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Summary Report: Stray Current Corrosion Control Evaluation

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SUMMARY REPORT

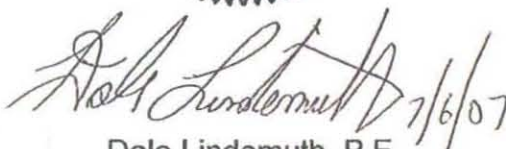
STRAY CURRENT CORROSION CONTROL EVALUATION

Various Facilities At The Texas Medical Center
That Are Impacted By Metro Light Rail Transit Operations
Houston, Texas

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July 6, 2007



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SUMMARY REPORT – STRAY CURRENT CORROSION CONTROL EVALUATION

VARIOUS FACILITIES THROUGHOUT THE TEXAS MEDICAL CENTER THAT ARE IMPACTED BY METRO LIGHT RAIL TRANSIT OPERATIONS

EXECUTIVE SUMMARY

This report presents the results of a comprehensive stray current corrosion control evaluation by Corpro Companies, Inc. for facilities throughout the Texas Medical Center (TMC). The evaluation focused on determining the presence and corrosion control significance of stray earth currents caused by operation of the Houston Metro light rail transit line.

Metro is a 7.5-mile long, direct current powered rail return transit line constructed almost exclusively with embedded street-running rails. This includes 1.8 miles through the TMC complex along Fannin Street, Braeswood Boulevard and Greenbriar Drive. Metro was designed with provisions intended to effectively minimize stray current electrical leakage directly at the source, i.e. the transit system. Unfortunately, construction of the track-way was plagued with many deficiencies that compromised (decreased) the in-service track to earth electrical resistance. Establishing and maintaining the highest practicable level of track to earth resistance is one primary means for limiting transit caused stray currents and the potential corrosion damaging effects of this current on nearby underground utility pipelines and other underground metallic facilities. Metro has acknowledged the construction deficiencies and has been taking corrective action over the last few years to remedy the situation.

Corpro's evaluation primarily addressed exterior (perimeter) steel reinforced concrete basement walls within many of the TMC institutions and incoming, underground metallic utility piping. The evaluation detected Metro caused stray current electrical effects on various TMC facilities. The significance of the stray current is not evenly distributed throughout the TMC and varies from facility to facility and structure to structure. The bar chart in Figure ES-1 presents the composite ranking (category) for each TMC facility evaluated,

Corpro recommends Metro develop, implement, and maintain an effective program to control stray current levels to within acceptable limits so they have no continued negative impact to facilities within the Texas Medical Center.

Present conditions determined by Corpro establish a sufficient foundation for TMC to institute a proactive stray current corrosion control surveillance program for their infrastructure. Transit system rail stray currents tend to increase as the system ages. TMC institutions should expect to continue a monitoring program for the life of the rail system.

Corpro recommends a TMC administered stray current monitoring program be designed and implemented for TMC facilities within the next two years. The cost effective program includes permanently installed data acquisition equipment linked to a maintenance computer. With this equipment in place, anomalous conditions which will undoubtedly occur can be detected quickly and prompt action taken as required. Also, the design of new, expansion, and replacement facilities within the TMC complex should include a stray current corrosion control needs assessment with appropriate measures incorporated into the construction.

TMC management and supporting institutions participating in the stray current corrosion control evaluation have taken an appropriate, proactive posture on this matter. This includes the installation of 84 permanent stray current monitoring test points within the participating institutions.

Corpro appreciates the support provided by the Texas Medical Center, Thermal Energy Corporation (TECO) and the various facility operators in performing this evaluation.

