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This study presents the results of a corrosion survey of galvanized and plain steel elements used as soil reinforcement in mechanically stabilized embankment applications. The work is a continuation of previous research and evaluation by Caltrans of mechanically stabilized embankment methods and materials.

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Based on this study, recommendations are made for the use of galvanized steel elements. Suggested areas for future research are described.

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

# INVESTIGATION OF CORROSION AT 14 MECHANICALLY STABILIZED EMBANKMENT SITES


Study Made by................................Geotechnical Branch

Under the Supervision of.....................Robert W. Reynolds, Chief

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# CONVERSION FACTORS

## English to Metric System (SI) of Measurement

| Quality | English unit | Multiply by | To get metric equivalent |
|---|---|---|---|
| Length | inches (in)or(") | 25.40 | millimetres (mm) |
| | | .02540 | metres (m) |
| | feet (ft)or(') | .3048 | metres (m) |
| | miles (mi) | 1.609 | kilometres (km) |
| Area | square inches ($in^2$) | $6.432 \times 10^{-4}$ | square metres ($m^2$) |
| | square feet ($ft^2$) | .09290 | square metres ($m^2$) |
| | acres | .4047 | hectares (ha) |
| Volume | gallons (gal) | 3.785 | litre (l) |
| | cubic feet ($ft^3$) | .02832 | cubic metres ($m^3$) |
| | cubic years ($yd^3$) | .7646 | cubic metres ($m^3$) |
| Volume/Time (Flow) | cubic feet per second ($ft^3/s$ | 28.317 | litres per second l/s) |
| | gallons per minute (gal/min) | .06309 | litres per second (l/s) |
| Mass | pounds (lb) | .4536 | kilograms (kg) |
| Velocity | miles per hour (mph) | .4470 | metres per second (m/s) |
| | feet per second (fps) | .3048 | metres per second (m/s) |
| Acceleration | feet per second squared ($ft/s^2$) | .3048 | metres per second squared ($m/s^2$) |
| | acceleration due to force of gravity (G) ($ft/s^2$) | 9.807 | metres per second squared ($m/s^2$) |
| Density | ($lb/ft^3$) | 16.02 | kilograms per cubic metre ($kg/m^3$) |
| Force | pounds (lbs) | 4.448 | newtons (N) |
| | (1000 lbs) kips | 4448 | newtons (N) |
| Thermal Energy | British termal unit (BTU) | 1055 | joules (J) |
| Mechanical Energy | foot-pounds (ft-lb) | 1.356 | joules (J) |
| | foot-kips (ft-k) | 1356 | joules (J) |
| Bending Moment or Torque | inch-pounds (in-lbs) | .1130 | newton-metres (Nm) |
| | foot-pounds (ft-lbs) | 1.356 | newton-metres (Nm) |
| Pressure | pounds per square inch (psi) | 6895 | pascals (Pa) |
| | pounds per square foot (psf) | 47.88 | pascals (Pa) |
| Stress Intensity | kips per square inch square root inch ($ksi\sqrt{in}$) | 1.0988 | mega pascals$\sqrt{metre}$ ($MPa\sqrt{m}$) |
| | pounds per square inch square root inch ($psi\sqrt{in}$) | 1.0988 | kilo pascals$\sqrt{metre}$ ($KPa\sqrt{m}$) |
| Plane Angle | degrees (°) | 0.0175 | radians (rad) |
| Temperature | degrees fahrenheit (F) | $\frac{+F - 32}{1.8} = +C$ | degrees celsius (°C) |

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# INTRODUCTION

This paper presents an investigation of corrosion to steel used as reinforcement in fourteen reinforced soil embankment walls constructed by the California Department of Transportation (Caltrans) between 1972 and 1983. The fourteen walls comprised five wall systems: three concrete-faced and one wood-faced Mechanically Stabilized Embankments (MSE), two concrete-faced and one steel-faced Reinforced Earth (RE) Walls, four Hilfiker Welded Wire Walls, one Salvaged Guardrail Wall (SGR), and three Tire Anchor Timber Walls (TAT).

Corrosion has been an important design concern since construction near Los Angeles of the first reinforced soil wall (1) by Caltrans in 1972. Empirical information generated by the National Bureau of Standards (NBS) (2) on corrosion of steel in various soils has been the primary source of data. The Caltrans Interim Design Criteria for corrosion of earth retaining systems (3) is based on relevant data from the NBS report. Since 1984 it has provided corrosion loss estimates (design values) for steel reinforcing elements based on soil type and years of service.

The Caltrans Interim Design Criteria was developed based on a review of the NBS data to determine the best correlation between soil pH and minimum resistivity and corrosion loss versus years of exposure. However, since the scatter of the data selected was too great to develop either nomographs or multiple regression equations relating corrosion loss to these parameters, a simpler straight line approximation (zero time to maximum reported exposure time) was used.

The NBS soils data were initially separated into four categories: "Very corrosive" (minimum resistivity (R) <1000 ohm-cm and CI->500 ppm and $SO_4$->2000 ppm); "corrosive" (R <1000 ohm-cm); "acidic" (R ≥1000 ohm-cm and pH <7) and "neutral and alkaline" (R ≥1000 ohm-cm and pH ≥7); a subset to each of the above was later added describing well aerated (i.e. free-draining) soils acknowledging that free-draining granular backfill was probably less corrosive than one which retained moisture.

Since, in nature metals do not corrode in soil in a uniform manner, loss of cross-sectional area will be greater along an element where either pitting or broader but still localized corrosion occurs than a loss computed by distributing corrosion uniformly over the whole element. As interpreted by Caltrans, the NBS data showed that corrosion in the regions of the deepest pits occurred to a depth up to five times the fictitious uniform loss. Since agressive pitting would not likely affect a large cross-sectional area of an element, or occur except at a relatively small percentage of sites, Caltrans assumed a factor of two above the statistically expected uniform rate. Hence, the Caltrans Interim Design Criteria should not be construed to imply either uniform corrosion or to predict the actual rate at a particular location, nor does it imply a "safety factor". Rather, it provides a design corrosion rate that accounts for some pitting and heavier localized corrosion.

In 1979, Caltrans Office of Structures Design instituted a policy to monitor wall performance and corrosion losses. During construction of several MSE walls inspection rods (non-stressed steel elements indentical to soil reinforcement elements) were incorporated at various locations through the wall face and at various distances into the fill. These rods are to be pulled for corrosion loss testing at given intervals throughout the design life of the project. Other reinforced soil wall systems constructed prior to that date could have pieces of their reinforcement exhumed for such testing if necessary.

As directed by the policy, inspection rods were retrieved from near the base of a 24-foot high MSE wall in Mariposa County (State Route 140) in June 1985, about 6 years after construction. These rods exhibited significant pitting and high corrosion losses. This finding prompted an immediate and systematic survey for corrosion effects at thirteen other sites (locations and descriptions of all sites can be found in the Appendix). The survey indicated corrosion losses at these thirteen sites were less than design values. However, two phenomena were uncovered. First, the steel in a MSE wall utilizing predominately silty gravel as backfill exhibited much higher corrosion in the three feet nearest the wall face than farther back. Second, several flat galvanized steel strips from two sites had much higher zinc consumption on their upper surfaces than on their bottom surfaces.

To achieve some understanding of the corrosion loss variations among the projects, extensive analysis of mineral and physical composition of both the steel and soil was undertaken including the moisture content and electrical half-cell potential of the soil. Also evaluated, as applicable, was a visual inspection of the concrete face panels for spalling or other indications of corrosion internal to the panel. Steel elements and soil backfill test specimens were generally retrieved from the uppermost layers of the reinforcement, although at some walls retrieval was accomplished from levels near the wall base.

Test data are presented in detail and observations are stated regarding corrosion losses for the projects studied herein. Corrosion losses to the soil reinforcement from four sites where plain steel reinforcement were used are compared to selected data from the NBS study. Data reported herein were developed from a limited sampling of steel elements and do not necessarily represent average corrosion throughout an individual site.

## SUMMARY


Soil reinforcement elements from fourteen mechanically stabilized embankments were inspected for corrosion. Inspection wire (non-stressed steel rods) or actual soil reinforcement sections were retrieved from all sites. Excavation to retrieve the soil reinforcement generally occurred in the uppermost 3 to 4 feet of the wall backfill close to the wall face; in some cases, excavation involved breaking through the wall facing near the wall base.

Soil types used for backfill varied widely, from sandy clays to well graded gravels. Saturation level of the backfill at the time of sampling were estimated as between 30 to 95% with most samples estimated to exceed 65%. (At time of construction, backfills are typically placed between 65% - 85% saturation.)

Corrosion to the steel base metal was virtually nonexistent for sites where galvanized steel was employed. Zinc was being consumed but observed to be covering, almost fully, all steel elements inspected. Due to the unknown thicknesses of the original galvanized layers, zinc consumption rates could not be calculated. However, visual inspection of exhumed reinforced earth straps revealed, in all but one instance, what appeared to be higher zinc consumption on the upper surface relative to the bottom or lower surface. Testing confirmed the visual observation and indicated about 30 to 60% more zinc remaining on the bottom surface.

Corrosion was apparent at the four sites using plain steel as soil reinforcement. Corrosion was judged to be more or less uniform in nature at three sites, but one site (Mariposa) exhibited serious pitting on all inspection rods.

The inspection rods at Mariposa which suffered pitting were

taken from the lower two-thirds of the wall. Pitting affected about 2% of the surface area. The corrosion for the more uniformly corroded sections of the inspection wires (excluding the pitted areas) exceeded the Caltrans' design value by 167%. Backfill consisted of a predominately rocky fraction set in a matrix of cohesive fines.

Soil reinforcement sections taken from the same site but from within three feet of the surface corroded in a more or less uniform fashion with corrosion equivalent to 25% of the design value. Backfill surrounding these elements classified as a well-graded clayey gravel.

The remaining three sites exhibited primarily uniform corrosion that ranged between 17 and 88% of that assumed by the Caltrans' design value. Soil at these sites classified as silty gravel.

Interestingly, the inspection rods at one of these sites (Baxter) exhibited more corrosion on that portion of the inspection rod located within three feet of the wall face than the corrosion found on the steel farther back. Very little difference in moisture content, soil gradation or salt content was measured at selected locations at this site. Density measurements were not taken of the frontal three feet but it was apparent from material extraction resistances of the backfill that this zone was much looser than the material farther back.

Steel compound additives such as sulfur, manganese, phosphorus, silicon and carbon content were measured on samples from all sites. Due to the limited number of samples it was not possible to quantify the effect (if any) of the steel compound additives against corrosion activity.

Saturated samples of the backfill were tested for water soluble iron (Fe) in the leacheate; an analysis showed a higher content at the Mariposa site (from 0.45 ppm to 1.6 ppm) than the other sites where plain steel was used (0.10-0.32 ppm).

Wall systems using concrete face panels (MSE and RE) were visually checked for corrosion at the connection point between concrete face panel and the steel element; no increased corrosion activity was noted.

Electrical potentials were measured at all sites. The reference cell was a copper-copper sulfate half-cell; the positive probe was attached to the soil reinforcement element and the negative probe was placed in nearby ground saturated for purposes of the test. On the postconstruction basis with randomly selected locations for measurements used in this project, no apparent relationship between corrosion activity and electrical potential was observed. This was likely due to the geometry of the reinforced soil walls hindering appropriate placement of the half-cells.

Corrosion variations along individual elements from locations within the same wall were seen to exist in both galvanized and plain steel sites.

## OBSERVATIONS

The following observations are based on the sampling conducted for this report.

### PLAIN STEEL SITES

1. Serious pitting and corrosion losses higher than design values were observed at Mariposa on elements located within a predominately rocky fill with cohesive fines. On elements located within backfill that was fine-grained, cohesive and rock content limited, pitting was not observed, and corrosion activity lower.

2. Corrosion of steel exhibited higher losses in loose soil than in denser soil all other factors being similar.

3. At sites where nonplastic, well-graded fine-grained or well-graded coarse-grained soil was used, corrosion losses were lower than the design values.

4. For this study, there was no apparent correlation between half-cell potential and corrosion activity. A series of measurements over time at discrete preselected locations may give indications of relative corrosion activity.

5. The connections between concrete face panels and steel reinforcing elements were not observed to have corrosion losses different than any other portion of reinforcement.

6. The resistance-welded cold-rolled steel used in the MSE applications showed no localized corrosion at weld points.

## GALVANIZED STEEL SITES

1. Connections between concrete face panels and steel reinforcing elements were not observed to have corrosion losses different than any other portion of the reinforcement.

2. Zinc acted as an excellent sacrificial coating for delaying steel corrosion.

3. Galvanized steel exhibited similar corrosion behavior in both plastic and nonplastic fine-grained and coarse-grained backfill.

4. The zinc coating cn the upper surface of the steel reinforcing strips for two projects showed corrosion losses estimated as 30-60% above those on the bottom surface.

# RECOMMENDATIONS

Based on this investigation, the following recommendations are made:

1. Placement and periodic evaluation of inspection wires should continue for all reinforced soil earth retaining systems and information such as contained herein should be developed and maintained on a permanent basis.

2. At the Mariposa site, new reference inspection wires should be placed and evaluated on a 1 to 2 year interval. In order to provide a basis for future evaluation, wires should be documented with respect to size. Both plain and galvanized wires should be placed. Evaluation should be continued for a minimum of 10 years, or longer if estimated initial corrosion rates do not show a drop-off in time.

3. No change is recommended to the Caltrans Interim Design Criteria regarding corrosion losses for plain steel elements.

4. Galvanized steel soil reinforcement is recommended for all future contracts.

5. A research project should investigate the corrosion variations (top versus bottom) experienced by steel straps placed between soil lifts compacted to different densities.

6. Consideration should be given to the development of a totally corrosion resistant reinforcement system. Fiberglass rods, epoxy-coated steel wire, or doubly protected steel rods (plastic-encased cement over steel rebars) are three suggested methods.

## IMPLEMENTATION

1. Increased sampling of soil reinforcement and backfill has been effected through a memorandum issued by the Office of Structures Design dated November 18, 1986 (File 852). A permanent database recording this data will be developed and maintained jointly by the Corrosion and Geotechnical Research Units of the Transportation Laboratory.

2. An increased number of inspection wires will be placed on all future reinforced soil embankment walls to allow more frequent monitoring of corrosion losses.

3. By memorandum from Translab to the Office of Structures Design dated October 6, 1986, it was recommended that specifications for future projects require that steel soil reinforcement be galvanized. Effective date of implementation is the responsibility of the Office of Structures Design.

