

LONG TERM CORROSION PERFORMANCE OF SOIL REINFORCEMENT IN MECHANICALLY STABILIZED EARTH WALLS

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ABSTRACT

Mechanically stabilized earth walls, MSEW, around Florida were instrumented through their concrete covers to survey corrosion rates of galvanized strip soil reinforcement by polarization measurements. The first broad survey was made 10 years ago as a baseline and a new survey is currently underway to assess long term corrosion rate trends. Initial results of an ongoing survey confirm low rates consistent with controlled backfill composition.

BACKGROUND

An MSEW is more advanced form of a retaining wall, often larger and being able to hold back more backfill. This is achieved by reinforcing strips or meshes (in the present case of galvanized steel) placed into the soil holding it in place by friction. The strips mechanically stabilize the earth while undergoing tension. The wall is covered with concrete medallions that connect to the reinforcements. The medallions have only a secondary structural role in holding up the wall but provide cover that protects the soil from washing away.

This configuration exposes metal to the soil environment with associated corrosion risk. If the reinforcement were to degrade prematurely by corrosion the soil could shift resulting in potential structural risk. Present durability criteria by Florida Department of Transportation (FDOT) establish a design service life of 75 years. To that end, FDOT specifies that the backfill in the walls meets electrochemical criteria (resistivity $> 3\ 000\ \Omega\cdot\text{cm}$; $5 < \text{pH} < 10$; soluble chloride $< 100\text{ppm}$; sulfate $< 200\text{ppm}$) chosen to minimize corrosion deterioration. Based on prior experience^{1,2} those criteria are expected to limit corrosion rates of less than $\frac{1}{2}$ mpy (13 $\mu\text{m}/\text{year}$) for the galvanized layers, which are consistent with tolerable residual reinforcement strength throughout the design life given usual reinforcement dimensions¹.

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Because widespread use of MSEWs began only about two decades ago, there is as yet only limited confirmation that the desired corrosion durability goals are being achieved. Moreover, environmental disturbances such as salt water inundation from hurricane surges may introduce adverse soil composition changes in otherwise well controlled MSEW soil backfill. Consequently, FDOT has sponsored periodic evaluations of MSEW reinforcement corrosion performance. This paper describes findings of those evaluations including baseline observations performed in the past and ongoing findings of a follow-up program.

METHODOLOGY

Eight FDOT MSEWs (Table 1) were selected ten years ago in geographically diverse places and with different amounts of time in service to determine reinforcement corrosion rates and find long term trends. A survey of the sites corrosion behavior was performed at that time and a follow up survey is currently continuing to verify the corrosion trends of the sites.

The field sites represented a collection of different ages in service and environments. At the time of the second survey all but one of the sites (No. 3) were still in use. The geographical variables were coastal vs inland character, and possible inundation with salt and fresh water. (Figure 1).

Periodic measurements at each site included determination of the potential of all of the buried elements with respect to a copper/copper sulfate electrode, CSE placed on the soil and on the surface of the concrete medallions, electrical resistance between the pair of elements in each set (using a Nilsson model 400 Soil Resistivity Meter), measurement of corrosion macrocell current in Structure 1A, and independent measurement of the corrosion potential and the polarization resistance (using a Gamry Reference 600 potentiostat) of each reinforcing element. Polarization Resistance Method (PRM) tests were conducted by shifting the potential (starting from the open-circuit potential) in the cathodic direction, at a scan rate of 0.125 mV/s. The test was interrupted when the potential reached 10 mV below the starting potential. The apparent polarization resistance was evaluated by taking the slope of the potential-current curve at 10 mV excursion and subtracting the ohmic drop. The counter electrode for the polarization-resistance tests was an adjacent reinforcement element, and an activated titanium electrode served as a reference. The electric resistance measurements provided (by application of a cell constant) an indirect indication of the in situ resistivity of the soil between the elements ².

