AC INTERFERENCE ANALYSIS & MITIGATION SYSTEM DESIGN

Prepared for:

San Diego Gas & Electric
Proposed TL 6975

Prepared By:

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EXECUTIVE SUMMARY

ARK Engineering & Technical Services, Inc. was contracted by San Diego Gas & Electric (SDG&E) to investigate AC electrical interference effects on the following pipelines from the proposed 69 kV TL 6975 electric transmission circuit:

- SDG&E L-1604 [redacted] pipeline
- SDG&E L-49-111 [redacted] pipeline
- SDG&E L-49-111 [redacted]" pipeline
- SDG&E L-49-106 [redacted] pipeline
- SDG&E L-49-369 [redacted] pipeline

The L-1604 pipeline segment under study starts at approximate GPS location [redacted] and travels 8.2 miles to approximate GPS location [redacted]

The L-49-111 [redacted] segment branches off the L-1604 pipeline at approximate GPS location [redacted] and travels 1.2 miles to approximate GPS location [redacted]

The L-49-111 [redacted] segment starts at the end of the L-49-111 [redacted]" segment at approximate GPS location [redacted] and travels 1.5 miles to approximate GPS location [redacted].

The L-49-106 segment branches off the L-1604 pipeline at approximate GPS location [redacted] and travels 0.2 miles to approximate GPS location [redacted]

The L-49-369 segment branches off the L-1604 pipeline at approximate GPS location [redacted] and travels 0.3 miles to approximate GPS location [redacted].

These pipelines are subject to AC electrical interference effects from six (6) existing and the proposed TL6975 SDG&E electric transmission circuits which parallel and cross the pipeline segments.

This report presents the predicted AC electrical interference effects on the pipelines due to AC inductive and conductive coupling effects during maximum load and fault conditions on the electric transmission circuits.

Single phase-to-ground fault conditions on these circuits were also simulated to determine AC inductive and conductive coupling effects to the pipeline.

AC Interference Effects to the pipelines

The results of this study indicate that steady state AC interference voltage levels on these pipeline sections are calculated below the design limit of fifteen (15) Volts.

1. For the existing conditions, (excluding the proposed TL6975 circuit) a maximum induced AC pipeline potential of approximately three (3) Volts, with respect to remote earth, was computed on the L-1604 pipeline at approximate pipeline GPS location [redacted].

2. For the existing conditions and including the proposed TL6975 circuit, a maximum induced AC pipeline potential of approximately eight (8) Volts, with respect to remote earth, was computed on the L-49-106 pipeline at approximate pipeline GPS location [redacted]

AC Density Analysis – AC Corrosion Effects

AC density calculations associated with AC corrosion mechanisms were completed for the pipelines under study.

1. For the existing conditions, (excluding the proposed TL6975 circuit), a peak AC density value of approximately twenty-one (21) A/m^2 was computed on the L-1604 line at approximate pipeline GPS location [redacted]

2. For the existing conditions and including the proposed TL6975 circuit, a peak AC density of fifty (50) A/m^2 was computed on the L-49-106 line at approximate pipeline GPS location [redacted]

Fault Current Simulation and Coating Stress Voltage Analysis

During simulated single phase-to-ground fault conditions on the electric transmission circuits, the maximum total pipeline coating stress voltage level was computed. This is the sum of the inductive and conductive AC interference effects on the pipeline.

The maximum computed coating stress voltage is below the design limit of five thousand (5,000) Volts.

Conclusions

Based on the software modeling results, additional AC mitigation methods are recommended. Two sections of AC mitigations are proposed to be installed to reduce the pipeline AC density. ARK Engineering also recommends the installation of two AC coupon test stations to monitor the pipeline AC density.

The annual pipeline survey data including AC & DC pipeline potentials and AC density values should be reviewed and analyzed. If an increase in pipeline AC induced potentials or AC density is recorded over time, this data should be provided to ARK Engineering for additional investigation.

TABLE OF CONTENTS

APPENDIX A – SOIL RESISTIVITY DATA
APPENDIX B – PIPELINE STEADY STATE, AC CURRENT DENSITY & FAULT PLOTS

- Steady State Induced
- AC Current Density
- Fault – Coating Stress Voltage

APPENDIX C –POWER & PIPELINE COMPANY DATA

APPENDIX D – ARK ENGINEERING DESIGN DRAWINGS

1 INTRODUCTION

1.1 Introduction

ARK Engineering & Technical Services, Inc. was contracted by SDG&E to investigate AC electrical interference effects to the following five (5) SDG&E pipeline segments as the result of the installation o[redacted] the proposed 69 kV TL 6975 electric transmission circuit.

Existing SDG&E Pipelines:

- SDG&E L-1604 [redacted]" pipeline
- SDG&E L-49-111 [redacted]" pipeline
- SDG&E L-49-111 [redacted]" pipeline
- SDG&E L-49-106 [redacted]" pipeline
- SDG&E L-49-369 [redacted]" pipeline

The pipeline segments under study and listed above are located in San Diego, California.

These pipeline segments are subject to AC electrical interference effects from six (6) existing and the proposed TL6975 SDG&E electric transmission circuits which parallel and cross the pipeline segments.

This report presents the predicted AC electrical interference effects on the pipeline due to AC inductive and conductive coupling effects during maximum load and fault conditions on the electric transmission circuits.

Single phase-to-ground fault conditions on these circuits were also simulated to determine AC inductive and conductive coupling effects to the pipeline.

Calculations and analysis were performed using state-of-the-art modeling software.

1.2 Joint Facility Corridor Overview

The pipeline sections under study are in San Diego, California. All pipeline GPS coordinates outlined in this report are based on Google Earth files provided by SDG&E.

The areas of concern, where the pipeline parallels and crosses the electric transmission circuits, are outlined below:

<u>SDG&E L-49-111 high pressure pipeline</u>

- From approximate GPS location [redacted] to [redacted], the "TL-13811" 138 kV electric transmission circuit parallels the L-49-111 pipeline.
- At approximate GPS location [redacted], the "TL-13811" 138 kV electric transmission circuit crosses the L-49-111 pipeline.
- From approximate GPS location [redacted] to [redacted], the

"TL-13825" 138 kV electric transmission circuit parallels the L-49-111 pipeline.

- At approximate GPS location [redacted], the "TL-13825" 138 kV electric transmission circuit crosses the L-49-111 pipeline.

<u>SDG&E L-1604 high pressure pipeline</u>

- From approximate GPS location [redacted] to [redacted], the "TL-680" 69 kV electric transmission circuit will parallel the L-1604 pipeline.
- At approximate GPS location [redacted], the "TL-680" 69 kV electric transmission circuit will cross the L-1604 pipeline.
- From approximate GPS location [redacted] to [redacted] and [redacted] to [redacted], the proposed "TL-6975" 69 kV electric transmission circuit will parallel the L-1604 pipeline.
- From approximate GPS location [redacted] to [redacted], the "TL-23014" 230 kV electric transmission circuit parallels the L-1604 pipeline.
- From approximate GPS location [redacted], [redacted], [redacted]1 the "TL-23015" 230 kV electric transmission circuit parallels the L-1604 pipeline.

<u>SDG&E L-46-369 high pressure pipeline</u>

- From approximate GPS location [redacted] to [redacted], the proposed "TL-6975" 69 kV electric transmission circuit parallels the L-49-369 pipeline.
- At approximate GPS location [redacted], the proposed "TL-6975" 69 kV electric transmission circuit crosses the L-49-369 pipeline.
- From approximate GPS location [redacted] to [redacted] the "TL-23011" 230 kV electric transmission circuit parallels the L-49-369 pipeline.
- From approximate GPS location [redacted], [redacted] the "TL-23051" 230 kV electric transmission circuit parallels the L-49-369 pipeline.
- From approximate GPS location [redacted] to [redacted] the "TL-23014" 230 kV electric transmission circuit parallels the L-49-369 pipeline.
- At approximate GPS location [redacted], the "TL-23014" 230 kV electric transmission circuit crosses the L-49-369 pipeline.
- From approximate GPS location [redacted] to [redacted], the "TL-23015" 230 kV electric transmission circuit parallels the L-49-369 pipeline.
- At approximate GPS location [redacted], the "TL-23015" 230 kV electric transmission circuit crosses the L-49-369 pipeline.

When metallic pipelines are in shared rights-of-way with high voltage electric transmission circuits, the pipelines can incur high induced voltages and currents due to AC interference effects. This situation can cause many safety issues if not mitigated effectively. The possible effects of this AC interference can include: personnel subject to electric shock up to a lethal level, accelerated corrosion, arcing through pipeline coating, arcing across insulators, disbondment or degradation of coating, or possibly perforation of the pipeline.

AC interference simulation programs were used as part of this project to model the right-of-way (ROW) and estimate the levels of induced and conductive AC voltage on the pipeline. These programs were also used to evaluate the effectiveness of the existing mitigation system design.

1.3 Objectives & Project Tasks

The primary objectives of this study were as follows:

- Determine the AC electrical interference effects to the pipeline section during steady state and fault conditions on the electric transmission circuits.
- If required, recommend AC mitigation methods to reduce the induced steady-state AC pipeline potentials to less than 15 Volts at all locations on the pipeline.
- If required, recommend AC mitigation methods to reduce the fault-induced coating-stress voltages on the pipeline to less than 5,000 Volts, for protection of the pipeline coating.
- Assess the induced AC density on the pipeline for the potential threat of AC corrosion effects.
- Perform calculations to determine the likelihood of AC corrosion effects to the pipeline, based upon the installation of an AC interference mitigation system.
- If AC corrosion effects are likely, based upon these calculations, determine if additional AC mitigation is required to reduce or eliminate the likelihood of AC corrosion effects.

The project tasks associated with this portion of the AC interference analysis and mitigation study consist of the following:

- <u>Soil Resistivity Analysis</u> - Soil resistivity measurements were recorded along the pipeline route. An equivalent multi-layer soil model was obtained from these measurements using the modeling software. This model was then applied to subsequent simulation steps. This task is described in Chapter 2, and detailed results are presented in Appendix A.
- <u>Inductive Interference Analysis</u> - Circuit models for the pipeline and the electric transmission circuits were developed and used to determine magnetically induced pipeline potentials during maximum steady-state and single phase-to-ground fault conditions on the electric transmission circuits. This task is described in Chapter 3, and detailed results are presented in Appendix B.
- <u>Conductive Interference Analysis</u> - The effects of single phase-to-ground faults of the electric transmission circuits on the pipeline was studied. These results were used to

calculate coating-stress voltages along the pipeline. This task is described in Chapter 3, and detailed results are presented in Appendix B.

1.4 A Brief Perspective on Electromagnetic Interference Mechanisms

The flow of energy transmitted by electric power is not totally confined within the power conductors. However, the spatial density of energy in the environment surrounding these circuits decreases sharply with an increase in distance from the conductors. Metallic conductors such as pipelines that are located near electric transmission circuits may capture a portion of the energy encompassed by the conductors' paths, particularly under unfavorable circumstances such as long parallel exposures and fault conditions. In such cases, high currents and voltages may develop along the conductors' lengths. Energy may also flow directly from power installations to pipeline installations via conductive paths common to both.

The electromagnetic interference mechanisms at low frequencies have been traditionally divided into three (3) categories: capacitive, inductive and conductive coupling. These categories and their possible effects are illustrated in Figure 1-1.

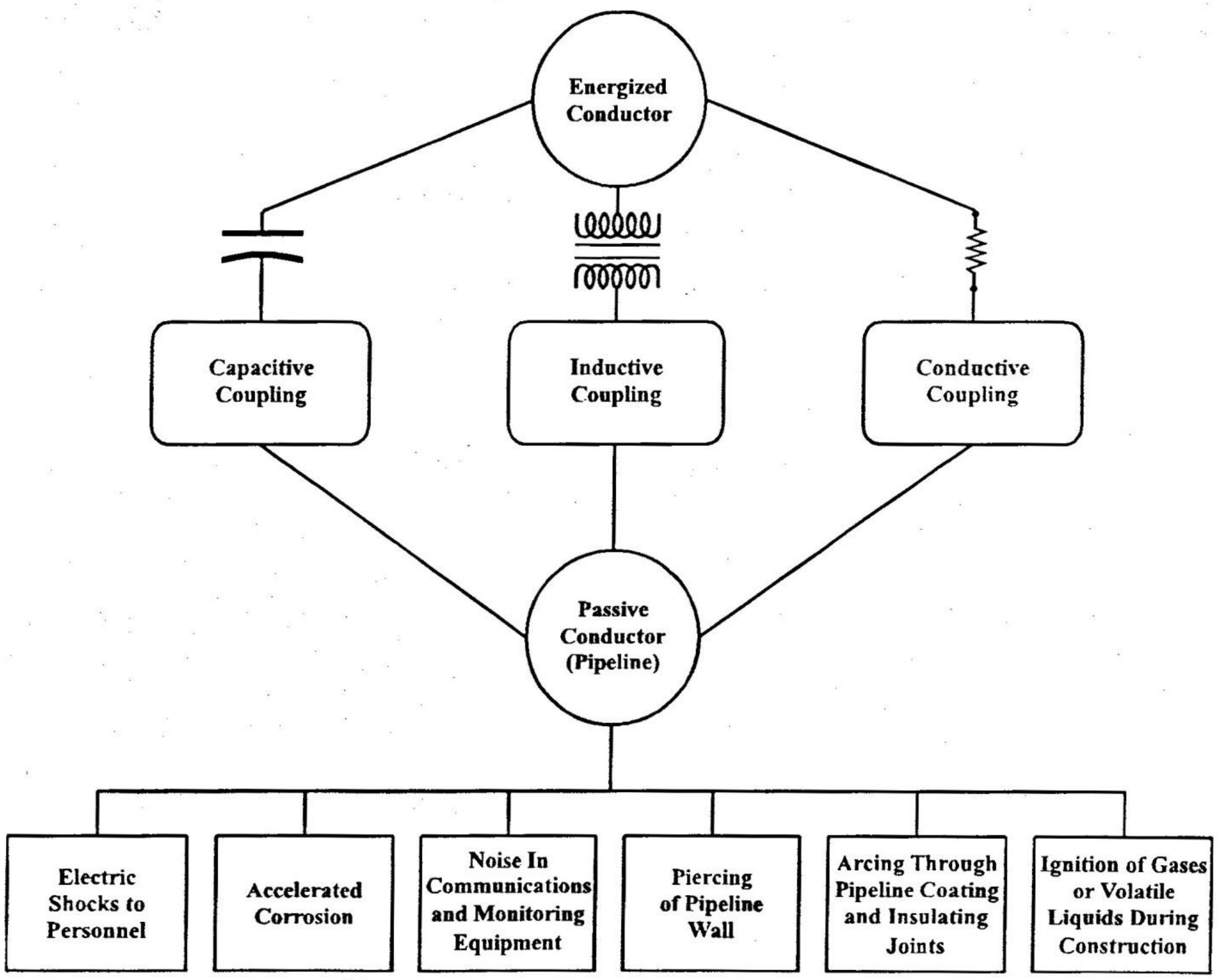


Figure 1-1: Interference Mechanisms and Effects on Pipeline

1.4.1 Capacitive Coupling

Mechanism:

Electrostatic or capacitive coupling results from the electric field gradient established between energized transmission circuit conductors and the earth. When the transmission circuit voltage is very high, a significant electric field gradient exists in the area of the transmission circuit. Large conductors, which are near and parallel to the transmission circuit and insulated from the earth, are liable to accumulate a significant electric charge, which represents a very real danger for personnel. Typically, such conductors include: equipment isolated from the earth, vehicles with rubber tires, aboveground pipelines, or pipelines under construction in dry areas when no precautions have been taken to establish adequate grounding for the pipeline lengths not yet installed in the ground. Hazards range from slight nuisance shocks to ignition of nearby volatile liquids with the accompanying risk of explosion, or electrocution of personnel.

Mitigation Measures:

Buried pipelines are relatively immune to interference due to capacitive coupling because, despite even an excellent coating, the length of exposure to the surrounding soil makes for an adequate ground to dissipate any significant charge that might otherwise accumulate. Aboveground pipelines, including pipelines under construction (which may or may not be buried in part) do not naturally have this protection. One means of protection is periodic grounding to earth, via ground rods, or other ground conductors judiciously placed to be unaffected by ground currents emanating from nearby towers during a fault.

1.4.2 Inductive Coupling

Mechanism:

Electromagnetic or inductive interference in a passive conductor (pipeline) results from an alternating current in another energized conductor (power line), which is more or less parallel to the first. This level of interference increases with decreasing separation and angle between the conductors, as well as with increasing current magnitude and frequency in the energized conductor. The combination of a high soil resistivity and passive conductors with good electrical characteristics (good coating, high conductivity and low permeability) also result in high-induced currents.

Peak potential values occur at discontinuities in either the energized or the passive conductor. When a transmission circuit and a pipeline are interacting, such discontinuities take the form of rapid changes in separation between the pipeline and transmission circuit, termination of the pipeline or an insulating junction in the pipeline (which amounts to the same thing), sudden changes in pipeline coating characteristics, a junction between two (2) or more pipelines or transposition of transmission phase conductors. Note that the induction effects on pipelines during normal power line operating conditions are small compared to the induction effects experienced by a pipeline during a power line fault. The most severe kind of fault is a single-phase-to-ground fault during which high currents circulate in one of the power line phases and are not attenuated by any similar currents in other phases. Hence, mitigation methods, which suffice for single-phase fault conditions, are often adequate for other conditions. It must be noted however, that the longer duration of the resulting potentials in the pipeline during steady state conditions makes the problem important to investigate from a perspective of human safety.

Unlike conductive interference, which tends to be a rather local phenomenon, inductive interference acts upon the entire length of the pipeline that is near to the power lines. Note, however, that conductive interference can involve long sections of a pipeline if several towers adjacent to the faulted tower discharge a significant portion of the fault current, or if a ground conductor connected to the pipeline (anode) and located near a faulted tower, picks up current from the soil.

The large potentials induced onto a pipeline during a fault can destroy insulated junctions, pierce holes in lengths of coating, and puncture pipeline walls. Equipment electrically connected to the pipeline, such as cathodic protection devices, communications equipment, and monitoring equipment can be damaged, and personnel exposed to metallic surfaces, which are continuous with the pipeline, can experience electrical shocks. Accelerated corrosion is another possible result. Implementing appropriate mitigative measures, as discussed below, can prevent this situation.

Although a pipeline equipped with mitigative measures appropriate to deal with phase-to-ground faults does not usually present a great safety hazard during normal conditions, several problems can still exist due to low magnitude induced alternating currents. Accelerated corrosion of steel can result if not offset by increased cathodic protection. This may mean a shortened life for sacrificial and impressed current anode beds. Small amounts of AC can also render impractical the use of a pipeline as a communication channel for data such as pressure and temperature readings to pumping and compressor stations.

Mitigation Measures:

Pipeline Coating Resistance - The coating resistance of the pipeline should be chosen as low as corrosion considerations permit. Pipeline coating resistance plays an important role in determining pipeline potentials during a fault condition. During a fault condition, on an electric transmission circuit, the pipeline coating conducts significant amounts of current and should be regarded more as a poor grounding system than an insulator. When this perspective is assumed, it is seen that lowering pipeline coating resistance and bonding grounded conductors to the pipeline steel are two (2) applications of the same principle.

Pipeline Section Length - In theory, the potential induced electromagnetically in a pipeline section insulated at both ends is roughly proportional to the length of the exposed region. When this relationship no longer holds, the pipeline is said to have exceeded its characteristic length. The maximum potential value in a section (with respect to remote ground) occurs at each extremity with roughly the same magnitude and opposite phase. This means that each insulating junction is subjected to a stress voltage that is double the peak value in the section. If insulating junctions are inserted frequently enough along a pipeline, then the section size is kept to a minimum, and consequently, so are the peak voltages in the pipeline. This constitutes one possible mitigation method. However, this thorough segmentation can result in very high construction and pipeline cathodic protection costs.

Grounding - Grounding of a pipeline, as a protection against the significant voltages that appear during an electrical fault condition, is one of the most effective mitigation measures available. A pipeline should be grounded at appropriate locations throughout its length. Typical grounding locations include: all termination points, both extremities of a segment which is grounded at both ends by an insulating junction, just before and just after a pipeline crosses a power line at a shallow angle, and any other important point of discontinuity likely to result in high induced voltages during a fault condition. Such points include locations where the passive conductor:

- Suddenly veers away from the power line.
- Suddenly changes coating characteristics.
- Emerges from the earth, or returns to the earth.

Other locations where high-induced voltages are likely are points where power line phases are transposed and points where two (2) or more pipelines meet.

In order not to load cathodic protection installations significantly, grounds should be made of an adequate sacrificial material such as zinc or should be made via solid-state-isolator or polarization cells. These DC decoupling devices (DCD) should be properly sized, spaced and physically secured to withstand the current resulting during a power line fault. Caution should be taken to locate grounds far enough away from any nearby power line structure, so that the soil potential near the ground does not rise to undesirable values during a power line fault condition. Soil potentials drop off rather quickly around a faulted structure injecting currents into the earth, so this is not an extremely difficult proposition.

Buried Mitigation Systems - A highly effective means of mitigating excessive AC pipeline potentials is the installation of gradient control wires or matting. These methods reduce both inductive and conductive interference. These gradient control wires consist of one or more bare conductors which are buried parallel and near to the pipeline and which are regularly connected to the pipeline. These wires provide grounding for the pipeline and thus lower the absolute value of the pipeline potential (i.e., the potential with respect to remote earth). They also raise earth potentials in the vicinity of the pipeline such that the difference in potential between the pipeline and local earth is reduced. As a result, touch voltages are significantly reduced.

1.4.3 Conductive Coupling

Mechanism:

When a single phase-to-ground fault occurs at a power line structure, the structure injects a large magnitude current into the earth raising soil potentials in the vicinity of the structure. If a pipeline is located near such a faulted structure, then the earth around the pipeline will be at a relatively high potential with respect to the pipeline potential. The pipeline potential will typically remain relatively low, especially if the pipeline coating has a high resistance. The difference in potential between the pipeline metal and the earth surface above the pipeline is the touch voltage to which a person would be subjected when standing near the pipeline and touching an exposed metallic appurtenance of the pipeline.

If the pipeline is perpendicular to the power line, then no induction will occur and the conductive component described above will constitute the entirety of the touch voltages and coating stress voltages appearing on the pipeline. If the pipeline is not perpendicular to the power line, then an induced potential peak will appear in the pipeline near the fault location. Based on previous interference studies, the induced potential peak in the pipeline is typically on the order of one hundred and fifty-five degrees (155^o) out of phase with the potential of the faulted structure and therefore with the potentials of the soil energized by the structure. Thus, the pipeline steel potential due to induction is essentially opposite in sign to the soil potentials due to conduction. Therefore, inductive and conductive effects reinforce each other in terms of coating stress voltages and touch voltages.

Mitigation Measures:

The magnitude of the conductive interference is primarily a function of the following factors:

i) <u>GPR of Transmission Circuit Structure</u>. Soil potentials and touch voltages due to conductive coupling are directly proportional to the ground potential rise (GPR) of the transmission circuit structure. This GPR value is a property of the entire transmission circuit system.

ii) <u>Separation Distance</u>. Although soil potentials and therefore touch voltages obviously decrease with increasing distance away from the faulted structure, the rate of decrease varies considerably from site to site, depending upon the soil structure, as described below.

iii) <u>Size of Structure Grounding System</u>. Soil potentials decrease much more sharply with increasing distance away from a small grounding system than that from a large grounding system. Conductive interference can be minimized by limiting the use of counterpoise conductors and ground rods, by the power company, at sites where pipelines are in proximity to the electric transmission system structures.

iv) <u>Soil Structure</u>. When the soil in which the structure grounding system is buried has a significantly higher resistivity than the deeper soil layers (particularly if the lower resistivity layers are not far below the structure grounding system), earth surface potentials decay relatively sharply with increasing distance away from the structure. When the inverse is true, i.e., when the structure grounding system is in low resistivity soil, which is under laid by higher resistivity layers, earth surface potentials may decay very slowly.

v) <u>Pipeline Coating Resistance</u>. When a pipeline has a low ground resistance (e.g., due to coating deterioration over time), the pipeline collects a significant amount of current from the surrounding soil and rises in potential. At the same time, earth surface potentials in the vicinity of the pipeline decrease due to the influence of the pipeline. As a result, the potential difference between the pipeline and the earth surface can be significantly reduced.

When a conductive interference problem is present, touch voltages can be reduced by: either reducing earth surface potentials in the vicinity of the pipeline, raising the pipeline potentials near the faulted structure, or a combination of these two (2) actions. The most effective mitigation systems perform both of these actions.

1.5 A Brief Perspective on AC Corrosion Mechanisms

1.5.1 AC Corrosion Mechanism

AC corrosion is the metal loss that occurs from AC current leaving a metallic pipeline at a coating holiday. The mechanism of AC corrosion occurs when AC current leaves the pipeline through a small holiday in low resistance soil conditions.

1.5.2 Mitigation of AC Corrosion

The main factors that influence the AC corrosion phenomena are:

- Induced AC pipeline voltage

- DC polarization of the pipeline
- Size of coating faults (holidays)
- Local soil resistivity at pipe depth

The induced AC pipeline voltage is considered the most important parameter when evaluating the likelihood of AC corrosion on a buried pipeline section.

The likelihood of AC corrosion can be reduced through mitigation of the induced AC pipeline voltage. The European Standard BS EN 15280:2013 "Evaluation of AC Corrosion Likelihood of Buried Pipelines - Application to Cathodically Protected Pipelines" recommends that AC pipeline voltages should not exceed the following:

- Ten (10) Volts where the local soil resistivity is greater than 25 ohm-meters.
- Four (4) Volts where the local soil resistivity is less than 25 ohm-meters.