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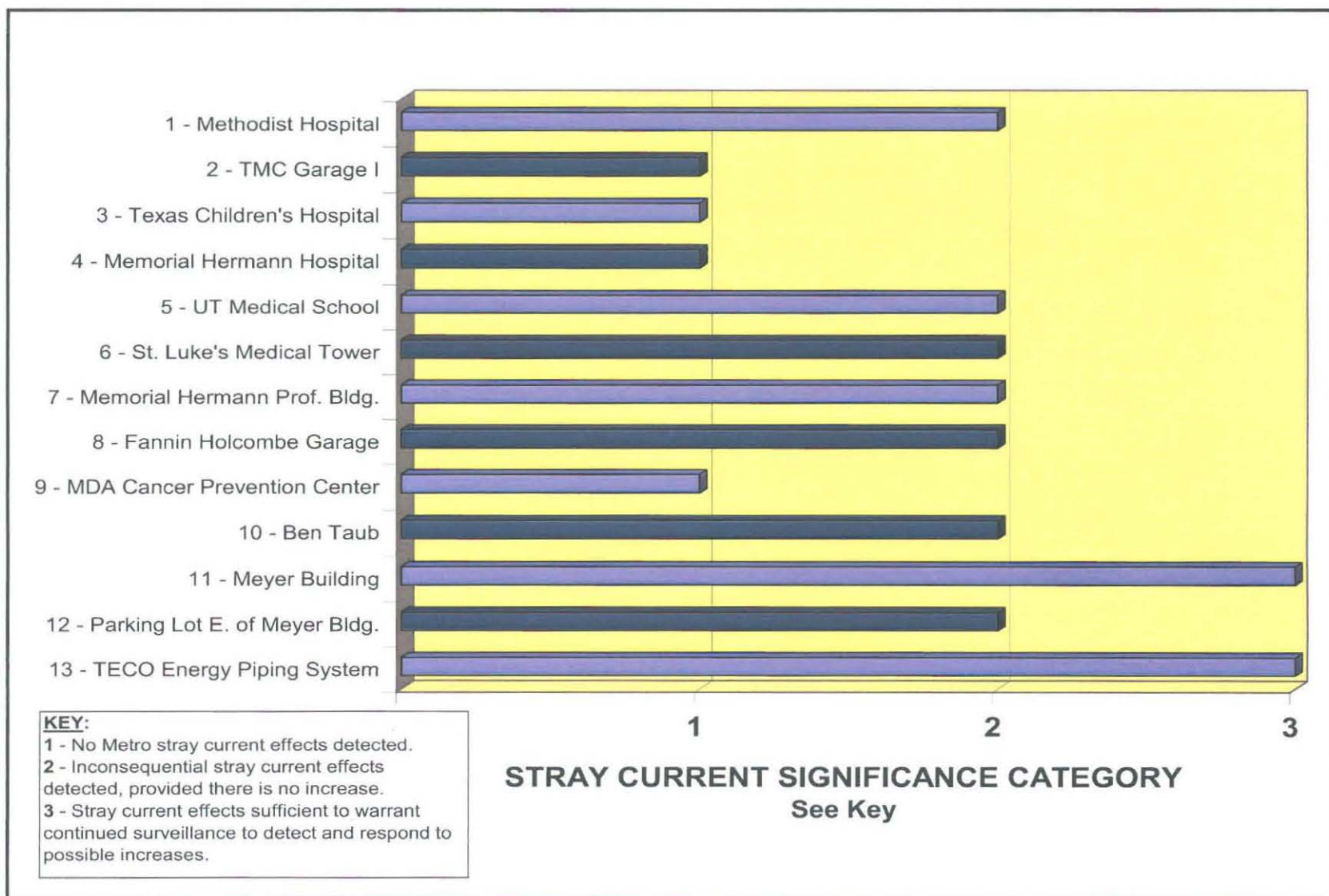


FIGURE ES-1 - Stray Current Corrosion Control Significance Summary

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VARIOUS FACILITIES THROUGHOUT THE TEXAS MEDICAL CENTER THAT ARE IMPACTED BY METRO LIGHT RAIL TRANSIT OPERATIONS

1. INTRODUCTION

Corrpro Companies, Inc. has been retained by Thermal Energy Corporation to determine the significance of Metro light rail transit operations on infrastructure corrosion rates throughout the Texas Medical Center complex. Thermal Energy Corporation (TECO) administered Corrpro's stray current corrosion evaluation in conjunction with the Texas Medical Center (TMC). The evaluation was funded by the Texas Medical Center member institutions that operate facilities within the Texas Medical Center Central Campus.

The TMC facilities included in Corrpro's stray current corrosion control evaluation are listed below.

Facility Reference No.	Facility Name
1	The Methodist Hospital
2	Texas Medical Center - Garage I
3	Texas Children's Hospital
4	Memorial Hermann Hospital
5	University of Texas Medical School
6	St. Luke's Medical Tower
7	Memorial Hermann Hospital Professional Building
8	Fannin Holcombe Garage
9	M.D. Anderson Cancer Prevention Center
10	Ben Taub
11	Meyer Building
12	Parking Lot East of Meyer Building
13	TECO Energy Piping System

This report summarizes the results of Corrpro's evaluation and provides recommendations for effective long-term stray current corrosion control of TMC facilities. The operation of the Metro light rail line through the TMC introduces a much greater potential for corrosion damage to surrounding structures from stray direct currents. TMC institutions should expect to continue a monitoring program for the life of the rail system. The degree of monitoring over time will depend on the level of stray current leakage from Metro and the resulting impact on TMC structures. New TMC facilities should be evaluated as they are designed to determine if stray current monitoring and or stray current corrosion control provisions should be included during construction.

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TMC management and supporting institutions participating in the stray current corrosion evaluation should be commended for their efforts in this matter. The actions to date represent an appropriate proactive approach to overall stray current corrosion control at TMC.

2. CONCLUSIONS

- 2.1. Metro caused stray current effects were detected by Corpro on various TMC facilities. The corrosion significance of the stray current varies depending on proximity to the Metro rail line and the electrical characteristics of the particular structure evaluated.
- 2.2. The major aspects of Corpro's stray current corrosion field evaluation occurred between November 2006 and April 2007. While not desired, the detected Metro caused stray current effects on the sampling of TMC facilities during this period are considered tolerable relative to near-term structure corrosion control and operational reliability for the particular facilities evaluated, provided there is no increase. The significance of the stray current at other TMC locations and or during other timeframes could be greater or less.
- 2.3. In August 2006 (and before) Metro reported the in-service level of track to earth electrical resistance along sections of the rail line to be less than the minimum established by their design criteria and construction specifications (250 ohms per thousand feet of track). This includes the track-way within and adjacent to the Medical Center complex. Increased track to earth resistance typically corresponds to decreased stray current electrical leakage and the resulting corrosion control impact on nearby structures.
- 2.4. Had Metro's installed track to earth resistance met or exceeded their minimum design and construction requirements, the stray current effects at the Medical Center would have been less than that detected by Corpro.
- 2.5. Stray current leakage from Metro will likely increase as the light rail system ages. Actions by Metro are essential to control stray current levels to within acceptable limits so they have no continued negative impacts to facilities within the Texas Medical Center.
- 2.6. The stray current effects measured on TMC facilities are sufficient to warrant the design and implementation of a cost effective stray current corrosion control surveillance program. Such a program is not uncommon for facilities along a direct current powered rail transit line to track conditions over time. Monitoring allows for a proactive response to changes which will undoubtedly occur and could result in a stray current corrosion problem.