The structures listed in Table 1 contained galvanized reinforcing strips except for structure 2, which has a galvanized reinforcing mesh with a diameter of 3/8 in. The galvanized strips were typically 0.16 in thick (except for Brickell Ave. where at lower elevations the thickness was 0.63 in. The reinforcements were typically 12 ft to 25 ft long; dimension details are given elsewhere ².

Typically 5 in-diameter holes were cored in the top and bottom concrete medallions of each panel set to accommodate permanent, externally accessible electrical connections to the reinforcement attached to that panel. Chiefly connections were made with stainless steel rods

clamped to the reinforcements. The holes were then filled with fresh soil and the concrete panels were patched with mortar. In Structures 1A and 1B, additional half-size galvanized reinforcing strips were installed, each having its own externally accessible electrical connection. The two halves were normally interconnected but the connection could be momentarily interrupted to permit measurement of the corrosion macrocell current.

Plain steel specimens were placed in the soil at the time of instrumentation in at least one panel of each of the sites examined. The plain steel specimens were usually placed halfway between the elevation of the upper and lower instrumented reinforcement elements. These specimens were intended to compare the behavior of the galvanized reinforcing elements with that of bare steel in the same soil. The specimens consisted of a 10 ft-long No. 4 plain steel rebar with the mill scale mechanically removed by steel wire brushing. An external contact was provided for each bar.

In addition to the connections to the soil reinforcement and to plain steel bars, activated titanium reference electrodes³ for polarization tests were permanently installed between the chosen reinforcement elements. An additional narrow hole was drilled in each panel set to permit temporary access by a copper-copper sulfate electrode (CSE) directly to the soil behind the panel.

FIRST SURVEY 1995-1997

From 1995 to 1997 data were collected on the sites to obtain a baseline representative of MSEW walls across the state. The soil in all sites was tested for pH, resistivity, pH, chloride content and sulfate contents. All of the sites were found to comply with FDOT backfill specifications, except for one instance in Structure 4B due to episodic direct contact of the wall with brackish water.

Visual examination of the reinforcement exposed at all the structures investigated revealed generally good to very good appearance of the galvanized surfaces. Microscopic examination of galvanized hardware extracted from the oldest wall in the State (Pensacola St.) showed only localized or partial loss of the galvanized layer and negligible corrosion of the plain steel substrate. Detailed examination of a newer wall showed negligible damage of the galvanized layer.

Field measurements of ACR of galvanized reinforcement are summarized in Figure 2a as a cumulative distribution¹. The rates had typically very low values, with an average of 0.04 mpy. The ACR of galvanized reinforcement did not vary significantly with age of the structure tested. The ACR of recently introduced plain steel rods had an average of 0.5 mpy. These values are comparable to the ones used in nominal service life estimates⁴. There was little correlation observed between the ACR of either material and the electrochemical properties of the soil in the low aggressively range explored.

¹ To facilitate comparison with current survey results the data for Structures 4B and 5, yet to be visited in the current survey, have not been included in Figure 2A. However, the overall distribution does not vary substantially upon introduction of those data¹.

SECOND SURVEY (2006-PRESENT)

The survey presently in progress started in 2006. As of the writing of this paper 5 of the 7 still extant instrumented sites were tested except for 4B and 5. The testing points were expanded at the Howard Frankland site where two additional sets of panels were instrumented and also served as sources for new soil and metal samples. The metal samples were cut from actual reinforcement (which in this bridge is in the form of rods welded as a reinforcing mesh as opposed to strips elsewhere) instead of being samples of attaching hardware, which had been the case in the previous survey for all structures examined ¹. The samples were sawed off the reinforcement directly next to the medallions, through the 5-inch diameter coring holes drilled through the medallion to install the test connection. The soil samples were extracted through the same holes.

This second survey repeated the same electrochemical measurements done previously across the sites. All structures were in good visual condition, except for corrosion of reinforcement of the medallions in Site No. 2. That corrosion was due to very low concrete cover of part of the concrete reinforcement, but does not appear to have affected the soil reinforcement. About 90% of the electric connections to reinforcement installed in the initial survey remained in good condition.

