.
    b. All components exposed to the job site should be protected within one working day after their exposure during installation.
    c. Ensure the minimum concrete cover over the tendon tail is 1-inch, or greater if required by the applicable building code.
    d. Caps and sleeves should be installed within one working day after the cutting of the tendon tails and acceptance of the elongation records by the engineer.
    e. Inspect the following to ensure the encapsulated system is completely watertight:

    i. Sheathing: Verify that all damaged areas, including pin-holes, are repaired.
    ii. Stressing tails: After removal, ensure they are cut to a length for proper installation of P/T coating filled end caps.
    iii. End caps: Ensure proper installation before patching the pocket former recesses.
    iv. Patching: Ensure the patch is of an approved material and mix design, and installed void-free.

f. Limit the access of direct runoff onto the anchorage area by designing proper drainage.

g. Provide at least 2 inches of space between finish grade and the anchorage area, or more if required by applicable building codes.

## CLOSURE

Our services have been performed with the usual thoroughness and competence of the engineering profession. No other warranty or representation, either expressed or implied, is included or intended.

Please call if you have any questions.

STEVEN R FOX
No. CR 1137
Exp. 3-31-13

Respectfully Submitted,
HDR ENGINEERING, INC.

Ian Budner
EIT Corrosion Technician

Steven R. Fox, P.E.
Vice President

11-1050SCS-RPT_Century_City-Constellation_IB_rev01_IB

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**SCHIFF ASSOCIATES**

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# Table 1 - Laboratory Tests on Soil Sample(s)

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, SA #11-0184LAB***
***21-Feb-11***

| **Sample ID** | | | 168 | 168 | 168 | 169 | 169 |
|---|---|---|---|---|---|---|---|
| | | | @ 1-5' | @ 38.5' | @ 72.5' | @ 26' | @ 72' |
| | | | CL - Fill | CL with Sand | SP | CL | SP-SM / SM |
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 8,000 | 2,640 | 4,000 | 6,400 | 1,480 |
| saturated | | ohm-cm | 1,680 | 840 | 3,040 | 920 | 960 |
| **pH** | | | 8.2 | 7.3 | 8.2 | 7.9 | 7.8 |
| **Electrical Conductivity** | | mS/cm | 0.09 | 0.07 | 0.13 | 0.46 | 0.29 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 21 | 27 | 34 | 73 | 135 |
| magnesium | $Mg^{2+}$ | mg/kg | 10 | 10 | 6.6 | 32 | 17 |
| sodium | $Na^{1+}$ | mg/kg | 115 | 88 | 132 | 377 | 129 |
| potassium | $K^{1+}$ | mg/kg | 3.3 | 5.6 | 6.4 | 11 | 26 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | 45 | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 143 | 98 | 142 | 183 | 259 |
| fluoride | $F^{1-}$ | mg/kg | 24 | 14 | 1.9 | 9.0 | 1.2 |
| chloride | $Cl^{1-}$ | mg/kg | 3.9 | 21 | 13 | 99 | 58 |
| sulfate | $SO_4^{2-}$ | mg/kg | 27 | 25 | 51 | 672 | 358 |
| phosphate | $PO_4^{3-}$ | mg/kg | 16 | 13 | ND | 1.5 | ND |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND | 3.7 |
| nitrate | $NO_3^{1-}$ | mg/kg | 2.8 | 2.3 | 4.2 | ND | 9.0 |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Sample(s)

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, SA #11-0184LAB***
***21-Feb-11***

| **Sample ID** | | | 169<br>@ 100.5'<br>ML |
|---|---|---|---|
| **Resistivity** | | **Units** | |
| as-received | | ohm-cm | 3,920 |
| saturated | | ohm-cm | 640 |
| **pH** | | | 7.7 |
| **Electrical Conductivity** | | mS/cm | 0.50 |
| **Chemical Analyses** | | | |
| **Cations** | | | |
| calcium | $Ca^{2+}$ | mg/kg | 289 |
| magnesium | $Mg^{2+}$ | mg/kg | 55 |
| sodium | $Na^{1+}$ | mg/kg | 84 |
| potassium | $K^{1+}$ | mg/kg | 76 |
| **Anions** | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 101 |
| fluoride | $F^{1-}$ | mg/kg | 0.5 |
| chloride | $Cl^{1-}$ | mg/kg | 45 |
| sulfate | $SO_4^{2-}$ | mg/kg | 968 |
| phosphate | $PO_4^{3-}$ | mg/kg | ND |
| **Other Tests** | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | 14 |
| nitrate | $NO_3^{1-}$ | mg/kg | ND |
| sulfide | $S^{2-}$ | qual | na |
| Redox | | mV | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
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# FIGURES F-10.68.1 THROUGH F-10.68.19 SOIL CORROSIVITY EVALUATION FOR WESTWOOD/UCLA STATION