These AC pipeline voltage limits are derived in part by calculating AC density at pipeline coating holidays. Since the AC current is mainly discharged to earth through the exposed steel at pipeline coating holidays, the AC corrosion rate can vary proportionately with increasing AC density at a coating holiday.

European Standard CEN/TS 15280 offers the following guidelines:

The pipeline is considered protected from AC corrosion if the root mean square (RMS) AC density is lower than 30 A/m^2. In practice, the evaluation of AC corrosion likelihood is done on a broader basis:

- Current density lower than 30 A/m^2: no or low likelihood of AC Corrosion effects
- Current density between 30 and 100 A/m^2: medium likelihood of AC Corrosion
- Current density higher than 100 A/m^2: very high likelihood of AC Corrosion

If the soil resistivity and the pipeline AC voltage are known, the risk of AC corrosion can be determined using the following formula in Equation 1 to calculate the current density at a holiday location.

$$I = (8 * V_{AC}) / (\rho * \pi * d) \qquad \text{(Equation 1)}$$

<u>Where</u>:

i = Current Density (A/m^2)

V_{AC} = Pipe-to-Soil Voltage (Volts)

ρ = Soil Resistivity (ohm-meters)

d = Holiday diameter (meters)

1.5.3 Determining Steady State Pipeline AC Voltage Limits

The primary factor in calculating AC density at coating holidays is induced AC voltage on the pipeline at these coating holidays. Since the local soil does not significantly change, lowering the induced AC pipeline voltage (by adding mitigation) also lowers the local AC density.

To analyze the possible AC corrosion effects on this pipeline section, calculations were completed to determine the AC current density exiting the pipeline, assuming a one (1) cm^2 circular coating holiday at each soil resistivity location.

1.6 Definitions

AC Electrical Interference (Electromagnetic Interference): A coupling of energy from an electrical source (such as an electrical power line) to a metallic conductor (such as a pipeline) which at low frequencies (in the range of power system frequencies) occurs in the form of three different mechanisms; capacitive, conductive and inductive coupling. Electrical interference can produce induced voltages and currents in the metallic conductors that may result in safety hazards and/or damage to equipment.

Coating Stress Voltage: This is the potential difference between the outer surface of a conductor (e.g., pipelines, cables, etc.) coating and the metal surface of the conductor, and results from inductive and conductive potentials.

Capacitive Coupling: Capacitive coupling occurs as a result of an energized electrical source (e.g., power line) that produces a power line voltage between a conductor (such as a pipeline) and earth where the conductor is electrically insulated from the earth. An electric field gradient from the electrical source induces a voltage onto the conductor insulated from earth, which varies primarily according to the distance between the source and the conductor, the voltage of the source and the length of parallelism.

Conductive Coupling: When a fault current flows from the power line conductor to ground, a potential rise is produced in the soil with regard to remote earth. A conductor located in the influence area of the ground for the power line structure, is subject to a potential difference between the local earth and the conductor potential. Conductive coupling is a localized phenomenon that acts upon the earth in the vicinity of the flow of current to ground.

Conductive Earth Potential: This is the potential that is induced onto a conductor due to the energization of the surrounding earth by the current leaking from the power line structure.

Dielectric Breakdown: The potential gradient at which electric failure or breakdown occurs. In this case, it is pertinent to the coating of the pipeline and the potential at which damage to the coating will occur.

Earth Surface Potential: When a single-phase-to-ground fault occurs at a power line structure, the structure injects a large magnitude current into the earth and therefore raises soil potentials in the vicinity of the structure. These potentials are referred to as earth surface potentials.

Fault Condition: A fault condition is a physical condition that causes a device, a component, or an element to fail to perform such as a short circuit or a broken wire. As a result, an abnormally high current flow from one conductor to ground or to another conductor.

Inductive Coupling: Inductive coupling is an association of two (2) or more circuits with one another by means of inductance mutual to the circuits. The coupling results from alternating current in an energized conductor (e.g., power line) which is more or less parallel with a passive (non-energized) conductor. Inductive coupling acts upon the entire length of a conductor.

Inductive Pipeline Potential: The potential induced onto a pipeline during steady state or fault conditions that result from the mutual coupling between the energized conductor (power line) and the pipeline.

Load Condition: A load condition for a circuit is the amount of rated operating electrical power that is transmitted in that circuit under normal operating conditions for a specific period of time.

Local Earth: Local earth is the earth in the vicinity of a conductor, which is raised to a potential, typically, as a result of the flow of fault current to ground. In the case of a pipeline, which has a good coating and does not have grounding conductors connected to the pipeline where the earth potential rise occurs, the "local" earth will be the same as the "remote" earth.

Permeability: Permeability is a term used to express various relationships between magnetic induction and magnetizing force.

Potential Difference: The relative voltage at a point in an electric circuit or field with respect to a reference point in the same circuit or field.

Remote Earth: Remote earth is a location of the earth away from where the origin of the earth potential rise occurs that represents a potential of zero Volts.

Steady State Condition: A steady state condition for a power system is a normal operating condition where there is negligible change in the electrical power transmitted in a circuit over a long period of time.

Step Voltage: The difference in surface potential experienced by a person bridging a 1-meter distance with his feet without contacting any other grounded conducting object.

Touch Voltage: The potential difference between the Ground Potential Rise and the surface potential at a point where a person is standing with his hand in contact with a grounded structure.

1.7 Mitigation System Design Objectives

An AC mitigation system designed to protect a pipeline subject to AC interference effects must achieve the following four (4) objectives:

i) During worst-case steady state load conditions on the electric transmission circuits, reduce AC pipeline potentials with respect to local earth to acceptable levels for the safety of operating personnel and the public.

ii) During fault conditions on the electric transmission circuits, ensure that pipeline coating stress voltages remain within acceptable limits to prevent damage to the coating or even to the pipeline steel.

Damage to the coating can result in accelerated corrosion of the pipeline itself. Coating damage can occur at voltages on the order of one thousand (1,000) to two thousand (2,000) Volts for bitumen coated pipelines, whereas damage to polyethylene or fusion bonded epoxy coated pipelines occurs at higher voltages, i.e., greater than five thousand (5,000) Volts.

iii) During fault conditions on the electric transmission circuits, ensure the safety of the public and of operating personnel at exposed pipeline appurtenances.

ANSI/IEEE Standard 80 specifies safety criteria for determining maximum acceptable touch and step voltages during fault conditions. Special precautions must be taken by maintenance personnel when excavating inaccessible portions of the pipeline system to ensure safety in case of a fault condition.

iv) During worst-case steady state load conditions on the electric transmission circuits, reduce AC current densities through coating holidays to prevent possible AC corrosion mechanisms on the pipeline.

Table 1-1 depicts the design criteria for the pipeline segment under study.

Table 1-1: Design Criteria for Personnel Safety, and Protection Against Damage to the Pipeline's Coating

Criteria	Steady State Maximum[1] (Volts)	Fault Maximum (Volts)
Exposed Pipeline Appurtenance Touch Voltage	15	-----
Exposed Pipeline Appurtenance Step Voltage	15	-----
Buried Pipeline Touch Voltage	15	-----
AC Current Density Through 1 cm^2 Coating Holiday	30 A/m^2 (Current)	-----
Coating Stress Voltage	-----	5,000

[1] With respect to "Local Earth"

2 FIELD DATA

2.1 Physical Layout

The following are the pipeline segments under study:

- SDG&E L-1604 [redacted]" pipeline
- SDG&E L-49-111 [redacted] pipeline
- SDG&E L-49-111 [redacted]" pipeline
- SDG&E L-49-106 [redacted]" pipeline
- SDG&E L-49-369 [redacted]" pipeline

These segments are approximately 8.2, 2.7, 0.2, 0.3 miles respectively and are in San Diego, California.

The electric transmission circuits that cross and parallel the pipeline are described below in Table 2-1

Table 2-1: Electric Circuits Included in this Analysis

Circuit Name	Power Company	Condition	Circuit Size (kV)	Pipeline GPS Coordinates
TL-13811	SDG&E	Existing	138	Parallelism from [redacted] on L-49-111 Crossing at [redacted] on L-49-111
TL-13825	SDG&E	Existing	138	Parallelism from [redacted] on L-49-111 Crossing at [redacted] on L-49-111
TL-680	SDG&E	Existing	69	Parallelism from [redacted] on L-1604 Crossing at [redacted] on L-1604
TL-6975	SDG&E	Proposed	69	Parallelism from [redacted] on L-1604 Parallelism from [redacted] on L-49-369 Crossing at [redacted] on L-49-369

TL-23011	SDG&E	Existing	230	Parallelism from [redacted] on L-49-369
TL-23051	SDG&E	Existing	230	Parallelism from [redacted] on L-49-369
TL-23014	SDG&E	Existing	230	Parallelism from [redacted] on L-49-369 Crossing at [redacted] on L-49-369 Parallelism from [redacted] L-1604
TL-23015	SDG&E	Existing	230	Parallelism from [redacted] on L-49-369 Crossing at [redacted] on L-49-369 Parallelism from [redacted] to [redacted] on L-1604

Note: All GPS coordinates outlined in this report are based on Google Earth files provided by SDG&E

2.2 Pipeline Data

The effective coating resistance of a pipeline is a conservative value obtained from previous research on coating resistances for in-service coated pipelines.

Coating Resistance of pipeline: 750,000 ohm-ft^2

The characteristics used for the pipeline, obtained from previous research on steel pipelines, are as follows:

- Relative resistivity: 10 (with respect to annealed copper)
- Relative permeability: 300 (with respect to free space)

The characteristics used for the L-1604 [redacted]" pipeline are as follows:

- Pipeline diameter: [redacted]
- Pipeline depth: 3.5'
- Pipeline wall thickness: [redacted]
- Pipeline coating: Fusion Bonded Epoxy

The characteristics used for the L-49-111 [redacted] pipeline are as follows:

- Pipeline diameter: [redacted]
- Pipeline depth: 3.5’
- Pipeline wall thickness: [redacted]”
- Pipeline coating: Fusion Bonded Epoxy

The characteristics used for the L-49-106 [redacted] pipeline are as follows:

- Pipeline diameter: [redacted]
- Pipeline depth: 3.5’
- Pipeline wall thickness: [redacted]”
- Pipeline coating: Fusion Bonded Epoxy

The characteristics used for the L-49-111 [redacted] pipeline are as follows:

- Pipeline diameter: [redacted]
- Pipeline depth: 3.5’
- Pipeline wall thickness: [redacted]
- Pipeline coating: Fusion Bonded Epoxy

The characteristics used for the L-49-369 [redacted] pipeline are as follows:

- Pipeline diameter: [redacted]
- Pipeline depth: 3.5’
- Pipeline wall thickness: [redacted]
- Pipeline coating: Fusion Bonded Epoxy

2.3 Soil Resistivity Measurements

This AC electrical interference analysis was based on soil resistivity measurements recorded at locations along the pipeline route, using equipment and procedures developed especially for this type of AC interference study. These soil resistivity measurements were recorded between February 23, 2017 through February 24, 2017. Soil resistivity measurements for this analysis were recorded at nine (9) sites.

This measurement data is outlined in Appendix A.

Soil resistivity measurements are used to calculate the ground resistance of electric transmission circuit structures, assess the gradient control performance of AC mitigation systems and gradient control mats, as well as to determine the conductive coupling of the pipeline system through the earth from nearby faulted electric transmission circuit structures. The conductive coupling has an important effect on touch and step voltages at proximate valve sites and on pipeline coating-stress voltages.

Prior experience has shown the need for a special measurement methodology for environments that are subject to electrical noise due to the presence of nearby high voltage electric transmission circuits. When conventional methods are used, the instrumentation can pick up noise from the nearby electric power circuits and indicate resistivity values much higher than reality at large electrode spacing, suggesting that deeper soil layers offer poorer grounding than actuality. Resistance readings can be inflated by a factor of four (4) or more. This error can result in conservative AC mitigation designs.

2.3.1 Soil Resistivity Measurement Methodology

Measurements conducted by ARK Engineering personnel were based upon the industry recognized Wenner four-pin method, in accordance with IEEE Standard 81, "IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System".

The electrode spacing varied from point one-five (0.15) meters to twenty-five (25) meters. Apparent resistivity values that correspond to the measured resistance values can be calculated using the expression:

$$\rho = 2\pi aR$$

Where:

ρ = Apparent soil resistivity, in ohm-meters (Ω-m)
a = Electrode separation, in meters (m)
R = Measured resistance, in ohms (Ω)

In practice, four rods are placed in a straight line at intervals "a", driven to a depth that does not exceed one-tenth of "a" (0.1*a).

This results in the approximate average resistance of the soil to a depth of "a" meters.

2.3.2 Soil Resistivity Data

Soil resistivity measurements were used to derive an equivalent soil structure model for the pipeline. This multilayer soil model is representative of the changing soil characteristics as a function of depth. The complete multilayer soil characteristics are used to calculate the conductive and total AC interference effects. Touch voltage, coating stress voltage, and touch & step safety limits all use the complete multilayer soil model.

Table 2-2: Bottom Layer Soil Resistivity Values

Soil Resistivity Location No.	Approx. GPS Coordinates	Resistivity at Pipeline Depth (Ω-m)	Bottom Layer Resistivity (Ω-m)
1	[redacted]	8	9
2	[redacted]	944	84
3	[redacted]	108	522
4	[redacted]	373	242
5	[redacted]	76	141
6	[redacted]	21	273
7	[redacted]	302	474
8	[redacted]	88	541
9	[redacted]	125	356

3 MODELING DETAILS

3.1 Steady State Conditions

Maximum AC load currents provided by Sempra were used to compute the maximum steady state inductive AC interference effects on the pipeline section under study.

Although these circuits may not be loaded to this level, the values constitute a realistic scenario if other critical circuits are out of service and the load must be redirected through this transmission circuit. Therefore, under normal conditions, the steady state AC interference levels should be significantly less than those reported in this study.

Table 3-1 indicates the maximum load currents used for this AC interference analysis.

Table 3-1: Transmission Circuit Maximum Current Ratings

Power Company	Circuit Name	Condition	Circuit Size (kV)	Maximum Load Current (A)
SEMPRA	HVAC 1-A	Existing	138	938
SEMPRA	HVAC 1-B	Existing	138	2,290
SEMPRA	HVAC 2-A	Existing	69	854
SEMPRA	HVAC 2-B	Proposed	69	1,179
SEMPRA	HVAC 3	Existing	230	2,290
SEMPRA	HVAC 4	Existing	230	2,290
SEMPRA	HVAC 5	Existing	230	2,000
SEMPRA	HVAC 6	Existing	230	2,000

3.2 Fault Conditions

To determine the maximum AC interference effects of the faulted circuits on the pipeline under study, the model included single phase-to-ground fault branch currents on the electric transmission circuits.

Fault conditions were simulated on the electric transmission circuits in the area of this analysis. Single phase-to-ground branch current values, provided by Sempra, were used to calculate fault currents on grounded tower structures along the electric transmission circuits.

Reference Appendix C for all fault data used in this analysis.

3.3 Modeled Interference Levels

ARK Engineering performed this AC interference analysis using state-of-the-art modeling software. The output file plots for the steady-state and simulated fault conditions on the electric transmission circuits are included in Appendix B.

3.3.1 Steady State Conditions

The induced AC pipeline potentials were computed with the electric transmission circuits operating at maximum load conditions. The results are summarized in Appendix B.

The computed induced AC pipeline potential was below the maximum allowable design limit of fifteen (15) Volts along all the pipeline routes. Without including the proposed TL-6975 circuit in the initial analysis:

For the L-1604 pipeline segment under study:

A maximum induced AC pipeline potential of approximately three (3) Volts, with respect to remote earth, was computed at approximate pipeline GPS location [redacted].

For the L-49-111 pipeline segment under study:

A maximum induced AC pipeline potential of approximately one (1) Volt, with respect to remote earth, was computed at approximate pipeline GPS location [redacted].

For the L-49-106 pipeline segment under study:

A maximum induced AC pipeline potential of approximately one (1) Volt, with respect to remote earth, was computed at approximate pipeline GPS location [redacted].

For the L-49-369 pipeline segment under study:

A maximum induced AC pipeline potential of approximately one (1) Volt, with respect to remote earth, was computed at approximate pipeline GPS location [redacted].

Including the proposed TL-6975 circuit in the analysis, the computed induced AC pipeline potential was also below the maximum allowable design limit of fifteen (15) Volts along all the pipeline routes.

For the L-1604 pipeline segment under study:

A maximum induced AC pipeline potential of approximately eight (8) Volts, with respect to remote earth, was computed at approximate pipeline GPS location [redacted].

For the L-49-111 pipeline segment under study:

A maximum induced AC pipeline potential of approximately four (4) Volts, with respect to remote earth, was computed at approximate pipeline GPS location [redacted].

For the L-49-106 pipeline segment under study:

A maximum induced AC pipeline potential of approximately eight (8) Volts, with respect to remote earth, was computed at approximate pipeline GPS location [redacted].

For the L-49-369 pipeline segment under study:

A maximum induced AC pipeline potential of approximately one (1) Volt, with respect to remote earth, was computed at approximate pipeline GPS location [redacted].

Including the proposed TL-6975 circuit in the analysis, with the proposed AC mitigation systems connected to the pipeline, the AC pipeline potential was also below the maximm allowable design limit of fifteen (15) Volts along all the pipeline routs.

For the L-1604 pipeline segment under study:

A maximum induced AC pipeline potential of approximately four (4) Volts, with respect to remote earth, was computed at approximate pipeline GPS location [redacted]

For the L-49-111 pipeline segment under study:

A maximum induced AC pipeline potential of approximately two (2) Volts, with respect to remote earth, was computed at approximate pipeline GPS location [redacted].

For the L-49-106 pipeline segment under study:

A maximum induced AC pipeline potential of approximately four (4) Volts, with respect to remote earth, was computed at approximate pipeline GPS location [redacted]

For the L-49-369 pipeline segment under study:

A maximum induced AC pipeline potential of approximately one (1) Volts, with respect to remote earth, was computed at approximate pipeline GPS location [redacted].

Table 3-2 outlines the computed maximum induced AC pipeline potentials during maximum load conditions on the electric transmission circuits.

Table 3-2: Maximum Induced Pipeline Potentials at Maximum Load Conditions

Pipeline	Circuit Conditions	Pipeline GPS coordinates	Maximum Induced Potential (V)	Design Limit (V)
L-1604	Without TL 6975	[redacted]	3.42	15
	With TL 6975	[redacted]	7.89	15
	With AC Mitigation	[redacted]	4.18	15
L-49-111	Without TL 6975	[redacted]	1.45	15
	With TL 6975	[redacted]	4.06	15
	With AC Mitigation	[redacted]	2.19	15

Pipeline	Circuit Conditions	Pipeline GPS coordinates	Maximum Induced Potential (V)	Design Limit (V)
L-49-106	Without TL 6975	[redacted]	1.20	15
	With TL 6975	[redacted]	7.98	15
	With AC Mitigation	[redacted]	3.83	15
L-49-369	Without TL 6975	[redacted]	1.20	15
	With TL 6975	[redacted]	1.34	15
	With AC Mitigation	[redacted]	1.34	15

Reference Appendix B for plots of the computed induced AC pipeline potentials on the pipelines.

3.3.2 Fault Conditions

As outlined in Chapter 1 of this report, when an electric transmission circuit fault occurs at a grounded structure (transmission tower) in proximity to a pipeline in a joint corridor, the induced AC pipeline potential is essentially out of phase with the earth potentials developed by conduction near the faulted structure. Therefore, inductive and conductive interference effects reinforce each other in terms of coating stress voltages and touch voltages.

3.3.2.1 **Inductive Interference** – Inductive AC interference effects to the pipeline were computed and analyzed during simulated fault conditions on the electric transmission circuits. This was undertaken to determine the maximum induced AC pipeline potentials at all points along the pipeline segment under study.

3.3.2.2 **Conductive Interference** – The configuration of the electric transmission circuit towers and their grounding systems was used to determine earth surface potentials in proximity to the structures and the pipeline during a simulated single phase-to-ground fault condition.

3.3.2.3 **Total Fault Current Interference** – The maximum total pipeline coating stress voltage was computed for each point along each pipeline in the study area. This is the sum of the inductive and conductive AC interference effects.

The maximum total coating stress voltage value is outlined below in Table 3-3.

Table 3-3: Maximum Coating Stress Voltage on the Pipelines under Simulated Fault Conditions

Pipeline	Circuit Conditions	Pipeline GPS Coordinates	Maximum Coating Stress Voltage (V)	Design Limit (V)

L-1604	Without TL 6975	[redacted]	686.79	5,000
	With TL 6975	[redacted]	1,179.46	5,000
	With AC Mitigation	[redacted]	975	5,000
L-49-111	Without TL 6975	[redacted]	96.84	5,000
	With TL 6975	[redacted]	1,102.13	5,000
	With AC Mitigation	[redacted]	963.31	5,000
L-49-106	Without TL 6975	[redacted]	15.61	5,000
	With TL 6975	[redacted]	1,179.58	5,000
	With AC Mitigation	[redacted]	750.08	5,000
L-49-369	Without TL 6975	[redacted]	59.06	5,000
	With TL 6975	[redacted]	593.21	5,000
	With AC Mitigation	[redacted]	416.96	5,000

Appendix B includes plots of the coating stress voltage levels on the pipeline during simulated fault conditions on the electric transmission circuits.

3.4 AC Mitigation System

The AC mitigation system designed and recommended by ARK Engineering for this pipeline will reduce the AC interference effects to acceptable levels during maximum steady state load conditions and single phase-to-ground fault conditions on the electric transmission circuits that parallel and cross the pipeline.

The proposed AC mitigation system design includes installation of gradient control wires (zinc ribbon anode or equivalent) and solid-state decoupling (SSD) devices in the areas of computed high pipeline AC potentials. This AC mitigation system will reduce pipeline AC interference effects to safe levels for personnel safety and pipeline integrity.

3.5 AC Corrosion Analysis Results

To analyze the possible AC corrosion effects to these pipeline segments, calculations were completed to determine the AC density based upon induced AC pipeline voltages, assuming a one (1) cm^2 circular coating holiday, along each pipeline. The computed induced pipeline voltages are shown in Appendix B.

Without including the proposed TL-6975 circuit in the initial analysis:

For the L-1604 pipeline segment:

A peak AC density of approximately twenty-one (21) A/m^2 was calculated at approximate pipeline GPS location [redacted].

For the L-49-111 pipeline segment:

A peak AC density of approximately nine (9) A/m^2 was calculated at approximate pipeline GPS location [redacted]

For the L-49-106 pipeline segment:

A peak AC density of approximately eight (8) A/m^2 was calculated at approximate pipeline GPS location [redacted]

For the L-49-369 pipeline segment:

A peak AC density of approximately seven (7) A/m^2 was calculated at approximate pipeline GPS location [redacted]

Including the proposed TL-6975 circuit in the analysis:

For the L-1604 pipeline segment:

A peak AC density of approximately forty-nine (49) A/m^2 was calculated at approximate pipeline GPS location [redacted].

For the L-49-111 pipeline segment:

A peak AC density of approximately twenty-five (3) A/m^2 was calculated at approximate pipeline GPS location [redacted].

For the L-49-106 pipeline segment:

A peak AC density of approximately fifty (50) A/m^2 was calculated at approximate pipeline GPS location [redacted].

For the L-49-369 pipeline segment:

A peak AC density of approximately seven (7) A/m^2 was calculated at approximate pipeline GPS location [redacted].

Including the proposed TL-6975 circuit in the analysis and the proposed AC mitigation design:

For the L-1604 pipeline segment:

A peak AC density of approximately twenty-six (26) A/m^2 was calculated at approximate pipeline GPS location [redacted].

For the L-49-111 pipeline segment:

A peak AC density of approximately fourteen (14) A/m^2 was calculated at approximate pipeline GPS location [redacted]

For the L-49-106 pipeline segment:

A peak AC density of approximately twenty-four (50) A/m^2 was calculated at approximate pipeline GPS location .

For the L-49-369 pipeline segment:

A peak AC density of approximately seven (7) A/m^2 was calculated at approximate pipeline GPS location

Table 3-4 outlines the computed maximum pipeline AC density at maximum load conditions on the electric transmission circuits.

Table 3-4: Maximum Coating Holiday Pipeline AC Current Density

Pipeline	Circuit Conditions	Pipeline GPS Coordinates	Maximum Current Density (A/m^2)	Design Limit (A/m^2)
L-1604	Without TL 6975		21.42	30
	With TL 6975		49.49	30
	With AC Mitigation		26.20	30
L-49-111	Without TL 6975		9.29	30
	With TL 6975		25.44	30
	With AC Mitigation		13.76	30
L-49-106	Without TL 6975		7.96	30
	With TL 6975		50.09	30
	With AC Mitigation		24.07	30
L-49-369	Without TL 6975		6.81	30
	With TL 6975		6.67	30
	With AC Mitigation		6.67	30

Appendix B includes plots of the computed AC density on each pipeline section under study.

4 CONCLUSIONS

4.1 Conclusions

The L-1604, L-49-111, L-49-106, and L-49-369 pipelines and the electric transmission circuits have been modeled and analyzed as described in this report.

Computer modeling and analysis, using maximum steady state load conditions and single phase-to-ground fault currents on the electric transmission circuits, indicate the following:

- Steady-state induced AC pipeline voltage are below the design limit of fifteen (15) Volts along the pipeline under these maximum load conditions on the electric transmission circuits.
- Pipeline coating stress voltages does not exceed the five thousand (5,000) Volt design limit for a single phase-to-ground fault on the electric transmission circuits.
- AC density across a 1 cm^2 coating holiday is above the thirty (30) A/m^2 design limit.

AC mitigation systems were designed to effectively reduce the induced AC interference effects and AC corrosion effects to acceptable levels.