Figure 2b is a cumulative distribution summary of the entire apparent corrosion rate data set obtained to date from the polarization tests in the present survey. The overall distribution varied relatively little from that obtained in the previous survey (Figure 2a). Figure 3 compares the average and range ACR results from both surveys for galvanized reinforcement of each specific structure. The rates of both surveys were comparable also within individual walls, with possible exception of No. 8 but there were only three data available from the earlier survey.

The Brickell Ave. site offered the opportunity of comparing ACR of freshly placed reinforcement (first survey) and its aged condition. The cumulative distributions in Figure 4 support the expectation that the corrosion rate would decay somewhat with time as the surface developed a more mature nearly passive condition in a benign backfill environment.

The electrochemical tests are nondestructive but provide only an indirect indication of corrosion rate, subject to potential artifacts as discussed above. The samples obtained from the Howard Frankland Bridge in the present survey provided a unique opportunity of performing direct visual and metallographic assessment of reinforcement condition in a 17-year old structure.

Figure 5 shows the overall appearance of one of the samples extracted, typical of all others. To the naked eye the surface was free of rust or other major deterioration, and was light grey in appearance.

Typical metallographic cross sections of the extracted reinforcement coating are shown in Figure 6, illustrating a case where a significant portion of the coating thickness had been converted into corrosion products (right), and another instance where much less corrosion attack had taken place (left).

The thickness of the remaining coating and of the corrosion product layer was measured in a total of 80 random locations of the perimeter of 7 mesh wire cross sections, with results shown in Figure 7. The average remaining coating thickness was 4.3 mil, and that of the corrosion product was 2.0 mil. Assuming on first approximation that the corrosion was not appreciably expansive, the thickness of metal loss would equal that of the corrosion product, indicating that on average the eta layer was lost as well as much of the zeta layer. Since the structure was 17 years old at the time the sample was extracted, the nominal average corrosion rate of the galvanized coating was 0.07 mpy. This value is in the order of that determined by polarization measurements in this and the other structures, and provides independent confirmation that the rate of galvanized coating wastage is moderate and not exceeding the values commonly assumed for these structures when the soil satisfies current specifications ².

Examination of the remaining structures is in progress and results will be reported in a subsequent paper.

CONCLUSIONS

- The apparent corrosion rates in 13 to 25 year old MSE walls for galvanized steel were low (average 0.02 ± 0.01 mpy). This value was comparable to that obtained in a survey of the same structures performed 10 years ago, indicating a stable corrosion regime consistent with expectations of high durability based on meeting backfill criteria that limit aggressive conditions. Additional testing of remaining structures is in progress.
- Average galvanized coating corrosion rate estimated from direct metallographic examination of extracted reinforcement was in the same order as rates determined by polarization resistance measurements.

REFERENCES

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Table 1 - Table of Sites

Structure #	Site and Location	# of Test Clusters*	Age (Years)†	Regime and Rationale	Tested
1A	Brickell Ave. Bridge NW Wall, Miami	2	10	Coastal, Possible inundation	√
1B	Brickell Ave. Bridge SE Wall, Miami	2	10	Coastal, Possible inundation	√
2	Howard Frankland Bridge, Tampa	6~	13	Coastal, Possible inundation	√
3	Pensacola Ave., Tallahassee	4	N/A	Land, oldest in FL 10 years ago	N/A
4A	Palm City Bridge NE Wall, Stuart	4	15	Coastal, Possible inundation	√
4B	Palm City Bridge NW Wall, Stuart	2	15	Coastal, Tidal Saltwater Aggressive Regime	X
5	Port St. Lucie Blvd., Port St. Lucie	2	14	Coastal, Tidal Saltwater Aggressive Regime	X
6	State Rd. 200, Ocala	2	23	Land, Old, Long Term Baseline	√
7	Acosta Bridge, Jacksonville	2	17	Coastal, Non-Spec. Backfill	√
8	Veteran's Expressway, Tampa	2	12	Land, Representative of Present Practice	√