# SOIL CORROSIVITY EVALUATION

*for the*

# WESTSIDE SUBWAY EXTENSION

# WESTWOOD/UCLA STATION

in

LOS ANGELES, CA

prepared for

**AMEC E&I**
5628 East Slauson Avenue
Los Angeles, CA  90040

Project No.: 4953-10-1561

PROJECT MANAGER: MR. MARTY HUDSON

prepared by

**HDR ENGINEERING, INC.**
*Consulting Corrosion Engineers*
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Claremont, California 91711

HDR|SCHIFF #172549

October 18, 2011

## EXECUTIVE SUMMARY

The Westside Subway Extension is a proposed extension of the Metro Purple Line subway westward from the Wilshire/Western Station to the Veterans Administration West Los Angeles Hospital. Westwood/UCLA station is one of the eight stations planned for the project. The station will be approximately 1,020 feet long and about 70 to 75 feet below ground surface.

Laboratory tests on the soil samples provided by AMEC E&I have been completed. 18 of the samples were selected for analysis. This soil is classified as severely corrosive to ferrous metals and aggressive to copper.

A dielectrically coated steel pipeline for this route should also have bonded joints and test stations. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

Cathodically protect and provide corrosion monitoring for hydraulic elevators and associated components as required for compliance with Title 23.

A dielectrically coated ductile iron pipe would also be a suitable choice. In addition, cathodic protection should be installed and applied concurrently with the pipeline. A polyethylene wrap may be used on non-pressurized iron pipe due to corrosive soils along portions of the route.

A polyvinyl chloride (PVC) pipe would also be a suitable choice. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating.

Type II cement may be used for concrete structures. Standard concrete cover over reinforcing steel may be used. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system.

Due to the soils at this site, post-tensioned slabs should be protected in accordance with soil considered aggressive (corrosive).

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## INTRODUCTION

The existing subway system is owned and operated by Los Angeles County Metropolitan Transportation Authority (MTA) and provides public transportation throughout the City of Los Angeles, and surrounding areas.

The Westside Subway Extension is a proposed extension of the Metro Purple Line subway westward from the Wilshire/Western Station to the Veterans Administration West Los Angeles Hospital. In the Century City area, two alternative alignments are considered; one with a station along Santa Monica Boulevard, and one with a station along Constellation Boulevard. The proposed subway alignment is about 9 miles long. The depth to tunnel invert varies along the alignment from 40 to 160 feet below grade. The subway will consist of heavy rail transit operated in a twin tunnel configuration with eight new passenger stations, with two options in Century City.

Westwood/UCLA station is one of the eight stations planned for the project. The station will be approximately 1,020 feet long and about 70 to 75 feet below ground surface. Ground water was encountered at depths of about 30 to 60 feet below ground surface. The station will include walls below grade, utility piping, hydraulic elevator systems, concrete structures, and post-tensioning systems.

An analysis of soil corrosivity along the route of the Metro rail alignment was requested. Laboratory tests on the provided soil samples provided by AMEC E&I have been completed. 18 of the samples were selected for analysis. HDR Engineering, Inc. (HDR|Schiff) assumes that the samples selected are representative of the most corrosive soils at the site.

The scope of this study is limited to a determination of soil corrosivity and general corrosion control recommendations for materials planned for construction. HDR|Schiff understands shoring piles will be used only temporarily during construction and will not be considered in this study. If steel piles are considered for use as permanent structures in the future, HDR|Schiff will be glad to perform Romanoff similitude analysis for metal loss and determine estimated corrosion rates.

## LABORATORY TESTS ON SOIL SAMPLES

The electrical resistivity of each of the 18 samples was measured in a soil box per ASTM G187 in its as-received condition and again after saturation with distilled water. Resistivities are at about their lowest value when the soil is saturated. The pH of the saturated samples was measured per ASTM G 51. A 5:1 water:soil extract from each sample was chemically analyzed for the major soluble salts commonly found in soil per ASTM D4327, D6919, and D513. Test results are shown in Table 1 in the Appendix to this report.