3. RECOMMENDATIONS

- 3.1. Metro should develop, implement, and maintain an ongoing, effective program to control stray current emanating from their rail line so they are within acceptable limits.
- 3.2. TMC should disseminate the results of Corpro's stray current corrosion control evaluation to participating institutions and other stakeholders as appropriate. The various facility operators should review the particular structures for which they are responsible for to determine if the sampling of conditions by Corpro is considered adequate for their particular service requirements, operational needs, and level of risk tolerance. Additional baseline stray current data should be gathered if deemed necessary by the different institutions.
- 3.3. A stray current corrosion control surveillance program should be designed and implemented within the next 2 years. A holistic approach administered through one entity rather than individual plans by and for different institutions is advised. This is because common data collected at strategic locations exterior to specific buildings will provide for reliable indicators of detrimental changes in stray current conditions, at a relatively low cost. The basic framework for the recommended surveillance program includes:
 - a. A written set of procedures including specific test points and guidelines to interpret the data.
 - b. Installation of a minimum of four permanent earth reference electrode pairs buried a few feet below grade at some to-be-determined distance apart (less than 50 feet). The electrode pairs will facilitate measuring earth voltage changes near a sampling of the Metro "hot spots" summarized in Section 4.5 of this report. One "control" location along a section of standard Metro rail construction within the limits of TMC should also be instrumented and monitored.
 - c. Permanent data acquisition equipment installed in conjunction with the reference electrode pairs that can transmit normal and upset information 24/7 via hardwire or wireless communication to a maintenance computer, with suitable alarms and trending. Equipment developed specifically for corrosion control monitoring is readily available commercially.
 - d. Inclusion of no more than five additional strategically determined monitoring points where data can be collected using portable data-loggers on an as needed basis to supplement the permanent monitoring locations.
 - e. Data collected within one month of installation of the monitoring equipment to be analyzed with one key output being the frequency of possible manual monitoring at some time in the future. (It is quite possible that the

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automated data capture alone may be sufficient to detect stray current anomalies requiring further investigation and or corrective action.)

- f. Maintaining the 84 structural steel stray current test points established during Corpro's evaluation. The test point cover plates and identification labels installed by TECO and as shown in Figure 1b are adequate for this purpose.

One possible means for the surveillance program is to incorporate it into the existing cathodic protection maintenance and monitoring program for the TECO piping, which would be easy to do at a reasonable cost.

4. DISCUSSION

4.1 Stray Current Corrosion Overview

Operation of a direct current (DC) powered light rail transit line such as the Houston Metro, that uses street-running guide rails as part of the traction power negative return circuit, inherently has the potential to increase corrosion rates and deterioration of nearby utilities, reinforced concrete building foundations, and other underground metallic structures, as well as the rails themselves and other transit facilities. While typically only a very small portion for most modern-day rail lines, some of the traction current that propels the transit vehicles inevitably flows through the ground, rather than through the guide rails which are intended as the predominant current carrying conductors.

Figure 2 presents a basic illustration of the electric current flow associated with a DC rail system. Stray current entering into the earth from the rails will result in corrosion deterioration of the rails. This is illustrated in the right-hand portion of Figure 2 where the transit vehicle is accelerating at some distance from the traction power substation supplying the electrical current. If the stray current leaking from the rails accumulates onto an underground metallic structure through an earth path, naturally occurring corrosion rates for that structure may be reduced to some degree, i.e. the stray current may provide for some level of cathodic protection. When stray current discharges from the structure to ground through an earth path (left-hand portion of Figure 2), corrosion rates will increase. The increase in corrosion rates is directly related to the magnitude and time duration of the stray current discharge into the ground and inversely related to the surface area over which the stray current is distributed. The corrosion deterioration that can be caused by the stray current discharge is illustrated by the data in Figure 3.

Transit caused stray currents typically vary throughout the day with a predictable signature as traction power demands fluctuate. The fluctuations are caused by transit vehicle acceleration and deceleration, and the number and location of vehicles on the system, among other influencing factors. Stray current effects on nearby structures are

typically caused by the combined operation of transit vehicles along the entire rail system, not just the vehicles operating in the immediate vicinity.

4.2 Background

Not uncommon for today's light rail systems, the design of the Houston Metro included various provisions to limit stray currents emanating from the transit operations. Most significantly, measures intended to increase the track to earth electrical isolation (resistance) were designed. This included an electrically high resistant "boot" for standard embedded rail and an insulating membrane arrangement ("bathtub") at switches and crossovers. Unfortunately, because of various factors, the minimum track to earth resistance design criteria of 250 ohms per thousand feet of track was not achieved for portions of the Metro track-way before light rail service opened to the public on January 1, 2004. This included much of the approximate 1.8 mile long section of rail line through the TMC complex. Photographs of some of the problematic construction deficiencies detected by Metro are presented in Figure 4.