This analysis results in AC interference levels that are conservative. Under normal operating conditions, the AC interference levels on the pipeline should be less than reported in this study.

4.2 Assumptions

During the modeling and analysis of the AC interference effects on the pipeline, various assumptions were required. These assumptions are outlined below in no particular order:

a. Low voltage distribution taps were not included in this analysis.

b. A coating resistance value of 750,000 Ω-ft^2 was used for existing pipelines.

c. A coating holiday size of 1 cm^2 was used in the calculation of AC current density.

5 RECOMMENDATIONS

5.1 Proposed Safety and AC Mitigation System Requirements

Having performed the modeling and analysis of the AC interference effects on the pipeline, ARK Engineering has designed two (2) alternative AC mitigation system (Horizontal grounding conductor and vertical deepwell systems) that will reduce the AC interference effects to safe level for pipeline integrity and personal safety.

Horizontal Grounding Conductor (Zinc ribbon or alternative conductor)

For the horizontal grounding conductor design, ARK Engineering recommends that gradient control wires (zinc ribbon anode or equivalent) be installed in the following areas:

Table 5-1: Pipeline AC Mitigation System– (Zinc Ribbon)

Mitigation Section No.	GPS Start	GPS End	No. of Strands	Zinc Ribbon Required (Ft)
1	[redacted]	[redacted]	1	3,710
2	[redacted]	[redacted]	1	4,255
			TOTAL:	**7,965**

ARK Engineering also recommends the installation of AC coupon test stations to monitor induced AC potential and AC current density levels at locations where the computed AC density values exceed thirty (20) A/m² along the pipeline.

The proposed coupon test station locations are outlined below:

Table 5-4: Pipeline AC Mitigation System – Proposed Coupon Test Locations- Design 1

Coupon Test Station Location No.	Approximate GPS Coordinates
1	[redacted]
2	[redacted]

Reference ARK Engineering design drawing package numbers: 16138-100 in Appendix D for AC mitigation system installation details.

16138-100 SDG&E – Proposed TL 6975 Electric Transmission Circuit
AC Mitigation System Designs
Zinc Ribbon Installation Drawings
San Diego, California

Please call the author if you have questions or require additional information regarding this report.

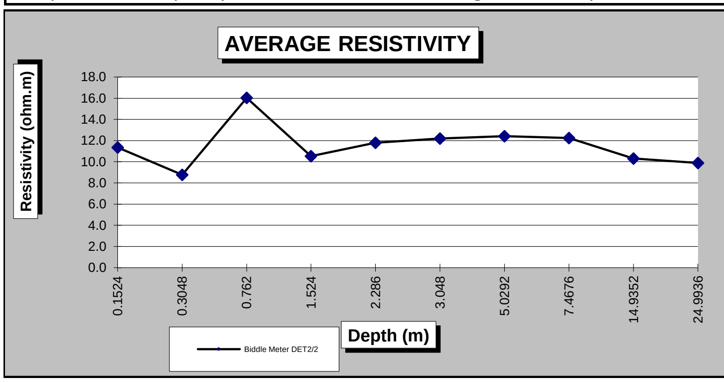
APPENDIX A –
SOIL RESISTIVITY DATA & GPS DATA

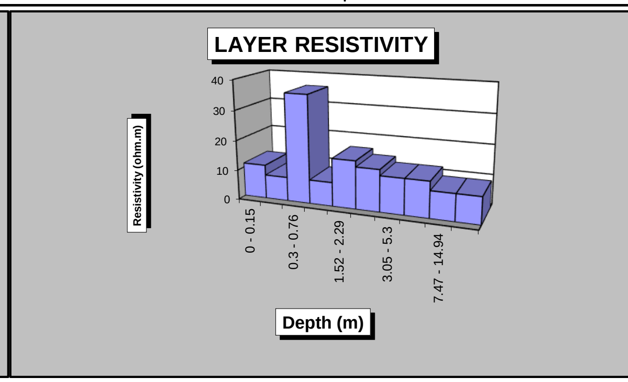
Project Name: 16138-E-AC-SDG&E-Proposed TL 6975
Date: 2/23/2017
Location:
Testers: J. Lovett, J. Pickens
Methodology: $\rho = 2\pi dR$, per ASTM G 57 & Barnes Method
Instrumentation: Mini Stinger
Weather: 58 degrees
Soil Description

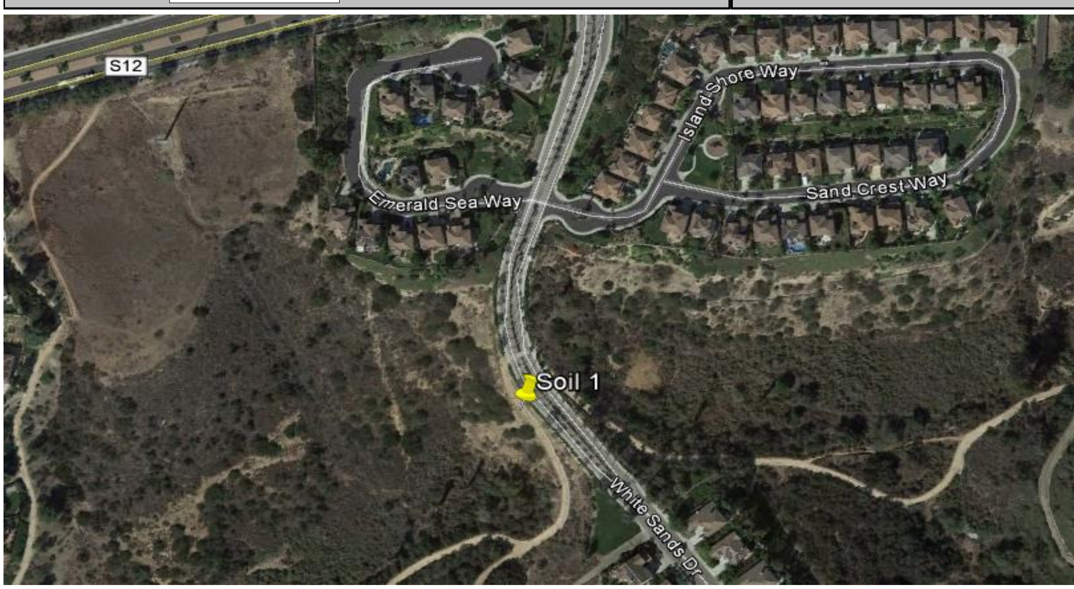
ARK® ENGINEERING & TECHNICAL SERVICES, INC.

4 Pin Wenner Data					Barnes Layer Analysis						
Depth (d) ft	Depth (d) m	R ohms	Spacing Factor	Resistivity ohm.m		1/R mhos	Δ 1/R mhos	1/(Δ 1/R) ohms	Spacing Factor	Layer Resistivity* Layer (m)	ohm.m
0.50	0.15	11.360	1	11.4	1136.0	0.08803	n/a	n/a	n/a	0 - 0.15	11
1.00	0.30	4.617	2	8.8	877.2	0.21659	0.12856	7.778	1	0.15 - 0.3	8
2.50	0.76	3.339	5	16.0	1602.7	0.29949	0.08290	12.063	3	0.3 - 0.76	36
5.00	1.52	1.097	10	10.5	1053.1	0.91158	0.61209	1.634	5	0.76 - 1.52	8
7.50	2.29	0.820	14	11.8	1180.8	1.21951	0.30794	3.247	5	1.52 - 2.29	16
10.00	3.05	0.635	19	12.2	1219.2	1.57480	0.35529	2.815	5	2.29 - 3.05	14
16.50	5.03	0.393	32	12.4	1241.9	2.54453	0.96973	1.031	12	3.05 - 5.3	12
24.50	7.47	0.261	47	12.2	1224.1	3.83142	1.28689	0.777	15	5.03 - 7.47	12
49.00	14.94	0.110	94	10.3	1031.8	9.09091	5.25949	0.190	47	7.47 - 14.94	9
82.00	24.99	0.063	157	9.9	989.1	15.87302	6.78211	0.147	63	14.94 - 25.0	9

* Layer Resistivity may not correlate with Average Resistivity because of soil characteristic variations with depth





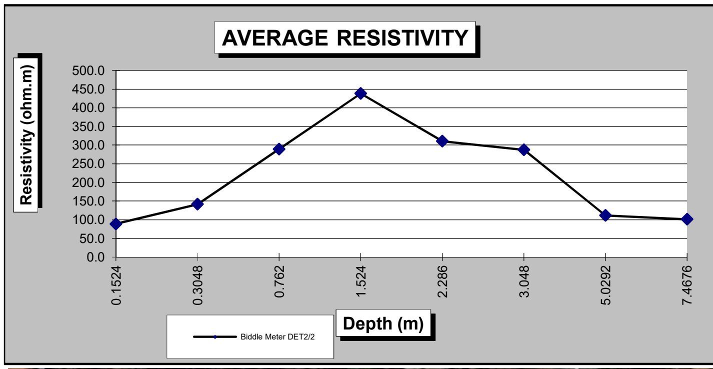


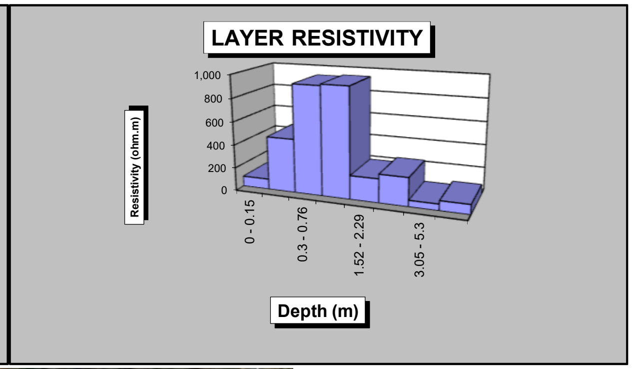
Project Name:	16138-E-AC-SDG&E-Proposed TL 6975
Date:	2/23/2017
Location:	
Testers:	J. Lovett, J. Pickens
Methodology:	$\rho = 2\pi dR$, per ASTM G 57 & Barnes Method
Instrumentation:	Mini Stinger
Weather:	58 degrees
Soil Description	

ARK® ENGINEERING & TECHNICAL SERVICES, INC.

4 Pin Wenner Data					Barnes Layer Analysis						
Depth (d) ft	Depth (d) m	R ohms	Spacing Factor	Resistivity ohm.m		1/R mhos	Δ 1/R mhos	1/(Δ 1/R) ohms	Spacing Factor	Layer Resistivity* Layer (m)	ohm.m
0.50	0.15	88.950	1	89.0	8895.0	0.01124	n/a	n/a	n/a	0 - 0.15	89
1.00	0.30	74.660	2	141.9	14185.4	0.01339	0.00215	464.731	1	0.15 - 0.3	465
2.50	0.76	60.200	5	289.0	28896.0	0.01661	0.00322	310.825	3	0.3 - 0.76	932
5.00	1.52	45.640	10	438.1	43814.4	0.02191	0.00530	188.704	5	0.76 - 1.52	944
7.50	2.29	21.600	14	311.0	31104.0	0.04630	0.02439	41.008	5	1.52 - 2.29	205
10.00	3.05	14.990	19	287.8	28780.8	0.06671	0.02041	48.984	5	2.29 - 3.05	245
16.50	5.03	3.530	32	111.5	11154.8	0.28329	0.21657	4.617	12	3.05 - 5.3	55
24.50	7.47	2.167	47	101.6	10163.2	0.46147	0.17818	5.612	15	5.03 - 7.47	84

* Layer Resistivity may not correlate with Average Resistivity because of soil characteristic variations with depth





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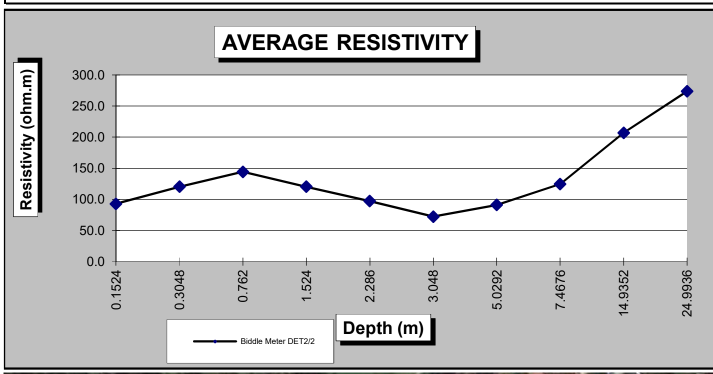
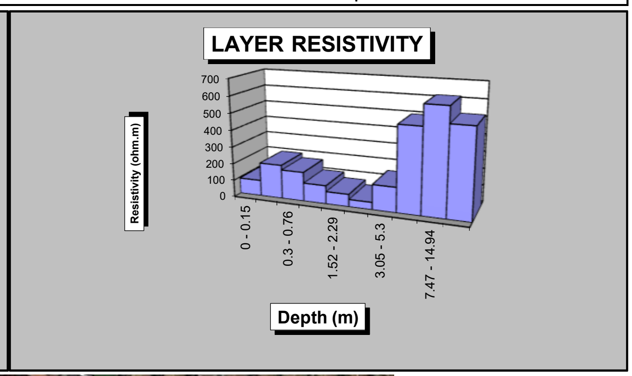
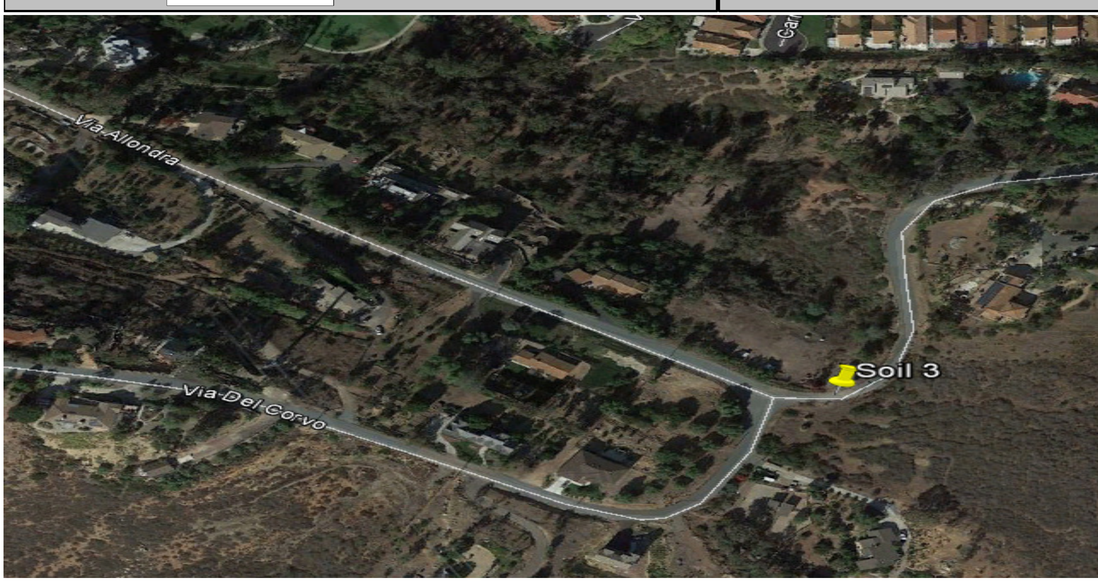
ARK Engineering & Technical Services, Inc.

4 Pin Wenner Data					Barnes Layer Analysis						
Depth (d) ft	Depth (d) m	R ohms	Spacing Factor	Resistivity ohm.m		1/R mhos	Δ 1/R mhos	1/(Δ 1/R) ohms	Spacing Factor	Layer Resistivity* Layer (m)	ohm.m
0.50	0.15	93.010	1	93.0	9301.0	0.01075	n/a	n/a	n/a	0 - 0.15	93
1.00	0.30	63.500	2	120.7	12065.0	0.01575	0.00500	200.140	1	0.15 - 0.3	200
2.50	0.76	30.090	5	144.4	14443.2	0.03323	0.01749	57.190	3	0.3 - 0.76	172
5.00	1.52	12.570	10	120.7	12067.2	0.07955	0.04632	21.589	5	0.76 - 1.52	108
7.50	2.29	6.764	14	97.4	9740.2	0.14784	0.06829	14.644	5	1.52 - 2.29	73
10.00	3.05	3.777	19	72.5	7251.8	0.26476	0.11692	8.553	5	2.29 - 3.05	43
16.50	5.03	2.887	32	91.2	9122.9	0.34638	0.08162	12.252	12	3.05 - 5.3	147
24.50	7.47	2.656	47	124.6	12456.6	0.37651	0.03013	33.194	15	5.03 - 7.47	498
49.00	14.94	2.209	94	207.2	20720.4	0.45269	0.07619	13.126	47	7.47 - 14.94	617
82.00	24.99	1.744	157	273.8	27380.8	0.57339	0.12070	8.285	63	14.94 - 25.0	522

* Layer Resistivity may not correlate with Average Resistivity because of soil characteristic variations with depth





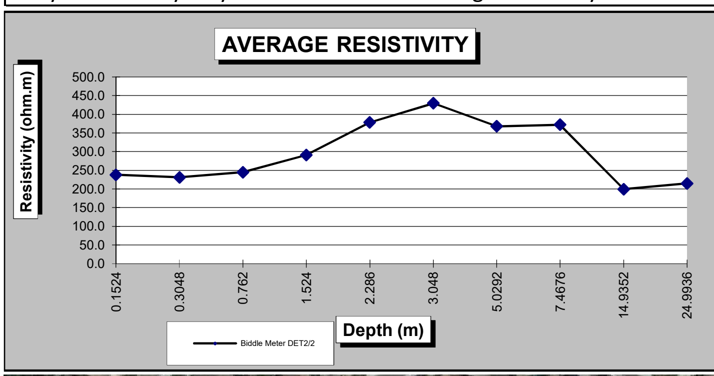


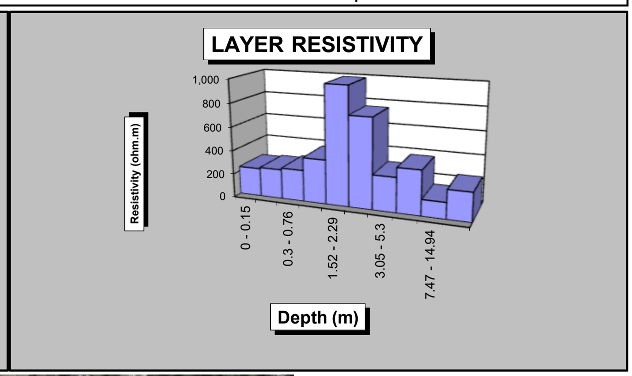
Project Name:	16138-E-AC-SDG&E-Proposed TL 6975
Date:	2/23/2017
Location:	
Testers:	J. Lovett, J. Pickens
Methodology:	ρ = 2πdR, per ASTM G 57 & Barnes Method
Instrumentation:	Mini Stinger
Weather:	58 degrees
Soil Description	

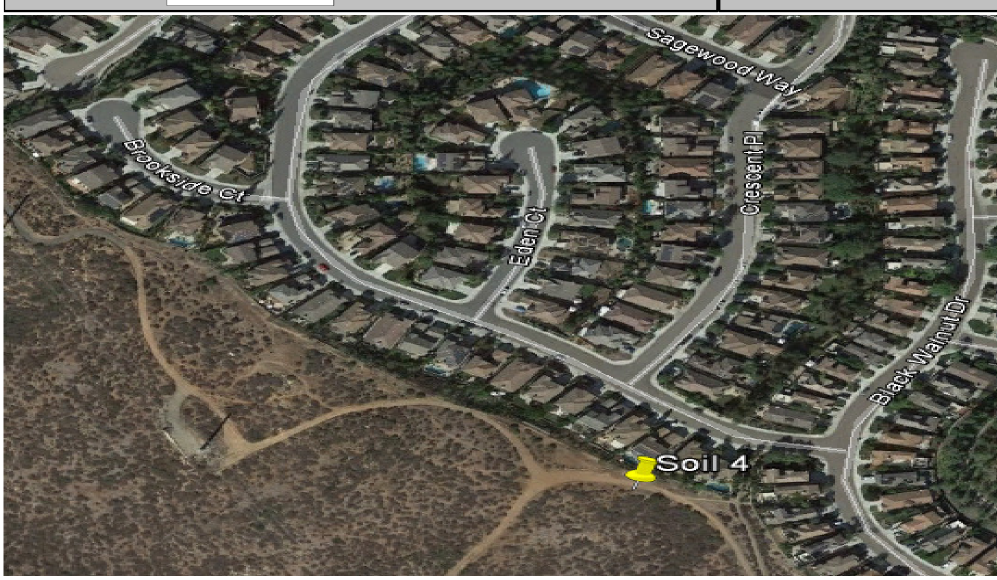
ARK® ENGINEERING & TECHNICAL SERVICES, INC.

4 Pin Wenner Data					**Barnes Layer Analysis**						
Depth (d) ft	**Depth (d) m**	**R ohms**	**Spacing Factor**	**Resistivity ohm.m**		**1/R mhos**	**Δ 1/R mhos**	**1/(Δ 1/R) ohms**	**Spacing Factor**	**Layer Resistivity* Layer (m)**	**ohm.m**
0.50	0.15	238.300	1	238.3	23830.0	0.00420	n/a	n/a	n/a	0 - 0.15	238
1.00	0.30	121.800	2	231.4	23142.0	0.00821	0.00401	249.141	1	0.15 - 0.3	249
2.50	0.76	51.050	5	245.0	24504.0	0.01959	0.01138	87.885	3	0.3 - 0.76	264
5.00	1.52	30.300	10	290.9	29088.0	0.03300	0.01341	74.545	5	0.76 - 1.52	373
7.50	2.29	26.280	14	378.4	37843.2	0.03805	0.00505	198.081	5	1.52 - 2.29	990
10.00	3.05	22.380	19	429.7	42969.6	0.04468	0.00663	150.807	5	2.29 - 3.05	754
16.50	5.03	11.660	32	368.5	36845.6	0.08576	0.04108	24.342	12	3.05 - 5.3	292
24.50	7.47	7.940	47	372.4	37238.6	0.12594	0.04018	24.887	15	5.03 - 7.47	373
49.00	14.94	2.128	94	199.6	19960.6	0.46992	0.34398	2.907	47	7.47 - 14.94	137
82.00	24.99	1.370	157	215.1	21509.0	0.72993	0.26000	3.846	63	14.94 - 25.0	242

* Layer Resistivity may not correlate with Average Resistivity because of soil characteristic variations with depth





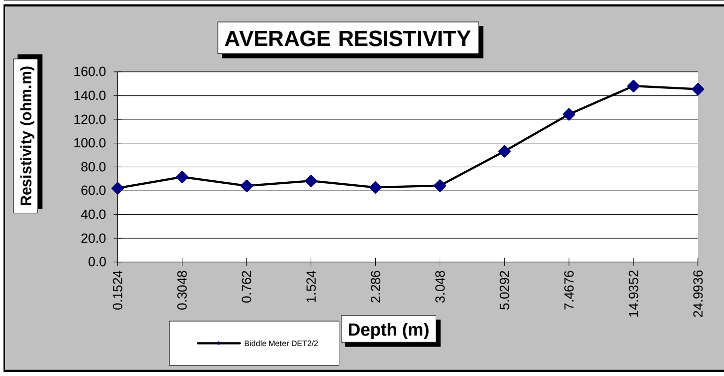


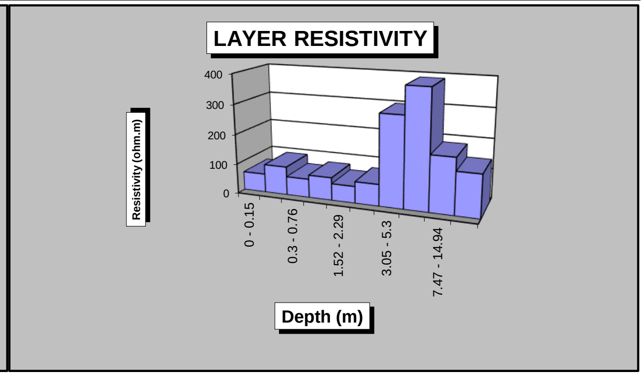
Project Name: 16138-E-AC-SDG&E-Proposed TL 6975
Date: 2/23/2017
Location:
Testers: J. Lovett, J. Pickens
Methodology: $\rho = 2\pi dR$, per ASTM G 57 & Barnes Method
Instrumentation: Mini Stinger
Weather: 58 degrees
Soil Description

ARK ENGINEERING & TECHNICAL SERVICES, INC.