# FIELD AND LAB DATA

This section briefly discusses the collection of field samples, corrosion measurements, site conditions, and probable factors outside the electro-chemical characteristics of the soil which stimulated corrosion. Charts and figures regarding possible correlations between corrosion and various soil and steel parameters are presented along with the Caltrans Interim Design Criteria and FHWA design values for corrosion losses. Provided in the Appendix is other detailed information on the wall systems, general design philosophy, basic mechanisms of corrosion, site descriptions, and the details of individual site investigations.

Corrosion losses discussed herein represent an average value based on a series of measurements on soil reinforcement specimens whose corrosion was more or less uniform. Corrosion losses were determined as follows: Original dimensions on retrieved inspection wires were measured by micrometer on an area of the wire protected from the air and earth. Measurements were taken at random locations along the nonprotected portion of the specimen and these measurements were compared to the original dimensions. Dimensional tolerances for all plain steel specimens were given by ASTM A82 as ±0.004 inch. In the absence of actual measurements taken on protected portions of a specimen to establish the original dimension, the nominal dimension was assumed.

For the four sites which employed plain steel reinforcement, corrosion loss data are presented along with selected National Bureau of Standard data.

## A. <u>Plain Steel Sites</u>

### 1. Site 1 Mechanically Stabilized Embankment

At the time of inspection the MSE wall at Site 1 (Mariposa) has been in service 6 years. Backfill in the upper one-third of the wall was different than the lower two-thirds of the wall. Backfill in the upper one-third portion of the wall consisted of 34% gravel, 31% sand, and 35% fines and exhibited the following properties: minimum electrical resistivity (R) = 3,500 ohm-cm, plasticity index (PI) = 7, soil acidity (pH) = 6.6. Backfill in the lower two-thirds of the wall consisted of 56% gravel, 25% sand, and 19% fines and exhibited the following properties: R = 3700 ohm-cm, PI = 11, pH = 6.6. Corrosion inspection of the upper one-third of the wall was obtained by exhuming bar mat sections and in the lower two-thirds of the wall by examining inspection rods. Exhumed bar mat sections were taken at a point ten feet behind the face at the one foot and three foot depths. Sampling occurred in the summer and surface soil moistures were low with saturation levels estimated at 30% at the one foot depth and 40 to 50% at the three foot depth. (Data on soil moisture for all sites found on Table IIB is reported as moisture content (%) rather than a saturation level (%) due to sampling techniques.) The exhumed steel bar mats showed corrosion losses equivalent to 25% of the design values.* Pitting was minimal.

Five 10-foot long inspection rods that were retrieved from the lower two-thirds of the wall exhibited higher corrosion than the steel sections exhumed from above. Saturation of the backfill in this lower section was estimated at over 90%. Measured (uniform) corrosion exceeded the design value by 167%. Pronounced pitting (deep, conically shaped holes) was observed in localized areas and covered an estimated 2% of the surface area.

Reasons for the high corrosion within the lower portion of the wall are speculative. Initially, sulfate-reducing bacteria were suspected since the inspection rods, when retrieved, the design exhibited a black coloration which changed to a brownish,

* Note that here and below, the design value referred to is the Caltrans Interim Design Criteria.

rust color soon after exposure to air. Also, during the sampling operation a distinct musty odor was reported by the field personnel. Both of these conditions are associated with sulfate-reducing bacteria (5, 7, 11, 12, 13, 14). However, the bacteria are reported to thrive only under anaerobic conditions and requires organic materials in the soil. The backfill around the inspection rods was characterized as very porous and free from organics making the necessary conditions unlikely to be achieved. Definitive testing was done to determine the presence of sulfide, a waste product of sulfate-reducing bacteria. Two inspection rods were treated with a 10% (volumetric) sulfuric acid ($H_2SO_4$) solution immediately upon removal; no sulfide was liberated, therefore eliminating the bacteria as a possible cause of the pitting.

While not explicative, conditions which are likely to cause pitting and high corrosion are the presence of moisture, moisture-retentive cohesive fines and a high soil porosity of the backfill. These conditions exist in this portion of the wall.

2. Site 2 Mechanically Stabilized Earth

At the time of inspection the MSE wall at Site 2 (Baxter) had been in service for 3 years. The five 10-foot long inspection rods that were retrieved from the lower half of the wall exhibited two distinct areas of corrosion activity; the first three feet, and the remainder of the rod. The front three feet exhibited losses more than three times that of corrosion on the remainder of the rod, and were equivalent to 88% and 25% of the design values, respectively. A hand-excavated bar mat sample removed from the top layer of reinforcement at the one foot depth immediately behind the wall face showed corrosion losses as equivalent to 88% of the design value. Pitting on all samples, by visual inspection, was minimal. Welds were visually inspected and showed little corrosion.

Reasons were sought to account for the distinct levels of corrosion. Since the surface of the backfill is paved to within three feet of the wall face, it was assumed that increased moisture content in the front three feet of backfill due to the infiltration of salt-laden water from roadway deicing operations was responsible. However, lab tests conducted for this project and values reported as part of other work (5) revealed reasonably uniform soil gradation, moisture content (with saturation levels between 80-90%), and low salt contents throughout the backfill. The only difference noted was soil density, and this subjectively. Material in the front three feet provided very little resistance to soil sampling probes relative to high resistence in the soil farther back. This signified a much looser density state in the first three feet. Thus, it is suspected that the higher initial oxygenation in the looser soil was a factor in the higher initial corrosion rate. Initial rates of corrosion are known to be associated with oxygen availability; an abundant availability of oxygen is usually associated with a high initial corrosion rate (19).

Contract specifications for this and all other walls studied herein required hand compaction equipment within three feet of the wall face and likely resulted in a lower density than the machine compacted areas especially due to the fine grained nature of this backfill. Differential compaction has been reported as a cause of corrosion (7, 14) and the frontal zone of backfill has been reported as the typical location of maximum corrosion activity (18).

Backfill samples tested for this study tested as nonplastic, but some preconstruction tests indicated plasticity indexes as high as 11 in certain test samples (5). Thus, high percentages of plastic or nonplastic fines is not the causative factor promoting rapid initial corrosion on this project. Fines support water retention, but availability of oxygen (with soil porosity as the index) is needed to promote the oxidation process - at least on an aggressive scale. Other investigators are also aware of this (6, 7, 8, 9, 14, 19) and information herein is supportive of those findings.

3. Site 3 Mechanically Stabilized Earth

At the time of inspection the MSE wall at Site 3 (Dunsmuir) had been in service 9 years. No inspection rods were installed. Sections of the soil reinforcement were exhumed from locations two feet behind the wall at depths of one and three feet. Measured corrosion losses were equivalent to 17% of the design values. No pitting was observed. Weld points showed little corrosion. Excavated backfill classified as a nonplastic gravelly sand with a median soil pH of 6.2 and minimum resistivity of 14,300 ohm-cm. Moistures were fairly high due to recent rains and saturation was estimated at between 80 and 90%. Retrieval of soil reinforcement from the lower section of the wall was not attempted.

4. Site 4 Mechanically Stabilized Earth

At the time of inspection the wood-faced MSE wall at Site 4 (Santa Barbara) had been in service 7 years. This site is the only wood-faced MSE wall. No inspection rods had been installed. A barmat section was retrieved from a point about two feet behind wall and at a depth of two feet. Despite low soil resistivities, corrosion was found to be equivalent to 17% of the design value. No pitting was observed. Welds showed little corrosion. Backfill material classified as a silty sand with a pH of 7.5 and minimum resistivity of 800 ohm-cm. Saturation at time of testing was estimated between at 60 and 80%. No sampling was attempted in the lower section of the wall.

## 5. Discussion

While realizing corrosion is a complex and interactive phenomenon, efforts were made to isolate specific site conditions which led to the corrosion variations. Amount and type of steel additives (carbon, silicon, manganese, phosphorus, and sulfur) in the soil elements were determined but no correlation was noted with respect to corrosion, in part possibly due to limited data. Specific soil characteristics such as chlorides, sulfates, soluble iron, pH, resistivity and plasticity were also compared - only the soil plasticity and soluble iron content appeared significantly different at Site 1 when compared to the other plain steel sites. Some literature (7, 13) is available to support a relationship between high corrosion and soluble iron content; however, at the concentration levels found, it is not believed an important factor in corrosion at the sites described herein. One site where galvanized steel was employed (Site 10, discussed later) indicated a higher soluble iron content (2.2 ppm versus form 0.45 to 1.6 ppm at Mariposa), yet zinc consumption at that site was within the range of other galvanized sites. Since Site 10 has a nonplastic sandy gravel backfill, comparison to the Mariposa site may be meaningless.

Information derived from Site 2 (Baxter) the RE galvanized steel sites discussed below and probably Site 1 (Mariposa) indicate that initial porosity may be a significant contributor to corrosion. It is highly likely that Site 1's rocky backfill in the lower two-thirds of the wall along with the good water retaining character of the clayey matrix provided conditions for the high corrosion and localized heavy pitting.

No relation was observed between corrosion activity and half-cell potential measurements. Other reports have stated this apparent lack of relationship (7). However, considering that the measurements were taken at random locations and were not part of a time-sequence series of measurements, the lack of correlation between the readings and corrosion may be overstated.

Calculated corrosion losses for field samples from the four sites are presented along with selected data from the Romanoff study on Table III.

## B. Galvanized Steel Sites

For the 10 walls discussed in this section, inspection of the galvanized steel reinforcement revealed virtually no base metal corrosion, and almost all zinc coating still intact. As result, only a general discussion of the findings for each wall system is in this section. Additional information on site climatology, drainage systems and test data is provided in the Appendix.

Inspection wires were placed in only one wall system, the Welded Wire walls. Some of these inspection rods were retrieved and steel mat sections were excavated for corrosion inspection. No inspection rods or strips were placed at time of construction for any of the remaining systems and steel specimens had to be excavated for inspection. In general, specimens were excavated from the upper portion of the backfill immediately behind the wall face. Depth of excavation was generally limited to three feet. In several instances, specimens were removed from the lower portion of the wall by breaking through the face. In instances where inspection took place at the top and bottom of the wall, little or no difference in the reinforcement condition could be noticed.

Backfill types in seven projects were clean sand and gravel mixtures. Three projects, a TAT Wall (Site 9) and two Welded Wire walls (Sites 11 and 13) had backfills exhibiting plasticity. All ten sites had resistivities of 1,300 ohm-cm or greater. Saturation at all inspected locations was estimated to be between 60 and 80%. Individual sites are discussed below.

1. Sites 5, 6 - Reinforced Earth

Two RE sites were inspected early in the study due to their long service life of 11 and 13 years - about three times longer than the other sites using galvanized reinforcement. The two projects are located at Dunsmuir (Site 5) and Los Angeles Route 39 (Site 6), respectively.

Inspection revealed all but one of the excavated strips were in good condition. The exception was a strip at Dunsmuir, located in a year-round wet area. Visual inspection indicated about a 50% zinc free area on the strip's upper surface. However, rusting was barely visible on the exposed base metal attesting to the protection zinc provides even at a distance. Galvanizing on the bottom of the strap appeared fresh.

Lab testing indicated an average 0.26 $oz/ft^2$ zinc remaining on the upper surface and 1.02 $oz/ft^2$ remaining on the lower surface; specifications required a minimum 0.8 $oz/ft^2$ covering at time of placement.

Inspection and testing of the other strips (seven specimens from Site 5) also indicated, in all but one instance, from 30 to 60% more galvanization remaining on the strips lower surface than the upper surface. This interesting condition led to a more thorough review of field notes and photos taken during the excavation to seek a reason for the higher zinc consumption on the upper surface.

Ultimately, six conditions were considered potential causes: 1) different moisture contents at upper and lower soil-strip interfaces, 2) galvanization variations, 3) differing soil types for each backfill lift, 4) soil abrasion, 5) strip bridging soil in area examined, or 6) differences in oxygenation between a possibly lower density soil on top of the strip relative to denser soil in contact with the bottom of the strip.

In the opinion of the writers, condition 1 was not considered a likely event due to wall age. In time, virtually uniform moisture conditions around the strip would exist due to capillarity and moisture spreading. Even if, however, for short periods water ponding were to occur on the upper surface, information shown on Figure 2 for similar soil types suggests that peak corrosion activity would still be more prevalent on the bottom of the strip where saturation levels would be lower and closer to the optimum moisture content for corrosion activity. Since field evidence contradicts this, other factors must be at work.

Conditions 2 and 3 were also discounted. Variations in borrow source or zinc plating, if differing between lifts or strip surface, would be random and randomness in zinc thickness was not seen. Condition 4, abrasion of the strips upper surface during compaction may produce subtle effects that promote corrosion but at this time no information is available to quantify impact. Condition 5, soil in contact on the top of the strip but not on its bottom may occur and support the observed phenomena. Due to the chance variation this would occur at all sites, it is not at this time considered a reasonable explanation. However, condition 6, oxygenation variations due to soil density variations above and below the strip appears to be the most resonable explanation to the observed phenomena.

Information from the Baxter project (Site 2) provides support to this. At Baxter, steel elements in low density soil exhibited higher corrosion activity than steel elements in denser soil. At the RE site or any other site, denser soil will more likely exist at the top of a compacted lift than at its base due to compaction energy losses with soil depth. Adding steel strips between the lifts can further restrict densification of the boundary soil layer immediately above the reinforcement at time of compaction due to strip stiffness. Thus, soil density variations may be the reason for the differential zinc consumption noticed.

It should be noted that no direct measurements to detect the differences in soil density described above were attempted.

2. Sites 7, 8, 9 Tire Anchored Timber Walls

All TAT walls are timber faced. At time of inspection, Sites 7 (Mammoth), 8 (Mar Monte) and 9 (Waldo) had been in service 4, 3 and 2 years, respectively. Portions of the reinforcement were exhumed from the upper soil layers three feet below the surface, and within three feet of the wall face. Remaining zinc exceeded original design specifications. Design specifications required a minimum of 2.0 oz/ft$^2$ while measured remaining zinc averaged 3.5 oz/ft$^2$. Sites 7 and 8 were comprised of nonplastic backfills; Site 9 had a backfill exhibiting plasticity. There were no major differences in zinc losses noticed among the sites.

3. Sites 10, 11, 12, 13 Welded Wire Walls

At the time of inspection, the Welded Wire walls at Site 10 (Los Angeles Rt 2), Site 11 (Lake), Site 12 (Trinity) and Site 13 (Castro Valley), had been in service 2, 3, 2, and 3 years, respectively.