Corrpro's stray current evaluation was prompted as a proactive effort by TMC because:

- Shortly after rail service began, unacceptably high transit caused stray current was detected on neighboring utilities and reported to Metro, most notably cathodically protected natural gas pipelines operated by CenterPoint Energy.
- Transit caused stray current was detected by Corrpro on the cathodically protected TECO energy piping within the TMC complex and reported by TECO to Metro.
- Public disclosure by Metro over the last few years indicating construction deficiencies with the track to earth electrical isolation and their efforts to remedy the situation.

The color coded map of the Metro rail line included in Appendix 1 summarizes the track to earth resistance levels previously reported by Metro (see 4th page of Appendix 1, slide titled "*Metro's Baseline Testing*"). As part of Metro's corrective action efforts, they have reported more recent track to earth resistance measurements have been made. Metro has indicated they will report on these data at the next meeting of the Houston Metro Corrosion Committee (HMCC). The HMCC is a voluntary forum coordinated by Metro and attended by area utility operators to exchange information on transit stray current matters. No meeting date has been established by Metro. The last meeting was August 2, 2006.

4.3 Evaluation Protocol

Corrpro's evaluation consisted of a series of electrical voltage, current and resistance measurements and data-logging. Structures investigated included:

- Exterior (perimeter) wall reinforcing bars, made by electrical test connections to the reinforcing bars through drilled holes on the interior face of the wall (Figure 1a).
- Building interior electrical ground connections.
- Buried sections of the TECO energy piping system, using existing cathodic protection monitoring points.
- Incoming water and natural gas utility piping, at the points of connection to various buildings.
- Exterior electrical ground connections, e.g. electrical grounds for light standards.

Table 1 lists the number of each type structure evaluated for each TMC facility.

Portable, digital data-loggers were used to collect much of the direct current (DC) electrical data. Monitoring duration typically ranged from several minutes to approximately one day, sometimes longer. In all, between November 2006 and April 2007 over 1,200 hours of data were logged. The extent of the data is considered comprehensive and sufficient to provide an overall characterization of Metro caused stray current influences at TMC. Analysis of the data has resulted in the conclusions and recommendations presented in this report.

4.4 Summary of Findings

Data from the various TMC institutions and facilities generally falls into one of the following three categories relative to stray current corrosion control significance:

- Category "1" – Non-existent, i.e. no Metro caused stray current effects detected.
- Category "2" – Metro caused stray current effects detected but of sufficiently low magnitude to represent no long term corrosion consequence, provided there is no increase.
- Category "3" – Magnitude of Metro caused stray current effects in the range where continued surveillance is appropriate to respond to possible increases over time.

The bar chart in Figure 5 presents the composite ranking (category) for each TMC facility evaluated, based on data from various structures and test points within that facility.

Based on data on the TECO piping system, there has been no readily apparent, substantial change (increase or decrease) in the Metro caused stray current influences over the last year.

At this point in time there is no reliable way to predict whether stray current conditions will increase further to unacceptable levels as the Metro system ages and or in the event an anomalous or other change occurs in Metro operations.

4.5 Stray Current Control Monitoring

Possible abrupt increases in Metro stray currents in the vicinity of TMC that can be of a long term corrosion control consequence (if not promptly corrected) will likely be related mainly to concentrated areas of decreased track to earth resistance. These "hot spots" will result in a corresponding increase in concentrated stray current electrical leakage. Specific, possible problematic conditions within and near the TMC complex include the following based on Metro track construction practices, corrective actions taken to date by Metro, and Corrpro experience:

- Lower track elevations where moisture and debris can accumulate and be retained around the track electrical insulating components, particularly when the insulating components are also subjected to increased mechanical wear and or damage, e.g. intersections, of which there are at least 12 along the rail line within the TMC Central Campus, and the Fannin Street underpass at Holcombe Boulevard.
- Crossovers, switches and signal circuits that have electrically operated and grounded equipment where the track electrical insulating components can sometimes fail resulting in a direct track to ground electrical short. In the vicinity of the TMC, this includes the single crossover in Fannin Street near Dryden Road, the signal for the Fannin-to-Braeswood transition south of Brays Bayou, and the pair of single crossovers at the Smith Lands passenger station in Greenbriar Drive.
- Special track construction used across the Brays Bayou Bridge on Fannin Street, particularly where the rails pass through the bridge expansion joints. While earlier track to earth resistance problems at this bridge have reportedly been corrected, mechanical vibration and wear can result in similar problems occurring in the future.

Long-term electrical surveillance of the above "hot spots", including the installation of permanent, unmanned remote monitoring units, should be an integral part of the stray current corrosion control monitoring for TMC facilities. This is because upset conditions at these locations are likely more readily detected and would typically be expected to have a greater corrosion impact.

Stray current data collected by Corrpro on the TECO energy piping in April, 2006 illustrated the effect rain can have on lowering Metro track to earth resistances with a corresponding increase in stray current effects under wet track conditions. For the three locations monitored, the rain resulted in increases ranging from 43% to 150% when compared to dry conditions. For 2006, a total precipitation of 51 inches and 80 precipitation days was recorded for Houston. The impact of rain on stray current conditions in the vicinity of TMC must be a definite consideration in establishing monitoring procedures.