4 Pin Wenner Data					Barnes Layer Analysis						
Depth (d) ft	Depth (d) m	R ohms	Spacing Factor	Resistivity ohm.m		1/R mhos	Δ 1/R mhos	1/(Δ 1/R) ohms	Spacing Factor	Layer Resistivity* Layer (m)	ohm.m
0.50	0.15	62.180	1	62.2	6218.0	0.01608	n/a	n/a	n/a	0 - 0.15	62
1.00	0.30	37.620	2	71.5	7147.8	0.02658	0.01050	95.245	1	0.15 - 0.3	95
2.50	0.76	13.360	5	64.1	6412.8	0.07485	0.04827	20.717	3	0.3 - 0.76	62
5.00	1.52	7.119	10	68.3	6834.2	0.14047	0.06562	15.240	5	0.76 - 1.52	76
7.50	2.29	4.358	14	62.8	6275.5	0.22946	0.08899	11.237	5	1.52 - 2.29	56
10.00	3.05	3.349	19	64.3	6430.1	0.29860	0.06913	14.465	5	2.29 - 3.05	72
16.50	5.03	2.952	32	93.3	9328.3	0.33875	0.04016	24.902	12	3.05 - 5.3	299
24.50	7.47	2.650	47	124.3	12428.5	0.37736	0.03861	25.903	15	5.03 - 7.47	389
49.00	14.94	1.579	94	148.1	14811.0	0.63331	0.25595	3.907	47	7.47 - 14.94	184
82.00	24.99	0.927	157	145.5	14553.9	1.07875	0.44544	2.245	63	14.94 - 25.0	141

* Layer Resistivity may not correlate with Average Resistivity because of soil characteristic variations with depth



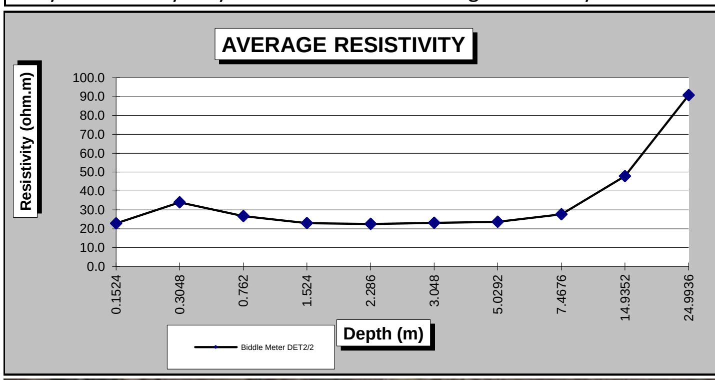


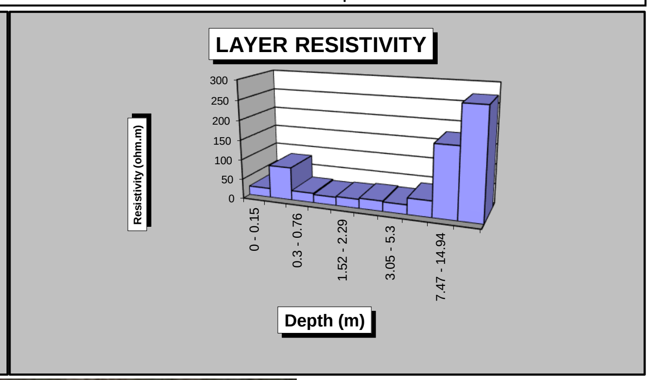
Project Name:	16138-E-AC-SDG&E-Proposed TL 6975
Date:	2/23/2017
Location:	
Testers:	J. Lovett, J. Pickens
Methodology:	ρ = 2πdR, per ASTM G 57 & Barnes Method
Instrumentation:	Mini Stinger
Weather:	58 degrees
Soil Description	

ARK ENGINEERING & TECHNICAL SERVICES, INC.

4 Pin Wenner Data					Barnes Layer Analysis						
Depth (d)	Depth (d)	R	Spacing	Resistivity		1/R	Δ 1/R	1/(Δ 1/R)	Spacing	Layer Resistivity*	
ft	m	ohms	Factor	ohm.m		mhos	mhos	ohms	Factor	Layer (m)	ohm.m
0.50	0.15	22.770	1	22.8	2277.0	0.04392	n/a	n/a	n/a	0 - 0.15	23
1.00	0.30	17.870	2	34.0	3395.3	0.05596	0.01204	83.041	1	0.15 - 0.3	83
2.50	0.76	5.559	5	26.7	2668.3	0.17989	0.12393	8.069	3	0.3 - 0.76	24
5.00	1.52	2.392	10	23.0	2296.3	0.41806	0.23817	4.199	5	0.76 - 1.52	21
7.50	2.29	1.562	14	22.5	2249.3	0.64020	0.22214	4.502	5	1.52 - 2.29	23
10.00	3.05	1.200	19	23.0	2304.0	0.83333	0.19313	5.178	5	2.29 - 3.05	26
16.50	5.03	0.750	32	23.7	2370.0	1.33333	0.50000	2.000	12	3.05 - 5.3	24
24.50	7.47	0.590	47	27.7	2767.1	1.69492	0.36158	2.766	15	5.03 - 7.47	41
49.00	14.94	0.510	94	47.8	4783.8	1.96078	0.26587	3.761	47	7.47 - 14.94	177
82.00	24.99	0.578	157	90.7	9074.6	1.73010	0.23068	4.335	63	14.94 - 25.0	273

* Layer Resistivity may not correlate with Average Resistivity because of soil characteristic variations with depth



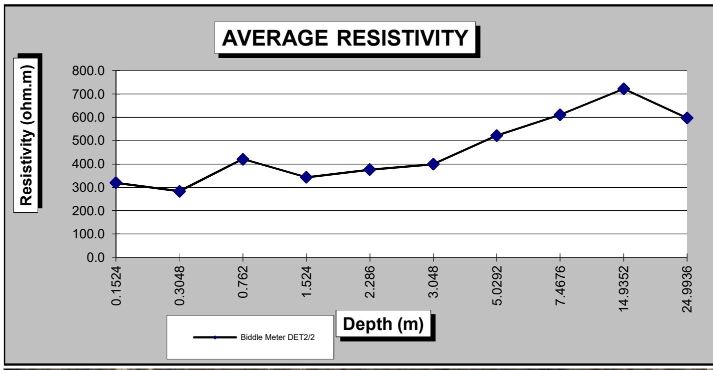


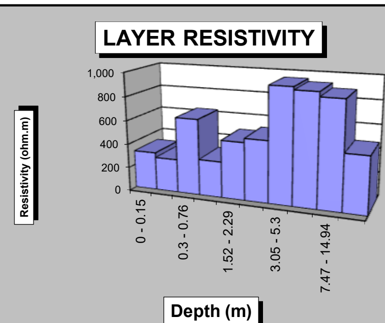
Project Name:	16138-E-AC-SDG&E-Proposed TL 6975
Date:	2/23/2017
Location:	
Testers:	J. Lovett, J. Pickens
Methodology:	ρ = 2πdR, per ASTM G 57 & Barnes Method
Instrumentation:	Mini Stinger
Weather:	58 degrees
Soil Description	

ARK ENGINEERING & TECHNICAL SERVICES, INC.

4 Pin Wenner Data					Barnes Layer Analysis						
Depth (d) ft	Depth (d) m	R ohms	Spacing Factor	Resistivity ohm.m		1/R mhos	Δ 1/R mhos	1/(Δ 1/R) ohms	Spacing Factor	Layer Resistivity* Layer (m)	ohm.m
0.50	0.15	319.900	1	319.9	31990.0	0.00313	n/a	n/a	n/a	0 - 0.15	320
1.00	0.30	149.400	2	283.9	28386.0	0.00669	0.00357	280.311	1	0.15 - 0.3	280
2.50	0.76	87.690	5	420.9	42091.2	0.01140	0.00471	212.298	3	0.3 - 0.76	637
5.00	1.52	35.800	10	343.7	34368.0	0.02793	0.01653	60.499	5	0.76 - 1.52	302
7.50	2.29	26.110	14	376.0	37598.4	0.03830	0.01037	96.464	5	1.52 - 2.29	482
10.00	3.05	20.840	19	400.1	40012.8	0.04798	0.00969	103.251	5	2.29 - 3.05	516
16.50	5.03	16.500	32	521.4	52140.0	0.06061	0.01262	79.230	12	3.05 - 5.3	951
24.50	7.47	13.020	47	610.6	61063.8	0.07680	0.01620	61.733	15	5.03 - 7.47	926
49.00	14.94	7.701	94	722.4	72235.4	0.12985	0.05305	18.851	47	7.47 - 14.94	886
82.00	24.99	3.804	157	597.2	59722.8	0.26288	0.13303	7.517	63	14.94 - 25.0	474

* Layer Resistivity may not correlate with Average Resistivity because of soil characteristic variations with depth



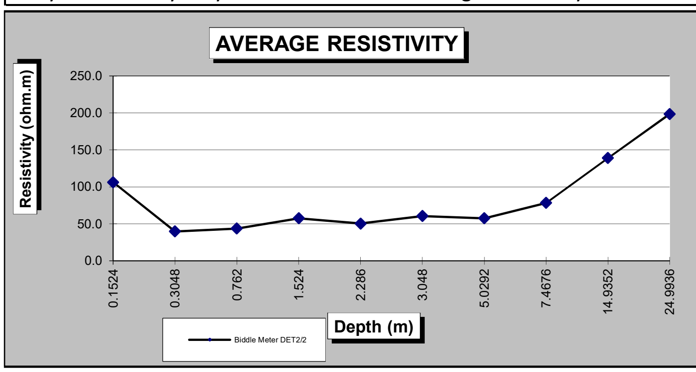


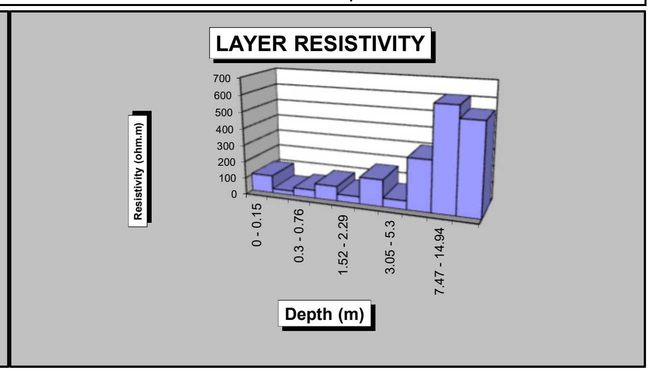
Project Name: 16138-E-AC-SDG&E-Proposed TL 6975
Date: 2/24/2017
Location:
Testers: J. Lovett, J. Pickens
Methodology: $\rho = 2\pi dR$, per ASTM G 57 & Barnes Method
Instrumentation: Mini Stinger
Weather: 52 degrees
Soil Description

ARK Engineering & Technical Services, Inc.

4 Pin Wenner Data					Barnes Layer Analysis						
Depth (d)	Depth (d)	R	Spacing	Resistivity		1/R	Δ 1/R	1/(Δ 1/R)	Spacing	Layer Resistivity*	
ft	m	ohms	Factor	ohm.m		mhos	mhos	ohms	Factor	Layer (m)	ohm.m
0.50	0.15	106.300	1	106.3	10630.0	0.00941	n/a	n/a	n/a	0 - 0.15	106
1.00	0.30	20.890	2	39.7	3969.1	0.04787	0.03846	25.999	1	0.15 - 0.3	26
2.50	0.76	9.078	5	43.6	4357.4	0.11016	0.06229	16.055	3	0.3 - 0.76	48
5.00	1.52	5.985	10	57.5	5745.6	0.16708	0.05693	17.566	5	0.76 - 1.52	88
7.50	2.29	3.503	14	50.4	5044.3	0.28547	0.11839	8.447	5	1.52 - 2.29	42
10.00	3.05	3.155	19	60.6	6057.6	0.31696	0.03149	31.759	5	2.29 - 3.05	159
16.50	5.03	1.823	32	57.6	5760.7	0.54855	0.23159	4.318	12	3.05 - 5.3	52
24.50	7.47	1.672	47	78.4	7841.7	0.59809	0.04954	20.186	15	5.03 - 7.47	303
49.00	14.94	1.482	94	139.0	13901.2	0.67476	0.07668	13.042	47	7.47 - 14.94	613
82.00	24.99	1.264	157	198.4	19844.8	0.79114	0.11638	8.593	63	14.94 - 25.0	541

* Layer Resistivity may not correlate with Average Resistivity because of soil characteristic variations with depth



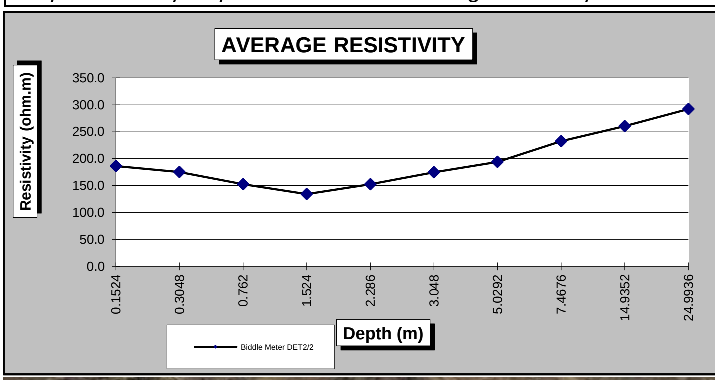


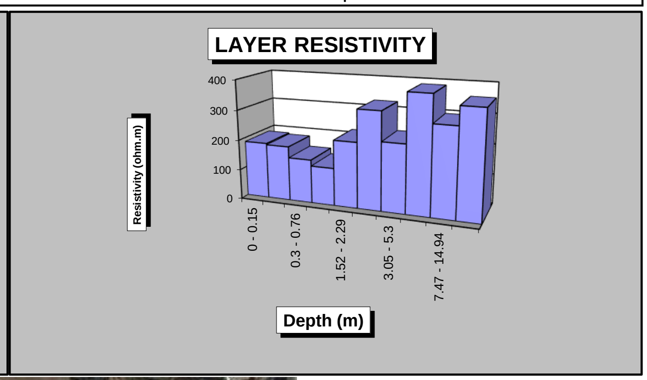
Project Name:	16138-E-AC-SDG&E-Proposed TL 6975
Date:	2/24/2017
Location:	
Testers:	J. Lovett, J. Pickens
Methodology:	$\rho = 2\pi dR$, per ASTM G 57 & Barnes Method
Instrumentation:	Mini Stinger
Weather:	52 degrees
Soil Description	

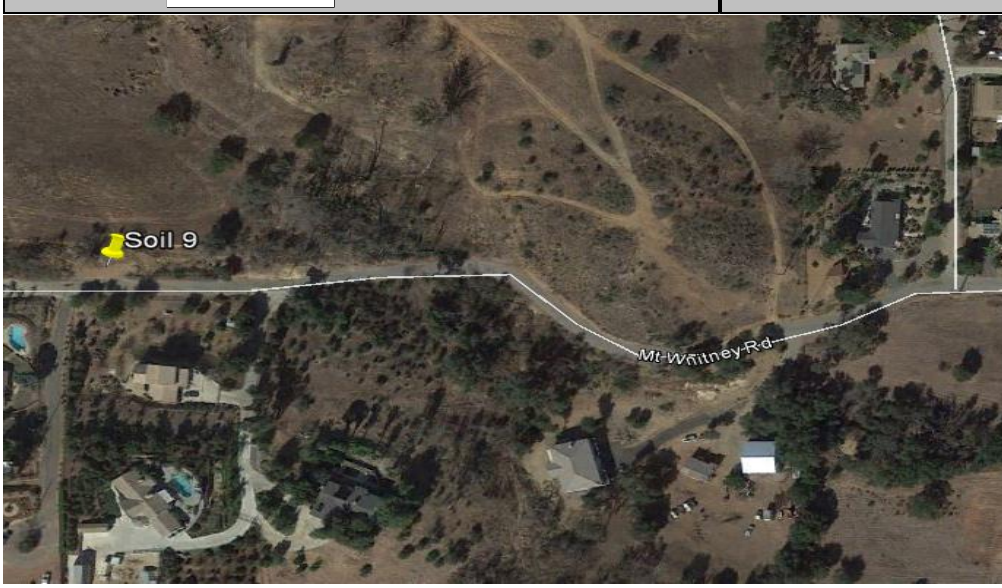
ARK® ENGINEERING & TECHNICAL SERVICES, INC.

4 Pin Wenner Data					Barnes Layer Analysis						
Depth (d) ft	Depth (d) m	R ohms	Spacing Factor	Resistivity ohm.m		1/R mhos	Δ 1/R mhos	1/(Δ 1/R) ohms	Spacing Factor	Layer Resistivity* Layer (m)	ohm.m
0.50	0.15	186.500	1	186.5	18650.0	0.00536	n/a	n/a	n/a	0 - 0.15	187
1.00	0.30	92.110	2	175.0	17500.9	0.01086	0.00549	181.995	1	0.15 - 0.3	182
2.50	0.76	31.770	5	152.5	15249.6	0.03148	0.02062	48.497	3	0.3 - 0.76	145
5.00	1.52	13.980	10	134.2	13420.8	0.07153	0.04005	24.966	5	0.76 - 1.52	125
7.50	2.29	10.590	14	152.5	15249.6	0.09443	0.02290	43.672	5	1.52 - 2.29	218
10.00	3.05	9.101	19	174.7	17473.9	0.10988	0.01545	64.728	5	2.29 - 3.05	324
16.50	5.03	6.142	32	194.1	19408.7	0.16281	0.05294	18.891	12	3.05 - 5.3	227
24.50	7.47	4.962	47	232.7	23271.8	0.20153	0.03872	25.828	15	5.03 - 7.47	387
49.00	14.94	2.775	94	260.3	26029.5	0.36036	0.15883	6.296	47	7.47 - 14.94	296
82.00	24.99	1.861	157	292.2	29217.7	0.53735	0.17699	5.650	63	14.94 - 25.0	356

* Layer Resistivity may not correlate with Average Resistivity because of soil characteristic variations with depth



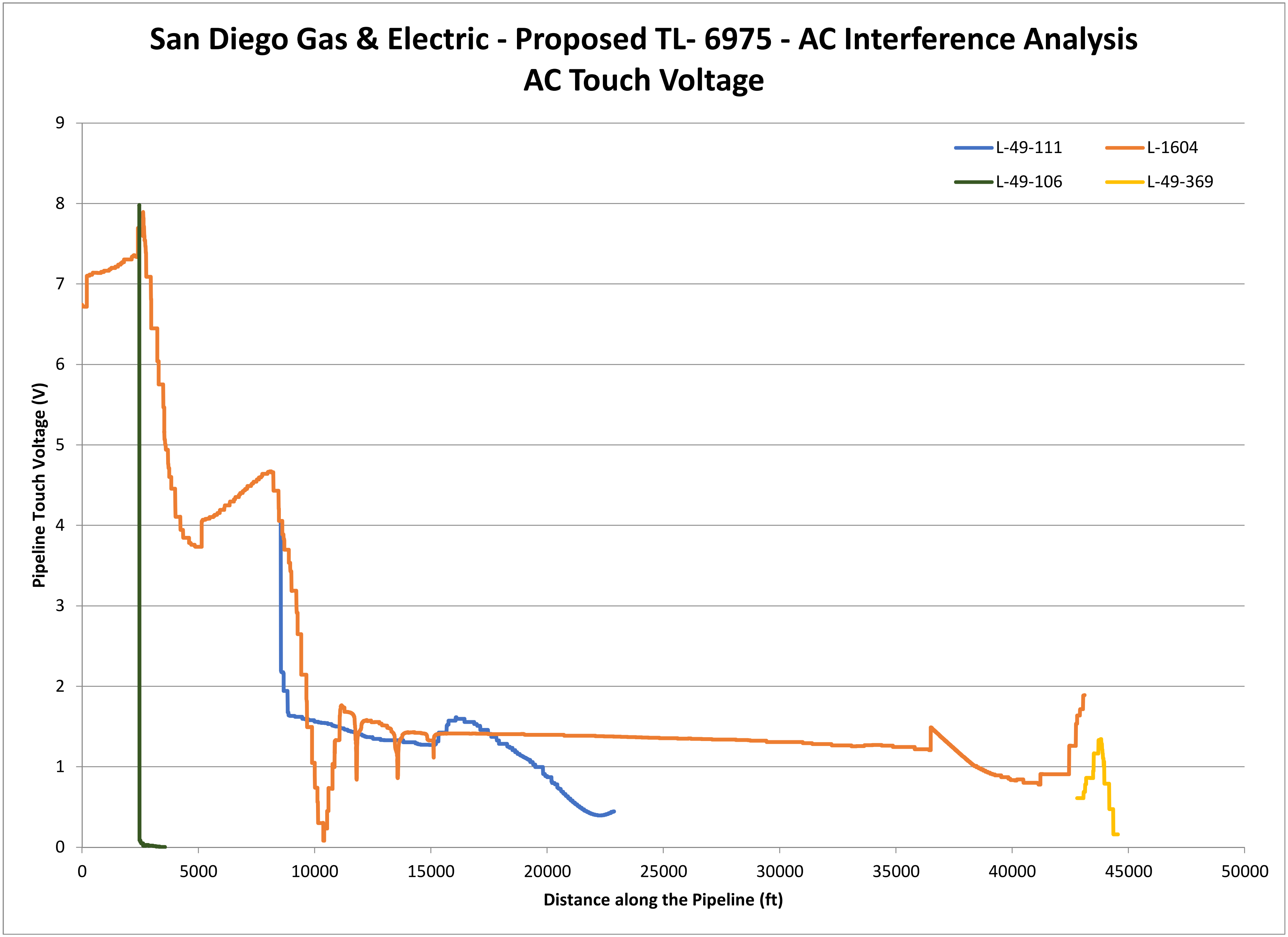


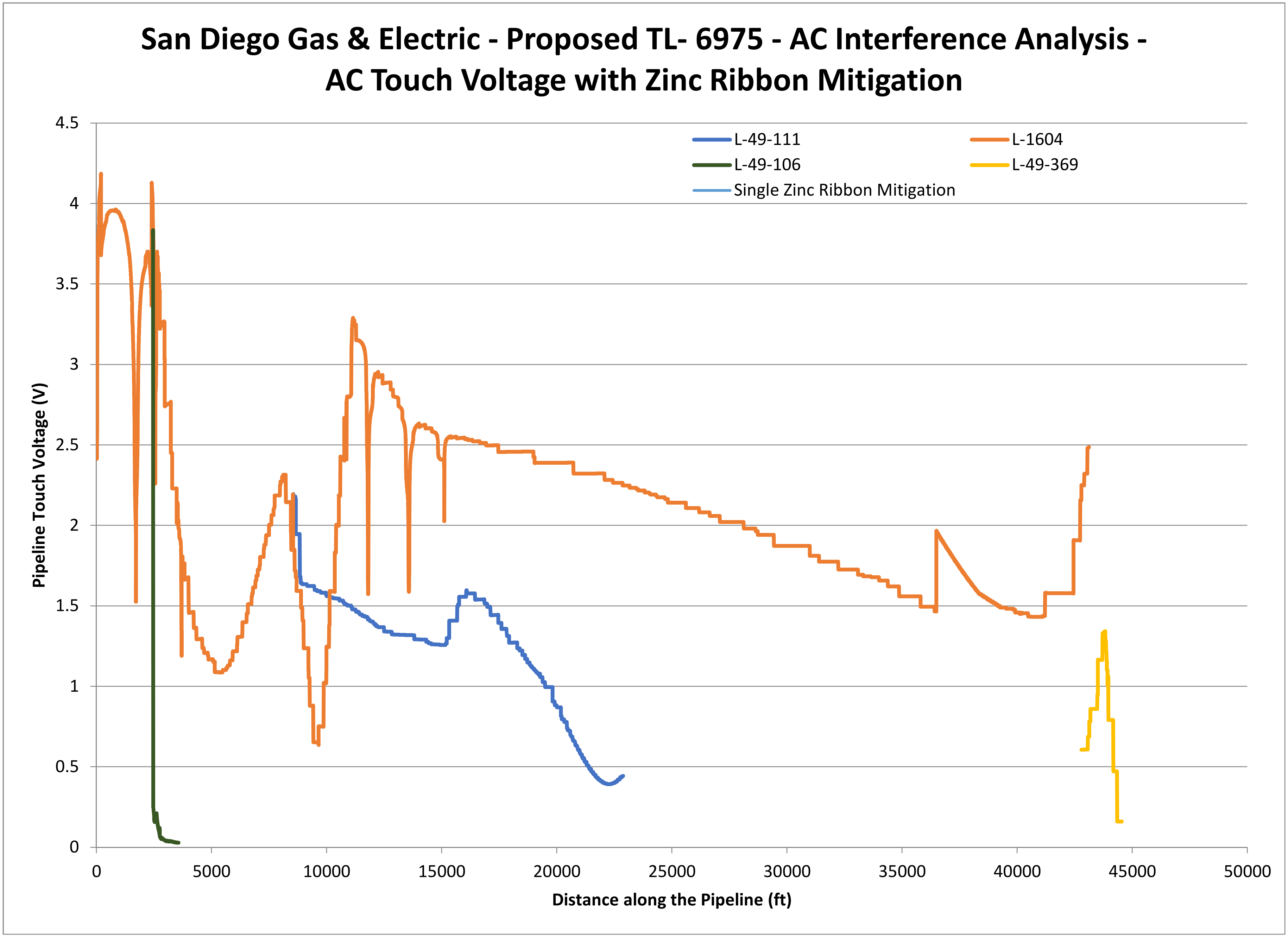


APPENDIX B –

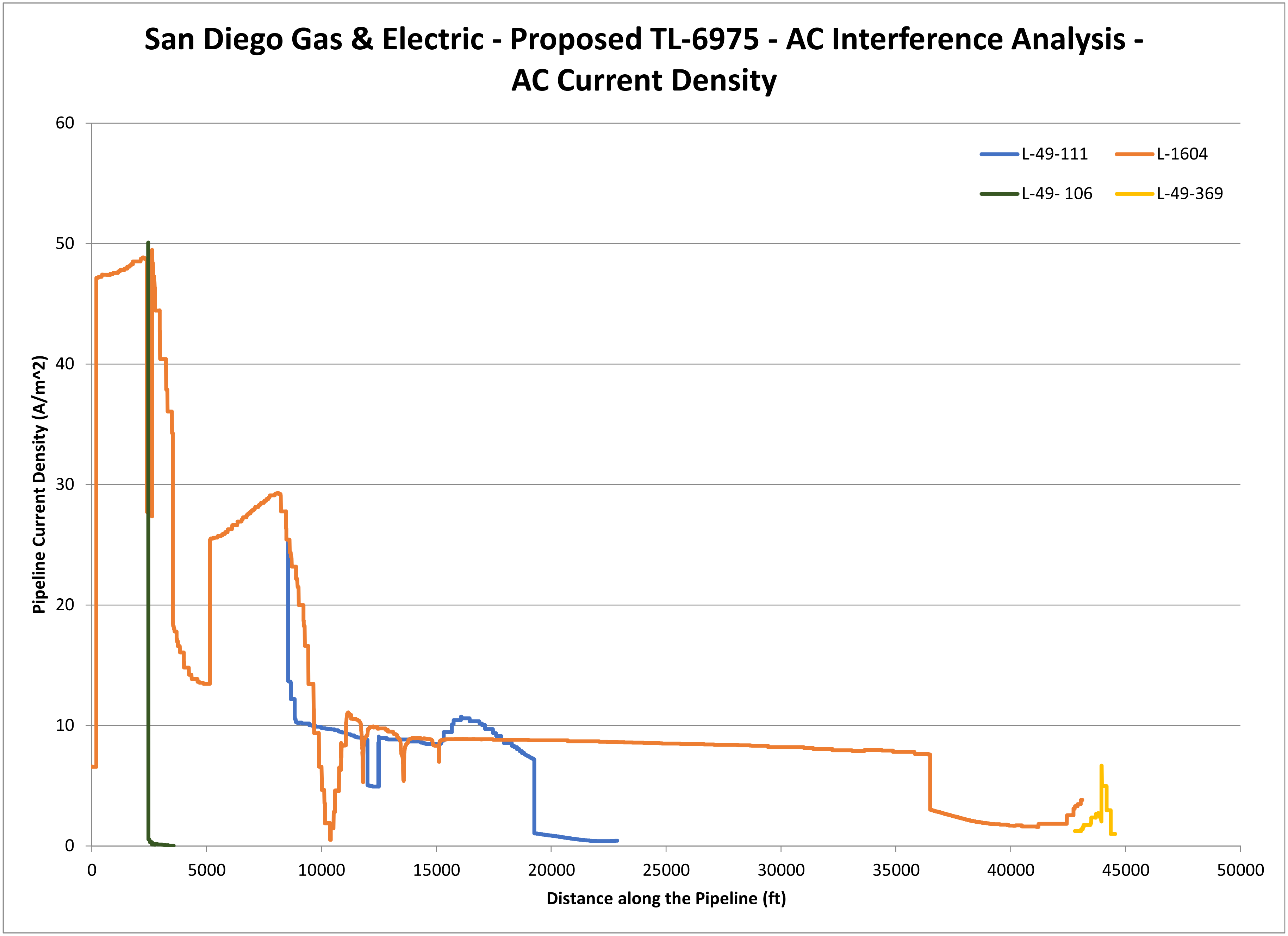
PIPELINE STEADY STATE, AC CURRENT DENSITY & FAULT PLOTS