Portions of the wire mat were retrieved from all walls for inspection. Retrieval generally took place through the face just below the wall crest and two to six feet behind the face. At Sites 11 and 12, portions of 10-foot long inspection wires were pulled for inspection. These wires broke within three feet of the wall face due to pullout resistances exceeding the wires ultimate strength. These wires were located several feet below the wall crest.

The remaining zinc coating varied from 0.24 oz/ft$^2$ to 5.7 oz/ft$^2$, while specifications required from 0.32 oz/ft$^2$ to 2.2 oz/ft$^2$. Backfill for Sites 10 and 12 classified as well graded gravel.

Site 11 classified as clayey sand with some plasticity and Site 13 classified as a clayey sand with low plasticity.

No major differences were noticed in corrosion losses between Sites 10, 11 and 12. Site 13 showed more corrosion on the portions of the wire mats farthest from the face. Zinc content measured at the face was 0.32 $oz/ft^2$ and five feet back, 0.24 $oz/ft^2$.

4. Site 14 Salvaged Guardrail

At the time of inspection the Salvaged Guardrail wall at Site 14 (Ventura) had been in service 4 years. Salvaged Steel sign posts, 1-14/16" x 1-14/16" x 1/8" in a structural hat shape, had been placed as the soil reinforcement. A portion of the steel wall face was removed from a point six feet below the wall crest. Excavation extended about 16 inches behind the face. The backfill classified as clean sand.

Galvanization remaining on the steel sign post exceeded the contract specifications. The required galvanization on the guardrail elements was specified as 2 $oz/ft^2$. Galvanization of the W-shaped facing element was measured at two places; on the lower inside portion of the W-shaped element where soil, by gravity effects alone, were found in direct metal contact, and on the upper inside portion of the W-shaped element where soil, either by consolidation or poor soil placement was not in intimate contact with the element. Zinc coating at the two locations of the face element were measured as 0.9 $oz/ft^2$ (lower portion) and 2.0 $oz/ft^2$ (upper portion).

Since it was not possible to excavate further into the backfill than about 16 inches, measurement of variations in the zinc coating along the length of the sign post was not attempted.

## 5. Discussion

The presence of galvanization on virtually all steel elements and the lack of knowledge regarding initial zinc coverage prevent any attempt at evaluating the impact of base metal composition or soil constituents on corrosion activity. Differences in the zinc consumption between top and bottom surfaces were noted at two sites. All data supported the action of zinc as a sacrificial coating which corrodes preferentially to the steel base metal, and the action of zinc in promoting uniform corrosion (15, 16). No interpretation of data would suggest that the design values established by the Caltrans Interim Design Criteria for zinc loss rates are inadequate.

## TABLES AND FIGURES

### TABLE I
### DESIGN VALUES FOR CORROSION TO SOIL REINFORCEMENT ELEMENTS

A) CALTRANS INTERIM DESIGN CRITERIA - 1984 (REVISED 7/25/84)

Algorithms for computing the cross-sectional area (%) remaining on steel reinforcing elements after corrosion loss, given soil type and years of service:

A) Round Rod Types

$$A = \frac{[D - 2K\ (Y-C)]^2}{D^2} \times 100\%$$

B) Flat Strip Types

$$A = \frac{[W - 2K\ (Y-C)]\quad [T - 2K\ (Y-C)]}{(W)\qquad\quad (T)} \times 100\%$$

where:

A = % of Original Cross-Sectional Area Remaining*

D = Original Diameter, inches

W = Original Strip Width, inches

T = Original Strip Thickness, inches

Y = Time of Exposure in Soils, years

K = General Corrosion Rate Factor

C = Useful Life of Coating, years. (For Bare Steel, C=0)

*Round calculated values of A to the nearest 5%.

| Soil Type | K | C | | |
|---|---|---|---|---|
| | | Paint | Galvanized with $2\ oz/ft^2$ | Galvanized with $3\ oz/ft^2$ |
| **Normal** | | | | |
| Neutral & Alkaline | .0011 | 5 | 10 | 15 |
| Acidic | .0013 | 5 | 10 | 15 |
| Corrosive | .0028 | 5 | 6 | 9 |
| **Select Granular** ** | | | | |
| Neutral & Alkaline | .0005 | 5 | 20 | 30 |
| Acidic | .0005 | 5 | 20 | 30 |
| Corrosive | .0010 | 5 | 12 | 20 |

Normal soils are classified according to one of the following criteria:

- Neutral and Alkaline: minimum resistivity >1000 ohm-cm and pH > 7
- Acidic: minimum resistivity >1000 ohm-cm and pH <7
- Corrosive: minimum resistivity < 1000
- Very Corrosive: minimum resistivity < 1000 with Chloride ion content > 500 ppm and Sulfate ion content > 2000 ppm.

(This soil type is not recommended for use as backfill and no K value is provided.)

Select granular soil is also classified according to the above criteria as well as the following:

| Sieve Size | Grading Limits, Percent Passing |
|---|---|
| 6 inches | 100 |
| 3 inches | 100 = 75 |
| No. 4 | 25 = 0 |
| No. 200 | 5 = 0 |

Plasticity Index < 6

## B) FEDERAL HIGHWAY ADMINISTRATION GUIDELINES FOR SERVICE LIFE OF MECHANICALLY STABILIZED EMBANKMENT*

The durability of buried metal reinforcements should be assessed at a project level by determining the potential corrosion aggressiveness of the specific site. The most comprehensive data available in the field of underground corrosion are the results of a 50-year field testing study on metal pipes and steel sheeting by the U.S. National Bureau of Standards. The major conclusions of the NBS studies which are presented in the NBS Circular 579 entitled "Underground Corrosion" are:

(1) The rate of corrosion is greatest in the first few years of burial and then levels off to a steady but significantly lower rate.

(2) A well-defined relationship between resistivity, pH, and corrosion does not exist. However, a trend of smaller metal losses with increased resistivity is clearly defined especially in resistivity ranges greater than 10,000 ohm-cms. It is also implied that to optimize longevity, the permissible pH range of the backfill soils should fall between 4.5 and 9.5.

A more recent analysis of the NBS data was undertaken by The Reinforced Earth Company in cooperation with Stuttgart University in Germany. This study concentrated on the NBS sites that can be characterized as well drained granular soils. Typically, the corrosion loss rates for both zinc and steel can be generalized as shown below indicating a rather rapid loss in the first 2 to 3 years for both galvanized or base steel specimens and then continuing at a reduced rate.

* Condensed from Geotechnical Advisor 5.3.5. (Jan. 1, 1986)

This information forms the basis for the design corrosion values below. For mildly corrosive backfills, the anticipated maximum loss rates are as follows:

For zinc

V1 = 6 um/year (first 2 years)

V2 = 2 um/year (following years)

For carbon steel

V1 = 45 um/year (first 2 years)

V2 = 9 um/year (following years)

Somewhat greater losses should be anticipated for conditions in backfill which will be affected by deicing salts; i.e., where the long-term concentration of chlorides will climb above 200 ppm. For these saline environments, the maximum loss rates anticipated are as follows:

For Zinc

V1 = 17 um/year (first 3 years)

V2 = 2 um/year (following years)

For carbon steel

V1 = 80 um/year (first 2 years)

V2 = 12 um/year (following years)

The corrosion rates in the empirical design procedure are supported by long-term, 50 test data from the NBS study, data from full scale structures up to 13 years old, the conservativeness of assuming that after complete removal of the zinc coating the corrosion rate of the underlying steel accelerates when it is known that under some conditions the insoluble by-product of zinc corrosion continues to protect the underlying metal, and by those (Stuttgart) test results associated with resistivities in the range of 1000-2000 ohm-cms.

Since the guideline backfill specification has a 3000 ohm-cms minimum, then the actual weight losses should be less. For purposes of this advisory, a mildly corrosive backfill has the following electrochemical properties:

> Resistivity > 3000 ohm-centimeters
> pH between 5 and 10
> Chlorides < 200 parts per million
> Sulfates < 1000 parts per million

It is extremely important to recognize the following project situations which fall outside the scope of this design procedure:

- structures exposed to marine environments
- structures exposed to stray currents
- structures constructed with backfill materials outside the suggested electrochemical guidelines shown above
- mechanically stabilized embankment systems where the reinforcing elements are not electrically isolated from any dissimilar metals within the facing panels.

Other backfill properties* assumed by the FHWA design guidelines:

Select Granular Backfill Material: All backfill material shall be reasonably free from organic or otherwise deleterious materials and shall conform to the following gradation limits as determined by AASHTO T-27:

| (I) Sieve Size | Percent Passing |
|---|---|
| 6 inch | 100 |
| 3 inch | 100 - 75 |
| No. 200 | 15 - 0 (1) |

Plasticity Index (P.I.) shall not exceed 6.

*Adapted from FHWA Geotechnical Advisory 5.3.2 (September 26, 1985)

(1) Results of laboratory and field pullout tests have indicated that most materials having up to 25 percent passing the No. 200 sieve shall provide adequate pullout and frictional resistance. However, some materials having 15-25 percent passing the No. 200 sieve may produce problems related to frost susceptibility, compaction, and drainage. The maximum percent passing the No. 200 sieve may be increased to 25 percent when all design criteria are met and the following physical requirements are satisfied:

(a) The plasticity index (P.I.) as determined by AASHTO T-90 does not exceed 6.

(b) The fraction finer than 15 microns (0.015mm) as determined by AASHTO T-88 does not exceed 15 percent.

(c) The material exhibits an angle of internal friction of not less than 34°, as determined by the standard Direct Shear Test, AASHTO T-236, utilizing a sample of the material compacted to 95 percent of AASHTO T-99, Methods C or D (with oversized correction as outlined in Note 7) at optimum moisture content.

(II) <u>Soundness</u>. The materials shall be substantially free of shale or other soft, poor durability particles. The material shall have magnesium sulfate soundness loss of less than 30 percent after four cycles.

## TABLE II A

### SYSTEM DATA AND REINFORCEMENT PROPERTIES

| SITE | WALL TYPE | FACING MATERIAL | GALVANIZATION SPECIFICATION/MEASURED (OZ/SQ.FT.) | YEARS IN SERVICE AT TIME OF INSPECTION | DRAINAGE BLANKET | ELEMENT DIAMETER * SPECIFICATION/MEASURED (INCHES) | STEEL COMPOSITION,% | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | CARBON | SILICON | MANGANESE | PHOSPHORUS | SULFUR |
| 1. MARIPOSA (A UPR WALL) | MSE | CONCR | NONE | 6 | Y | A .299/.295 | .06 | .07 | .42 | .01 | .02 |
| ST. RT. 140 (B LWR WALL) | | | | | | B .374/.348 | .08 | .14 | .43 | .01 | .02 |
| 2. BAXTER (A FRNT 0'-3') | MSE | CONCR | NONE | 3 | Y | A .300/.293 | .22 | .30 | .88 | .01 | .02 |
| I-80 (B BK 3'-10') | | | | | | B .300/.298 | | | | | |
| 3. DUNSMUIR I-5 | MSE | CONCR | NONE | 9 | Y | .380/.376 | .36 | .29 | 1.0 | .01 | .03 |
| 4. SANTA BARBARA ST. RT. 192 | MSE | WOOD | NONE | 7 | N | .252/.249 | .06 | .17 | .39 | .03 | .02 |
| 5. DUNSMUIR I-5 | RE | CONCR | 0.8/1.2 | 11 | Y | *.118/.118 | .24 | .05 | .49 | .003 | .02 |
| 6. LOS ANGELES ST. RT. 39 | RE | STEEL | 0.8/0.38 | 13 | Y | *.118/.118 | .43 | .04 | .31 | .02 | .02 |
| 7. MAMMOTH ST. RT. 203 | TAT | WOOD | 2.0/3.0 | 4 | N | .625/.625 | .38 | .08 | 1.15 | .03 | .04 |
| 8. MAR MONTE ST. RT. 1 | TAT | WOOD | 2.0/3.9 | 3 | Y | .750/.750 | .40 | .31 | 1.36 | .03 | .04 |
| 9. WALDO ST. RT. 101 | TAT | WOOD | 2.0/4.5 | 2 | Y | .875/.875 | .46 | .03 | 1.28 | .03 | .06 |
| 10. LOS ANGELES ST. RT. 2 | WW | WIRE | 0.8/5.7 | 2 | N | .148/.148 | .06 | .24 | .36 | .08 | .03 |
| 11. LAKE CO. ST. RT. 20 | WW | WIRE | 0.8/3.0 | 3 | N | .148/.148 | .04 | .19 | .03 | .01 | .03 |
| 12. TRINITY ST. RT. 299 | WW | WIRE | 2.2/1.3 | 2 | N | .177/.177 | .08 | .10 | .38 | .07 | .03 |
| 13. CASTRO VALLEY I-580 | WW | WIRE | 0.32/0.28 | 3 | N | .177/.177 | .06 | .19 | .39 | .02 | .02 |
| 14. VENTURA ST. RT. 101 | SGR | STEEL | 1.8/>2.0 | 4 | Y | *.14/.14 | .55 | .17 | .39 | .03 | .02 |