4.6 Data Documentation

Figure 6 shows a sample data-logger recording. Referencing this figure as an example, the variations over time of the reinforcing bar to earth voltage are definitely caused by Metro generated stray currents. There is good agreement between when Metro does not operate the light rail line during the early morning hours and the lack of time varying reinforcing bar voltages during this same period. The magnitudes of the voltage variations at this particular location and time do not suggest a structural/corrosion problem requiring immediate remediation. However, like other TMC test locations, they are of sufficient magnitude to establish the basic need for implementing a stray current surveillance program to detect any changes over time that could influence long-term facility reliability and mission critical operations at TMC.

As part of the evaluation, TECO pipeline voltage data collected in April 2007 was compared with that collected in April 2006. The April 2006 data was obtained as part of Corpro's ongoing cathodic protection maintenance and monitoring program for TECO. From these data it is concluded that there has been little if any change in stray current influences at TMC over the last year.

Appendices 2 through 15 contain the various data collected during the stray current corrosion control evaluation. The data are organized by TMC facility with one or two summary tables at the beginning of each appendix. This information represents a thorough baseline and should be used for reference in designing and implementing the recommended stray current monitoring program.

4.7 Preservation of Electrical Test Connections to Structural Reinforcing Bars

Eighty-four electrical test connections to structural reinforcing bars have been made by Corpro. These connections should be preserved for monitoring that is essential for tracking stray current influences over time. Reasonable electrical surveillance is prudent to determine and adequately address possibly unacceptable stray current conditions which may occur in the future.

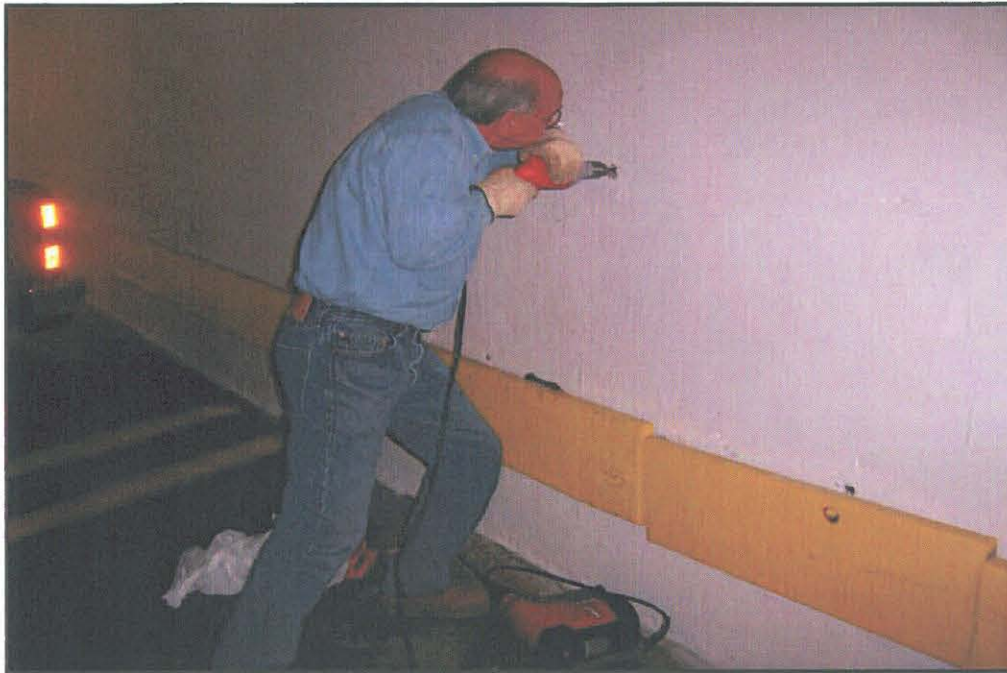
TECO has completed the installation of wall plates and test point identification labels for the electrical test connections. The photograph in Figure 1b illustrates a typical location.

TABLE 1 - Structures Evaluated

Facility Reference No. (Appendix)	Facility Name	Structural Steel Test Areas	Embedded Reinforcing Bar Test Connections	Electrical Ground Connections	Utility Pipelines
1 (2)	The Methodist Hospital	2	8	2	2
2 (3)	Texas Medical Center – Garage I	2	8	2	0
3 (4)	Texas Children's Hospital	2	8	2	2
4 (5)	Memorial Hermann Hospital	2	8	2	2
5 (6)	University of Texas Medical School	2	8	2	2
6 (7)	St. Luke's Medical Tower	2	8	2	2
7 (8)	Memorial Hermann Hospital Professional Building	2	8	2	2
8 (9)	Fannin Holcombe Garage	2	8	2	2
9 (10)	M.D. Anderson Cancer Prevention Center	2	8	2	2
10 (11)	Ben Taub	1	4	1	2
11 (12)	Meyer Building	2	8	2	1
12 (13)	Parking Lot East of Meyer Building	0	0	1	0
13 (14)	TECO Energy Piping System	0	0	0	9
-- (15)	Exterior Electrical Ground Connections	0	0	6	0
TOTALS		21	84	28	28