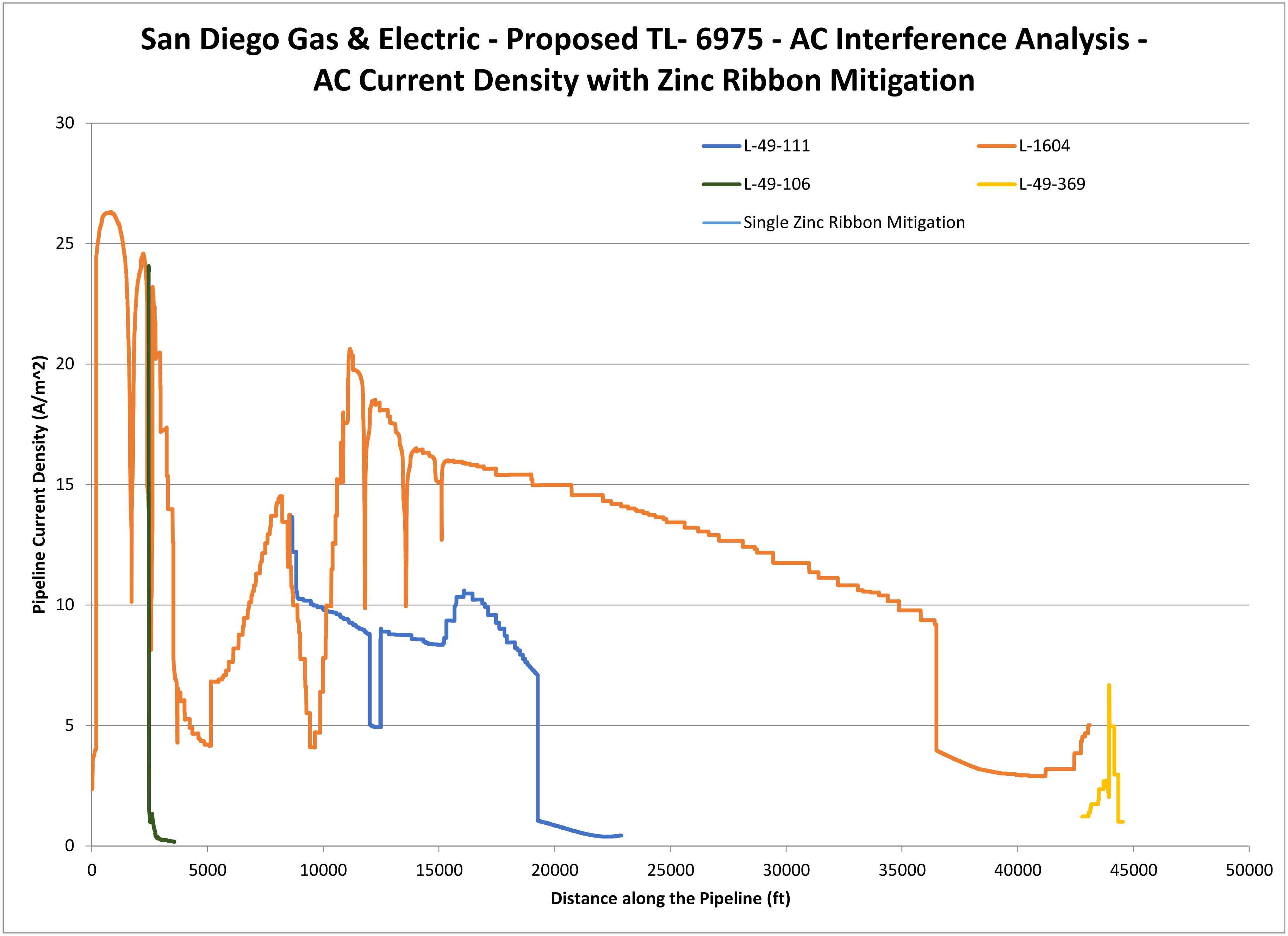
STEADY STATE INDUCED


San Diego Gas & Electric - Proposed TL- 6975 - AC Interference Analysis
AC Touch Voltage
Pipeline Touch Voltage (V)
Distance along the Pipeline (ft)
L-49-111
L-1604
L-49-106
L-49-369
0
1
2
3
4
5
6
7
8
9
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000

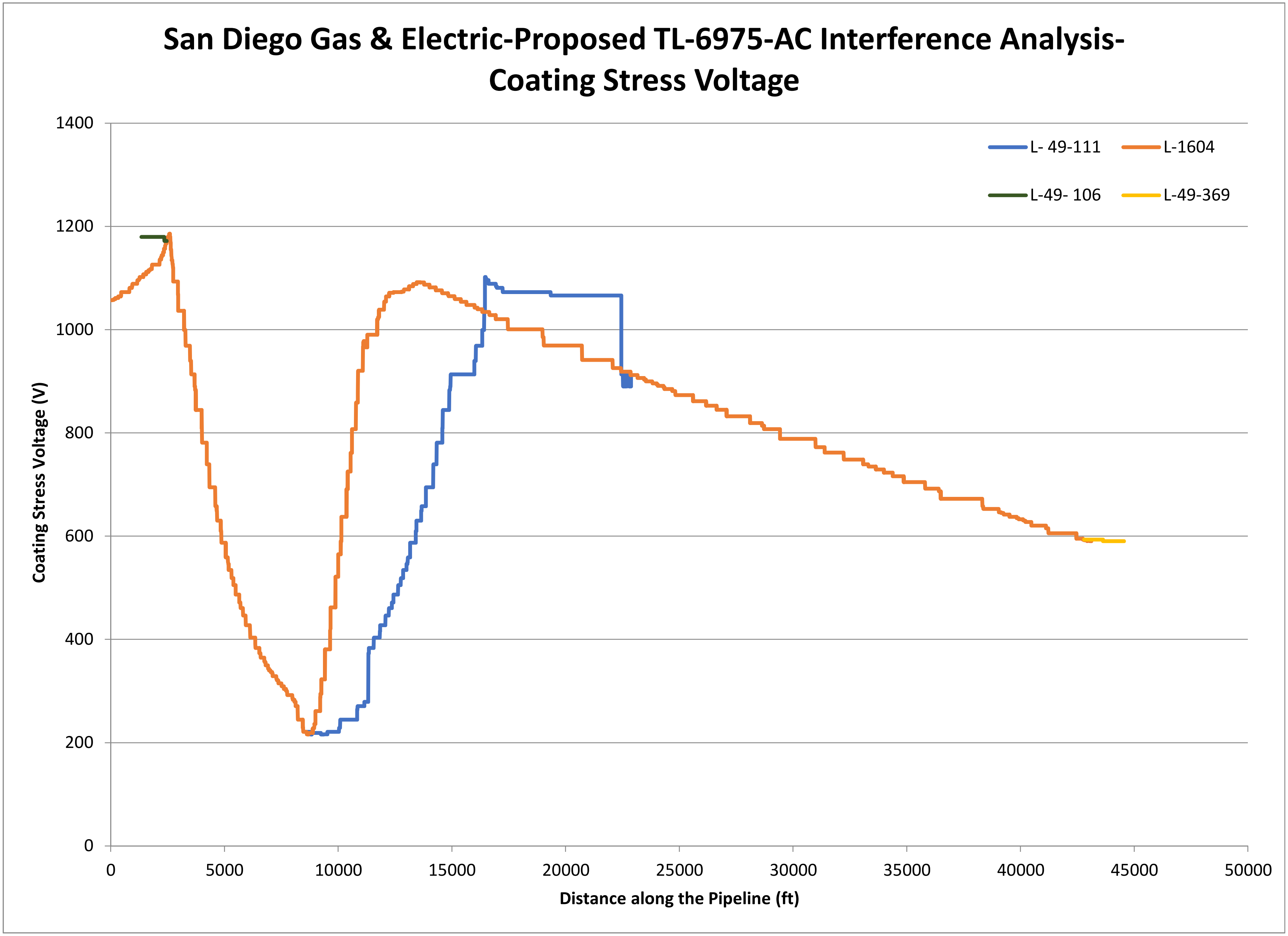

San Diego Gas & Electric - Proposed TL- 6975 - AC Interference Analysis -
AC Touch Voltage with Zinc Ribbon Mitigation
L-49-111
L-1604
L-49-106
L-49-369
Single Zinc Ribbon Mitigation
Pipeline Touch Voltage (V)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Distance along the Pipeline (ft)

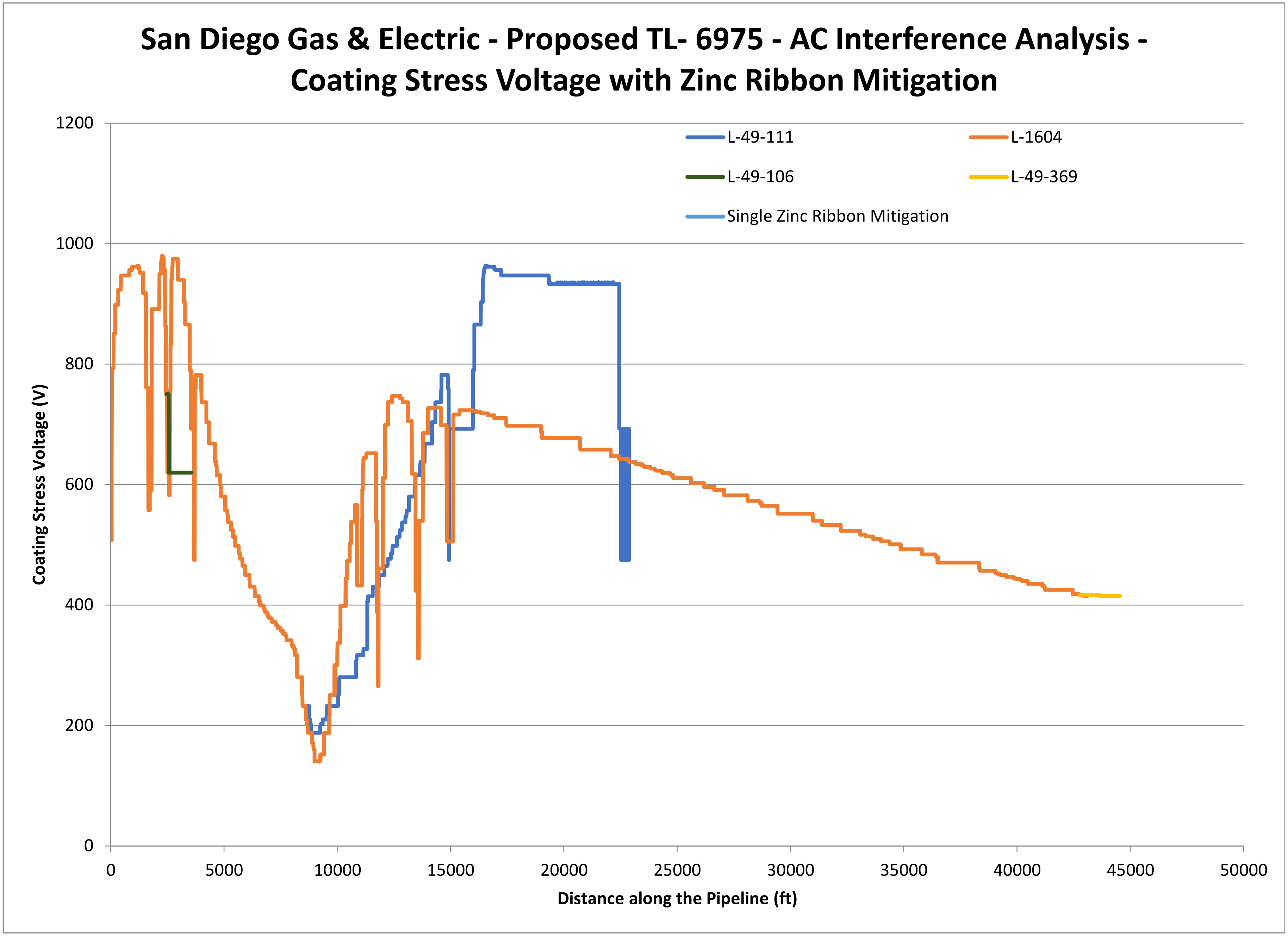
AC CURRENT DENSITY


San Diego Gas & Electric - Proposed TL-6975 - AC Interference Analysis -
AC Current Density
Pipeline Current Density (A/m^2)
Distance along the Pipeline (ft)
L-49-111
L-1604
L-49- 106
L-49-369
0
10
20
30
40
50
60
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000


San Diego Gas & Electric - Proposed TL- 6975 - AC Interference Analysis -
AC Current Density with Zinc Ribbon Mitigation
L-49-111
L-1604
L-49-106
L-49-369
Single Zinc Ribbon Mitigation
Pipeline Current Density (A/m^2)
Distance along the Pipeline (ft)
0
5
10
15
20
25
30
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000

FAULT – COATING STRESS VOLTAGE


San Diego Gas & Electric-Proposed TL-6975-AC Interference Analysis-
Coating Stress Voltage
Coating Stress Voltage (V)
1400
1200
1000
800
600
400
200
0
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Distance along the Pipeline (ft)
L- 49-111
L-1604
L-49- 106
L-49-369


San Diego Gas & Electric - Proposed TL- 6975 - AC Interference Analysis -
Coating Stress Voltage with Zinc Ribbon Mitigation
L-49-111
L-1604
L-49-106
L-49-369
Single Zinc Ribbon Mitigation
Coating Stress Voltage (V)
1200
1000
800
600
400
200
0
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Distance along the Pipeline (ft)

APPENDIX C –
POWER COMPANY DATA

ARK Data Request

Line Information			Shield Conductors					Phase Wires						Circuit	Current Load (A)		Fault Current Parameters		
Transmission Line Name	Future / Existing	Voltage (kv)	# of Conductors	Type	Average Height above ground (ft)	Minimum Height above ground (ft)	Horizontal distance from tower center (ft)	# of Conductors Per Phase	Type	Avg height a/b/c (ft)	Minimum height a/b/c (ft)	Horizontal Distance from tower center a/b/c (ft)	Phasing a/b/c (degrees)	Tower Type & Configuration (ex. Steel Tower, Vertical)	Peak	Emergency	Avg tower resistance to remote (Ω)	Tower Grounding Configuration	Primary fault clearing times OR breaker failure clearing times (each line)
HVAC 1-A	13811/Exist	138	N/A	N/A (use 7/16 EHS Steel)	N/A	N/A	N/A	2	1033.5 ACSR/AW	54/69/84	39/54/69	7		Steel Pole, Vertical	938				
HVAC 1-B	13825/Exist	138	N/A	N/A (use 7/16 EHS Steel)	N/A	N/A	N/A	2	1033.5 ACSR/AW	54/69/84	39/54/69	7		Steel Pole, Vertical	2290				
HVAC 2-A	680/Exist	69	N/A	N/A (use 3/8 EHS Steel)	N/A	N/A	N/A	1	636 ACSR/AW	48/51/54	45/48/51	4		Wood Pole, Delta	854				
HVAC 2-A	680/Proposed	69	N/A	N/A (use 3/8 EHS Steel)	N/A	N/A	N/A	1	636 ACSR/AW	66/72/78	62/68/74	5		Steel Pole, Vertical	854				
HVAC 2-B	6975/Proposed	69	N/A	N/A (use 3/8 EHS Steel)	N/A	N/A	N/A	1	636 ACSS/AW	66/72/78	62/68/74	5		Steel Pole, Vertical	1179				
HVAC-3	23011/Exist	230	1	7 #10 Alumoweld	126	115	0	2	1109 ACAR, 900 ACSS/AW	73/90/106	62/78/95	13.5		Steel Tower, Vertical	2290				
HVAC-4	23051/Exist	230	1	7 #10 Alumoweld	126	115	0	2	1110 ACAR, 900 ACSS/AW	73/90/106	62/78/95	13.5		Steel Tower, Vertical	2290				
HVAC-5	23014/Exist	230	1	7 #8 Alumoweld	153	140	0	2	900 ACSS/AW, 605 ACSS/AW	97/115/133	84/102/120	10		Steel Pole, Vertical	2000				
HVAC-6	23015/Exist	230	1	7 #8 Alumoweld	153	140	0	2	900 ACSS/AW, 605 ACSS/AW	97/115/133	84/102/120	10		Steel Pole, Vertical	2000				

Transmission Line	Fault Location	Contributing Substation	Pole to Sub Miles	Line Length Miles	%	Single Phase to Ground Fault Current at Tower (Amps)	Single Phase to Ground Fault Angle at Tower (Degrees)	
HVAC 1-A	Fault 1: Z119753	North (SH)	0.74	4.53	16%	12464	-84	TL13811
		South (NCM)				0		
		From CC				2010	96	
	Fault 2: Z119756	North (SH)	0.94	4.53	21%	12198	-84	
		South (NCM)				0		
		From CC				2068	96	
	Fault 3: Z119762	North (SH)	2.15	4.53	47%	11086	-84	
		South (NCM)				0		
		From CC				2379	96	
	Fault 4: Z119767	North (SH)	3.12	4.53	69%	10424	-84	
		South (NCM)				0		
		From CC				2663	95	
	Fault 5: Z119773	North (SH)	3.8	4.53	84%	9920	96	
		South (NCM)				0		
		From CC				2765	96	
	Fault 9: Z101769	North (SH)	3.94	4.53	87%	9709	97	
		South (NCM)				0		
		From CC				2706	96	
	Fault 10: Z101771	North (SH)	4.04	4.53	89%	9573	97	
		South (NCM)				0		
		South (NCM)				2668	96	
	Fault 1: Z119753	North (SH)	0.74	6.58	11%	9341	-85	TL13825
		South (BQ)				5775	-82	
	Fault 2: Z119756	North (SH)	0.94	6.58	14%	9114	-85	
		South (BQ)				5962	-82	
	Fault 3: Z119762	North (SH)	2.15	6.58	33%	8093	-85	
		South (BQ)				7311	-83	
	Fault 4: Z119767	North (SH)	3.12	6.58	47%	7496	-85	
		South (BQ)				8574	-83	

	~~Fault 5: Z119773~~							
HVAC 2-A	Fault 22: TL680 SM Rack	North (Tap)	6.33	6.33	100%	2713	-112	TL680
		South (SM)				6018	-113	
	Fault 21: Z817834	North (Tap)	6	6.33	95%	2857	-112	
		South (SM)				5494	-113	
	Fault 19: Z815955	East (SM)	0.8	6.33	13%	4733	-113	
		West (Tap)				3131	-112	
	Fault 18: Z815952	East (SM)	0.95	6.33	15%	4579	-113	
		West (Tap)				3207	-112	
	Fault 17: Z114456	East (SM)	2.08	6.33	33%	3539	-112	
		West Tap)				4082	-113	
	Fault 6: Z114457	South (SM)	2.27	6.33	36%	3409	-112	
		North (Tap)				4274	-113	
HVAC 2-B	Fault 22: TL680 SM Rack	East (SM)	0	12.41	0%	6554	-113	line that does not exist yet.
		West (ES)	12.41	12.41	100%	2121	-112	
	Fault 21 (Z817834)	East (SM)	0.28	12.41	2%	6276	-113	
		West (ES)	12.13	12.41	98%	2155	-112	
	Fault 19 (Z815955)	East (SM)	0.75	12.41	6%	5637	-113	
		West (ES)	11.67	12.41	94%	2251	-112	
	Fault 18 (Z815952)	East (SM)	0.9	12.41	7%	5497	-113	
		West (ES)	11.51	12.41	93%	2276	-112	
	Fault 17 (Z114456)	North (SM)	2.04	12.41	16%	4483	-113	
		South (ES)	10.37	12.41	84%	2519	-112	
	Fault 7: Z100272	North (SM)	3.14	12.41	25%	3775	-112	
		South (ES)	9.27	12.41	75%	2810	-112	
	Fault 3 (Z100273)	North (SM)	3.77	12.41	30%	3465	-112	
		South (ES)	8.64	12.41	70%	2999	-112	
	Fault 4 (Z100278)	North (SM)	4.75	12.41	38%	3055	-112	
		South (ES)	7.66	12.41	62%	3355	-112	
	Fault 5 (Z119773)	West (SM)	5.4	12.41	44%	2799	-113	
		East (ES)	7.01	12.41	56%	3681	-112	

	Fault 11 (Z414912)	West (SM)	6.69	12.41	54%	2440	-113	This is a proposed
		East (ES)	5.73	12.41	46%	4384	-112	
	Fault 12 (Z414916)	West (SM)	7.62	12.41	61%	2223	-113	
		East (ES)	4.8	12.41	39%	5056	-112	
	Fault 13 (Z414921)	West (SM)	8.58	12.41	69%	1997	-113	
		East (ES)	3.84	12.41	31%	6124	-112	
	Fault 29 (Z414925)	West (SM)	9.43	12.41	76%	1805	-113	
		East (ES)	2.98	12.41	24%	7506	-112	
	Fault 33 (Z250083)	South (SM)	9.69	12.41	78%	1749	-112	
		North (ES)	2.72	12.41	22%	8023	-113	
	Fault 30 (Z414930)	West (SM)	10.51	12.41	85%	1535	-112	
		East (ES)	1.9	12.41	15%	10561	-113	
	Fault 16 (Z202017)	South (SM)	11.51	12.41	93%	1193	-113	
		North (ES)	0.9	12.41	7%	16517	-114	
	Fault 16.5 (Z202020)	South (SM)	12.3	12.41	99%	664	-113	
		North (ES)	0.11	12.41	1%	28557	-116	
HVAC-3	Fault 16: Z202011	East (PEN)	0.65	15.03	4%	22914	-87	TL23011
		West (EA)	14.5	15.03	96%	3386	-79	
	Fault 30: Z710025	East (PEN)	1.62	15.03	11%	19534	-86	
		West (EA)	13.5	15.03	90%	4247	-80	
	Fault 33: Z250083	East (PEN)	2.46	15.03	16%	17710	-86	
		West (EA)	12.7	15.03	84%	4830	-81	
	Fault 29: Z710021	East (PEN)	2.71	15.03	18%	17082	-85	
		West (EA)	12.4	15.03	83%	5062	-81	
	Fault 28: Z710017	East (PEN)	3.59	15.03	24%	15470	-85	
		West (EA)	11.6	15.03	77%	5765	-81	
	Fault 27: Z710013	East (PEN)	4.55	15.03	30%	14181	-85	
		West (EA)	10.6	15.03	71%	6504	-82	
	Fault 26: Z710009	East (PEN)	5.45	15.03	36%	13136	-85	
		West (EA)	9.68	15.03	64%	7306	-82	
	Fault 24: Z710002	East (PEN)	6.65	15.03	44%	12005	-85	
		West (EA)	8.49	15.03	56%	8530	-82	

	Fault 25: Z718348	East (PEN)	6.75	15.03	45%	11802	-85	
		West (EA)	8.38	15.03	56%	8702	-82	
HVAC-4	Fault 16: Z202011	North (PEN)	1.1	24.77	4%	22406	-86	TL23051
		South (SX)	24	24.77	97%	2394	-81	
	Fault 30: Z710025	East (PEN)	1.62	24.77	7%	20178	-86	
		West (SX)	23	24.77	93%	2744	-82	
	Fault 33: Z250083	East (PEN)	2.43	24.77	10%	18406	-85	
		West (SX)	22.2	24.77	90%	3070	-83	
	Fault 29: Z710021	East (PEN)	2.7	24.77	11%	17894	-85	
		West (SX)	21.9	24.77	88%	3175	-83	
	Fault 28: Z710017	East (PEN)	3.57	24.77	14%	16549	-85	
		West (SX)	21	24.77	85%	3485	-83	
	Fault 27: Z710013	East (PEN)	4.54	24.77	18%	15109	-84	
		West (SX)	20.1	24.77	81%	3894	-83	
	Fault 26: Z710009	East (PEN)	5.43	24.77	22%	13972	-84	
		West (SX)	19.2	24.77	78%	4316	-84	
HVAC-5	Fault 16.5: Z202015	North (ES)	0.08	0.37	22%	16499	-87	TL23014
		South (PEN)	0.29	0.37	78%	11267	-86	
HVAC-6	Fault 16.5: Z202015	North (ES)	0.08	0.37	22%	16491	-87	TL23015
		South (PEN)	0.29	0.37	78%	11275	-86	

APPENDIX D –
ARK ENGINEERING DESIGN DRAWINGS

REV	DESCRIPTION	DATE	APPROVED
0	PRELIMINARY TEST STATION INSTALLATION	9/13/17	BW
1	PRELIMINARY ZINC RIBBON SYSTEM DESIGN	9/22/17	BW

SAN DIEGO GAS & ELECTRIC

PROPOSED TL 6975

AC MITIGATION SYSTEM DESIGN
ZINC RIBBON INSTALLATION DRAWINGS
SAN DIEGO COUNTY, CALIFORNIA

PROJECT DRAWING LISTING

DRAWING NO.	SHEETS	REV	TITLE
16138-100	1	1	COVER SHEET
16138-200	1	1	ZINC RIBBON INSTALLATION SECTION
16138-201	1	1	ZINC RIBBON AND SSD WIRING DETAILS
16138-202	1	1	ZINC RIBBON CROSSING PIPELINE DETAILS
16138-203	1	1	ZINC RIBBON INSTALLATION LOCATIONS AND REQUIRED MATERIALS
16138-204	1	1	SSD LOCATIONS
16138-300	1	1	CABLE TO PIPELINE CONNECTION DETAILS
16138-301	1	1	EXOTHERMIC WELD CONNECTION DETAILS
16138-302	1	1	SOLID STATE DECOUPLER (SSD) DEVICE DETAILS
16138-303	1	1	COUPON TEST STATION LOCATIONS & WIRING DETAILS
16138-400	1	1	MATERIALS LIST

- PRELIMINARY -
FOR CLIENT REVIEW ONLY
NOT FOR CONSTRUCTION
ENGR: BW
DATE: 9/22/17

CLIENT: SAN DIEGO GAS & ELECTRIC
SITE: PROPOSED TL 6975 ZINC RIBBON SYSTEM
PROJECT NO.: 16-E-138-AC

ARK ENGINEERING & TECHNICAL SERVICES, INC.
ARK ENGINEERING & TECH. SERVICES, INC.
639 GRANITE STREET
SUITE 200
BRAINTREE, MA
02184 U.S.A.