* MINIMUM STRIP DIMENSION

## TABLE II B
## BACKFILL PROPERTIES

| SITE | UNIFIED SOIL CLASSIFICATION | GRADATION, % PASSING: No. 4 Sieve | No. 200 Sieve | 5 micron | PLASTIC LIMITS LL-PL (PI), % | FIELD MOISTURE AT TIME OF INSPECT., % | MINIMUM SOIL RESISTIVITY (OHM-CM) | SOIL pH | SULFATES, PPM | CHLORIDES, PPM | SOLUBLE Fe, PPM |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. MARIPOSA (A UPR WALL) | GC-GM | 66 | 35 | 14 | 29-22 (7) | - - | 3,500 | 6.6 | 9 | 0 | 1.60 |
| ST. RT. 140 (B LWR WALL) | GM | 44 | 19 | 8 | 36-25 (11) | 15 | 3,700 | 6.6 | 10 | 0 | 0.45 |
| 2. BAXTER I-80 | GM | 71 | 43 | 16 | (NP) | 7 | 3,300 | 5.2 | 48 | 90 | 0.10 |
| 3. DUNSMUIR I-5 | GM | 60 | 24 | 10 | (NP) | 18 | 14,300 | 6.5 | 5 | 0 | 0.32 |
| 4. SANTA BARBARA ST. RT. 192 | SM | 97 | 21 | 12 | (NP) | 14 | 800 | 7.4 | 1650 | 0 | 0.21 |
| 5. DUNSMUIR I-5 | SM | 66 | 24 | 9 | (NP) | 22 | 19,900 | 6.4 | 7 | 0 | 0.26 |
| 6. LOS ANGELES ST. RT. 39 | SW | 59 | 14 | 5 | (NP) | 12 | 13,800 | 8.2 | 1 | 0 | 0.45 |
| 7. MAMMOTH ST. RT. 203 | SW | 62 | 12 | 2 | (NP) | ≈1 | 9,500 | 7.6 | 0 | 0 | 0.17 |
| 8. MAR MONTE ST. RT. 1 | SM | 76 | 27 | 19 | (NP) | 11 | 2,400 | 7.7 | 43 | 7 | 0.12 |
| 9. WALDO ST. RT. 101 | GM | 63 | 30 | 14 | 36-27 (9) | 14 | 2,900 | 6.2 | 85 | 0 | 0.11 |
| 10. LOS ANGELES ST. RT. 2 | GW | 48 | 12 | 3 | (NP) | ≈1 | 10,300 | 7.5 | 0 | 0 | 2.20 |
| 11. LAKE CO. ST. RT. 20 | SC | 61 | 17 | 15 | 30-22 (8) | 14 | 3,250 | 7.7 | 20 | 0 | 0.16 |
| 12. TRINITY ST. RT. 299 | GW | 41 | 8 | 4 | (NP) | 6 | 1,500 | 3.1 | 680 | 0 | 0.75 |
| 13. CASTRO VALLEY I-580 | SC-CL | 69 | 46 | 19 | 30-21 (9) | 14 | 1,300 | 7.7 | 140 | 35 | 0.09 |
| 14. VENTURA ST. RT. 101 | SP | 93 | 10 | 16 | (NP) | 8 | 10,700 | 8.1 | 3 | 0 | 0.74 |

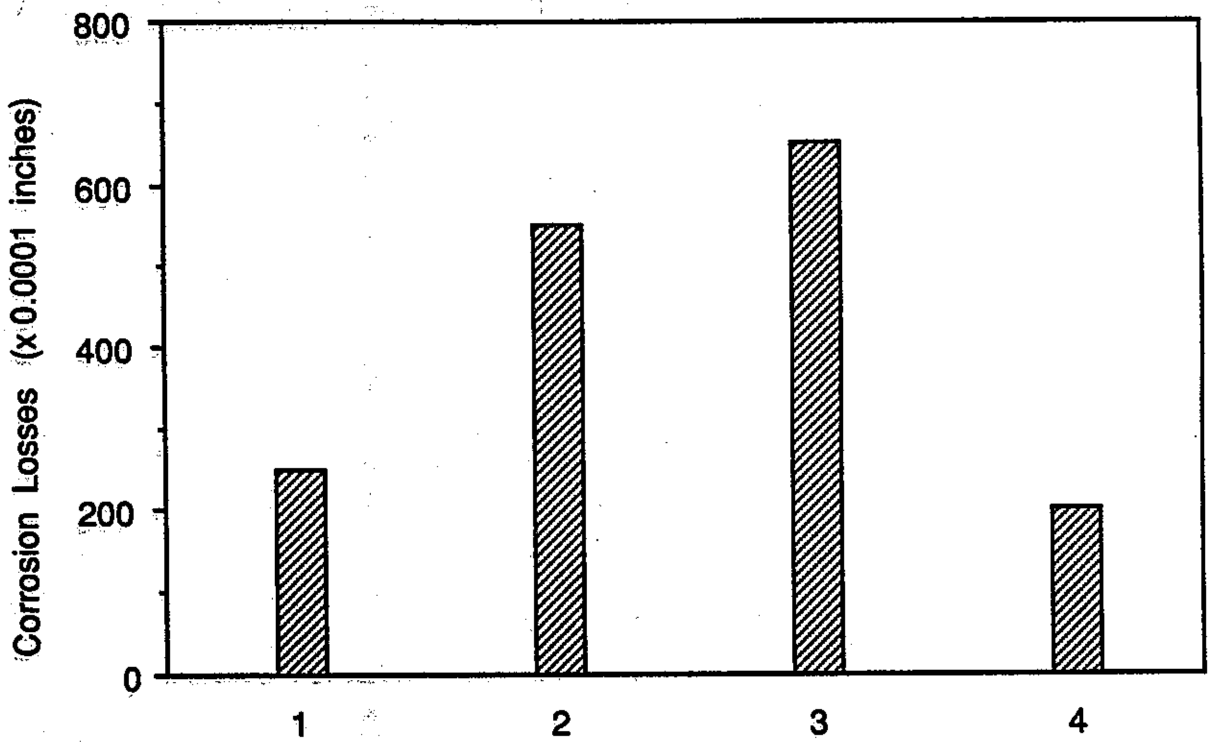
TABLE III

CALCULATED AVERAGE CORROSION LOSSES FROM 4 CALTRANS STUDY SITES AND 13 SELECTED NATIONAL BUREAU OF STANDARDS (ROMANOFF) SITES (AFTER 6)

| SITE OR SOIL SAMPLE | MINIMUM RESISTIVITY (ohm-cm) | SOIL pH | MEASURED LOSS PER SIDE ($inches x 10^{-3}$) | CALCULATED RATE* ($inches/year x 10^{-3}$) | DESIGN LOSS PER SIDE** ($inches x 10^{-3}$) | |
|---|---|---|---|---|---|---|
| | | | | | CALTRANS | FHWA |
| Mariposa B | 3,700 | 6.6 | 13.0 @ 6 years | 2.2 | 7.8 | 4.9 |
| Baxter A | 3,300 | 5.2 | 3.5 @ 3 years | 1.1 | 3.9 | 3.9 |
| NBS 22 | 5,150 | 4.9 | 11.4 @10 years | 1.1 | 13.0 | 6.3 |
| NBS 16 | 8,290 | 4.4 | 10.6 @10 years | 1.1 | 13.0 | 6.3 |
| NBS 41 | 1,320 | 5.5 | 8.7 @10 years | 0.87 | 13.0 | 6.3 |
| NBS 14 | 3,250 | 6.2 | 7.1 @10 years | 0.71 | 13.0 | 6.3 |
| NBS 46 | 1,500 | 7.0 | 6.7 @10 years | 0.67 | 13.0 | 6.3 |
| NBS 12 | 3,190 | 7.1 | 6.3 @10 years | 0.63 | 13.0 | 6.3 |
| NBS 19 | 1,970 | 4.6 | 4.7 @10 years | 0.47 | 13.0 | 6.3 |
| NBS 26 | 2,980 | 7.3 | 4.7 @10 years | 0.47 | 13.0 | 6.3 |
| NBS 32 | 5,700 | 7.3 | 4.7 @10 years | 0.47 | 13.0 | 6.3 |
| NBS 18 | 1,410 | 7.3 | 4.6 @10 years | 0.46 | 13.0 | 6.3 |
| NBS 25 | 1,780 | 7.2 | 3.9 @10 years | 0.39 | 13.0 | 6.3 |
| NBS 35 | 2,060 | 7.3 | 3.9 @10 years | 0.39 | 13.0 | 6.3 |
| NBS 44 | 1,000 | 5.8 | 3.8 @10 years | 0.38 | 13.0 | 6.3 |
| Baxter B | 3,300 | 5.2 | 1.0 @ 3 years | 0.33 | 3.9 | 3.9 |
| Mariposa A | 3,500 | 6.6 | 2.0 @ 6 years | 0.33 | 7.8 | 4.9 |
| Dunsmuir | 14,300 | 6.5 | 2.0 @ 9 years | 0.22 | 11.7 | 6.0 |
| Santa Barbara | 800 | 7.4 | 1.5 @ 7 years | 0.21 | 7.7 | 5.3 |

*Rates are shown for comparative purposes only and were calculated by dividing corrosion by years in service. It should be noted that the NBS report postulated that corrosion in soil follows an exponential rate ($X=Kt^n$ where n is always less than 1), resulting in decreasing losses over time.

**See text for interpretation of the descriptive "design".




1 - Caltrans I.D.C. with "select" backfill

2 - Caltrans I.D.C. with "normal" backfill
and soil pH ≥ 7.0

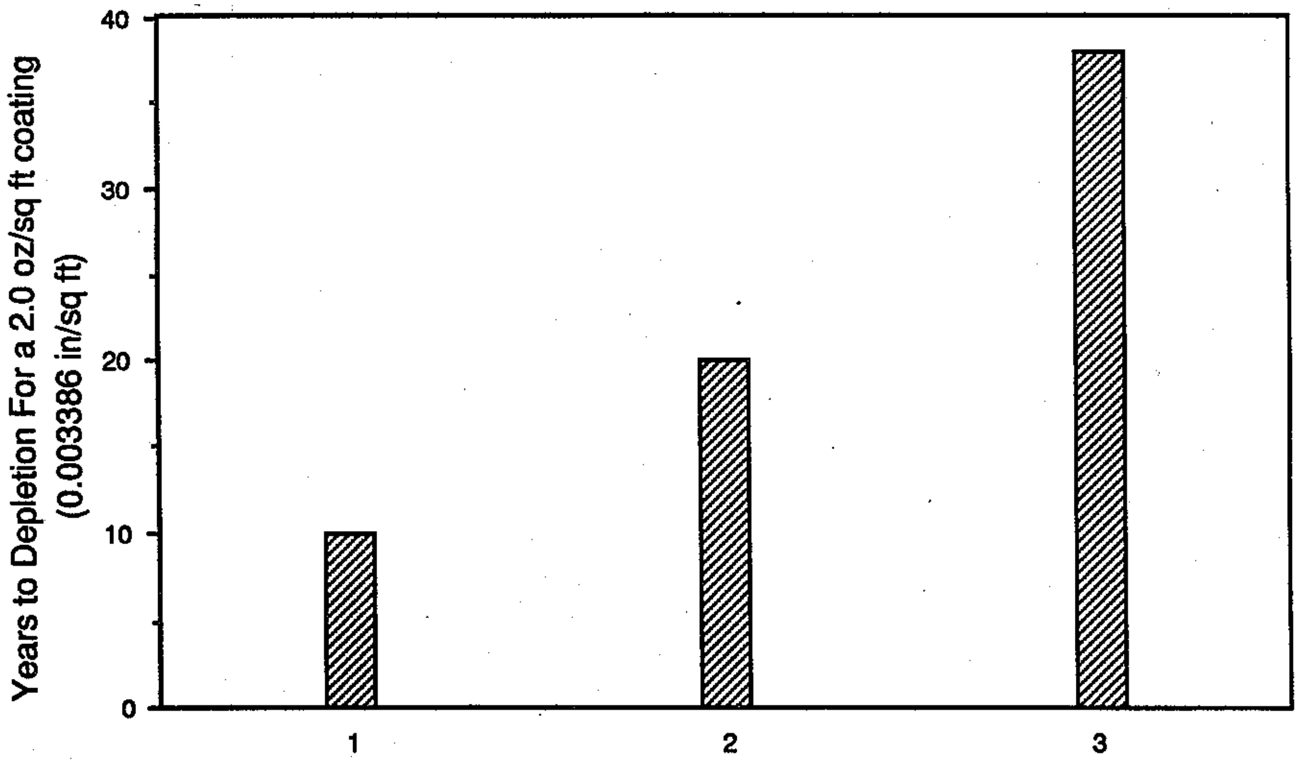
3 - Caltrans I.D.C. with "normal" backfill
and soil pH ≤ 7.0

4 - FHWA

Soils meet all other design parameters:
minimum resistivity, and sulfate and chloride content.
See Table 1 for values

I.D.C. = Interim Design Criteria

**FIGURE 1A - Caltrans and FHWA Design Corrosion Values For Plain Steel At 50 Years**




1 - Caltrans I.D.C. for neutral, alkaline or acidic soils
2 - Caltrans I.D.C. for "select" granular neutral, alkaline, and acidic soils
3 - FHWA

Soils meet all other design parameters:
minimum resistivity, and sulfate and chloride content.
See Table 1 for values

I.D.C. = Interim Design Criteria

**FIGURE 1B - Caltrans and FHWA Design Corrosion Values For Zinc**

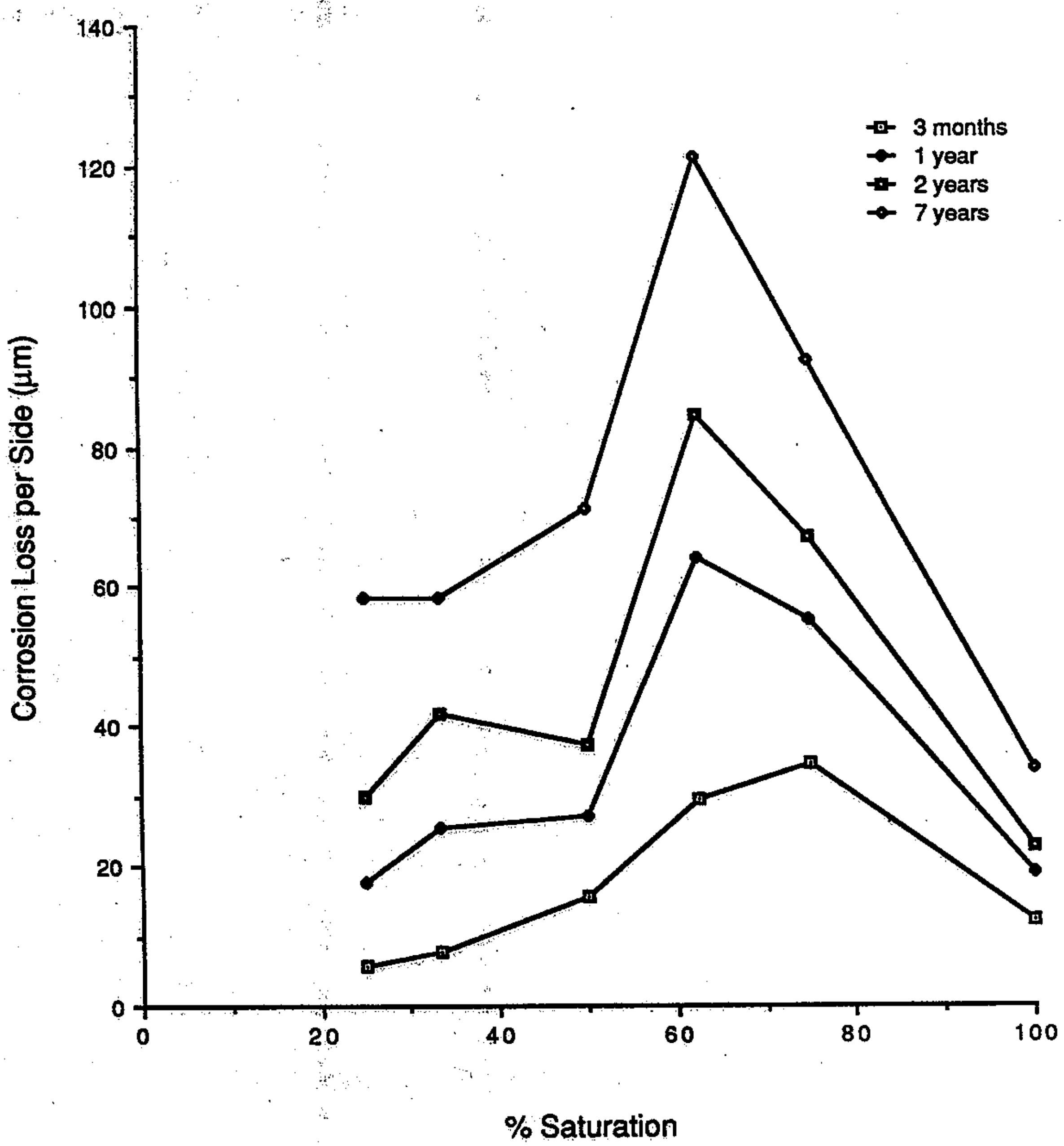



Figure 2 - Effect of Saturation Levels on Corrosion
Loire River Sand + 500 ppm of Sulphate (after 10)