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a) Drilling Hole Through Concrete To Drill/Tab Test Connection Into Reinforcing Bar



b) TECO-Installed Wall Plate Over Test Connection

FIGURE 1 - Typical Structural Steel Test Point
Inside Face of Exterior Building Wall

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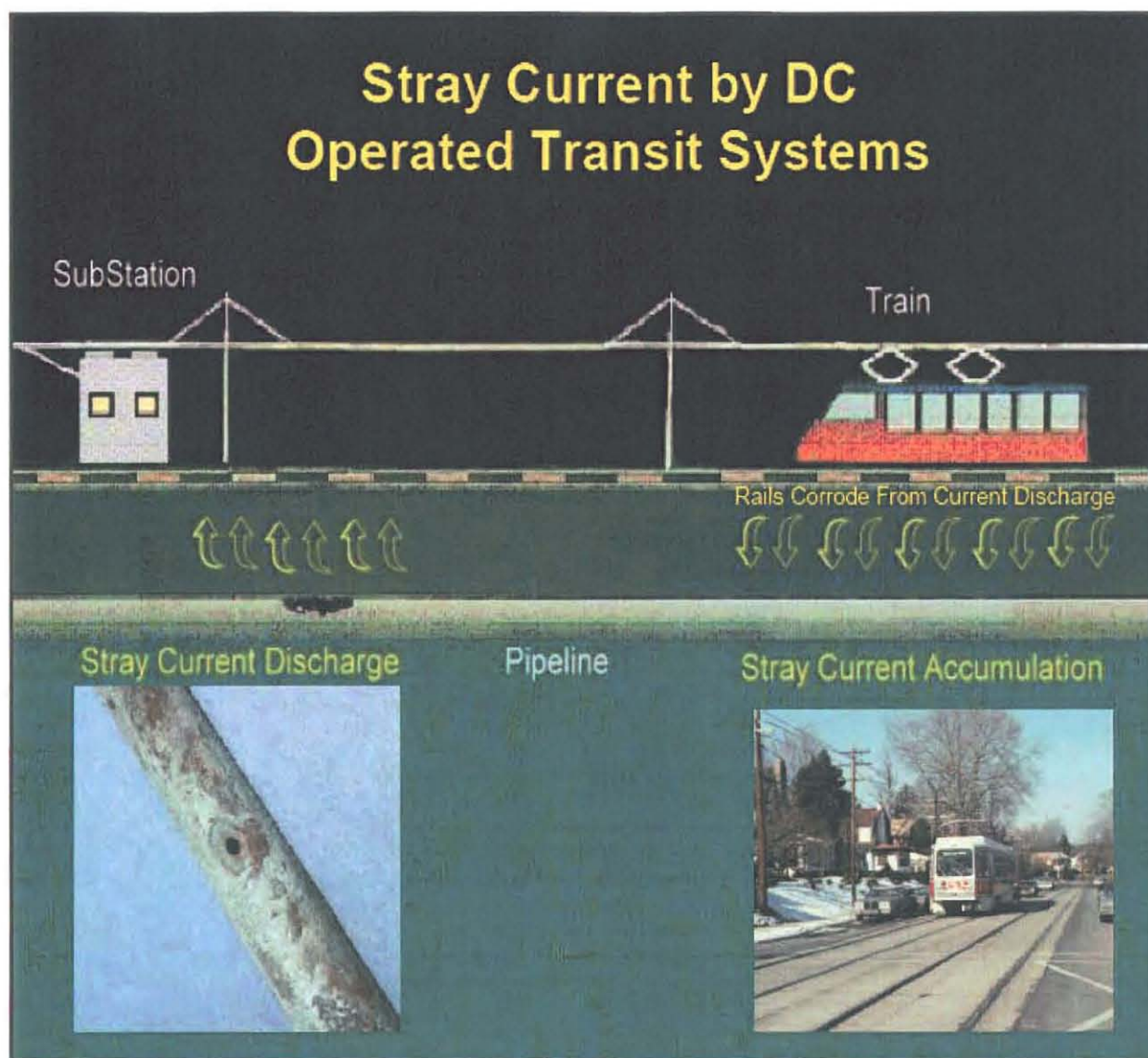


FIGURE 2 – Stray Current Leakage From DC Operated Transit Systems

Time-Varying Stray Current Discharged From Structure To Earth, 30% Duty Cycle	CORROSION DETERIORATION	
	STEEL PIPE	STEEL REINFORCING BAR
	1 Square Inch Having 0.25-Inch Wall Thickness, Complete Perforation	6-Inch Long Section of #4 Bar, 0.5-Inch Diameter, 50% Loss
1 Ampere	4.3 Days	10 Days
0.1 Ampere	43 Days	100 Days
0.01 Ampere	1.2 Years	2.8 Years
0.001 Ampere	12 Years	28 Years
0.0001 Ampere	120 Years	280 Years