## SOIL CORROSIVITY

A major factor in determining soil corrosivity is electrical resistivity. The electrical resistivity of a soil is a measure of its resistance to the flow of electrical current. Corrosion of buried metal is an electrochemical process in which the amount of metal loss due to corrosion is directly proportional to the flow of electrical current (DC) from the metal into the soil. Corrosion currents, following Ohm's Law, are inversely proportional to soil resistivity. Lower electrical resistivities result from higher moisture and soluble salt contents and indicate corrosive soil.

A correlation between electrical resistivity and corrosivity toward ferrous metals is (Romanoff, 1989):

| Soil Resistivity in ohm-centimeters | Corrosivity Category |
|---|---|
| Greater than 10,000 | Mildly Corrosive |
| 2,001 to 10,000 | Moderately Corrosive |
| 1,001 to 2,000 | Corrosive |
| 0 to 1,000 | Severely Corrosive |

Other soil characteristics that may influence corrosivity towards metals are pH, soluble salt content, soil types, aeration, anaerobic conditions, and site drainage.

Electrical resistivities were in the mildly corrosive to severelycorrosive categories with as-received moisture. When saturated, the resistivities were in the mildly to severely corrosive categories. Some as-received resistivities were at or near their saturated values. The remaining resistivities dropped considerably with added moisture because the samples were dry as-received. The wide variations in soil resistivity can create concentration type corrosion cells that increase corrosion rates above what would be expected from the chemical characteristics alone.

Soil pH values varied from 7.2 to 8.0. This range is neutral to moderately alkaline (Romanoff, 1989). These values do not particularly increase soil corrosivity.

The soluble salt content of the samples was low.

The nitrate concentration was high enough to be deleterious to copper.

Some of the samples were tested for sulfides as they exhibited characteristics typically associated with anaerobic conditions. Sulfide, which is aggressive to copper and ferrous metals, showed no reaction in a qualitative test. The positive redox potentials measured in the samples from G-190 @ 20-21.5’, 50’, 70’, and 80’ indicates oxidizing conditions in which anaerobic, sulfide-producing bacteria are inactive.

The variation in soil types can create differential-aeration corrosion cells that would affect all metals.

This soil is classified as severely corrosive to ferrous metals and aggressive to copper.

Heavy rail transit systems can present a multitude of DC stray current issues. These issues can affect not only the system of concern, but also other metallic utilities or structures proximal to rails, and DC substations if the proper mitigation practices are not followed. Stray current can increase corrosion rates above what would be expected from the chemical characteristics.

## CONCLUSIONS

This soil is classified as severely corrosive to ferrous metals and aggressive to copper.

A dielectrically coated steel pipeline for this route should also have bonded joints and test stations. In addition, cathodic protection should be installed and applied concurrently with the pipeline.

Cathodically protect and provide corrosion monitoring for hydraulic elevators and associated components as required for compliance with Title 23.

A dielectrically coated ductile iron pipe would also be a suitable choice. In addition, cathodic protection should be installed and applied concurrently with the pipeline. A polyethylene wrap may be used on non-pressurized iron pipe due to corrosive soils along portions of the route.

A polyvinyl chloride (PVC) pipe would also be a suitable choice. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating.

Type II cement may be used for concrete structures. Standard concrete cover over reinforcing steel may be used. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system.

Due to the soils at this site, post-tensioned slabs should be protected in accordance with soil considered aggressive (corrosive).

Due to the nature and magnitude of the project and the long design service life requirements, tolerance for corrosion on all project components is low. Based on the need for high reliability and the corrosivity considerations discussed above, it is clear that corrosion protection must be provided for the components exposed to the environment discussed with consideration given to the level of risk and practicality.

## RECOMMENDATIONS

### DC Stray Current

A study of the impact of the DC powered heavy rail system was not detailed as part of the scope work in this project. It is recommended that the client pursue such a study in order to take the necessary precautions to avoid the deleterious effects known to result from DC stray current.

## Steel Pipe

Implement *all* the following measures.

1. Underground steel pipe with rubber gasketed, mechanical, grooved end, or other nonconductive type joints should be bonded for electrical continuity. For pipe diameters less 18 inches use two joint bonds. For pipe diameters greater than or equal to 18 inches use three joint bonds. Electrical continuity is necessary for corrosion monitoring and cathodic protection.

