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The performance of buried galvanized steel earth reinforcements after 20 years in service

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ABSTRACT: Reinforced Earth® was invented more than 30 years ago by French Engineer and Architect, Henri Vidal, Today there are thousands of Reinforced Earth Structures, reinforced with galvanized steel earth reinforcements, that have been in service for more than twenty years. Recently two of these structures, one in California and one in Virginia, were investigated. Samples of the galvanized steel earth reinforcements and samples of the backfill surrounding the reinforcements were retrieved from each of the structures. Measurements have been taken of the remaining zinc thickness, and the electrochemical properties of the backfill have been tested and confirmed to be within industry standards. The thickness of zinc remaining on the reinforcements is subtracted from the original zinc thickness, and the resulting loss in zinc is compared with the linear loss model used to estimate the service life of the zinc coating. After twenty years in service, the zinc coating is performing better than the loss model and no corrosion of the base metal has occurred. Similar findings are being discovered throughout the United States by Department of Transportation owners, as they unearth galvanized steel earth reinforcements in actual structures that have been in service for many years. These studies suggest that the linear loss model currently in use for the design of Mechanically Stabilized Earth structures may be overly conservative.

1 INTRODUCTION

Reinforced Earth® was invented more than 30 years ago by French Engineer and Architect, Henri Vidal. Today there are tens of thousands of Reinforced Earth structures in service worldwide. One very important consideration in the design of Reinforced Earth structures is the service life of the buried galvanized steel earth reinforcement. The corrosion resistance of buried galvanized steel has been studied for nearly a century, beginning with studies launched by The National Bureau of Standards (NBS) in 1910 and reported by Romanoff in 1957 [1]. Terre Armee Internationale carried out additional studies to extend the understanding of underground corrosion as it pertains to Reinforced Earth walls. Results of these studies were published by Darbin in 1986 [2].

Today, with thousands of structures having been in service for twenty years or more, there are many opportunities to retrieve galvanized steel reinforcing strip samples that have been in service for many years. The corrosion resistance of the retrieved samples can then be compared with the corrosion model currently used for design.

2 THE CORROSION MODEL

The following corrosion model is currently used for the design of Reinforced Earth structures.

Loss of Zinc (first 2 years):	15 um/yr
Loss of Zinc (to depletion):	4 um/yr
Loss of steel (after zinc depletion):	12 um/yr

The above metal loss rates were recommended in 1990 by Elias [3] for design of Reinforced Earth structures reinforced with galvanized steel earth reinforcements in backfill meeting the following electrochemical requirements:

Resistivity > 5000 ohm/cm @ saturation
pH > 4.5 <9.5

If the resistivity at saturation is less than 5000 ohm/cm, but greater than 2000 ohm/cm, the soluable salt content of the soil should be within the following limits:

Chlorides ≤ 100 mg/kg (PPM)
Sulfates ≤ 200 mg/kg (PPM)

Considering that a minimum zinc thickness of 86 um is required by specification, the zinc coating should be depleted in just 16 years based on the corrosion model.

3 RETRIEVAL OF REINFORCING STRIP SAMPLES

Galvanized steel reinforcing strip samples and select granular backfill were retrieved from two Reinforced Earth structures after nearly twenty years in service. One of the structures supports Route 101 in San Luis Obispo, California, and the other is located adjacent to Interstate Route 66 in Arlington, Virginia.

The San Luis Obispo structure was constructed in 1980, and the samples were retrieved twenty years later in 2000. The I-66 structure was constructed in 1979 and the samples were retrieved nineteen years later in 1998.

4 SAMPLING AND TESTING PROCEDURES

One coupon was cut from each of three reinforcing strip samples taken from each structure and labeled for ease of identification.

The samples were carefully cleaned of soil with a wire brush, making sure not to remove the zinc oxide on the surface. A thickness measurement was taken at three locations on each coupon using an LVDT extensometer. The extensometer is accurate to within three (3) microns (um). The coupon samples were then put into a saturated solution of ammonium acetate for fifteen minutes. After removing the samples from the solution, they were wire brushed to remove the zinc oxide. Some of the samples were re-immersed and brushed again until all of the zinc oxide was removed.

The coupons were rinsed with hot tap water, and then with distilled water, and then dried. A thickness measurement was taken at each of the three (3) locations on each coupon using the LVDT extensometer. On-half of the difference in thickness before and after removal of the zinc oxide represents the average thickness of zinc oxide per side.

The remaining zinc thickness was also meassured at the three locations on each coupon using a coating thickness gauge (electrometer).