FIGURE 3 – Stray Current Corrosion Deterioration Of Steel Structures

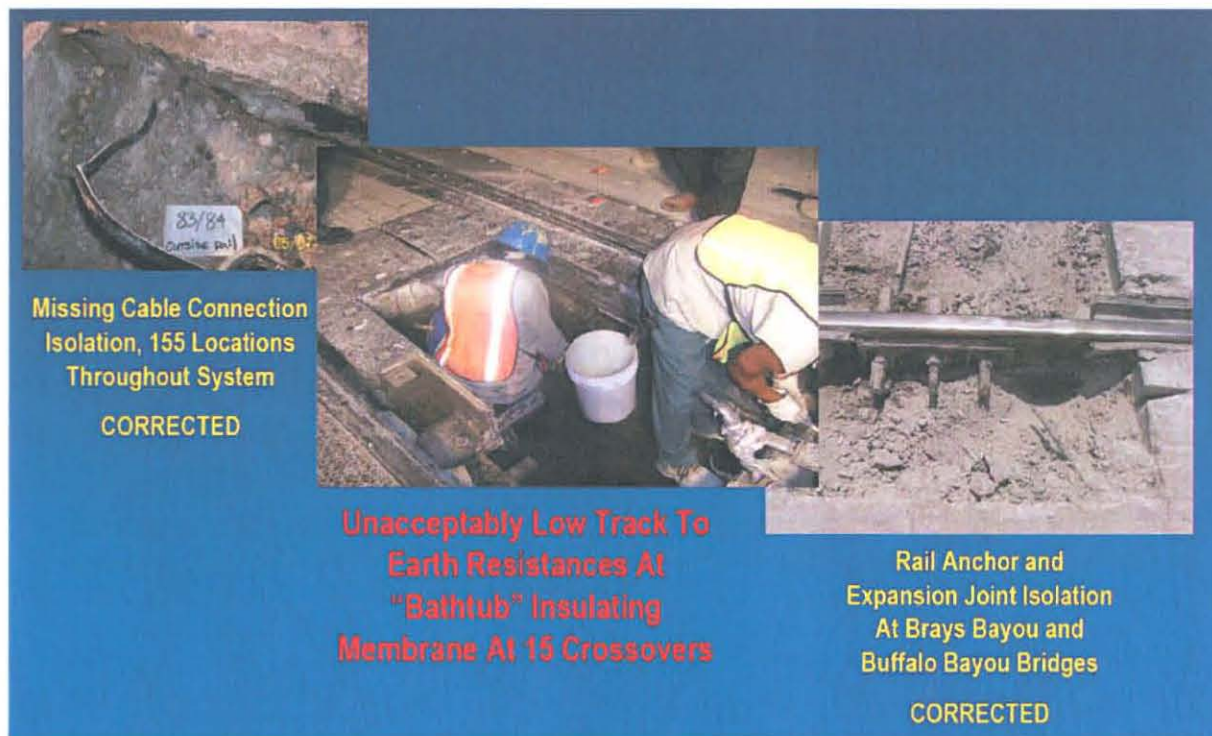


FIGURE 4 – Corrosion Control Construction Deficiencies Detected By Metro

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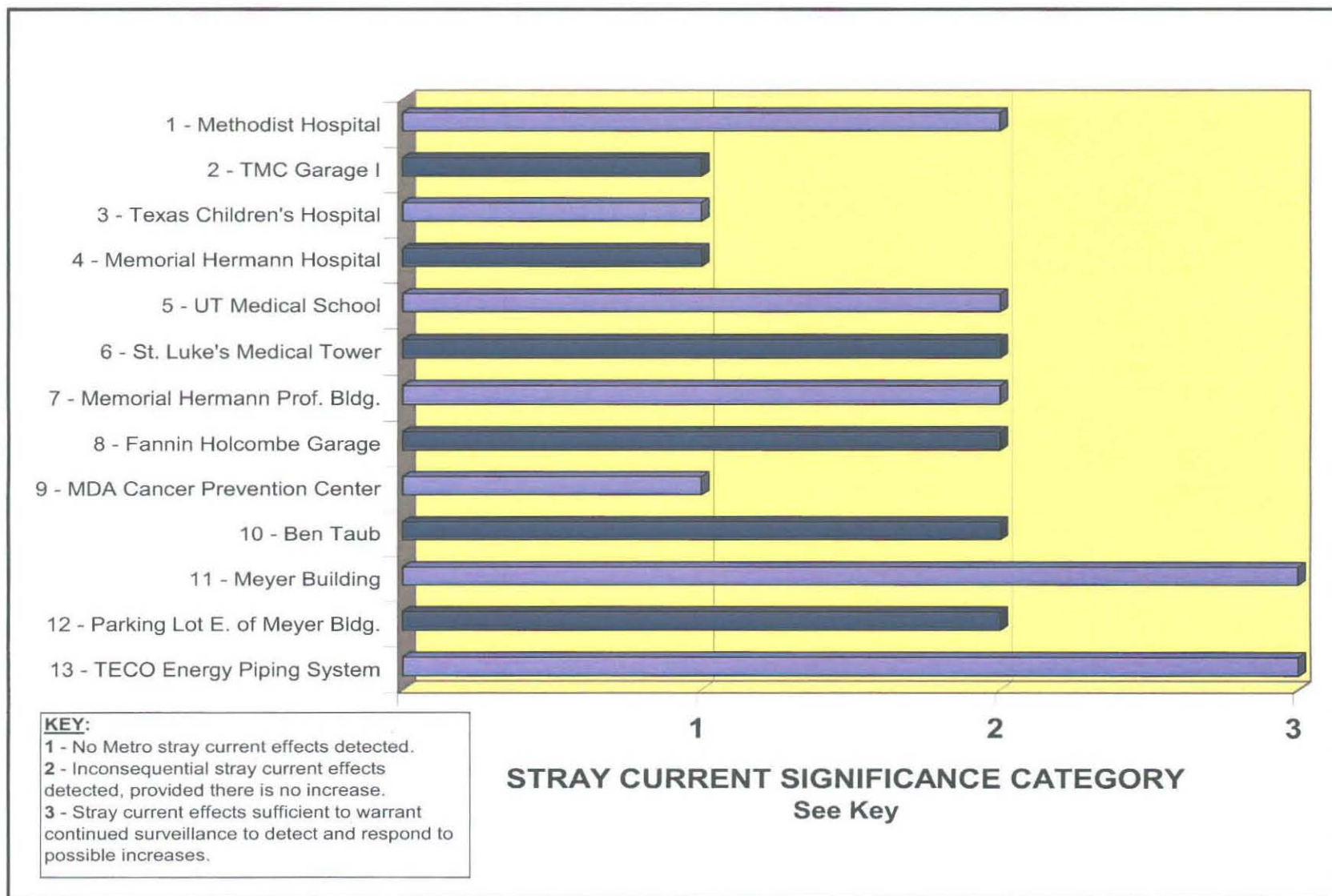