2. Install corrosion monitoring test stations to facilitate corrosion monitoring and the application of cathodic protection:
    a. Two or four-wire test stations at each end of the pipeline depending on how the pipe terminates.
    b. Four-wire test stations at all buried insulating joints.
    c. Four-wire test stations at each end of all casings.
    d. Two-wire test stations at other locations as necessary so the interval between test stations does not exceed 1,200 feet.

    Where 4-wire test stations are required, use wires of difference size or insulation color for identification. Each wire should be independently welded or pin-brazed to the pipe.

3. To prevent dissimilar metal corrosion cells and to facilitate the application of cathodic protection, electrically isolate each buried steel pipeline per NACE Standard SP0286 from:
    a. Pumping plants.
    b. Reservoirs.
    c. Flow meters.
    d. Motorized operated valves.
    e. Dissimilar metals.
    f. Dissimilarly coated piping (cement-mortar vs. dielectric).
    g. Above ground steel pipe.
    h. All existing piping.

    Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

4. Prevent contact between the steel pipe and concrete and/or reinforcing steel, such as at wall penetrations and thrust blocks, with such items as plastic sleeves, rubber seals, or 20 mil plastic tape.

5. Apply a suitable dielectric coating intended for underground use such as:
    a. Polyurethane per AWWA C222 *or*
    b. Extruded polyethylene per AWWA C215 *or*
    c. A tape coating system per AWWA C214 *or*

   d. Hot applied coal tar enamel per AWWA C203 *or*
   e. Fusion bonded epoxy per AWWA C213.

6. Buried steel and iron pipe, fittings, and valves in appurtenances, such as air valves and blowoffs, should be coated with a material listed above or with coal-tar epoxy, wax tape, moldable sealant, or equivalent. If copper is used, electrically insulate it from the steel with an insulating joint or with a dielectric union.

7. Apply cathodic protection to steel piping as per NACE Standard SP0169.

8. To insure that corrosion control is properly designed, preliminary construction drawings should be reviewed by a qualified corrosion engineer.

9. After the pipeline is backfilled, but before the construction contract is completed, the pipeline should be tested to insure that the joint bonds are intact and test stations properly installed. Also, native pipe-to-soil potentials should be measured and recorded. These data will be useful in determining if pipeline conditions change in the future.

10. Pipe-to-soil potentials should be measured biennially to determine if conditions on the pipeline are changing.

## Hydraulic Elevator

1. Coat hydraulic elevator cylinders as described above for steel pipe, item #5 that is resistant to petroleum products (hydraulic fluid).
2. Electrically insulate each cylinder from building metals by installing dielectric material between the piston platen and car, insulating the bolts, and installing an insulated joint in the oil line.
3. Place each cylinder in a non-metallic casing with a plastic watertight seal at the bottom. Fill the annulus with dry sand with a minimum resistivity of 25,000 ohm-centimeters, a pH of between 6.5 and 7.5 and a maximum chloride content of 200 ppm.
4. A removable moisture-proof sealing lid installed on the top of the casing prior to installation of the cylinder. The top of the casing shall be permanently sealed against moisture intrusion after installation of the cylinder.
5. Provide permanent test facilities and apply cathodic protection to hydraulic cylinders as per NACE Standard SP0169.
6. The elevator oil line should be placed above ground if possible but, if underground, should be protected by one of the following corrosion control options:

   **OPTION 1**
   a. Provide a bonded dielectric coating.
   b. Electrically isolate the pipeline.
   c. Apply cathodic protection to steel piping as per NACE Standard SP0169.

**OPTION 2**

   a. Place the oil line in a PVC casing pipe with solvent-welded joints to prevent contact with soil and soil moisture.

7. If steel underground storage tanks are used, cathodic protection and corrosion control requirements shall comply with Title 23.

## Reinforced Concrete Pipe

Implement *all* the following measures.

1. To prevent dissimilar metal corrosion cells electrically isolate the storm drain per NACE Standard SP0286 from all structures and facilities.

   Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

2. Prevent contact between the steel pipe and concrete and/or reinforcing steel, such as at wall penetrations and thrust blocks, with such items as plastic sleeves, rubber seals, or 20 mil plastic tape.

3. Buried steel and iron pipe and fittings in appurtenances should be cement-mortar coated or concrete or cement slurry encased where possible. Otherwise, they should be wrapped with wax tape per AWWA Standard C-217

4. To insure that corrosion control is properly designed, preliminary construction drawings should be reviewed by a qualified corrosion engineer.

5. Apply a suitable dielectric waterproofing coating intended for underground use. This coating is to be compatible with and applied over the concrete/cement-mortar.