TITLE: COVER SHEET

DRAWN BY	DATE	SIZE	DWG. NO.	REV
SRM	9/13/17	B	16138-100	1

APPROVED BY	DATE	SCALE	CAD FILE NAME	SHEET
BW		NTS	16138-100-1-R1	1 OF 1

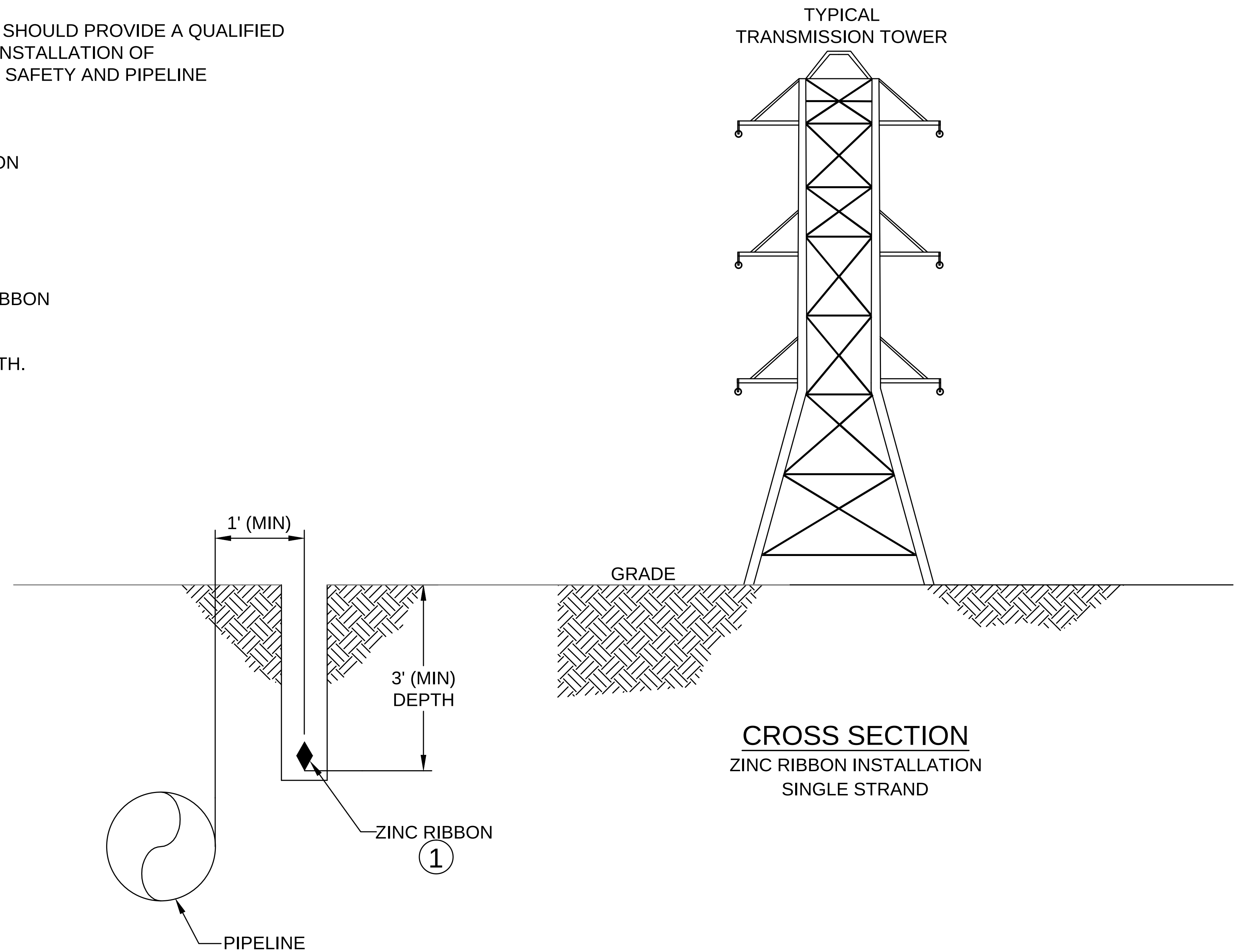
REV	DESCRIPTION	DATE	APPROVED
0	PRELIMINARY TEST STATION INSTALLATION	9/13/17	BW
1	PRELIMINARY ZINC RIBBON SYSTEM DESIGN	9/22/17	BW

SAFETY NOTES:

1. THE PIPELINE AND APPURTENANCES AT OR NEAR THESE LOCATIONS CAN POSSESS POTENTIALLY LETHAL ELECTRICAL SHOCK HAZARDS UNTIL ALL GROUNDING IS INSTALLED.
2. SAN DIEGO GAS & ELECTRIC OR ARK ENGINEERING SHOULD PROVIDE A QUALIFIED ELECTRICAL SAFETY INSPECTOR ON-SITE DURING INSTALLATION OF THESE GROUND SYSTEMS TO ASSURE PERSONNEL SAFETY AND PIPELINE INTEGRITY.
3. ZINC RIBBON DEPTH AND SPACING ARE MINIMUM REQUIREMENTS. ADDITIONAL DEPTH OF ZINC RIBBON AND ADDITIONAL SPACING FROM THE PIPELINE IS ACCEPTABLE.

INSTALLATION NOTES:

1. HORIZONTAL DISTANCE FROM PIPELINE TO ZINC RIBBON CAN VARY BETWEEN 1' AND 25'.
2. INSTALL ZINC RIBBON TO SPECIFIED MINIMUM DEPTH.



CROSS SECTION

ZINC RIBBON INSTALLATION
SINGLE STRAND

- PRELIMINARY -

FOR CLIENT REVIEW ONLY
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ENGR: BW

DATE: 9/22/17

CAUTION:

ZINC RIBBON MUST NOT TOUCH PIPE.

CLIENT: SAN DIEGO GAS & ELECTRIC

SITE: PROPOSED TL 6975 ZINC RIBBON SYSTEM

PROJECT NO. 16-E-138-AC

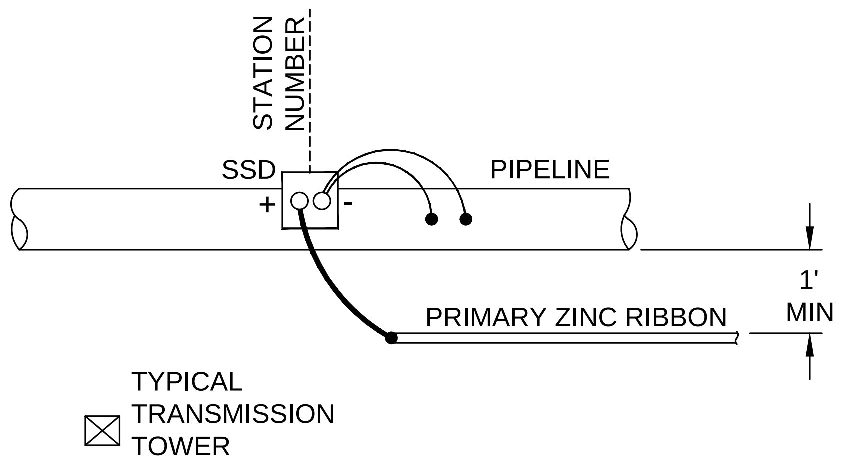
ARK ENGINEERING & TECHNICAL SERVICES, INC.

ARK ENGINEERING & TECH. SERVICES, INC.
639 GRANITE STREET
SUITE 200
BRAINTREE, MA
02184 U.S.A.

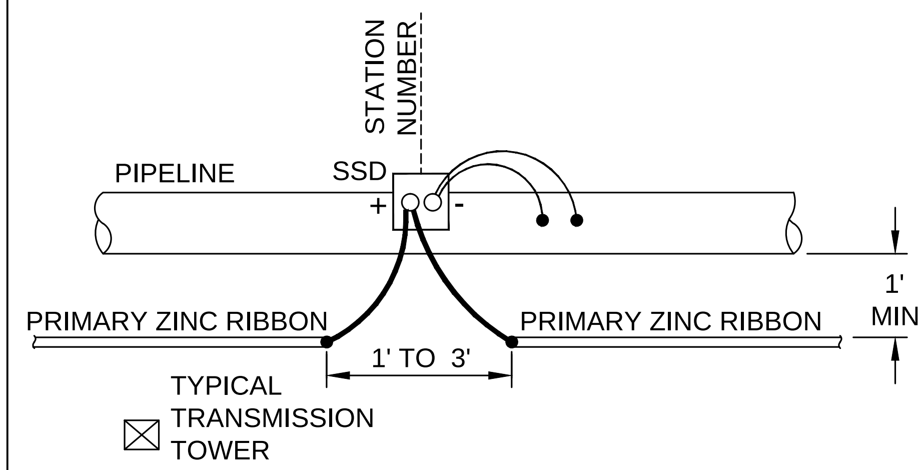
TITLE: ZINC RIBBON INSTALLATION SECTION DETAILS

DRAWN BY	DATE	SIZE		DWG. NO.	REV
SRM	9/13/17	B	The information contained on this drawing is confidential and is the sole property of ARK Engineering. Transferring this information to a third party or reproducing in part or in full without a written consent from ARK Engineering is prohibited.	16138-200	1
APPROVED BY: BW	DATE:	SCALE: NTS	CAD FILE NAME: 16138-200-1-R1	SHEET: 1 OF 1	

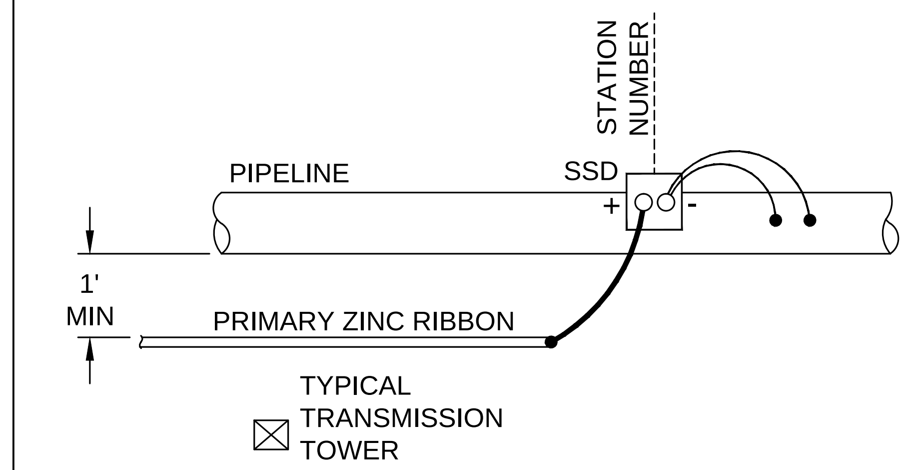
REV	DESCRIPTION	DATE	APPROVED
0	PRELIMINARY TEST STATION INSTALLATION	9/13/17	BW
1	PRELIMINARY ZINC RIBBON SYSTEM DESIGN	9/22/17	BW



ZINC INSTALLATION PLAN VIEW ZN-1A
SINGLE STRAND WIRING DETAIL



ZINC INSTALLATION PLAN VIEW ZN-1B
SINGLE STRAND WIRING DETAIL



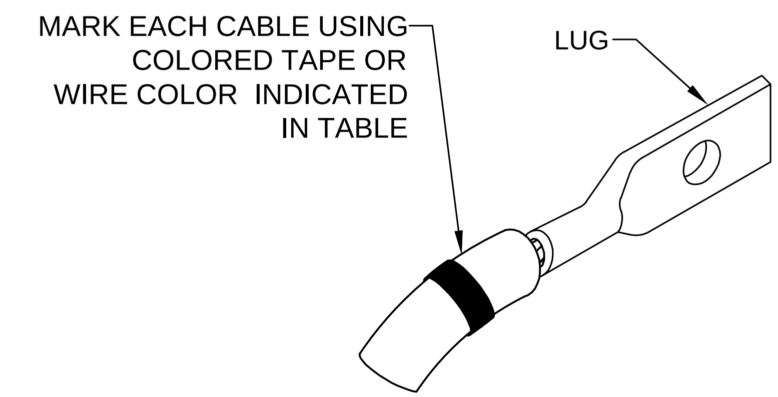
ZINC INSTALLATION PLAN VIEW ZN-1C
SINGLE STRAND WIRING DETAIL

SSD WIRING AND LABELING SCHEDULE

CONNECTIONS TO	WIRE SIZE & TYPE	SSD TERMINAL	LOCATION	TAPE OR WIRE COLOR
PRIMARY DOWNSTREAM ZINC RIBBON	#2 AWG HMWPE	POSITIVE	BETWEEN TRANSMISSION TOWER & PIPE	RED
PRIMARY UPSTREAM ZINC RIBBON	#2 AWG HMWPE	POSITIVE	BETWEEN TRANSMISSION TOWER & PIPE	GREEN
PIPELINE	#6 AWG HMWPE	NEGATIVE	12:00 O'CLOCK	NONE
PIPELINE	#6 AWG HMWPE	NEGATIVE	12:00 O'CLOCK	NONE

NOTES:

1. INSTALL SSD AT STATION NUMBERS INDICATED IN TABLE ON DRAWING 16138-224.
2. INSTALL SINGLE STRAND ZINC RIBBON WITH ENDS AT STATION NUMBERS INDICATED IN TABLE ON DRAWING 16138-223, REFERENCE DRAWINGS 16138-320 & 321 FOR WELD DETAILS.
3. INSTALL SINGLE STRAND ZINC RIBBON BETWEEN PIPELINE AND TRANSMISSION TOWER. REFERENCE DRAWING 16138-222 WHEN ROW CONFIGURATION CHANGES.
4. (2) #6 AWG CABLES ARE CONNECTED TO (-) NEGATIVE TERMINAL ON SSD. REFERENCE DRAWING 16138-322.
5. LABEL #2 AWG CABLE WITH TAPE COLOR SHOWN IN TABLE. WRAP TAPE WITHIN 6" OF LUG.



CABLE TAPE DETAIL

- PRELIMINARY -
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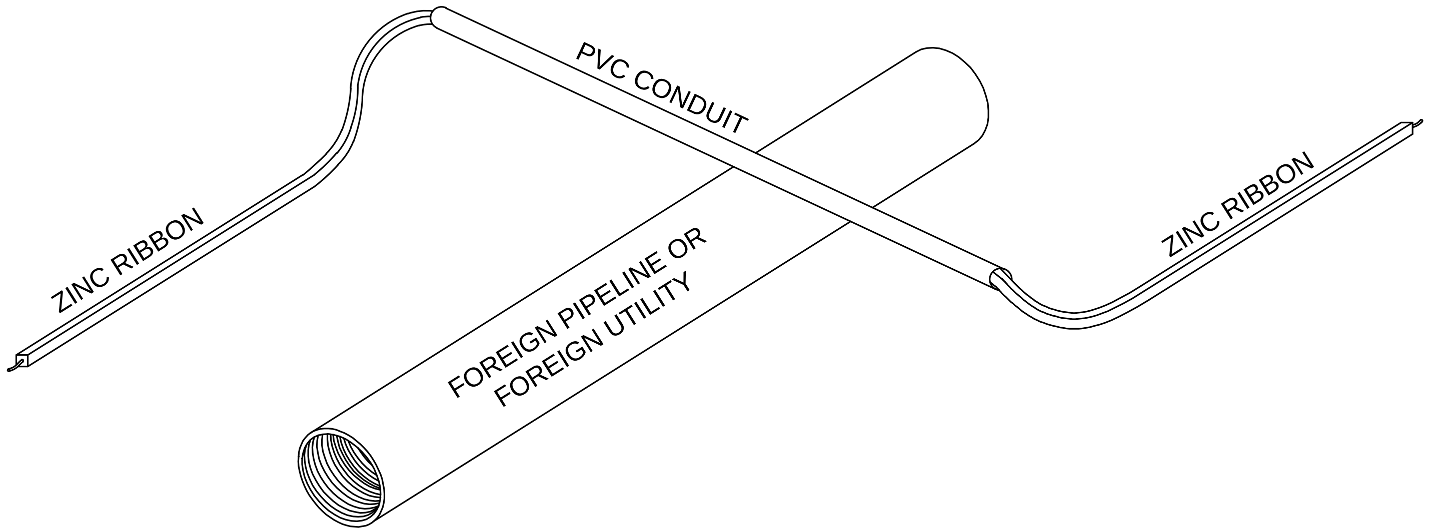
ENGR: BW
DATE: 9/22/17

CAUTION:
ZINC RIBBON MUST NOT TOUCH PIPE.

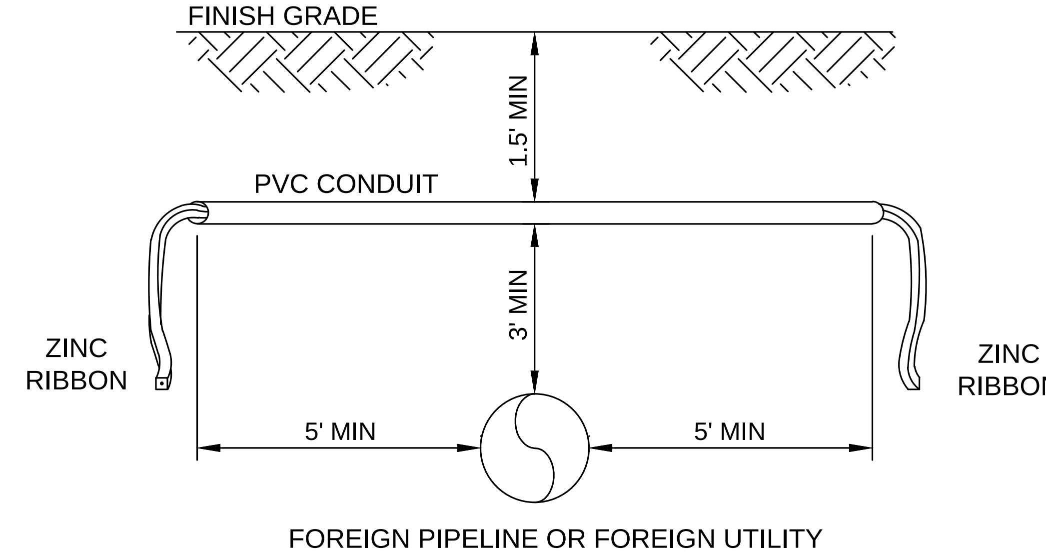
CLIENT: SAN DIEGO GAS & ELECTRIC SITE: PROPOSED TL 6975 ZINC RIBBON SYSTEM	ARK ENGINEERING & TECHNICAL SERVICES, INC. ARK ENGINEERING & TECH. SERVICES, INC. 639 GRANITE STREET SUITE 200 BRAINTREE, MA 02184 U.S.A.	TITLE: ZINC RIBBON AND SSD WIRING DETAILS	
DRAWN BY: SRM	DATE: 9/13/17	SIZE: B	DWG. NO. 16138-201 — REV 1
PROJECT NO. 16-E-138-AC	APPROVED BY: BW	DATE:	SCALE: NTS — CAD FILE NAME: 16138-201-1-R1 — SHEET 1 OF 1

REV	DESCRIPTION	DATE	APPROVED
0	PRELIMINARY TEST STATION INSTALLATION	9/13/17	BW
1	PRELIMINARY ZINC RIBBON SYSTEM DESIGN	9/22/17	BW

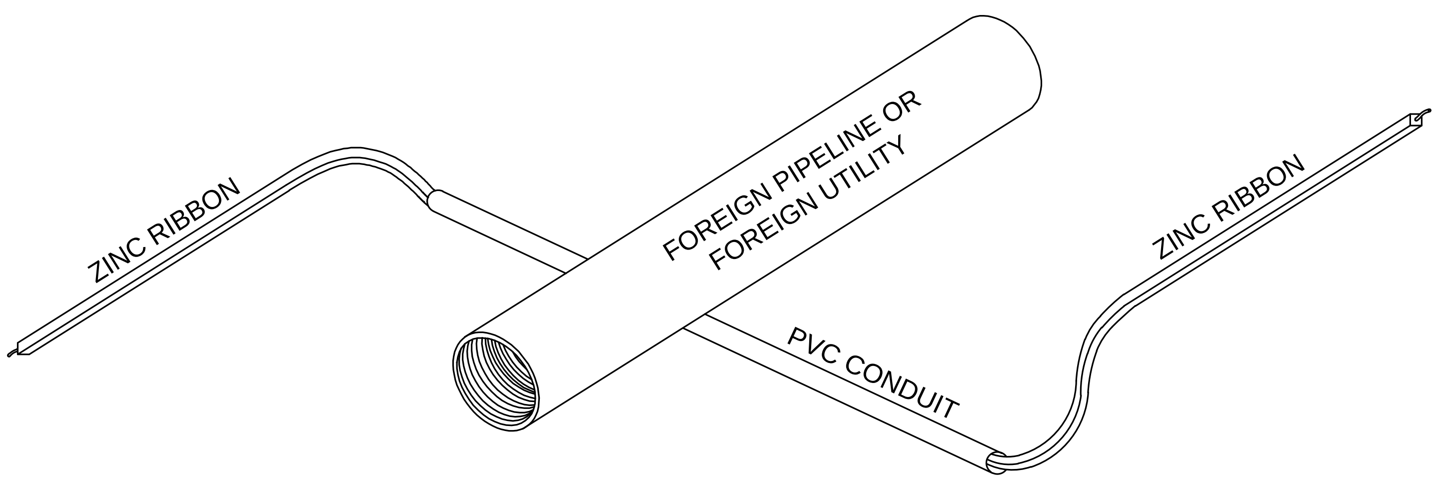


ZINC RIBBON CROSSING ABOVE FOREIGN PIPELINE OR FOREIGN UTILITY

(SEE DETAIL 'A' FOR SECTION VIEW)

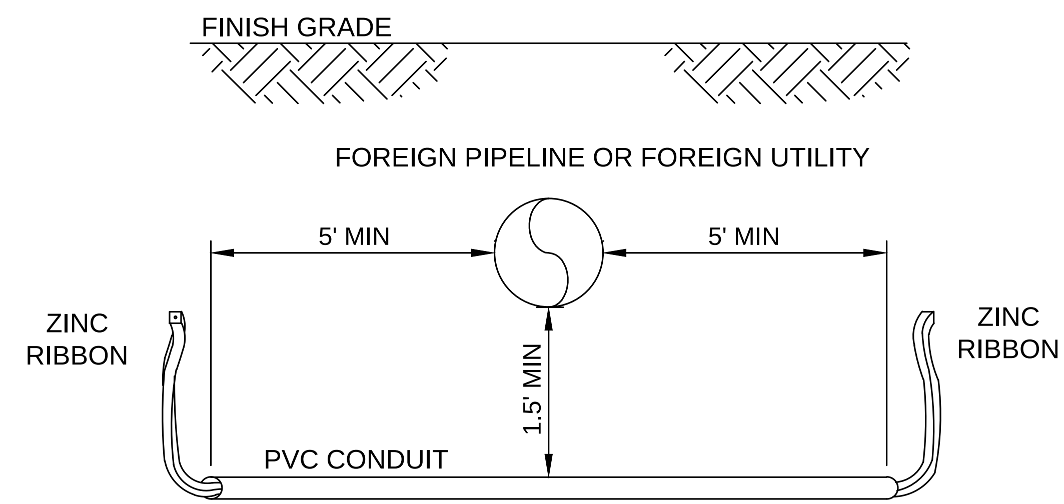


DETAIL 'A'



ZINC RIBBON CROSSING BELOW FOREIGN PIPELINE OR FOREIGN UTILITY

(SEE DETAIL 'B' FOR SECTION VIEW)



DETAIL 'B'

- PRELIMINARY -
FOR CLIENT REVIEW ONLY
NOT FOR CONSTRUCTION
ENGR:
DATE: 9/22/17

CAUTION:
ZINC RIBBON MUST NOT TOUCH PIPE.