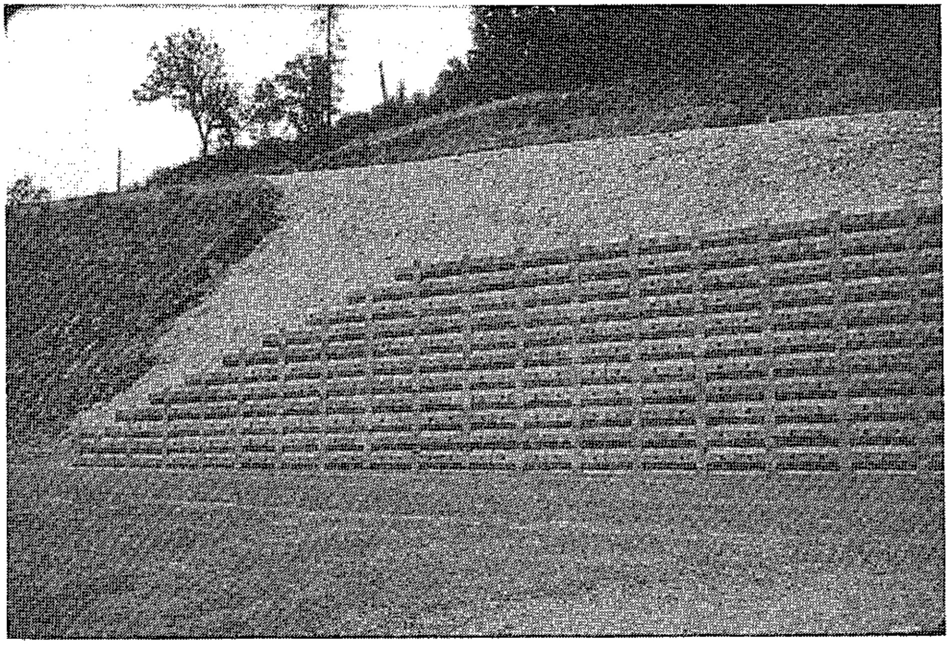


Photo 1 - Site 1 (Mariposa) Caltrans MSE System

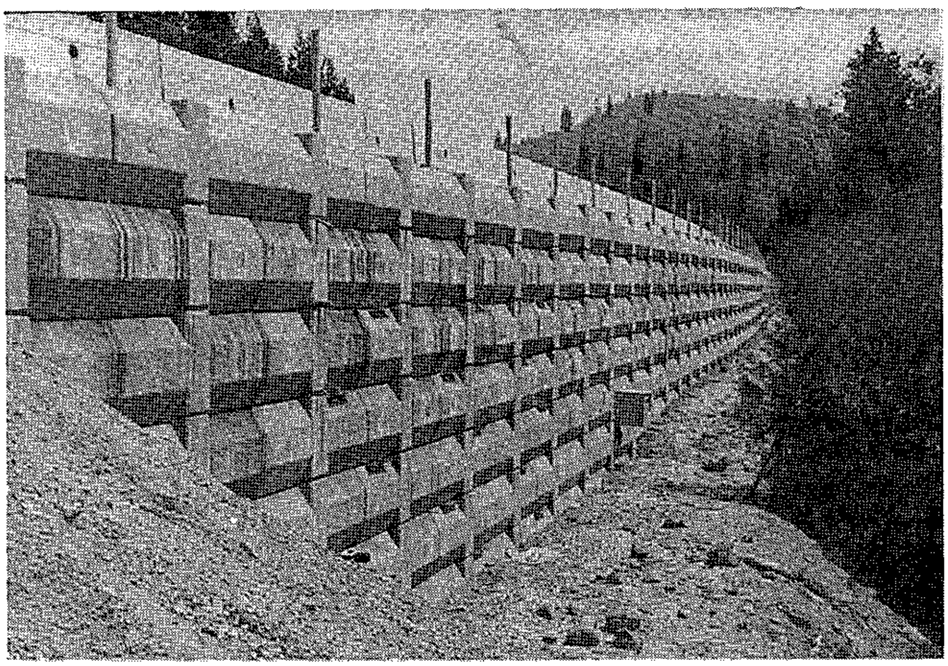


Photo 2 - Site 2 (Baxter) Caltrans MSE System

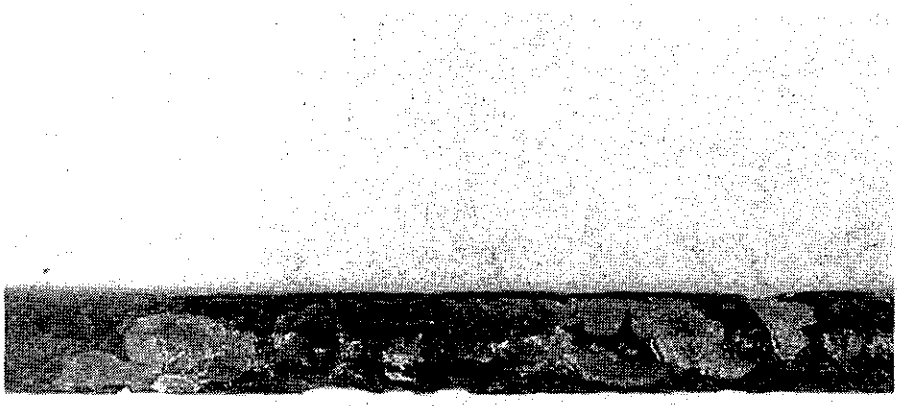


Photo 3 - Inspection wire removed from MSE wall near Mariposa, California; age 6 years.

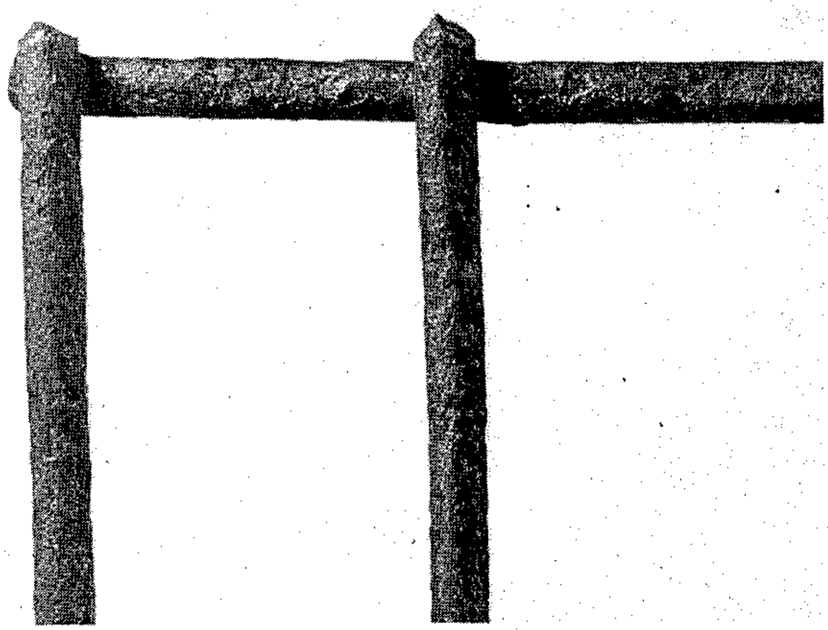


Photo 4 - Section of bar-mat removed from top of MSE wall near Mariposa, California

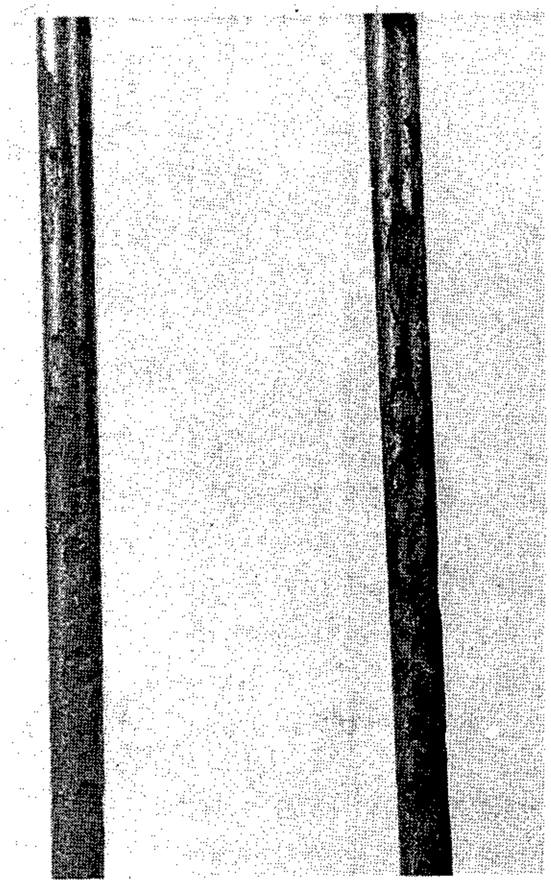


Photo 5 - Photo of two inspection wires removed from the MSE wall near Baxter, California.

Note transition area between corroded lower section and non corroded upper section; age 3 years.

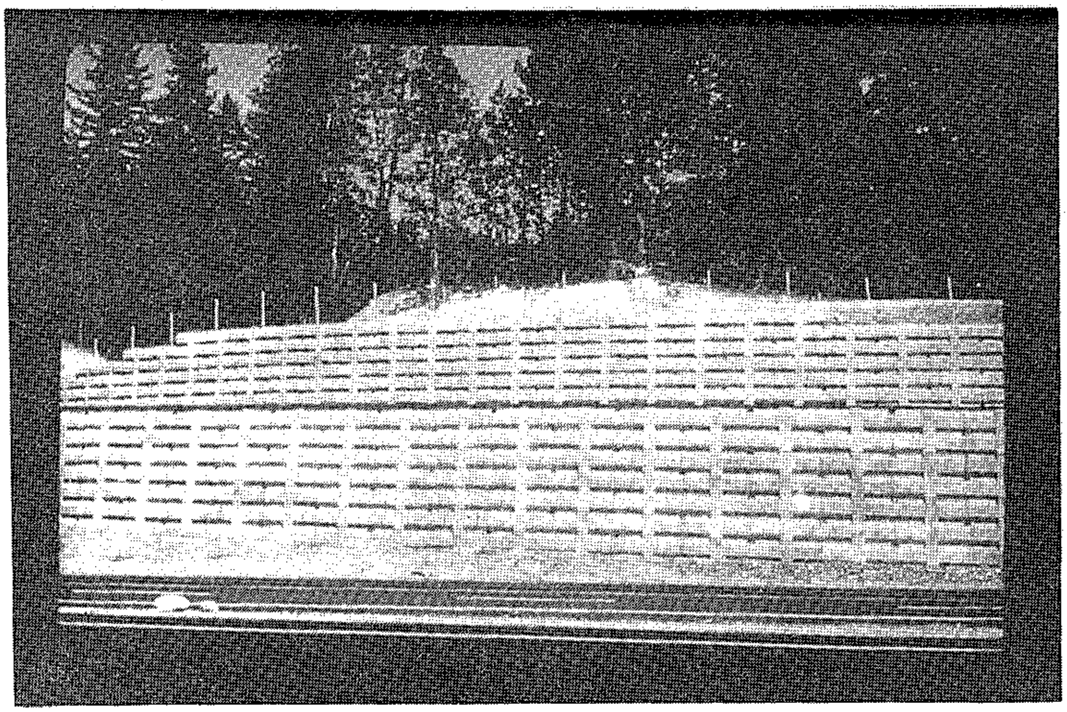


Photo 6 - Site 3 (Dunsmuir) Caltrans MSE System

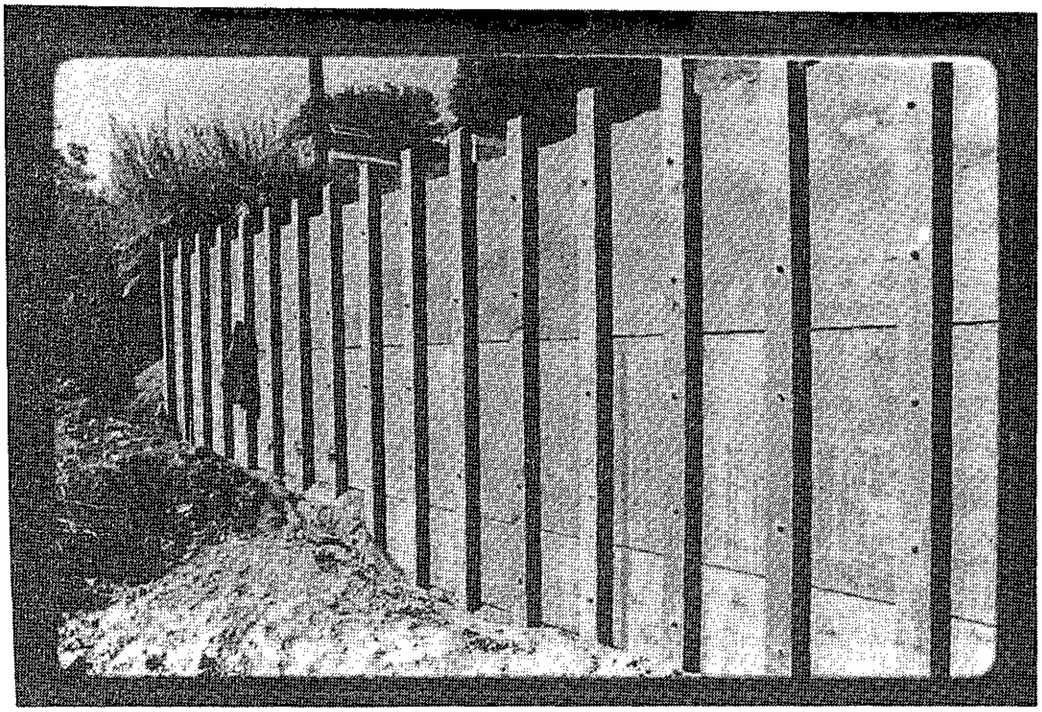


Photo 7 - Site 4 (Santa Barbara) Caltrans Wood-faced MSE System

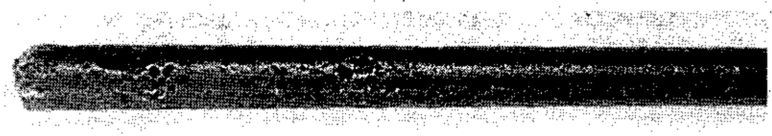


Photo 8 - 3/8" wire from MSE bar-mat removed from Dunsmuir, California. Slight pitting only; age 9 years.