## Iron Pipe

Implement *all* the following measures:

1. To prevent dissimilar metal corrosion cells and to facilitate the application of cathodic protection, electrically isolate each buried iron pipeline per NACE Standard SP0286 from:
   a. Pumping plants.
   b. Reservoirs.
   c. Flow meters.
   d. Motorized operated valves.
   e. Dissimilar metals.
   f. Dissimilarly coated piping (cement-mortar vs. dielectric).
   g. Above ground steel pipe.
   h. All existing piping.

Insulated joints should be placed above grade or in vaults where possible. Wrap all buried insulators with wax tape per AWWA C217.

2. Bond all nonconductive type joints for electrical continuity. Electrical continuity is necessary for corrosion monitoring and cathodic protection. For pipe diameters less 18 inches use two joint bonds. For pipe diameters greater than or equal to 18 inches use three joint bonds. Electrical continuity is necessary for corrosion monitoring and cathodic protection.

3. Install corrosion monitoring test stations to facilitate corrosion monitoring and the application of cathodic protection:
   a. Two or four-wire test stations at each end of the pipeline depending on how the pipe terminates.
   b. Four-wire test stations at all buried insulating joints.
   c. Four-wire test stations at each end of all casings.
   d. Two-wire test stations at other locations as necessary so the interval between test stations does not exceed 1,200 feet.

   Where 4-wire test stations are required, use wires of difference size or insulation color for identification. Each wire should be independently welded or pin-brazed to the pipe.

4. Use iron pipe, fittings, and valves in appurtenances to the extent possible to avoid creating dissimilar metal corrosion cells. Steel appurtenances such as bolts should be coated with wax tape. If copper is used, electrically isolate it from the iron.

5. Prevent contact between iron and concrete including reinforcing steel, using such items as plastic sleeves, rubber seals, two layers of 8 mil thick polyethylene plastic, or 20 mil plastic tape.

6. Apply a suitable coating intended for underground use such as:
   a. Polyethylene encasement per AWWA C105; *or*
   b. Epoxy coating; *or*
   c. Polyurethane; *or*
   d. Wax tape.

   NOTE: The thin factory-applied asphaltic coating applied to ductile iron pipe for transportation and aesthetic purposes does not constitute a corrosion control coating.

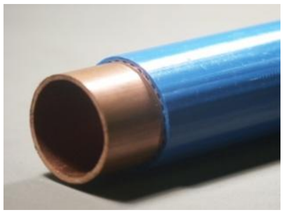
7. Apply cathodic protection to cast and ductile iron piping as per NACE Standard SP0169.

## Iron Pipe (Non-Pressurized)

1. Encase iron pipe, fittings, and valves in an 8 mil polyethylene wrap per AWWA Standard C105/ANSI 21.5.

## Copper Pipe

Protect buried copper pipe by *one* of the following measures:



1. Installation of a factory-coated copper pipe with a minimum 25-mil thickness such as Kamco's Aqua Shield™, Mueller's Streamline Protec™, or equal. The coating must be continuous with no cuts or defects.
2. Installation of 12-mil polyethylene pipe wrapping tape with butyl rubber mastic over a suitable primer. Protect wrapped copper tubing by applying cathodic protection per NACE Standard SP0169.

## Polyvinyl Chloride (PVC) Pipe

1. No special measures are required to protect PVC.
2. Coat any iron parts, such as fittings and valves, with a high quality dielectric coating such as wax tape per AWWA C217, plastic pipe wrapping tape, coal tar epoxy, polyurethane, or equivalent.
3. Install electrically insulated joints in iron riser connections to above grade metallic piping.
4. Use iron pipe, fittings, and valves in appurtenances, such as air valves and blowoffs, to the extent possible to avoid creating dissimilar metal corrosion cells. Steel appurtenances such as bolts should be coated as described above. If copper is used, electrically isolate it from the iron.

## All Pipe

1. On all pipes, appurtenances, and fittings not protected by cathodic protection or encased in concrete, coat pipe specials such as valves, bolts, flange joints, joint harnesses, and flexible couplings with wax tape per AWWA C217 after assembly.
2. Where metallic pipelines penetrate concrete structures such as building floors, vault walls, and thrust blocks use plastic sleeves, rubber seals, or other dielectric material to prevent pipe contact with the concrete and reinforcing steel.