The samples were then carefully measured and weighed prior to removing the remaining zinc by ASTM A90. The samples were then weighed to determine the mass of zinc removed. Based on the density of zinc, the average zinc thickness remaining on each sample is recorded and compared with the coating thickness measured by the thickness gauge. In all cases, the thickness gauge under estimated the thickness of zinc remaining. Samples of the backfill material were retrieved from each structure in the same area as the galvanized steel reinforcing strip samples were retrieved. The backfill samples were tested for gradation, resistivity and pH. The backfill materials were found to be within the acceptable range for use within a Reinforced Earth structure. The test results are presented in Tables 1 and 2 for the I-66 and San Luis Obispo structures respectively.

Of course the lineal loss model is a mathematical model for design and not intended to precisely model the actual behavior of the zinc coating.

However, if the model greatly under estimates the life of the zinc, the model will likely over estimate the loss of steel during the service life of the structure.

TABLE 1: I-66 ARLINGTON, VA.

Description	Well graded sand and gravel with 12.2 percent fines
Resistivity	19,090 OHM-CM @ SATURATION
pH	4.9

AVERAGE THICKNESS OF SAMPLE BY LVDT (μm)

Sample	As Received	After Removal of Oxide	Thickness of Zinc Oxide Per Side
Coupon 1	5207	5126	41
Coupon 2	5215	5131	42
Coupon 3	5136	5050	43
Average	5186	5102	42

THICKNESS OF ZINC REMAINING (μm/SIDE)

Sample	By Electrometer	By Weight
Coupon 1	31	40
Coupon 2	36	42
Coupon 3	36	46
Average	34	43

PERFORMANCE OF ZINC COATING

Estimated original zinc thickness	86 um/side*
Average thickness of zinc oxide:	42 um/side
Average thickness of zinc remaining:	43 um/side
Loss of zinc thickness:	43 um/side
Duration in service:	19 years
Loss of Zinc (first 2 years)	30 um/side
Loss of Zinc (subsequent)	0.76 um/yr/side

*Specified minimum thickness of zinc

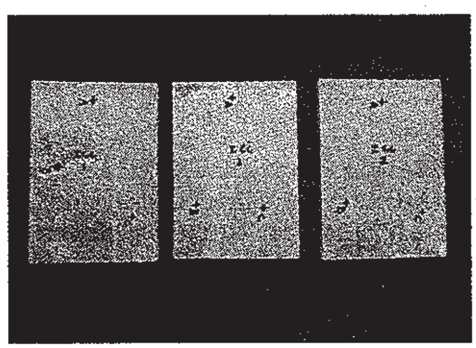

Figure 1. – I-66, Arlington, VA. Samples.

TABLE 2: SAN LUIS OBISPO, CA.

Description: Uniform medium sand with 8.5 percent fines
Resistivity: 54,000 ohm-cm @ saturation
pH 7.1

AVERAGE THICKNESS OF SAMPLE BY LVDT (μm)

Sample	As Received	After Removal of Oxide	Thickness of Zinc Oxide Per Side
Coupon 1	5382	5286	48
Coupon 2	5359	5304	28
Coupon 3	5385	5298	44
Average	5375	5296	40

THICKNESS OF ZINC REMAINING (μm/SIDE)

Sample	By Electrometer	By Weight
Coupon 1	66	81
Coupon 2	66	71
Coupon 3	61	66
Average	64	73

PERFORMANCE OF ZINC COATING

Estimated original zinc thickness	113 um/side*
Average thickness of zinc oxide:	40 um/side
Average thickness of zinc remaining:	73 um/side
Loss of zinc thickness:	40 um/side
Duration in service:	20 years
Loss of Zinc (first 2 years)	30 um/side
Loss of Zinc (subsequent)	0.56 um/yr/side

*Assume = thickness of zinc remaining + oxide thickness

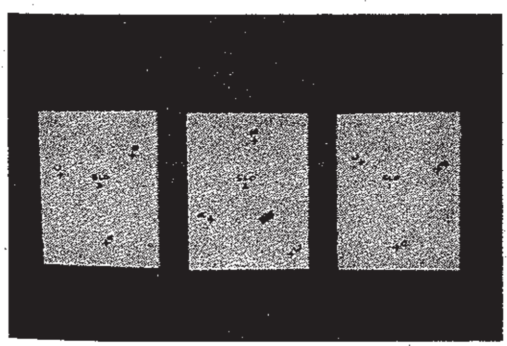

Figure 2. – San Luis Obispo, CA. Samples.