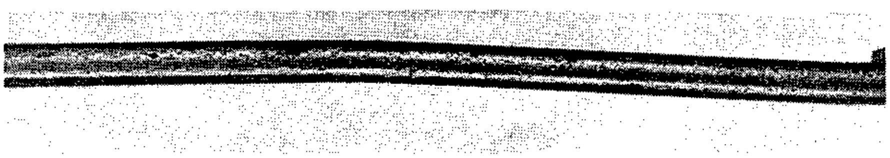


Photo 9 - Single wire of bar-mat from the Plywood/Bar-mat wall in Santa Barbara. Excellent condition; age 7 years.

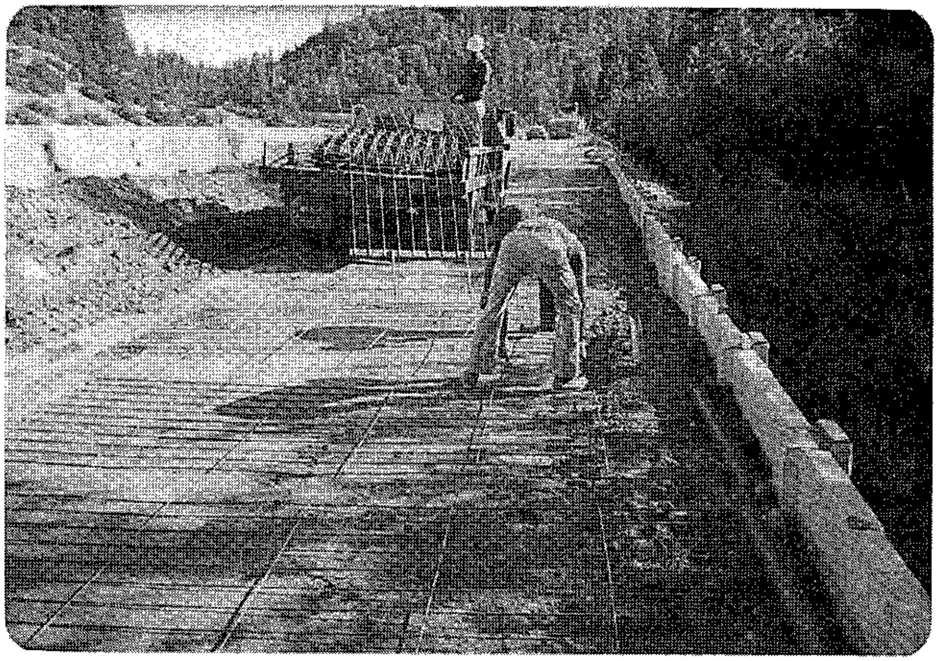


Photo 10 - Caltrans MSE Bar-mat Reinforcement

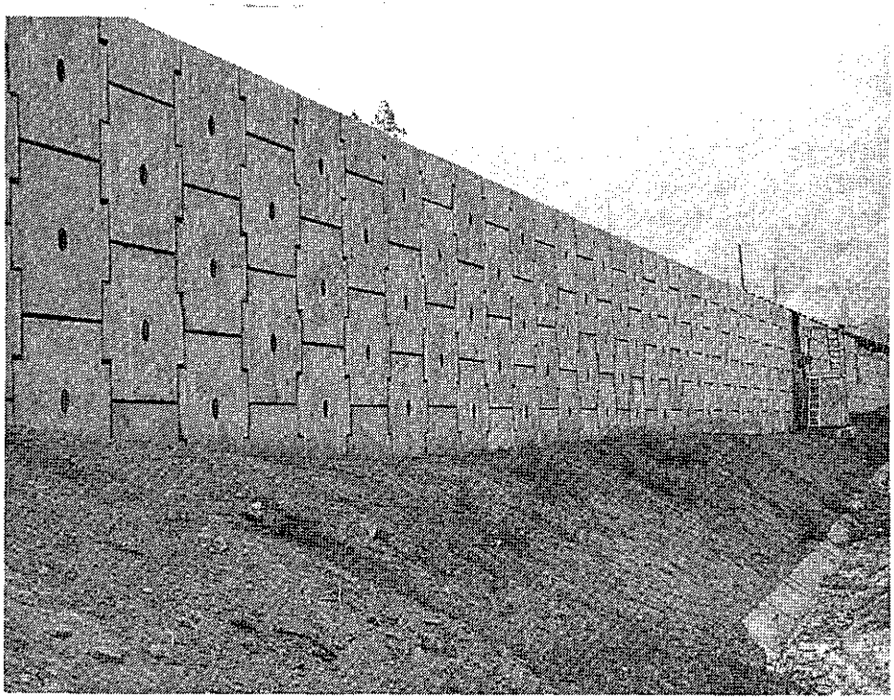


Photo 11 - Site 5 (Dunsmuir) RE System

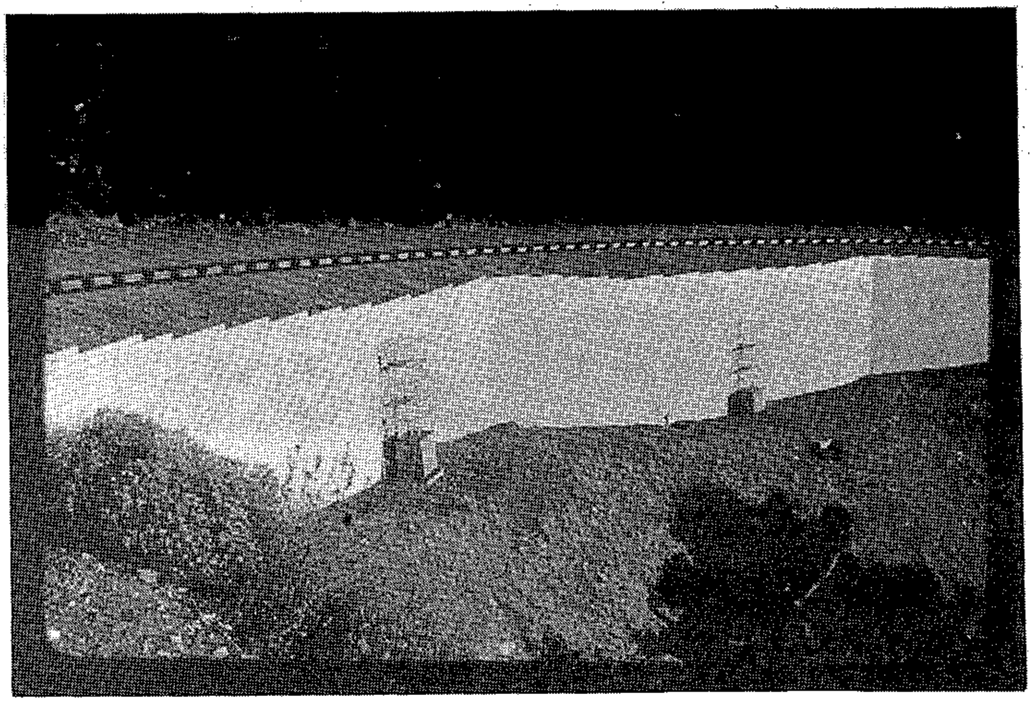


Photo 12 - Site 6 (Los Angeles Rt 39)  RE Steel-faced System

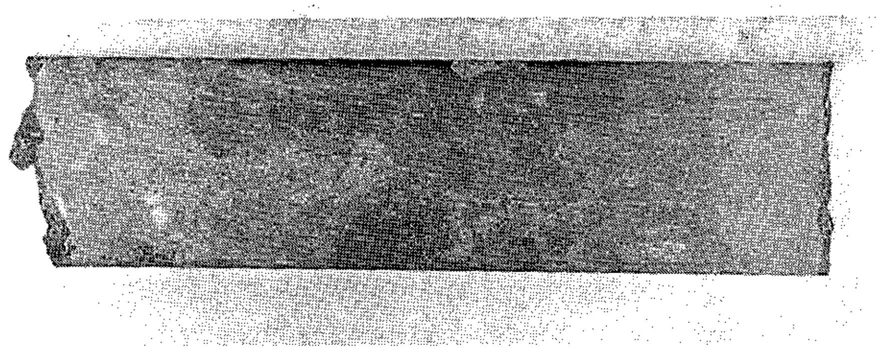


Photo 13 - Reinforcing strap removed near the base of the RE wall in the San Gabriel Mountains on Rt 39 near Los Angeles.  Strap is in excellent condition after 13 years.

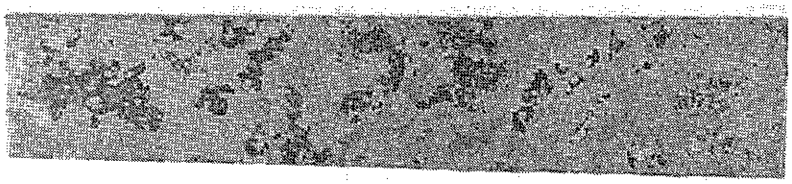


Photo 14 - Photo of slightly corroded galvanized strap from the RE wall in Dunsmuir. Age 11 years.