## Concrete Structures

The concrete mix design should provide the least permeable and mostly crack-free matrix to reduce penetration of aggressive ions and oxygen into the concrete.  The concrete mixture should be designed to help protect the steel adequately from corrosion. Factors in concrete mix design that can reduce the permeability of the concrete include lowering the water-to-cement ratio by either increasing the cement content or decreasing water content. Finely divided materials such as fly ash, granulated blast furnace slag, silica fume, and other pozzolons can further reduce permeability of the concrete.

In addition, aggregates having water-soluble chloride ions on their surfaces, or even within their particles, can cause corrosion problems. If enough surface-borne chlorides are present, a portion will not be bound within the solid "paste" phase during hydration of the cement. Most of the chlorides released from the interior of an aggregate particle after the first few hours of hydration will not be bound at all. Unbound chloride ions can cause passivity breakdown of the steel created by the alkaline cement.

The following standards contain important guidelines for the maximum concentration of chloride, sulfate and carbonate ions on the mixing water and admixture:

- Portland Cement Association PCA Publication E B.001, Design and Control of Concrete mixtures
- American Concrete Institute ACI 318, Building Code Requirements for Reinforced Concrete Structures
- American Concrete Institute ACI 222, Corrosion of Metals in Concrete

Nevertheless, there are certain steps that can be taken to enhance the protective properties of the concrete. The most important factor is keeping the cement content high enough to maintain a pH of 12.5 or greater.

1. From a corrosion standpoint, Type II cement may be used for concrete structures and pipe because the sulfate concentration is negligible, 0 to 0.1 percent.

2. Standard concrete cover over reinforcing steel may be used for concrete structures and pipe in contact with these soils due to the low chloride concentration found onsite.

3. Due to the high ground water table encountered at this site, cyclical or continual wetting may be an issue. Any contact between concrete structures and ground water should be prevented. Contact can be prevented with an impermeable waterproofing system.

## Post Tensioning Slabs: Unbonded Single-Stranded Tendons and Anchors

1. Soil is considered an aggressive environment for post-tensioning strands and anchors. Therefore, due to the soils found on-site, protect post-tensioning strands and anchors against corrosion in this aggressive (corrosive) environment. Implement *all* the following measures: (ACI 2001)(PTI 2006)(PTI 2000)
    a. Completely encapsulate the tendon and anchor with polyethylene to create a watertight seal.
    b. All components exposed to the job site should be protected within one working day after their exposure during installation.
    c. Ensure the minimum concrete cover over the tendon tail is 1-inch, or greater if required by the applicable building code.
    d. Caps and sleeves should be installed within one working day after the cutting of the tendon tails and acceptance of the elongation records by the engineer.
    e. Inspect the following to ensure the encapsulated system is completely watertight:

    i. Sheathing: Verify that all damaged areas, including pin-holes, are repaired.
    ii. Stressing tails: After removal, ensure they are cut to a length for proper installation of P/T coating filled end caps.
    iii. End caps: Ensure proper installation before patching the pocket former recesses.
    iv. Patching: Ensure the patch is of an approved material and mix design, and installed void-free.

f. Limit the access of direct runoff onto the anchorage area by designing proper drainage.

g. Provide at least 2 inches of space between finish grade and the anchorage area, or more if required by applicable building codes.

## CLOSURE

Our services have been performed with the usual thoroughness and competence of the engineering profession. No other warranty or representation, either expressed or implied, is included or intended.

Please call if you have any questions.

Respectfully Submitted,
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11-1050SCS-RPT_Westwood-UCLA_IB_rev00

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Romanoff, M. (1989). Underground Corrosion, National Bureau of Standards (NBS) Circular 579. Houston, TX, United States of America: Reprinted by NACE.

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# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0633LAB***
***7-Jul-11***