*Set of reinforcements instrumented for electrical contacts
 †Age of the structure when visited during the current survey.
 ~4 Original clusters and two new ones from 2006

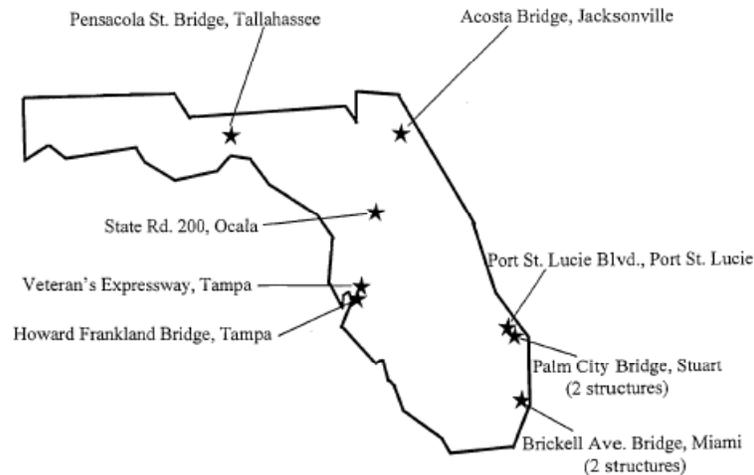


Figure 1 - Map of where the sites are located in Florida

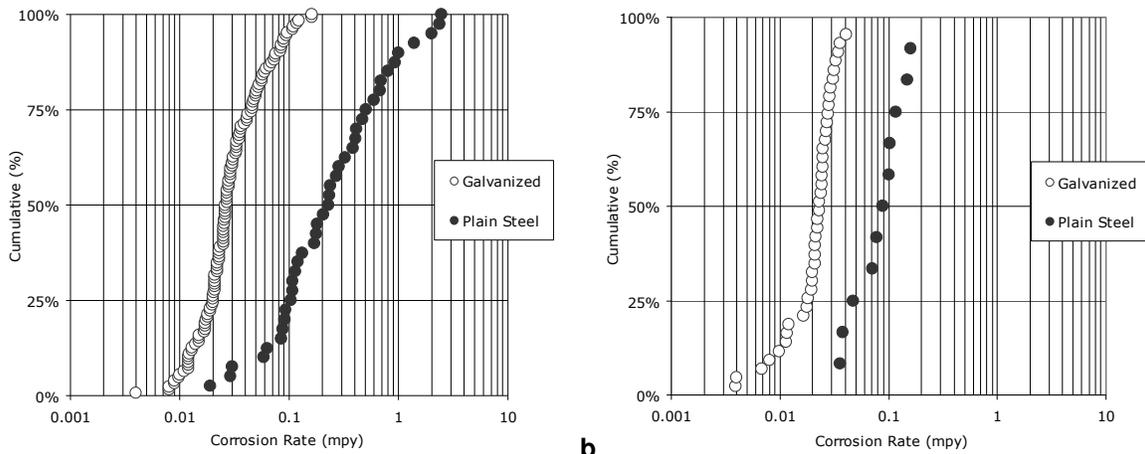


Figure 2 - (a) Cumulative percentage of apparent corrosion rates in MSE structures from the first survey. (b) Cumulative percentage of rates in MSE structures from the second survey.