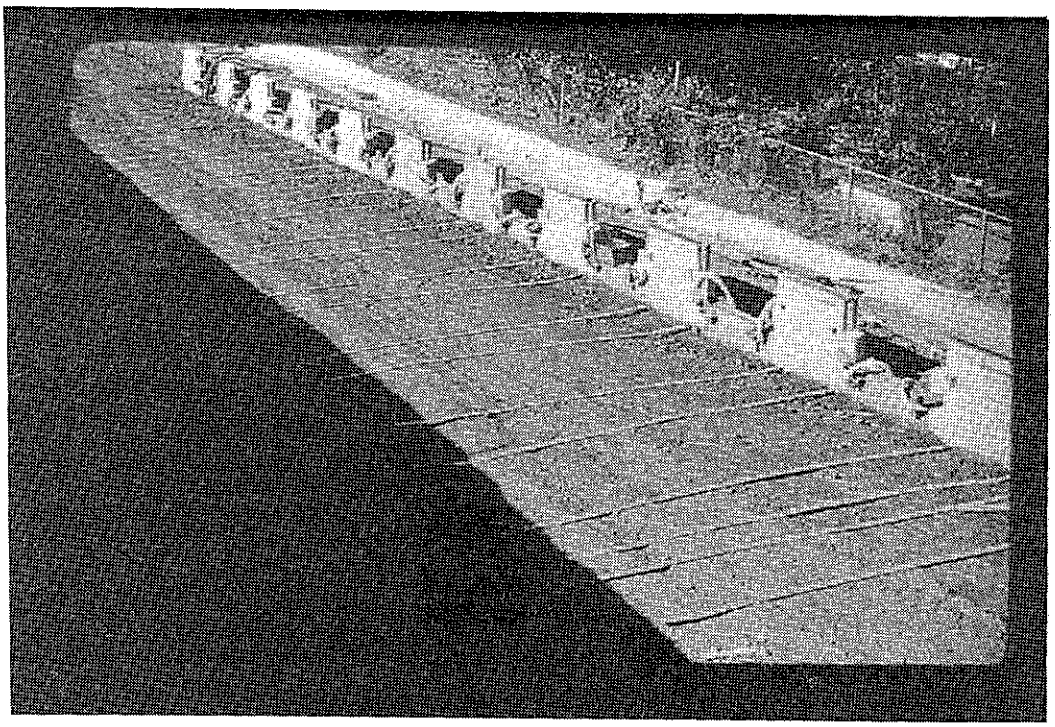


Photo 15 - Typical strip reinforcement for RE System

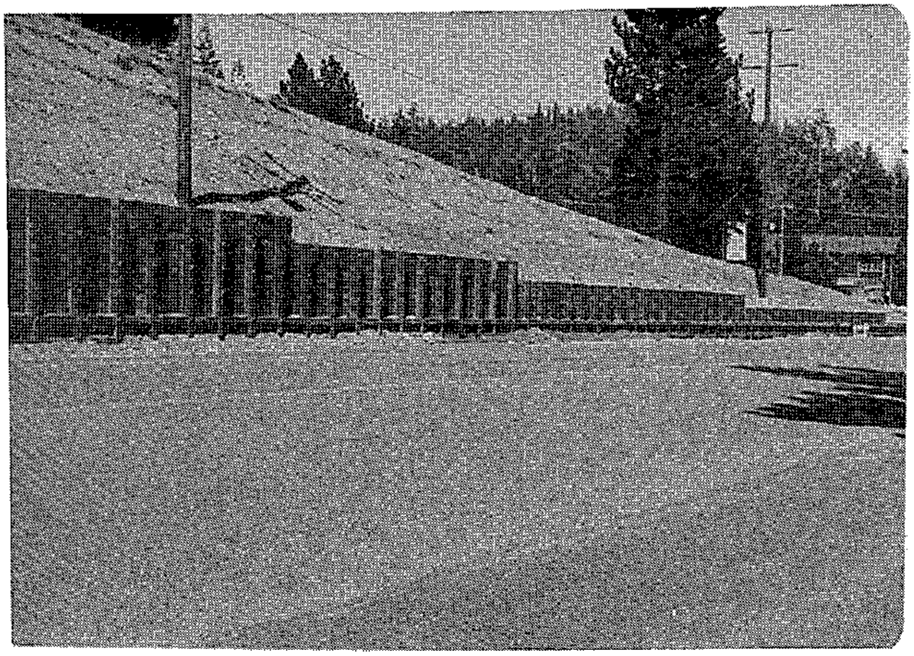


Photo 16 - Site 7 (Mammoth)  Caltrans TAT System

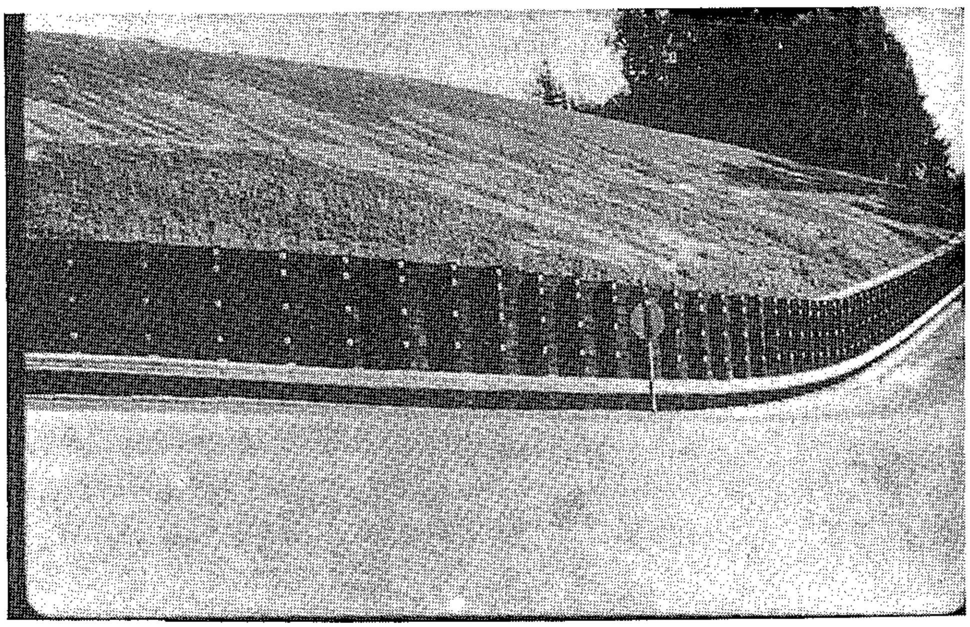


Photo 17 - Site 8 (Mar Monte)  Caltrans TAT System

Photo 18 - Site 9 (Waldo) Caltrans TAT System

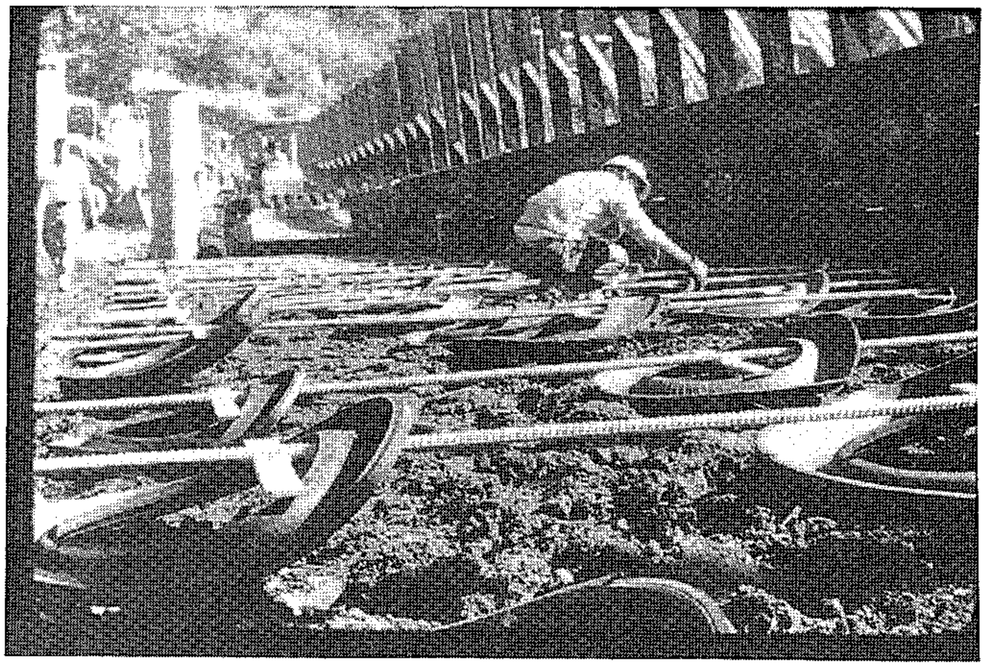


Photo 19 - Caltrans TAT Tire Anchorage Reinforcement

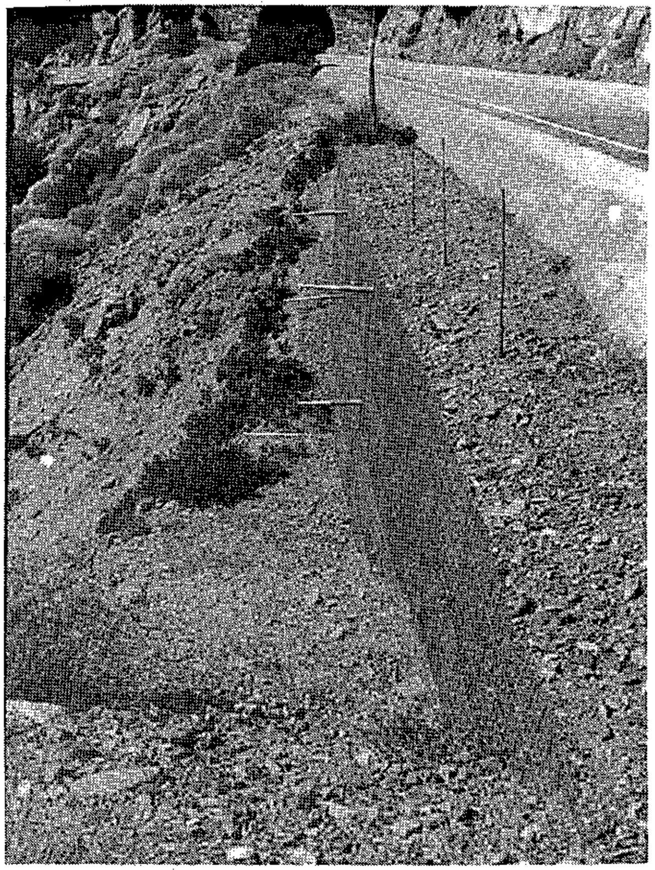


Photo 20 - Site 10 (Los Angeles) Hilfiker Welded Wire Wall System

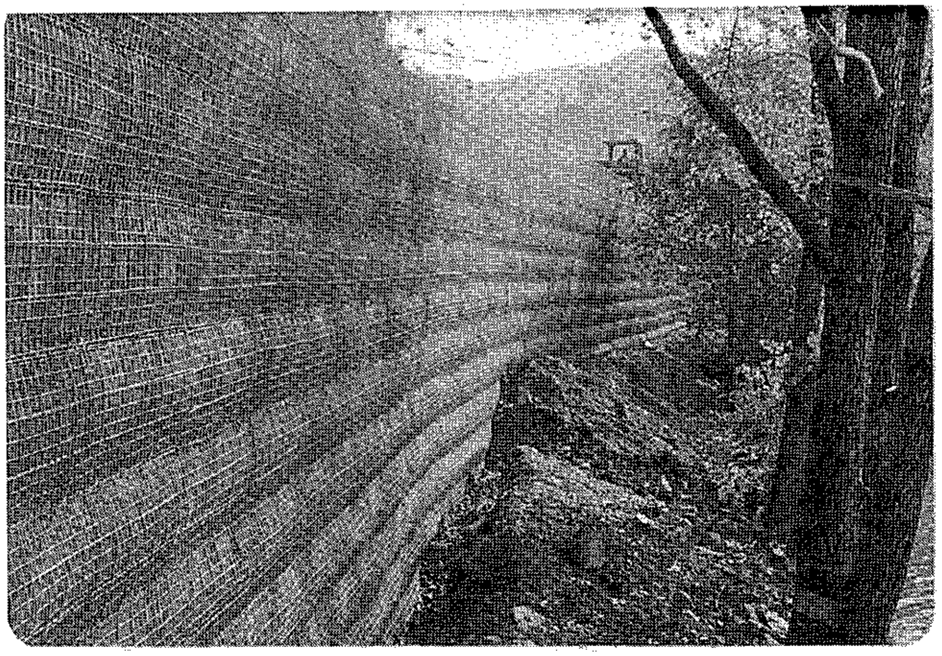


Photo 21 - Site 11 (Lake Co.) Hilfiker Welded Wire Wall System

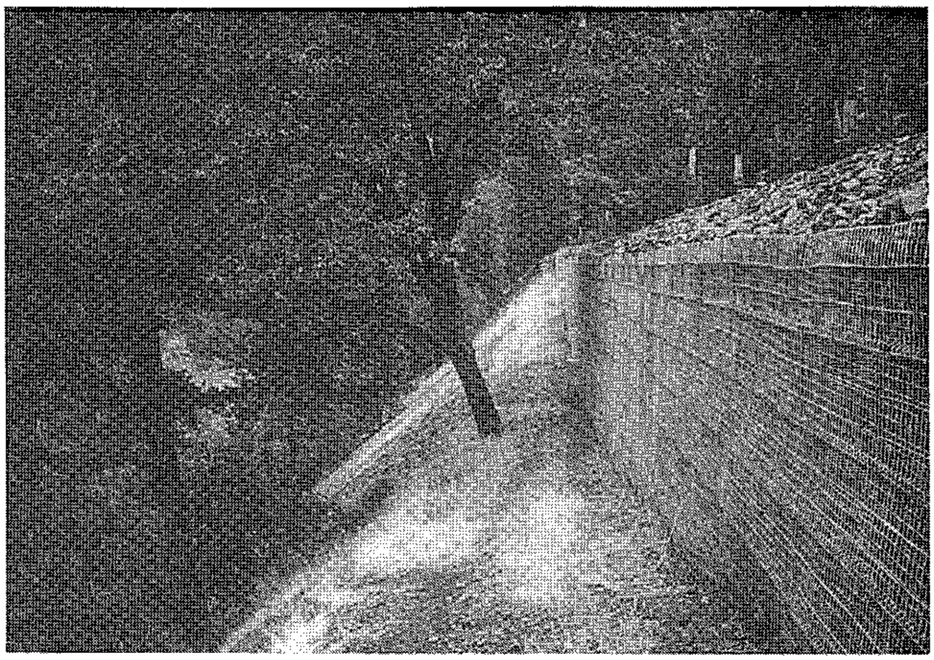


Photo 22 - Site 12 (Trinity) Hilfiker Welded Wire Wall

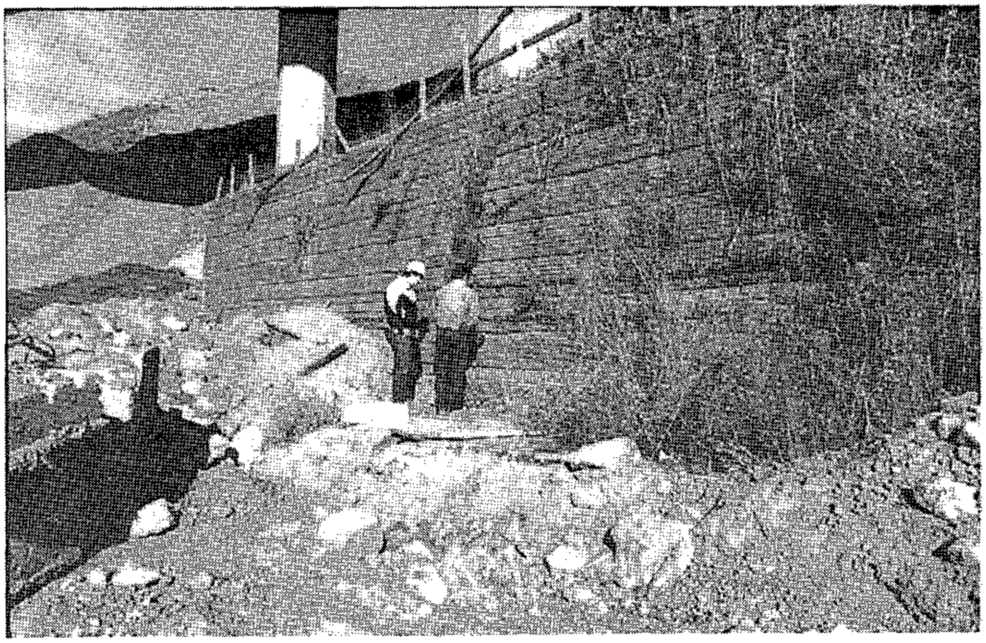


Photo 23 - Site 13 (Castro Valley) Hilfiker Welded Wire Wall

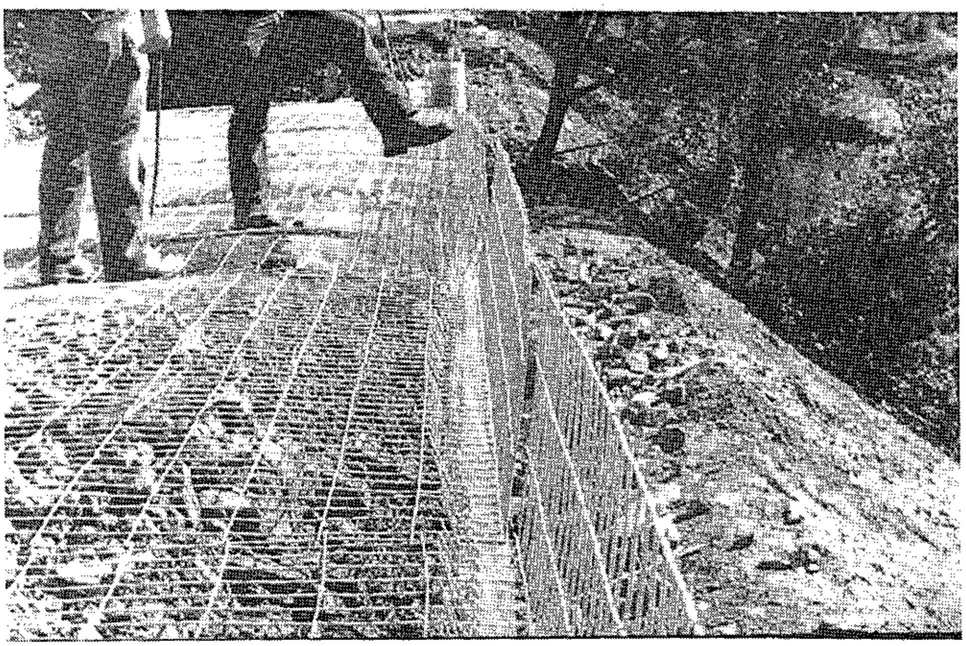


Photo 24 - Typical installation of reinforcement in Hilfiker Welded Wire Wall System