| **Sample ID** | | | S-114 @ 27-28' SM | S-114 @ 49-50' CL | S-114 @ 61-62' CL/ML | S-114 @ 83-84' ML |
|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | |
| as-received | | ohm-cm | 312,000 | 1,680 | 2,600 | 1,840 |
| saturated | | ohm-cm | 22,400 | 1,680 | 1,880 | 1,160 |
| **pH** | | | 7.7 | 7.3 | 7.3 | 7.6 |
| **Electrical Conductivity** | | mS/cm | 0.03 | 0.09 | 0.07 | 0.20 |
| **Chemical Analyses** | | | | | | |
| **Cations** | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 27 | 45 | 34 | 92 |
| magnesium | $Mg^{2+}$ | mg/kg | 5.6 | 11 | 7.4 | 18 |
| sodium | $Na^{1+}$ | mg/kg | 14 | 54 | 43 | 72 |
| potassium | $K^{1+}$ | mg/kg | 6.9 | 9.8 | 11.2 | 24.3 |
| **Anions** | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | 9.0 |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 52 | 64 | 49 | 265 |
| fluoride | $F^{1-}$ | mg/kg | 0.9 | 3.4 | 4.5 | 6.3 |
| chloride | $Cl^{1-}$ | mg/kg | 3.4 | 22 | 13 | 9.2 |
| sulfate | $SO_4^{2-}$ | mg/kg | 20 | 83 | 72 | 94 |
| phosphate | $PO_4^{3-}$ | mg/kg | 2.1 | 3.1 | 2.9 | 1.4 |
| **Other Tests** | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | ND | 3.3 | 2.4 | 3.9 |
| sulfide | $S^{2-}$ | qual | na | na | na | na |
| Redox | | mV | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

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# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0673LAB***
***14-Jul-11***

| **Sample ID** | | | G-186 | G-186 | G-186 |
|---|---|---|---|---|---|
| | | | @ 30.5' | @ 75.5' | @ 85.5 |
| | | | CL | CL-ML | CL |
| **Resistivity** | | **Units** | | | |
| as-received | | ohm-cm | 2,920 | 2,880 | 1,640 |
| saturated | | ohm-cm | 2,480 | 1,480 | 1,120 |
| **pH** | | | 7.9 | 7.7 | 7.7 |
| **Electrical Conductivity** | | mS/cm | 0.09 | 0.13 | 0.12 |
| **Chemical Analyses** | | | | | |
| **Cations** | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 64 | 70 | 65 |
| magnesium | $Mg^{2+}$ | mg/kg | 11.4 | 16 | 15 |
| sodium | $Na^{1+}$ | mg/kg | 28 | 51 | 51 |
| potassium | $K^{1+}$ | mg/kg | 7.1 | 13 | 10 |
| **Anions** | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | 12 | 9.0 | 9.0 |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 169 | 215 | 178 |
| fluoride | $F^{1-}$ | mg/kg | 1.7 | 4.6 | 0.8 |
| chloride | $Cl^{1-}$ | mg/kg | 2.1 | 3.5 | 7.0 |
| sulfate | $SO_4^{2-}$ | mg/kg | 24 | 51 | 62 |
| phosphate | $PO_4^{3-}$ | mg/kg | 3.3 | 2.1 | 2.0 |
| **Other Tests** | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 0.8 | 1.9 | 1.6 |
| sulfide | $S^{2-}$ | qual | na | na | na |
| Redox | | mV | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0674LAB***
***14-Jul-11***

| **Sample ID** | | | G-189<br>@ 10'<br>ML | G-189<br>@ 40'<br>SW | G-189<br>@ 70'<br>ML | G-189<br>@ 100'<br>CL | G-191<br>@ 15-16.5'<br>SP |
|---|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | | |
| as-received | | ohm-cm | 1,760 | 28,400 | 2,280 | 1,720 | 5,200 |
| saturated | | ohm-cm | 1,760 | 4,800 | 2,280 | 1,400 | 3,680 |
| **pH** | | | 7.6 | 7.6 | 7.3 | 7.2 | 7.8 |
| **Electrical Conductivity** | | mS/cm | 0.06 | 0.04 | 0.04 | 0.05 | 0.10 |
| **Chemical Analyses** | | | | | | | |
| **Cations** | | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 49 | 20 | 22 | 30 | 69 |
| magnesium | $Mg^{2+}$ | mg/kg | 7.8 | 6.2 | 5.5 | 6.8 | 11 |
| sodium | $Na^{1+}$ | mg/kg | 29 | 33 | 32 | 35 | 36 |
| potassium | $K^{1+}$ | mg/kg | 3.5 | 3.2 | 46 | 9.6 | 12 |
| **Anions** | | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | ND | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 143 | 70 | 46 | 67 | 229 |
| fluoride | $F^{1-}$ | mg/kg | 2.5 | 2.8 | 2.5 | 3.4 | 2.3 |
| chloride | $Cl^{1-}$ | mg/kg | 1.7 | 6.3 | 11 | 5.6 | 2.2 |
| sulfate | $SO_4^{2-}$ | mg/kg | 14 | 19 | 33 | 54 | 45 |
| phosphate | $PO_4^{3-}$ | mg/kg | 3.6 | 4.7 | 2.0 | 2.1 | 4.1 |
| **Other Tests** | | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 10 | 22 | 2.5 | 2.7 | 28 |
| sulfide | $S^{2-}$ | qual | na | na | na | na | na |
| Redox | | mV | na | na | na | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0674LAB***
***14-Jul-11***