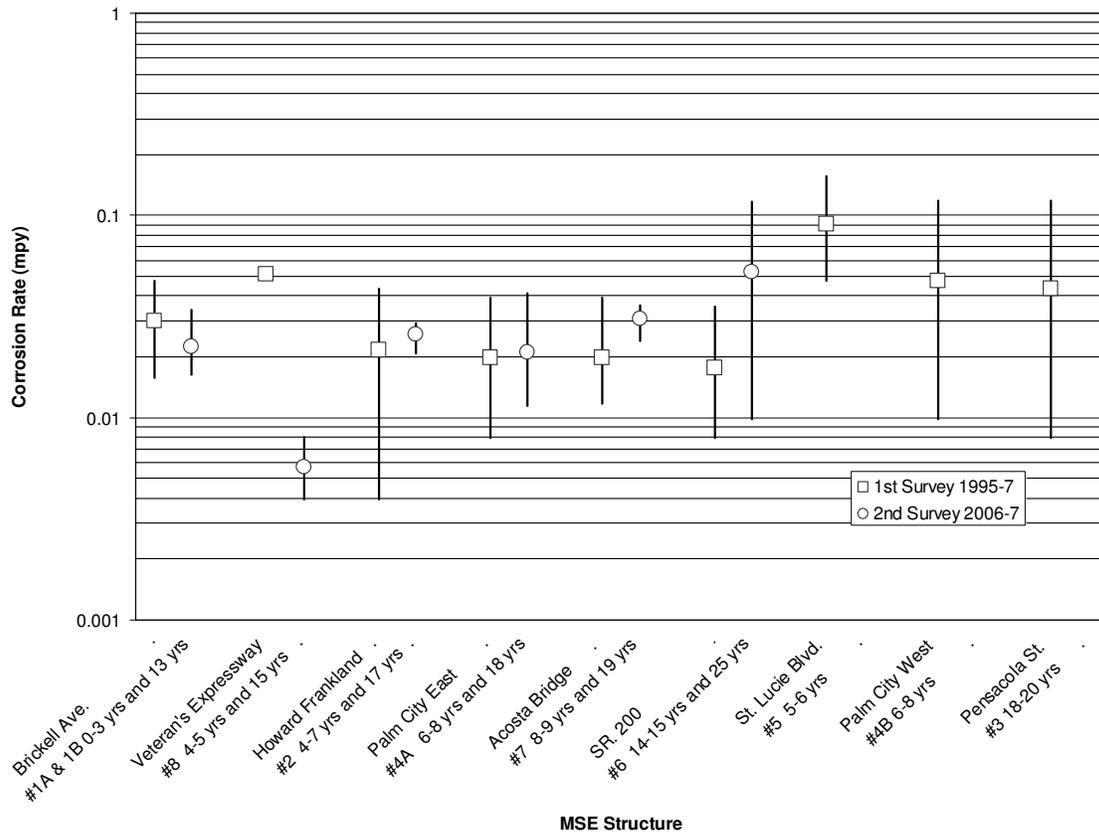


Figure 3 - Average and range of apparent corrosion rates of galvanized steel of the previous and present surveys (as available) for individual sites.

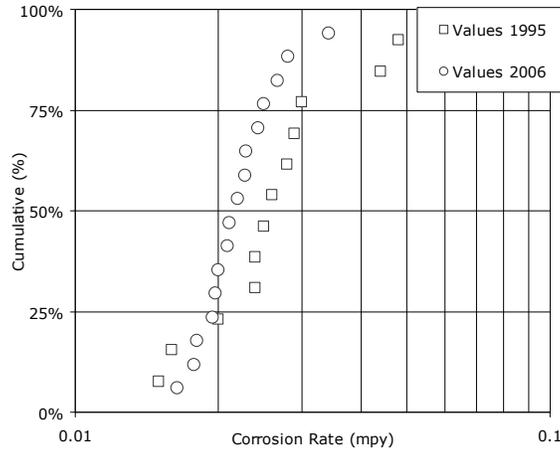


Figure 4 - Cumulative percentage of apparent corrosion rates in the galvanized strips in the Brickell Avenue Bridge's SE MSE Wall from 2006 and 1995.



Figure 5 - A sample from the Howard Frankland MSE Wall Reinforcement (3/8" diameter) cut up for metallography.