FIGURE 5 - Stray Current Corrosion Control Significance Summary

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MEYER BUILDING EXTERIOR WALL REINFORCING

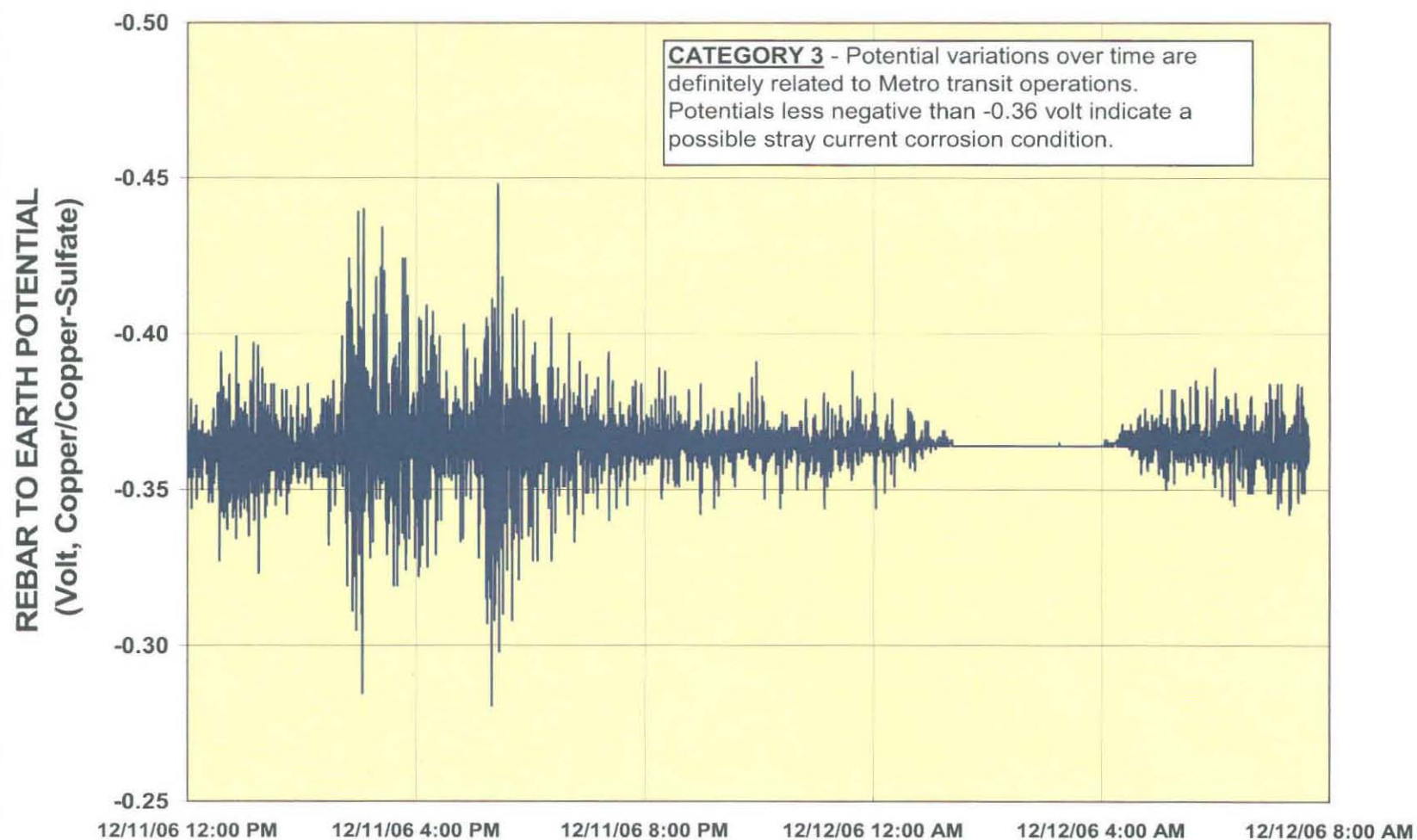


FIGURE 6 – Sample Stray Current Data, Significance Category 3

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