| **Sample ID** | | | G-191<br>@ 45-46.5'<br>SP-SM | G-191<br>@ 95-96'<br>CL-ML |
|---|---|---|---|---|
| **Resistivity** | | **Units** | | |
| as-received | | ohm-cm | 13,200 | 880 |
| saturated | | ohm-cm | 5,200 | 880 |
| **pH** | | | 7.7 | 7.6 |
| **Electrical Conductivity** | | mS/cm | 0.05 | 0.12 |
| **Chemical Analyses** | | | | |
| **Cations** | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 19 | 48 |
| magnesium | $Mg^{2+}$ | mg/kg | 3.7 | 11 |
| sodium | $Na^{1+}$ | mg/kg | 45 | 61 |
| potassium | $K^{1+}$ | mg/kg | 2.3 | 11 |
| **Anions** | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 55 | 140 |
| fluoride | $F^{1-}$ | mg/kg | 3.5 | 4.6 |
| chloride | $Cl^{1-}$ | mg/kg | 5.0 | 11 |
| sulfate | $SO_4^{2-}$ | mg/kg | 6.1 | 103 |
| phosphate | $PO_4^{3-}$ | mg/kg | 3.6 | 3.0 |
| **Other Tests** | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 22 | 3.9 |
| sulfide | $S^{2-}$ | qual | na | na |
| Redox | | mV | na | na |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

HDR | SCHIFF

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*Corrosion Control and Condition Assessment (C3A) Department*

# Table 1 - Laboratory Tests on Soil Samples

***AMEC E&I***
***Westside Subway Extension***
***Your #4953-10-1561, HDR|Schiff #11-0793LAB***
***8-Aug-11***

| **Sample ID** | | | G-190<br>@ 20-21.5'<br>ML | G-190<br>@ 50'<br>ML | G-190<br>@ 70'<br>ML/SM | G-190<br>@ 80'<br>ML |
|---|---|---|---|---|---|---|
| **Resistivity** | | **Units** | | | | |
| as-received | | ohm-cm | 1,560 | 2,200 | 1,400 | 1,360 |
| saturated | | ohm-cm | 1,000 | 2,040 | 1,400 | 1,360 |
| **pH** | | | 7.9 | 7.8 | 8.0 | 8.0 |
| **Electrical Conductivity** | | mS/cm | 0.17 | 0.06 | 0.11 | 0.13 |
| **Chemical Analyses** | | | | | | |
| **Cations** | | | | | | |
| calcium | $Ca^{2+}$ | mg/kg | 90 | 35 | 65 | 96 |
| magnesium | $Mg^{2+}$ | mg/kg | 19 | 8.7 | 16 | 17 |
| sodium | $Na^{1+}$ | mg/kg | 68 | 45 | 48 | 48 |
| potassium | $K^{1+}$ | mg/kg | 6.3 | 4.3 | 8.7 | 8.9 |
| **Anions** | | | | | | |
| carbonate | $CO_3^{2-}$ | mg/kg | ND | ND | 9.0 | 18 |
| bicarbonate | $HCO_3^{1-}$ | mg/kg | 223 | 58 | 156 | 194 |
| fluoride | $F^{1-}$ | mg/kg | 4.1 | 3.6 | 4.0 | 6.1 |
| chloride | $Cl^{1-}$ | mg/kg | 3.9 | 18 | 11 | 6.7 |
| sulfate | $SO_4^{2-}$ | mg/kg | 9.2 | 57 | 52 | 80 |
| phosphate | $PO_4^{3-}$ | mg/kg | 1.8 | 2.1 | 1.4 | 1.7 |
| **Other Tests** | | | | | | |
| ammonium | $NH_4^{1+}$ | mg/kg | ND | ND | ND | ND |
| nitrate | $NO_3^{1-}$ | mg/kg | 176 | 6.7 | 6.1 | 5.6 |
| sulfide | $S^{2-}$ | qual | Negative | Negative | Negative | Negative |
| Redox | | mV | 68 | 47 | 2 | 56 |

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

# FIGURES F-10.69.1 THROUGH F-10.69.19 SOIL CORROSIVITY EVALUATION FOR WESTWOOD/VA HOSPITAL STATION