5 PERFORMANCE OF INVESTIGATED STRUCTURES

Reinforcing strips retrieved from San Luis Obispo and I-66 have a significant thickness of zinc remaining and a significant thickness of zinc oxide builtup on the surfaces of the strips. The zinc oxide essentially protects the zinc, and the zinc protects the base metal (steel) from corrosion. It appears that the zinc coating had not reached its half life in either structure, after nearly twenty years in service. No loss of steel was evident on any of the reinforcing strips in either structure.

6 INTERPRETATION OF RESULTS

Since the original thickness of zinc put on the reinforcing strip samples is not known, it can only be estimated by adding the thickness of zinc remaining to the thickness of zinc oxide built up on the surface. In the case of the I-66 samples, the original zinc thickness is estimated to have been about 86 um/side. This is the specified minimum coating thickness required for earth reinforcing strips. In the case of the San Luis Obispo samples, the original zinc thickness is estimated to have been 113 um/side.

It is interesting to note that the thickness of zinc oxide built up on the surface of the zinc was about the same (40 um/side) in both the I-66 and San Luis Obispo structures.

As generally agreed by experts of underground corrosion, the loss rate is generally greatest in the first few years and continues to decrease with time.

Applying the loss rate of 15 um/year/side for the first two (2) years, one can determine the subsequent loss rate of zinc for the remaining years such that the result is equal to the apparent loss of zinc over the 19 or 20 year period.

In both cases, the loss rate is less than one (1) um/yr/side. This loss rate is considerably less than the loss rate of 4 um/side recommended by Elias [3].

7 OTHER RECENT STUDIES

Saqüés et al has studied the corrosion performance of galvanized steel strips in nine (9) Florida DOT structures [4]. The age of the structures varied from two to seventeen years. For the most part, the backfill environments were within industry standards.

The following conclusion with regard to the apparent corrosion rate was reached by Saqüés: "The results of the field investigation showed that apparent corrosion rates (ACR) of the galvanized reinforcement were very small in most of the elements examined. The average ACR was 1.04 μm/y; and 95% of the elements tested had ACR <2.54 μm/y."

William Medford has monitored the corrosion resistance of galvanized steel earth reinforcements in five (5) North Carolina DOT structures [5]. The age of the structures varied from eight to nineteen years. The electrochemical properties of the backfill conformed with the required standards in four out of the five structures.

The zinc coating remained on the reinforcing strips in all five structures. The maximum loss of zinc was less than 2 μm/y with the exception of the structure with backfill outside of the required limits.

8 ADJUSTMENT IN THE LOSS RATES

As discussed in FHWA publication No. RD-89-186 [3], the long term zinc loss rate proposed by Stuttgart University for both non-saturated and saturated soils with resistivities greater than 1000 ohm-cm is 2 um/yr. This loss rate is taken after an accelerated rate for the first few years.

Using the Stuttgart model, Elias conservatively recommended that the zinc loss rate be taken as 4 um/yr. In light of the two structures investigated in this paper, the five investigated by Medford and the nine investigated by Saqüés, it appears that the zinc loss rate should have remained 2 um/yr as recommended by Stuttgart University.

Therefore, the loss rates for design should become:

Loss zinc (first 2 yrs):	15 um/yr
Loss of zinc (to depletion):	2 um/yr
Loss of steel (after zinc depletion):	12 um/yr

Comparing the above model to the results of this study, the loss of zinc after 19 and 20 years in service would be 64 um and 66 um respectively. Therefore at least 20 um of zinc would remain on the surface of the strip after 20 years in service. The above loss rates are still conservative when compared with the findings of this study. However, using the above model in the interim until we can confirm just how conservative it is, is a step in the right direction.

Based on the above loss rates the effective life of the 86 um zinc coating will be 30 years instead of only 16.

REFERENCES

Romanoff, M., Underground corrosion, NBS circular 579, U.S. Department of Commerce, 1957.

Darbin M., Jailloux JM, Montuelle J., La perennite des ouvrages en terre armee, Bulletin de Liason Laboratory Central des ponts et chaussees, Paris, France, Jan. – Fev. 1986.

Elias V., Durabiilty/corrosion of soil reinforced structures, report No. FHWA-RD-89-186, NTIS, Springfield, VA. December, 1990.

Saqüés A.A., Scott R., Rossi J., Peña J.A., Powers R. Corrosion performance of galvainzed strips in Florida mechanically stabilized earth walls. Transportation research board 78th annual meeting, January 10-14, 1999, Washington, D.C.

Medford W.M., Monitoring the corrosion of galvanized earth wall reinforcement. North Carolina Department of Transportation Field Investigation, not publish Presented at 78th annual meeting of TRB, January 13, 1999, Washington, D.C.