NOTES:

1. WHEN MITIGATION CROSSES METALLIC FOREIGN PIPE OR FOREIGN UTILITY, INSTALL ZINC RIBBON IN 2" PVC CONDUIT FOR A MINIMUM DISTANCE OF 5' ON EACH SIDE BEYOND THE UTILITY CROSSING, A MINIMUM OF 3' SEPARATION ABOVE OR BELOW THE UTILITY CROSSING, AND A MINIMUM OF 3' BELOW GRADE OR FOLLOW FOREIGN LINE OPERATOR'S STANDARD ON SEPARATION.
2. ZINC RIBBON SHOULD BE INSTALLED BETWEEN TRANSMISSION TOWER AND PIPELINE.
3. ZINC RIBBON TO REMAIN CONTINUOUS THROUGH PVC PIPING.

CLIENT: SAN DIEGO GAS & ELECTRIC	ARK ENGINEERING & TECHNICAL SERVICES, INC. — ARK ENGINEERING & TECH. SERVICES, INC. 639 GRANITE STREET SUITE 200 BRAINTREE, MA 02184 U.S.A.		TITLE: ZINC RIBBON CROSSING PIPELINE DETAILS	
SITE: PROPOSED TL 6975 ZINC RIBBON SYSTEM	DRAWN BY: SRM	DATE: 9/13/17	SIZE: B	DWG. NO.: 16138-202 / REV: 1
PROJECT NO.: 16-E-138-AC	APPROVED BY: BW	DATE:	SCALE: NTS	CAD FILE NAME: 16138-202-1-R1 / SHEET: 1 OF 1

REV	DESCRIPTION	DATE	APPROVED
0	PRELIMINARY TEST STATION INSTALLATION	9/13/17	BW
1	PRELIMINARY ZINC RIBBON SYSTEM DESIGN	9/22/17	BW

ZINC RIBBON INSTALLATION LOCATIONS AND REQUIRED MATERIALS

SECTION NO.	GPS START	GPS END	DISTANCE FROM START TO END (FT)	NUMBER OF STRANDS	TOTAL LENGTH OF ZINC RIBBON (FT)	NUMBER OF SSDs	#2 AWG COPPER CABLE SSD TO ZINC RIBBON (FT)	#6 AWG COPPER CABLE SSD TO PIPE (FT)	#6 AWG COPPER CABLE TO PIPELINE EXOTHERMIC WELD CONNECTIONS	#2 AWG COPPER CABLE TO ZINC RIBBON EXOTHERMIC WELD CONNECTIONS	SSD PEDASTALS
1	33.129386, -117.236272	33.131539, -117.224564	3,710	1	3,710	3	125	350	6	4	3
2	33.131366, -117.201753	33.134715, -117.188476	4,255	1	4,255	4	395	890	8	6	4
				TOTAL:	**7,965**	**7**	**520**	**1,240**	**14**	**10**	**7**

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ENGR: BW
DATE: 9/22/17

NOTES:

1. ZINC RIBBON BASED ON 2,000 FT. REEL. REFERENCE DRAWING 16138-301 DETAIL "B" FOR ZINC RIBBON TO ZINC RIBBON EXOTHERMIC WELD, WHERE ZINC RIBBON MUST BE SPLICED.

CLIENT: SAN DIEGO GAS & ELECTRIC

SITE: PROPOSED TL 6975 ZINC RIBBON SYSTEM

PROJECT NO.: 16-E-138-AC

ARK ENGINEERING & TECHNICAL SERVICES, INC.
ARK ENGINEERING & TECH. SERVICES, INC.
639 GRANITE STREET
SUITE 200
BRAINTREE, MA
02184 U.S.A.

TITLE: ZINC RIBBON INSTALLATION LOCATIONS AND REQUIRED MATERIALS

DRAWN BY: SRM | DATE: 9/13/17 | SIZE: B
APPROVED BY: BW | DATE: | SCALE: NTS

DWG. NO.: 16138-203 | REV: 1
CAD FILE NAME: 16138-203-1-R1 | SHEET 1 OF 1

REV	DESCRIPTION	DATE	APPROVED
0	PRELIMINARY TEST STATION INSTALLATION	9/13/17	BW
1	PRELIMINARY ZINC RIBBON SYSTEM DESIGN	9/22/17	BW

SSD LOCATIONS

SECTION NO.	GPS LOCATION	SSD WIRING DETAIL (REF DWG 16138-201)
1	[redacted]	ZN-1A
		ZN-1B
		ZN-1C
2		ZN-1A
		ZN-1B
		ZN-1B
		ZN-1C

- PRELIMINARY -
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NOT FOR CONSTRUCTION
ENGR: BW
DATE: 9/22/17

NOTES:

1. REFERENCE DRAWING 16138-201 FOR WIRING AND TAPING DETAILS.

CLIENT	SAN DIEGO GAS & ELECTRIC
SITE	PROPOSED TL 6975 ZINC RIBBON SYSTEM
PROJECT NO.	16-E-138-AC
TITLE	SSD LOCATIONS
DRAWN BY	SRM
DATE	9/13/17
APPROVED BY	BW
DATE	
SIZE	B
SCALE	NTS
DWG. NO.	16138-204
REV	1
CAD FILE NAME	16138-204-1-R1
SHEET	1 OF 1

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REV	DESCRIPTION	DATE	APPROVED
0	PRELIMINARY TEST STATION INSTALLATION	9/13/17	BW
1	PRELIMINARY ZINC RIBBON SYSTEM DESIGN	9/22/17	BW

EXOTHERMIC WELD INSTRUCTIONS:

1. FIRST DETERMINE IF THE PIPELINE IS SUITABLE FOR EXOTHERMIC WELDING BY CONDUCTING THE FOLLOWING TESTS:

   A) DETERMINE THAT THE PIPELINE SMYS (SPECIFIED MINIMUM YIELD STRENGTH) IS <80,000 PSI.

   B) DETERMINE THAT PIPELINE WALL THICKNESS IS ⅛" (0.125") OR GREATER.

   C) PERFORM ULTRASONIC TESTING TO PIPELINE TO DETERMINE THAT NO SURFACE OR INTERNAL DEFECTS EXIST.

2. FOR EACH CABLE TO PIPELINE CONNECTION (EXOTHERMIC WELD), REMOVE A 3"X3" MAX AREA OF PIPELINE COATING AT THE 12:00 O'CLOCK POSITION ON THE PIPELINE AND BRUSH UNTIL SHINY. ANY ADJACENT CABLE CONNECTIONS SHALL BE NO CLOSER THAN 9" AND NO FURTHER THAN 18".

3. PREPARE PIPELINE SURFACE AS SPECIFIED BY PIPELINE COATING MANUFACTURER.

4. DETAIL "A" SHOWS POSSIBLE METHOD OF CABLE STRAIN RELIEF FOR NEW PIPE INSTALLATIONS. THIS METHOD IS NOT A REQUIREMENT. OTHER MEANS OF STRAIN RELIEF MAY BE USED.

5. STRIP BACK ANY CABLE INSULATION 1"-2" AND TAPE CABLE TO PIPE.

6. ENSURE THAT THE PIPELINE WELD AREA AND CABLE ARE CLEAN AND DRY PRIOR TO WELDING.

7. USE SPECIFIC WELD MOLD AND WELD METAL AS INDICATED IN DRAWING MATERIALS LIST.

8. IF INDICATED, USE COPPER HEAT SLEEVE ON CABLE END TO BE WELDED.

9. USE ONLY A 15 GRAM WELDING CHARGE. DO NOT EXCEED.

10. PLACE THE METAL RETAINER DISK IN THE SPECIFIED WELD MOLD AND DUMP (DO NOT POUR) WELD METAL POWDER ONTO THE DISK. MAKE SURE THAT ALL OF THE FINE STARTING POWDER IS IN THE MOLD. IF ANY POWDER REMAINS IN THE CARTRIDGE BOTTOM, SQUEEZE OUT INTO MOLD AND BREAK UP.

11. CLOSE MOLD LID.

12. REPLACE CAP ON EMPTY WELD METAL CARTRIDGE AND PLACE BACK INTO CARTRIDGE PACK BOX UPSIDE DOWN TO KEEP THE REMAINING CARTRIDGES UPRIGHT.

13. LAY THE CABLE END ON THE PREPARED PIPE SURFACE USING A SPRING LOADED CHAIN CLAMP TO HOLD CRUCIBLE TIGHT TO PIPELINE.

14. USING EYE AND HAND PROTECTION, STAND ON THE OPPOSITE SIDE OF THE CRUCIBLE FROM THE TOUCH HOLE AND IGNITE POWDER WITH SPARK FROM FLINT GUN. *CAUTION: POWDER WILL FLASH WHEN IGNITED*

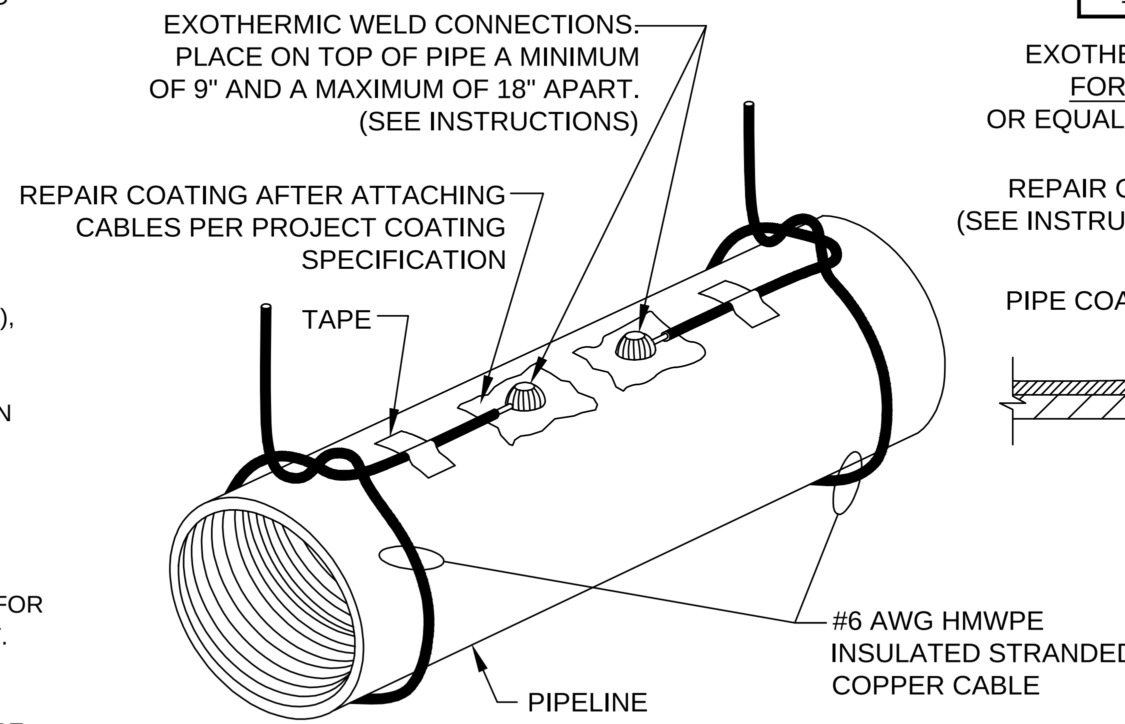
15. WHEN WELD HAS SET, REMOVE WELD MOLD AND TEST CONNECTION BY RAPPING SHARPLY WITH A SLAG HAMMER. IF THERE IS ANY INDICATION THAT A COMPLETE WELD HAS NOT BEEN ACHIEVED, REMOVE THE WELD AND RE-APPLY.

16. IF WELD IS GOOD, REMOVE ANY SLAG WITH HAMMER AND CLEAN USING A WIRE BRUSH.

17. ONCE THE WELD CONNECTION AND AREA HAVE BEEN CLEANED, REPAIR COATING USING TWO-PART EPOXY COATING REPAIR KIT AS SPECIFIED IN THE DRAWING MATERIALS LIST (OR APPROVED COATING AS SPECIFIED BY SAN DIEGO GAS & ELECTRIC).

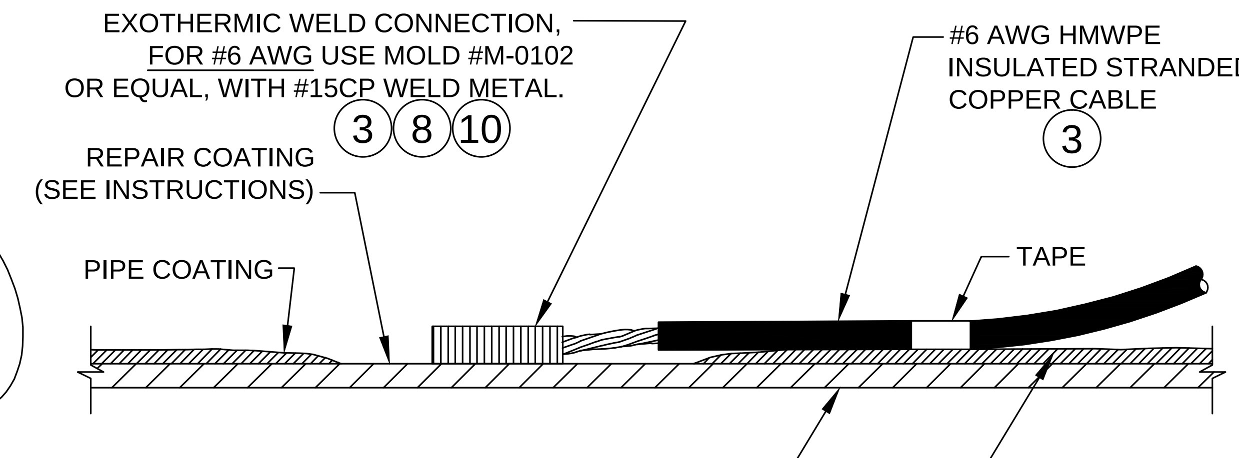
18. REFER TO SAN DIEGO GAS & ELECTRIC REPAIR SPECIFICATIONS AND PRODUCT DATA SHEET TO DETERMINE IF REPAIR IS ACCEPTABLE.

19. AFTER REPAIR COATING HAS CURED ACCORDING TO MANUFACTURER'S SPECIFICATIONS, HOLIDAY DETECTION MUST BE PERFORMED.



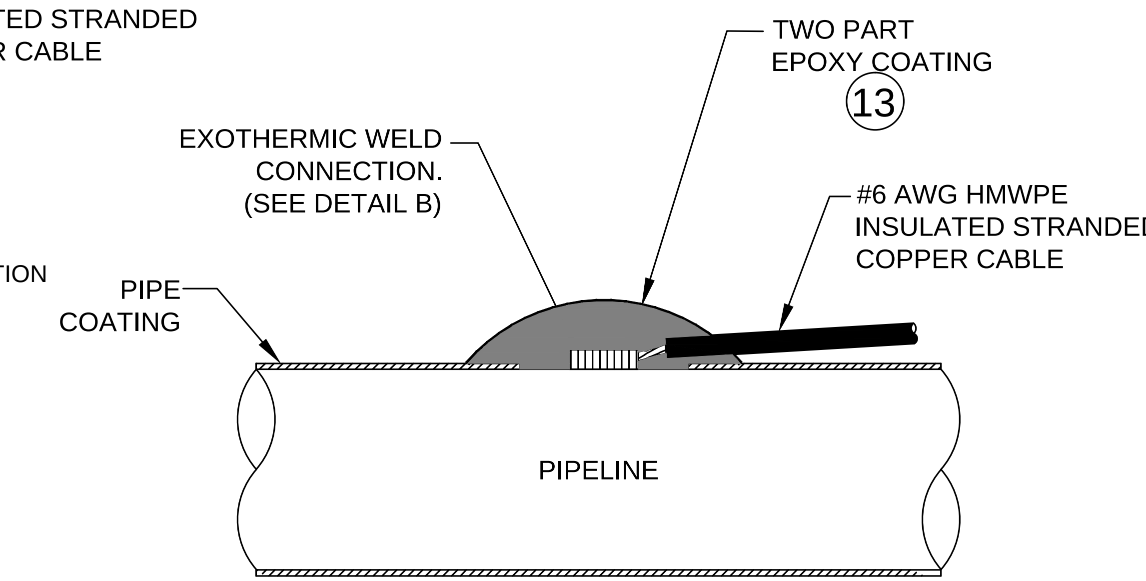
DETAIL 'A'

CABLE TO PIPELINE ATTACHMENT DETAIL



DETAIL 'B'

EXOTHERMIC WELD CONNECTION



DETAIL 'C'

CORROSION PROTECTION SEAL

- PRELIMINARY -
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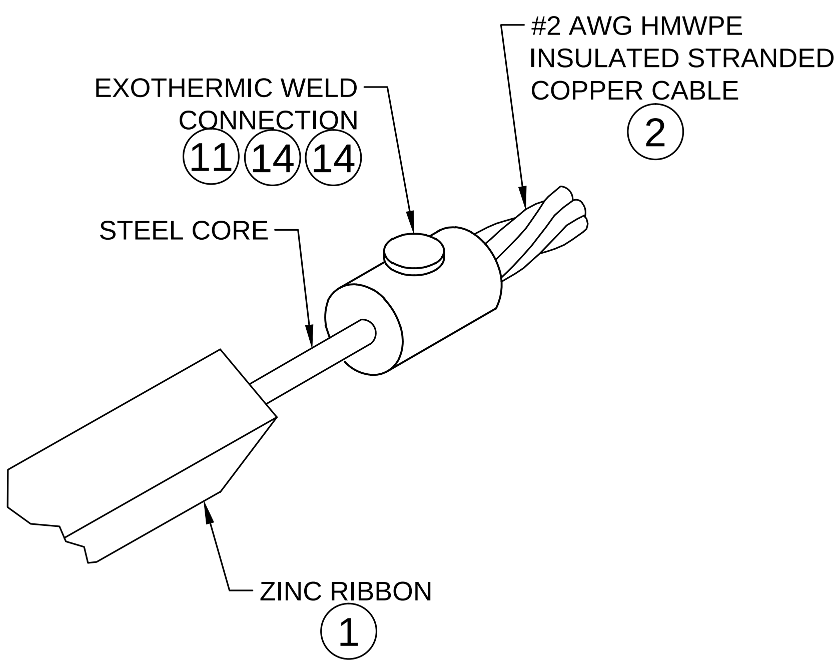
ENGR: B W
DATE: 9/22/17

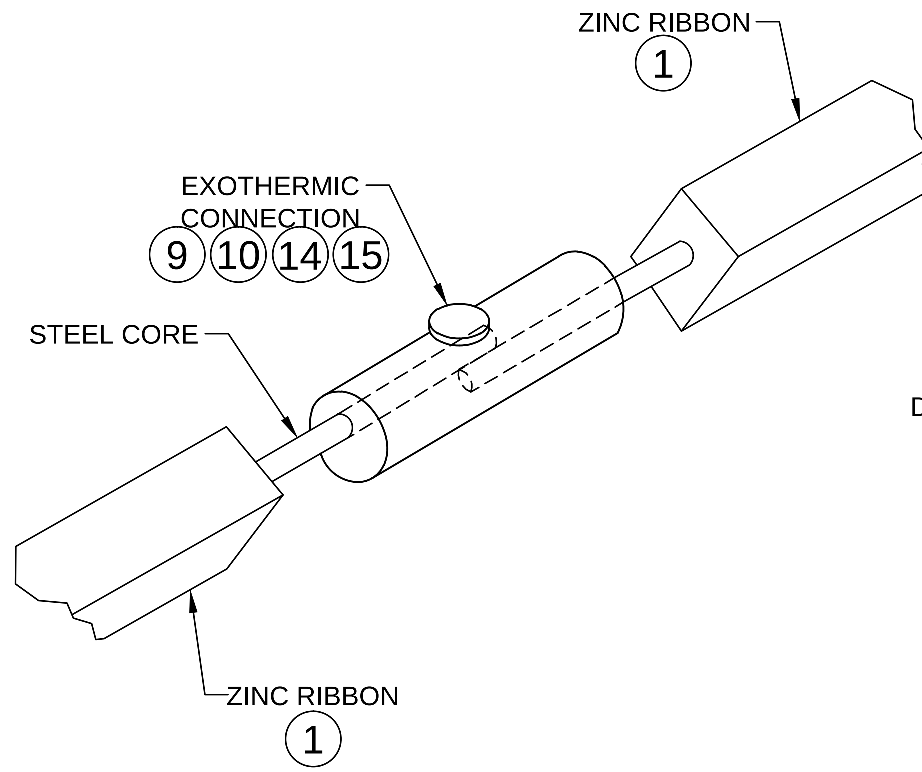
CLIENT: SAN DIEGO GAS & ELECTRIC SITE: PROPOSED TL 6975 ZINC RIBBON SYSTEM	ARK ENGINEERING & TECHNICAL SERVICES, INC. ARK ENGINEERING & TECH. SERVICES, INC. 639 GRANITE STREET SUITE 200 BRAINTREE, MA 02184 U.S.A.	TITLE: CABLE TO PIPELINE CONNECTION DETAILS	
DRAWN BY: SRM	DATE: 9/13/17	SIZE: B	DWG. NO.: 16138-300 / REV: 1
PROJECT NO.: 16-E-138-AC	APPROVED BY: BW	DATE:	SCALE: NTS / CAD FILE NAME: 16138-300-1-R1 / SHEET: 1 OF 1

REV	DESCRIPTION	DATE	APPROVED
0	PRELIMINARY TEST STATION INSTALLATION	9/13/17	BW
1	PRELIMINARY ZINC RIBBON SYSTEM DESIGN	9/22/17	BW



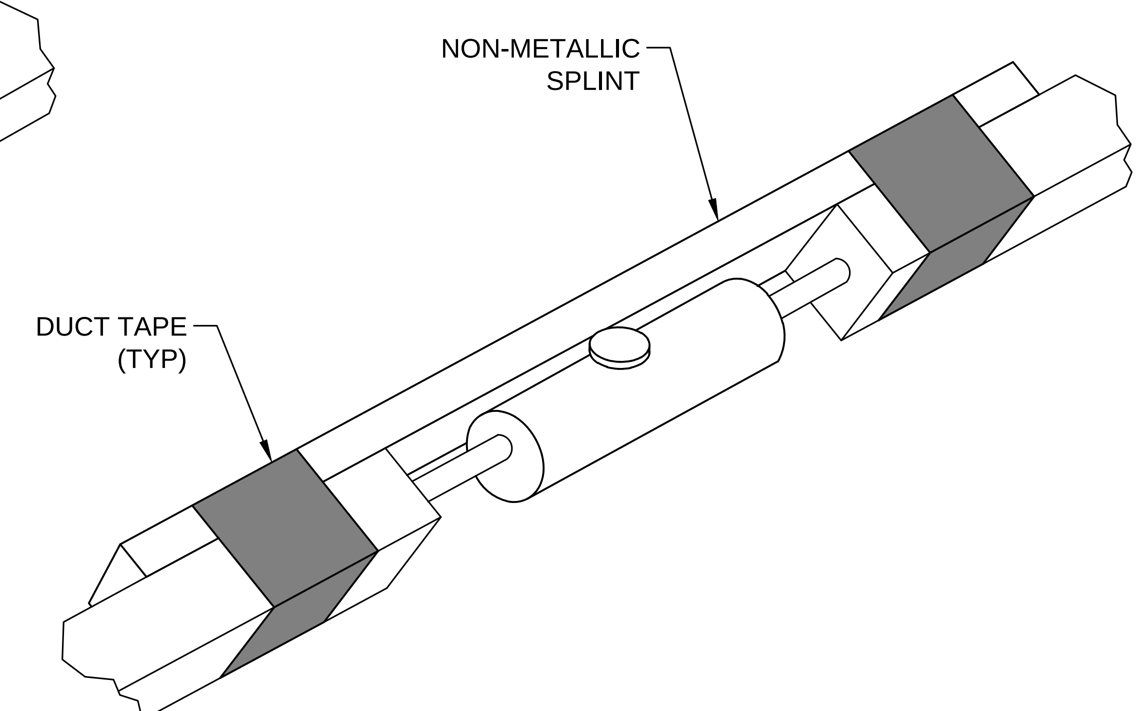
DETAIL 'A'

ZINC RIBBON TO #2 AWG STRANDED COPPER CABLE
EXOTHERMIC WELD INSTALLATION



DETAIL 'B'

ZINC RIBBON TO ZINC RIBBON
IN-LINE EXOTHERMIC WELD INSTALLATION



DETAIL 'C'

NON-METALLIC SPLINT INSTALLATION

`DETAIL	MOLD	WELD METAL	TYPE
'A'	M-11638	#32CP	IN-LINE SPLICE
'B'	M-7233	#15CP	IN-LINE SPLICE

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NOT FOR CONSTRUCTION
ENGR: BW
DATE: 9/22/17

NOTES:

1. ALL EXOTHERMIC WELD CONNECTIONS ARE TO BE SEALED WITH ROYSTON "SPLICE RIGHT" SPLICE KIT (ITEM 14), OR SAN DIEGO GAS & ELECTRIC APPROVED ALTERNATIVE.