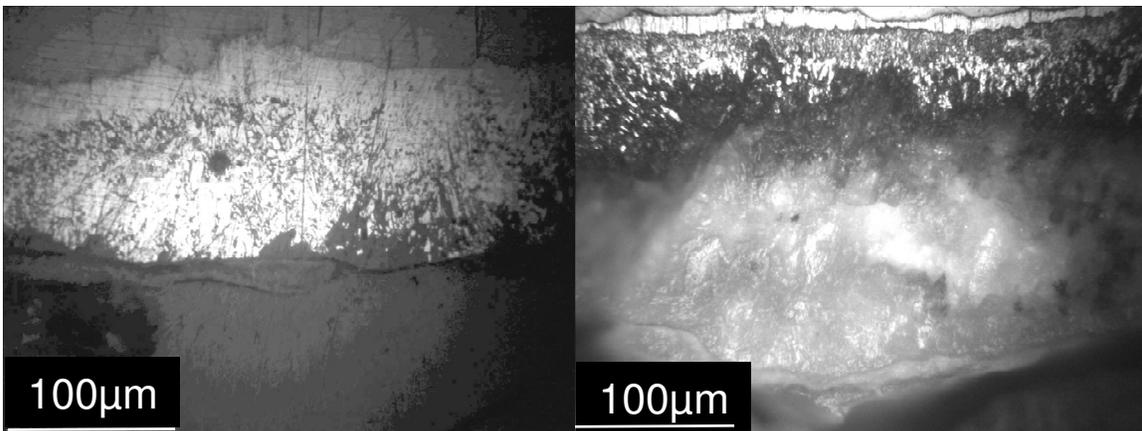


Figure 6 - Metallographic cross sections near the surface of the sample in Figure 5, showing (left) showing barely any corrosion and (right) a case of attack on the galvanized layer and a significant corrosion layer.

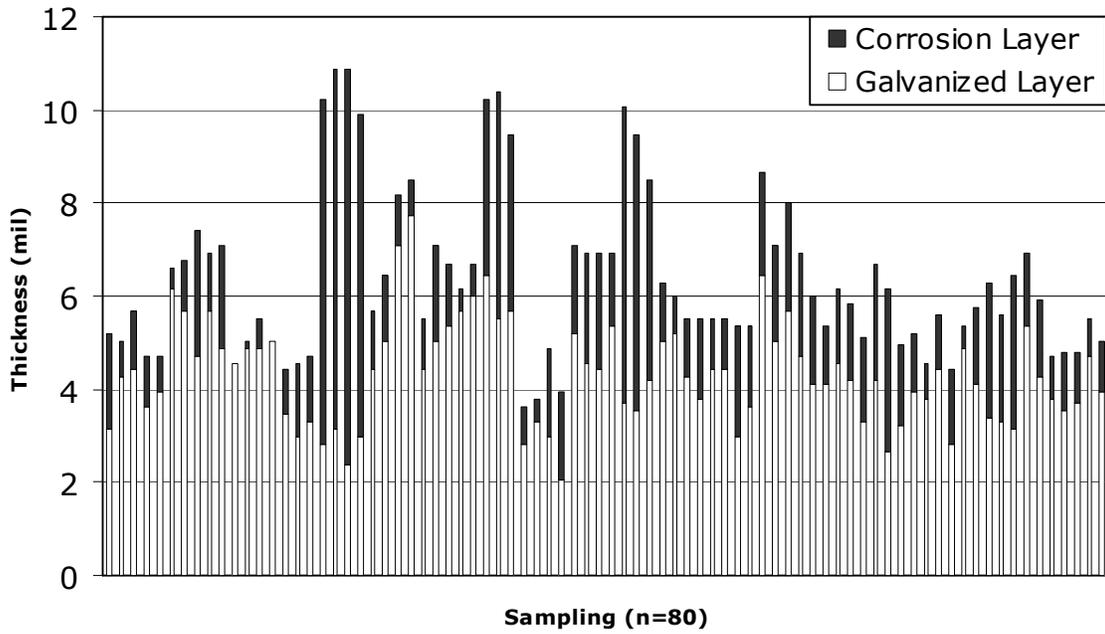


Figure 7 - Sampling thickness of the galvanized layer and the corrosion product.
Galvanized: 4.3 ± 1.1 mil
Corrosion Product: 2.0 ± 1.7 mil