2. FOR ALL ZINC RIBBON EXOTHERMIC WELD CONNECTIONS, USE A NON-METALLIC SPLINT TO REINFORCE WELD. WRAP DUCT TAPE AROUND SPLINT AND ZINC RIBBON FOR ADDED SUPPORT (SEE DETAIL 'C').

CLIENT: SAN DIEGO GAS & ELECTRIC

SITE: PROPOSED TL 6975 ZINC RIBBON SYSTEM

PROJECT NO.: 16-E-138-AC

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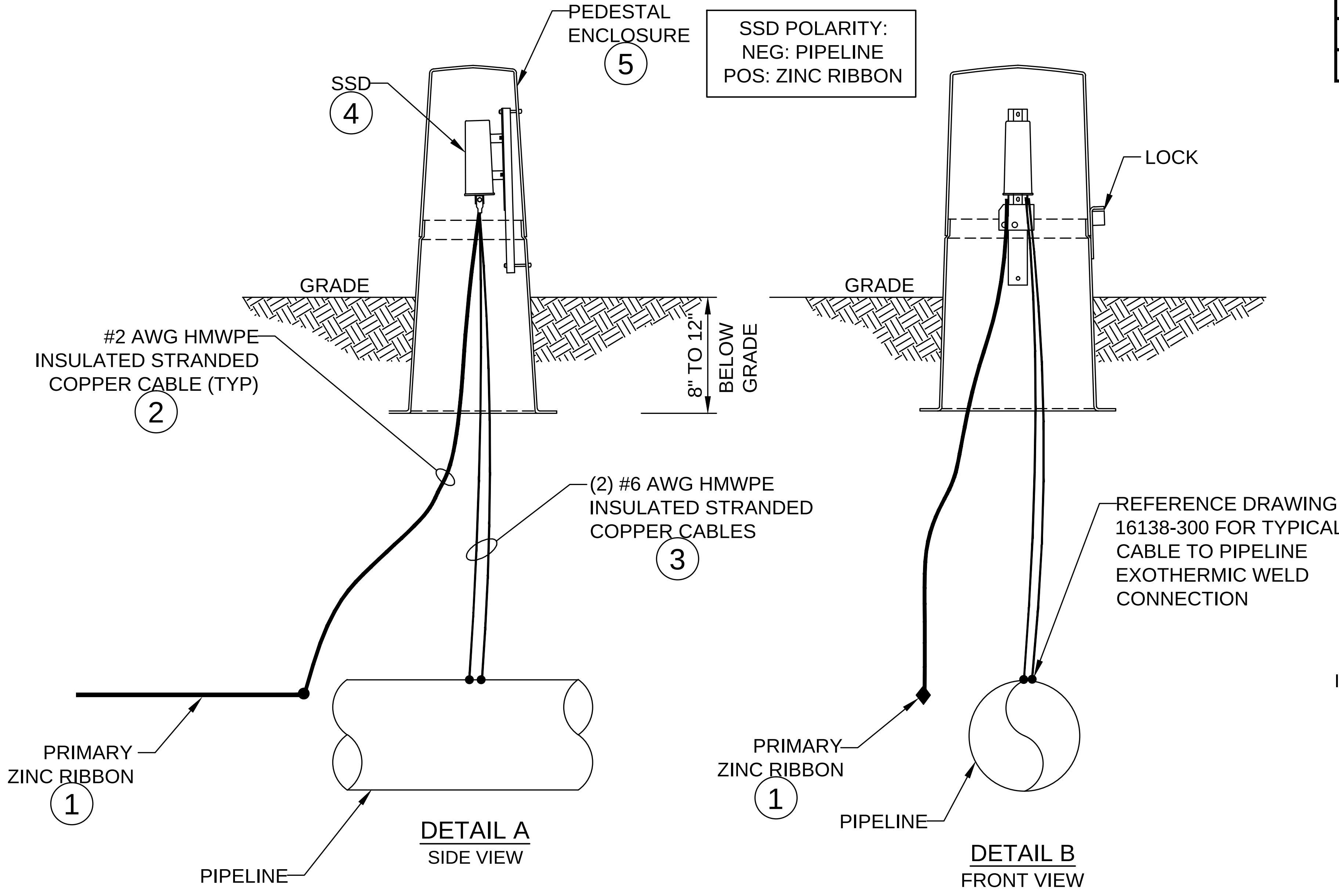
SUITE 200
BRAINTREE, MA
02184 U.S.A.

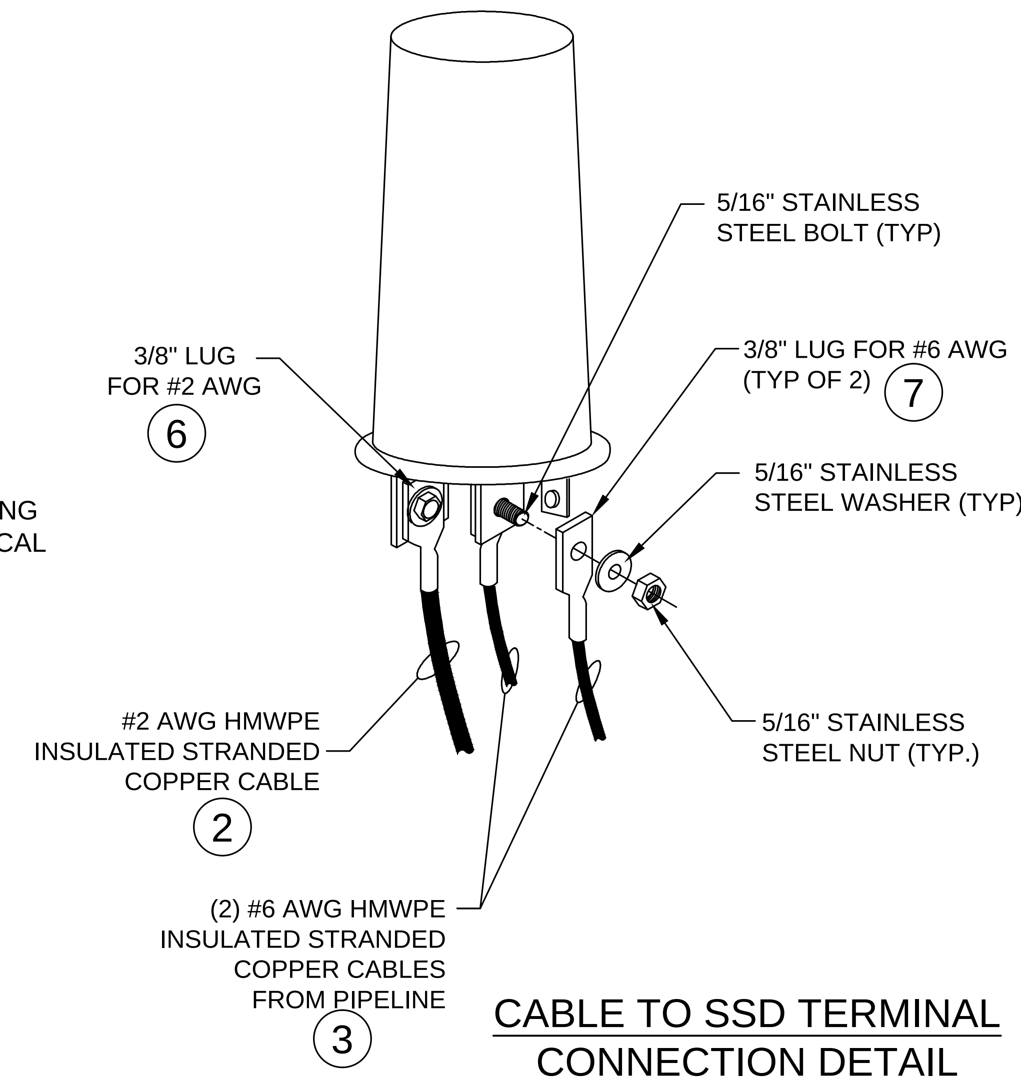
TITLE: EXOTHERMIC WELD CONNECTION DETAILS

DRAWN BY	DATE	SIZE		DWG. NO.	REV
SRM	9/13/17	B	The information contained on this drawing is confidential and is the sole property of ARK Engineering. Transferring this information to a third party or reproducing in part or in full without a written consent from ARK Engineering is prohibited.	16138-301	1
APPROVED BY: BW	DATE:	SCALE: NTS	CAD FILE NAME: 16138-301-1-R1	SHEET: 1 OF 1	

REV	DESCRIPTION	DATE	APPROVED
0	PRELIMINARY TEST STATION INSTALLATION	9/13/17	BW
1	PRELIMINARY ZINC RIBBON SYSTEM DESIGN	9/22/17	BW



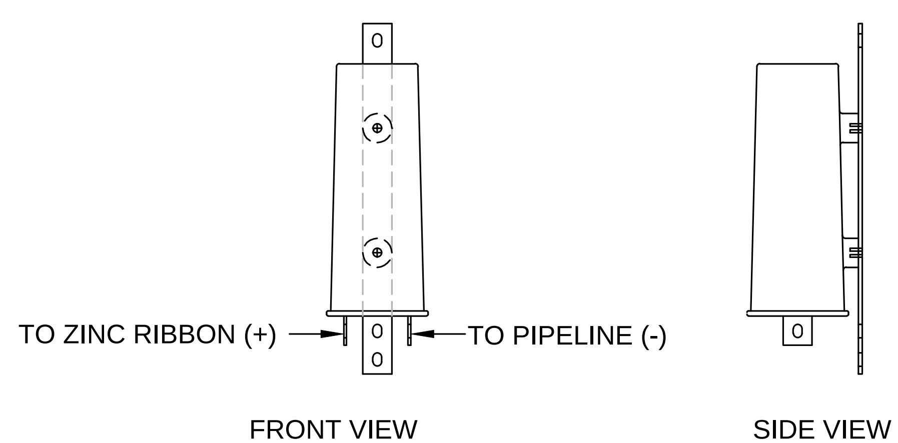
SSD INSTALLATION DETAILS



CABLE TO SSD TERMINAL CONNECTION DETAIL

NOTES:

1. SSD IS TO BE MOUNTED INSIDE THE FIBERGLASS PEDESTAL. ALL COPPER CABLES ARE TO PASS THROUGH BOTTOM OF PEDESTAL.
2. INSTALL PEDESTAL AS CLOSE AS POSSIBLE TO PIPING CONNECTIONS TO REDUCE LEAD LENGTHS.
3. WIRING ON THIS SHEET DEPICTS ZN-1A CONFIGURATION. REFERENCE DRAWING 16138-201 FOR SPECIFIC WIRING DETAILS.



SOLID STATE DECOUPLER DEVICE (SSD)

- PRELIMINARY -
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ENGR: BW
DATE: 9/22/17

CLIENT: SAN DIEGO GAS & ELECTRIC SITE: PROPOSED TL 6975 ZINC RIBBON SYSTEM	ARK ENGINEERING & TECHNICAL SERVICES, INC. ARK ENGINEERING & TECH. SERVICES, INC. 639 GRANITE STREET SUITE 200 BRAINTREE, MA 02184 U.S.A.	TITLE: SOLID STATE DECOUPLER (SSD) DEVICE DETAILS
PROJECT NO. 16-E-138-AC	DRAWN BY: SRM; DATE: 9/13/17; APPROVED BY: BW; DATE:	SIZE: B; SCALE: NTS; DWG. NO. 16138-302; REV 1; CAD FILE NAME: 16138-302-1-R1; SHEET 1 OF 1

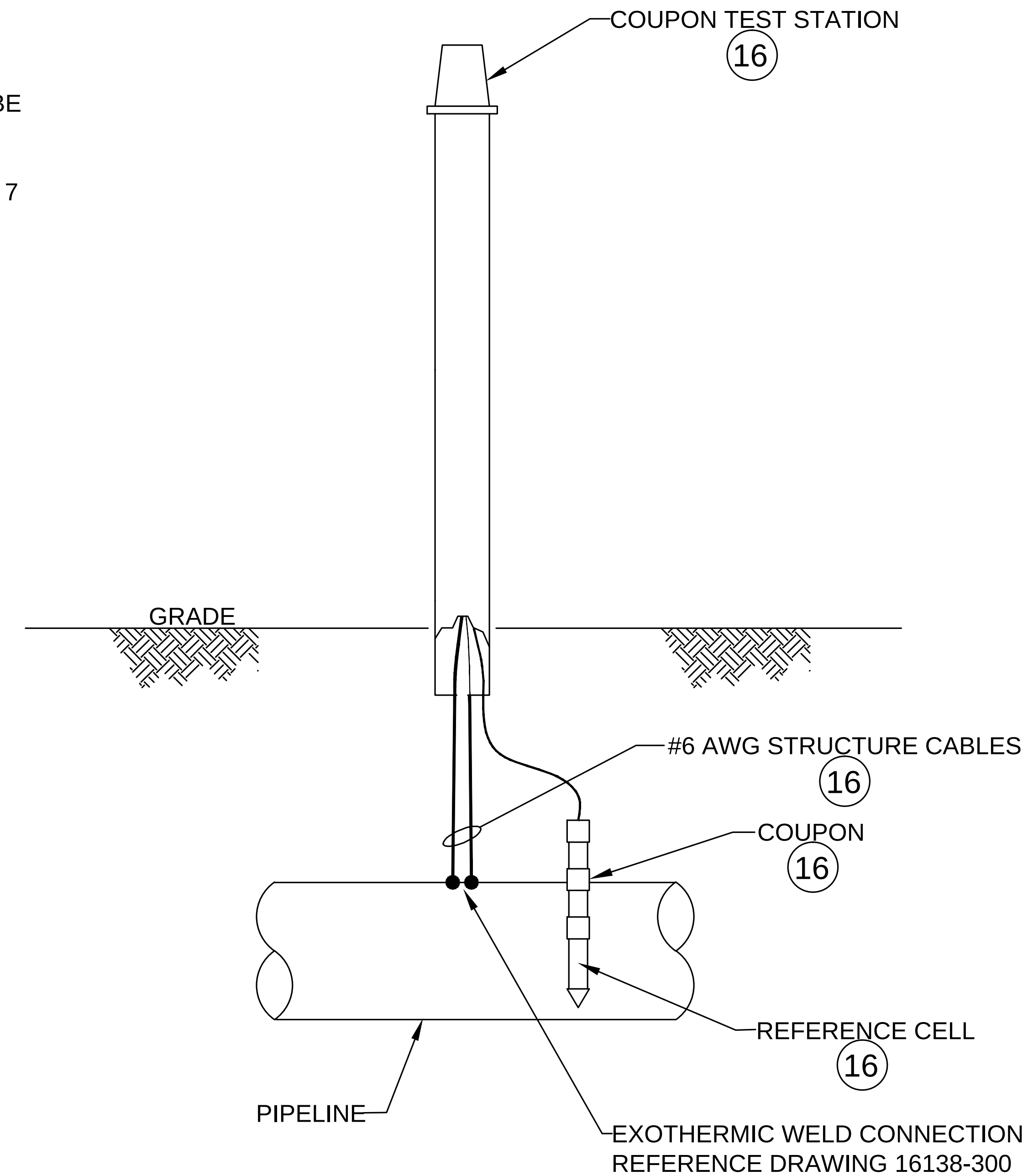
REV	DESCRIPTION	DATE	APPROVED
0	PRELIMINARY TEST STATION INSTALLATION	9/13/17	BW
1	PRELIMINARY ZINC RIBBON SYSTEM DESIGN	9/22/17	BW

NOTES:

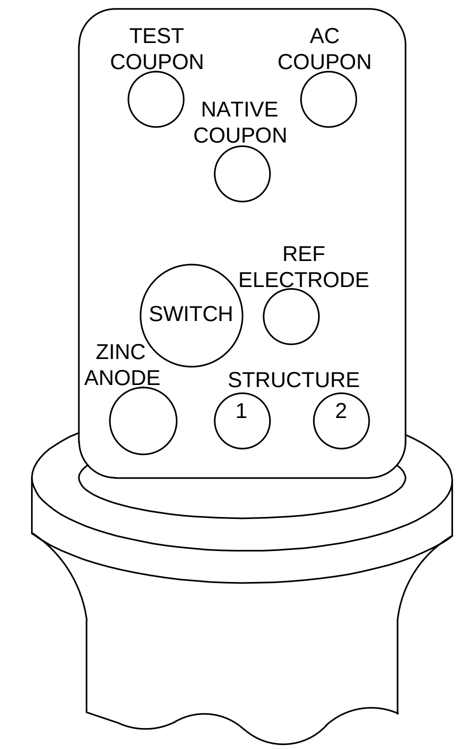
1. TEST STATION TO BE INSTALLED DIRECTLY ABOVE BURIED PIPE WHEN ALLOWED.
2. COUPON TEST STATION TO BE PROVIDED AS A KIT WITH STEEL COUPONS, WIRING, AND TEST HEAD INCLUDED (ITEM 16).
3. COUPON TO BE INSTALLED 4-12" LATERALLY FROM THE PIPE AND TO BE INSTALLED AT THE BOTTOM 1/3 OF THE PIPE (0"-8"). THE ASSEMBLY MUST BE INSTALLED IN A VERTICAL POSITION WITH THE MIDPOINT OF THE REFERENCE CELL AT A DEPTH RELATIVE TO THE PIPELINE'S 5 OR 7 O'CLOCK POSITION.
4. THE CU/CUSO4 REFERENCE CELL SHOULD BE INSTALLED AT THE 9 O'CLOCK POSITION ON THE PIPE.
5. PACK NATIVE SOIL INSIDE TEST STATION TUBE 1' ABOVE GRADE.
6. LEAVE TEST STATION SWITCH IN "OFF" POSITION UNTIL COUPONS ARE POLARIZED.
7. REFERENCE TABLE BELOW FOR COUPON TEST STATION LOCATIONS.

COUPON TEST STATION LOCATIONS

LOCATION NO.	GPS LOCATION
1	[illegible]
2	[illegible]



COUPON TEST STATION
WIRING DETAILS



COUPON TEST STATION - TERMINAL BOARD
(COVER REMOVED)

CONNECTIONS TO:		QUANTITY	WIRE SIZE & TYPE	TAPE OR WIRE COLOR
TEST STATION	PIPE/DEVICE			
STRUCTURE 1	PIPELINE	1	#6 AWG THHN	RED
STRUCTURE 2	PIPELINE	1	#6 AWG THHN	WHITE
REFERENCE ELECTRODE	CP COUPON	1	#14 AWG THHN	YELLOW
NATIVE COUPON	COUPON ASSEMBLY	NOT USED	-	-
TEST COUPON	COUPON ASSEMBLY	1	#14 AWG THHN	BLUE
AC COUPON	COUPON ASSEMBLY	1	#14 AWG THHN	ORANGE

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ENGR: BW
DATE: 9/22/17

CLIENT: SAN DIEGO GAS & ELECTRIC
SITE: PROPOSED TL 6975 ZINC RIBBON SYSTEM
PROJECT NO.: 16-E-138-AC

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02184 U.S.A.

TITLE: COUPON TEST STATION LOCATIONS & WIRING DETAILS

DRAWN BY: SRM | DATE: 9/13/17 | SIZE: B
APPROVED BY: BW | DATE:
SCALE: NTS

DWG. NO.: 16138-303 | REV: 1
CAD FILE NAME: 16138-303-1-R1 | SHEET: 1 OF 1

REV	DESCRIPTION	DATE	APPROVED
0	PRELIMINARY TEST STATION INSTALLATION	9/13/17	BW
1	PRELIMINARY ZINC RIBBON SYSTEM DESIGN	9/22/17	BW

ITEM	QUANTITY	DESCRIPTION
1	7,965	**ZINC RIBBON ANODE:** HIGH GRADE ELECTROLYTIC ZINC, 99.99% PURE. CONFORMS IN COMPOSITION TO ASTM B-418-73 TYPE II; 5/8" X 7/8" CROSS SECTION WITH 0.135" DIAMETER GALVANIZED STEEL CORE CABLE; NOMINAL WEIGHT OF 1.2 POUNDS PER FOOT. PLATT BROS. PLATTLINE II PLUS REEL. PACKAGE NUMBER PP2, 1-1017P.
2	520	**#2 AWG HMWPE INSULATED, STRANDED COPPER CABLE:** SOFT-DRAWN, COMMERCIALLY PURE COPPER, ASTM B8, CLASS B STD. USED FOR CONNECTIONS OF ZINC RIBBON TO SOLID STATE DECOUPLING DEVICES.
3	1,240'	**#6 AWG HMWPE INSULATED, STRANDED COPPER CABLE:** SOFT-DRAWN, COMMERCIALLY PURE COPPER, ASTM B8, CLASS B STD. USED FOR CONNECTIONS OF SOLID STATE DECOUPLING DEVICES TO PIPE.
4	7	**SOLID STATE DECOUPLER (SSD):** -2V/+2V BLOCKING VOLTAGE, 5KA FAULT CURRENT RATING (30 CYCLES) AT 50/60HZ, 100KA LIGHTNING SURGE CURRENT RATING (4 X 10 WAVEFORM). DAIRYLAND ELECTRICAL INDUSTRIES, P/N SSD-2/2-5.0-100-R.
5	7	**SSD PEDESTAL:** FIBERGLASS CASE: 9" X 14" X 36" HIGH, WITH MOUNTING BRACKET. FOR MOUNTING THE SOLID STATE DECOUPLING DEVICE. DAIRYLAND ELECTRICAL INDUSTRIES. P/N MTP-36.
6	10	**COMPRESSION LUG FOR #2 AWG STRANDED COPPER CABLE:** ONE HOLE, 3/8" HOLE, LONG BARREL. FOR ZINC TO SSD CONNECTIONS. BURNDY, P/N YAZ2C-TC38.
7	14	**COMPRESSION LUG FOR #6 AWG STRANDED COPPER CABLE:** ONE HOLE, 3/8" HOLE, LONG BARREL. FOR SSD CONNECTION TO PIPE. BURNDY, P/N YAZ6C-TC38. TWO (2) PER SSD.
8	1	**M-0102 EXOTHERMIC WELD MOLD:** THERMOWELD, USED FOR EXOTHERMIC WELD CONNECTION OF #6 AWG CABLE TO PIPE. USE #15CP WELD METAL. HANDLE CLAMP AND FLINT IGNITOR INCLUDED.
9	1	**M-7233 EXOTHERMIC WELD MOLD:** THERMOWELD, USED FOR ZINC RIBBON TO ZINC RIBBON IN-LINE SPLICE CONNECTIONS. USE #15CP WELD METAL.
10	1 BOX	**#15CP EXOTHERMIC WELD METAL:** THERMOWELD, BONDS #6 AWG CABLE TO PIPELINE. ALSO USED FOR ZINC RIBBON TO ZINC RIBBON. 20 SHOTS PER BOX.
11	1	**M-11638 EXOTHERMIC WELD MOLD:** USED FOR IN-LINE SPLICE OF ZINC RIBBON TO #2 AWG CABLE. USE #32CP WELD METAL.
12	2 BOXES	**#32CP EXOTHERMIC WELD METAL**: THERMOWELD, USED FOR #2 AWG CABLE TO ZINC RIBBON CONNECTIONS. 10 SHOTS PER BOX.
13	9 TUBES	**TWO PART EPOXY:** SPECIALTY POLYMER COATINGS, INC SP-2888. FOR REPAIRING PIPE COATING AT #6 AWG CONNECTIONS TO PIPE. APPLY 20 MLS THICK MINIMUM. 50 ML TUBE WILL REPAIR TWO #6 EXOTHERMIC WELDS TO PIPELINE.
14	14 KITS	**ROYSTON SPLICERIGHT KIT (OR APPROVED EQUAL):** INSULATION KIT FOR EXOTHERMIC WELD SPLICE CONNECTIONS.
15	2	**HANDLE CLAMP AND FLINT IGNITOR:** FOR EXOTHERMIC WELD MOLDS. THERMOWELD P/N 40-0106-00.
16	2	**COUPON TEST STATION**: AMERICAN INNOVATIONS TRITON, INCLUDES CU/CUS04 REFERENCE ELECTRODE, (2) 100 SQUARE CENTIMETER STEEL COUPONS, & (1) 1 SQUARE CENTIMETER STEEL COUPON. ALSO INCLUDES 30 FEET OF #6 AWG THHN & 30 FEET OF #14 AWG THHN (5 CONDUCTOR) WIRE.

- PRELIMINARY -
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ENGR: BW
DATE: 9/22/17

NOTE:

ARK ENGINEERING CAN PROVIDE ALL MATERIALS LISTED ABOVE AND INSTALLATION SERVICES. PLEASE CALL 1-800-469-3436 FOR A MATERIAL OR INSTALLATION QUOTATION.

CLIENT: SAN DIEGO GAS & ELECTRIC

SITE: PROPOSED TL 6975 ZINC RIBBON SYSTEM

ARK ENGINEERING & TECHNICAL SERVICES, INC.
ARK ENGINEERING & TECH. SERVICES, INC.
639 GRANITE STREET
SUITE 200
BRAINTREE, MA
02184 U.S.A.

TITLE: MATERIALS LIST

DRAWN BY	DATE	SIZE	DWG. NO.	REV
SRM	9/13/17	B	16138-400	1

PROJECT NO.	APPROVED BY	DATE	SCALE	CAD FILE NAME	SHEET
16-E-138-AC	BW		NTS	16138-400-1-R1	1 OF 1