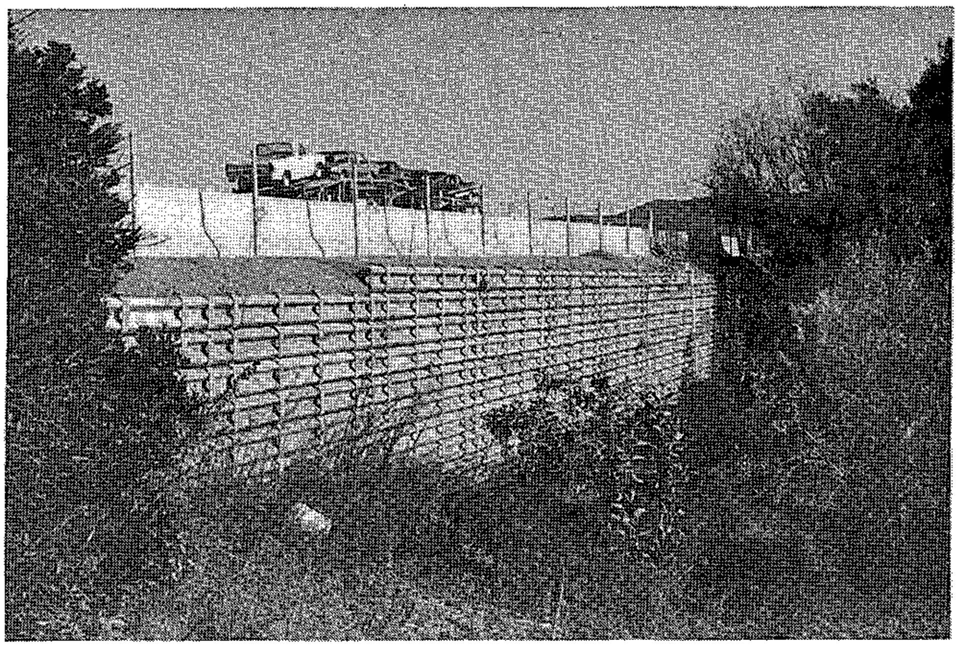


Photo 25 - Site 14 (Ventura) Caltrans Salvaged Guard Rail Wall System

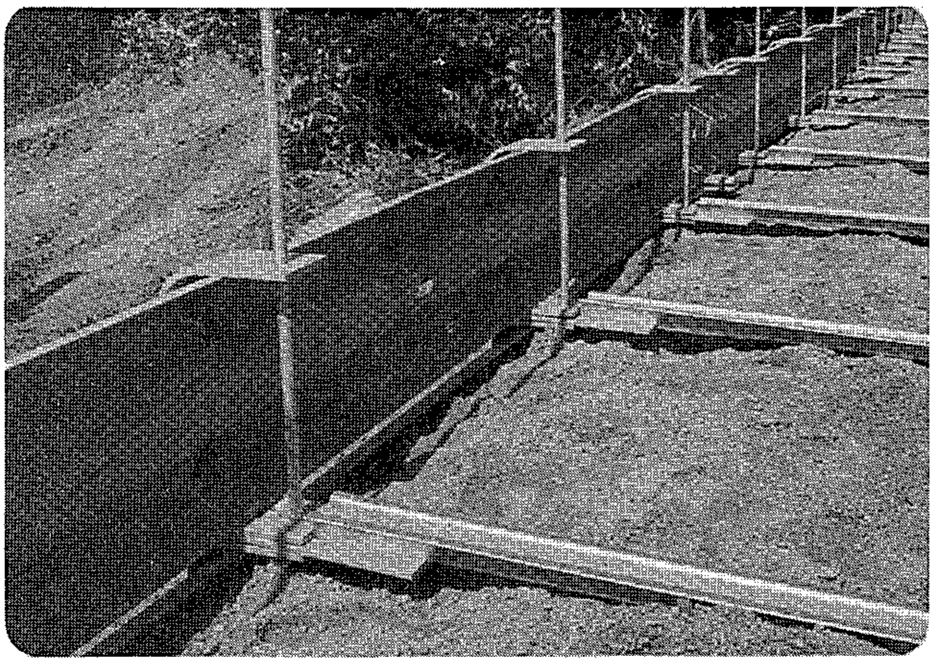


Photo 26 - Typical installation of salvaged sign posts used as reinforcement in the SGR System

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APPENDICES

## APPENDIX A
## DESIGN PHILOSOPHY

Critical to the earth-reinforced wall systems is the long-term protection of the connectors and soil reinforcing elements, both of which are typically metallic. The lateral forces acting on the wall panels are resisted by tension stresses at the connection between the panels and soil reinforcement elements and those forces within the soil-reinforced backfill are resisted by stresses taken up by the soil-reinforcing elements. A loss of cross-sectional area to either element through corrosion could lead to overstressing and breakage. Therefore, all potential losses during the design life of the wall system must be accomodated in its initial design.

Methods to accomodate the corrosive effects may be by any of the following: add "sacrificial" steel in the amount of estimated corrosion loss to that amount needed to resist tensile stresses; restrict water intrusion into the wall backfill by use of a clay surface layer in order to lessen corrosion by reducing the available electrolyte; provide a free draining backfill to minimize the electrolite presence; galvanize metallic elements to provide anodic protection; provide a cathodic protection system; use of a more corrosion-resistant configuration (e.g. use of plastic) for the soil elements.

## APPENDIX B

## BASIC MECHANICS OF CORROSION

Corrosion can be defined as the destruction of metal by chemical or electrochemical means. For this report, only the electrochemical means of corrosion will be discussed.

Four requirements are needed for corrosion to occur: An anode and a cathode metallically connected within an electrolytic medium. The anode corrodes (that is, loses metal) due to a difference in electromotive potential with respect to the cathode. These elements define a galvanic cell and will hereafter be referred to as a corrosion cell.

With that as background, localized corrosion will be caused or accelerated by differences in the electromotive potential arising from a connection between dissimilar metals and/or due to different soil environments along an individual steel reinforcing element.

Physical characteristics of the soil, such as, pH, resistivity, soluble salt content, organic content, moisture content, density, and gradation all affect corrosion rate. Corrosion is a complex phenomenon. The large number of soil parameters affecting corrosion, their interactive effects and the fact that some parameters can change over time make the corrosion rate extremely hard to predict on an individual site basis.

APPENDIX C

TEST METHODS

| Parameter | Test Number | Test Agency |
|---|---|---|
| SOIL | | |
| Gradation | 202,203 | 1 |
| Moisture Content | 226 | 1 |
| Atterburg Limits | 204 | 1 |
| Soluble Salts | | |
| Sulfates | 417 | 1 |
| Chlorides | 422 | 1 |
| pH | 643 | 1 |
| Electrical Resistivity | 643 | 1 |
| Half-Cell Potential Measurements | C 876* | 2 |
| Water-Soluble Iron | 8A** | 3 |
| STEEL | | |
| Zinc Layer Thickness | 652 | 1 |
| Steel Compound Additives | | |
| Carbon | E 350 | 2 |
| Silicon | E 350 | 2 |
| Manganese | E 350 | 2 |
| Phosphorus | E 350 | 2 |
| Sulphur | E 350 | 2 |

Test Agency

1. California Department of Transportation.

2. American Society for Testing and Materials

3. United State Department of Agriculture Soils Investigation Manual No. 1

* As applicable

** Liquid extract then processed by atomic absorption methods.

# APPENDIX D

## SUMMARY OF WALL SYSTEM FEATURES

Of the five wall types studied, four (MSE, TAT, SGR and Welded Wire Walls) are of the 'passive' type reinforcing system and the fifth wall type, RE, is an 'active' type system. In the passive systems, the soil reinforcement has the capability of developing a passive force due to transverse (that is, perpendicular to the direction of pullout) sections along its length. In addition, friction forces developed in the longitudinal direction can also be mobilized to resist pullout. Backfill in these systems can vary from purely frictional to cohesive types. The RE is considered an 'active' type reinforcing system since it depends almost totally on frictional forces developed between the element and soil for pullout resistance. Backfill must be predominately cohesionless. The following is a brief description of each system type. Photos of each system are shown with each wall site in Appendix D.

### Reinforced Earth (RE)

This system, patented by Henri Vidal in France in 1966, uses galvanized (0.8 to 2 oz/ft$^2$) steel straps (typically 50mm x 4mm in cross section) for the reinforcing element. In special applications, other metals may be used. Steel is AISI 1020 (low carbon) and cold rolled. Steel strength is rated as 51 ksi (kips per square inch) yield and 61 ksi ultimate. Smooth strips were used prior to 1978 at which time they changed to ribbed strips. Early face panels were steel and after 1973 are made of concrete. Strips are bolted to steel tabs projecting from the facing. In the concrete panels, the tabs spread out to resist pullout through the shearing and tensile resistance of the concrete and are not internally connected to the panel reinforcement. Corrosion in the RE system can occur on the soil reinforcement elements, on the connector tab either within the concrete face panels or outside the panel or internally within the reinforced concrete panel.

In this study two Reinforced Earth walls were studied, one with steel facing members and one with concrete facing members.

## Mechanically Stabilized Embankment (MSE)

The MSE system was developed by Caltrans in 1972. It uses concrete facing panels and bar mats (grids) as reinforcement. In special applications plywood facing panels are also used. The MSE reinforcement is a bar mat fabricated by resistance welding at the joints. Bars (or wires) are ungalvanized and, for the projects herein, wire diameter varied between 0.30 and 0.38 inches. Typically, mats use AISI 1020 steel that develops a 51 ksi yield strength and 61 ksi ultimate strength. MSE walls studied for this report employ a threaded extension of the mat to pass through the concrete facing panel into a recess for eventual securing of the panels to the mats. After securing, the recess is mortared over. Later MSE designs employed a tab cast into the panel similar to the RE system and mechanically connected to the mat. Where wood facing was used, bolts and washers were left exposed on the face.

Corrosion can occur are on the rebars within the concrete panel, on the connection between the panel and the mat, at weld-points on the mat, and elsewhere along the individual wires making up the soil reinforcement.

## Tire Anchor Timber Wall (TAT)

The TAT wall was developed by Caltrans in 1978 for the specific purpose of using discarded tire sidewalls as a means of earthwork reinforcement. This system used a deformed #5 or larger rebar ASTM A-615 Grade 60 that develops 60 ksi yield strength and

90 ksi ultimate strength. Flat A-36 steel bars (16 inch x 2 inch x 1/4 inch) are welded at 4-foot intervals along the rebar to provide anchorage for the tire sidewalls. The reinforcement is galvanized with a minimum of 2 oz/ft$^2$ after fabrication.

Facing material consists of heavy timbers for lagging and vertical posts, which are preservative-treated to provide longevity. Rebars are end-threaded, passed through the face members and are secured to the timber facing with a plate washer and nut.

Corrosion can occur along the rebar, on the plate and at the weld.

Salvaged Guard Rail Wall (SGR)

The SGR system was developed and constructed by Caltrans in 1981 and utilized salvaged highway materials for reinforcement and facing elements. The SGR wall evaluated in this project employed salvaged sign posts (approximately 1-1/2 inch wide V-shaped structural steel sections) as reinforcing elements. A passive element was attached at the back end of the sign posts and consisted of salvaged C-channel sections (AISC C 6x8.2). Facing elements are salvaged guardrail sections commonly called 'W' sections because of their shape. All steel was A-36 (36 ksi yield). All connections are bolted. Bolts were A-307 steel with a 36 ksi yield strength (60 ksi ultimate strength). A minimum of 1.8 oz/ft$^2$ of galvanization is required.

Corrosion can occur on the guard rail facing and along the sign posts and C-channel.

Welded Wire Wall

The Welded Wire Wall is a patented system. The Hilfiker Company (Eureka, California) is the patent holder and supplier. The Welded Wire Wall uses 5, 7 or 9 gage wire (0.21, 0.18 and 0.15

inches in diameter, respectively). The wire is fabricated into a grid by resistance welding before galvanization. A minimum of 0.8 $oz/ft^2$ galvanization is applied for corrosion protection. Facing is wire and an extension of the mats. Wire is AISI 1020 cold rolled steel and develops a 65 ksi yield strength and 75 ksi ultimate strength. Possible locations of corrosion are on the wire and at the weld points.

## APPENDIX E
## WALL SITES

### SITE 1 - Mariposa

District 10
Mariposa County
Rte. 140 P.M. 30.4

In October 1979, a Caltrans' Mechanically Stabilized Embankment (MSE) retaining wall was constructed along Route 140. The site is located near Midpines, California, west of Yosemite National Park. Located in the southern Sierra Nevada, the site receives 32 inches of annual precipitation.

Wall height varies from 12 feet at the ends to 24 feet at the center. The wall retains an unpaved horizontal backfill for 20 feet which then changes to a limited 1:1 slope.

A drainage blanket was placed between the backfill material and the original ground. The blanket is a one foot layer of coarse gravel placed between filter fabric material. In elevation view, the blanket extends from the wall base to within five feet of finished embankment. It was placed on a 1:1 slope beginning just beyond the reinforced backfill. Within the bottom of the blanket is a perforated pipe to carry off influent water.

This wall was built with 22 inspection wires placed within the wall backfill. Each wire was positioned such that its end exited the face at the junction of four adjacent face panels. In June 1985, five inspection wires were retrieved. All the wires showed substantial metal loss and some pitting.

Other field work consisted of soil sampling with a 1-inch diameter sampler at the 5 locations adjacent to the removed inspection wires.

Also retrieved were two soil reinforcement mat segments. They were exhumed by hand digging from a location 10 feet behind the wall crest, at depths of 1 and 3 feet below the surface. Visual inspection showed the bar mats were in good condition with no pitting. Measured corrosion was only about one-sixth that of the inspection wires located in the lower two-thirds of the fill.

Soil samples adjacent to the bar mats were collected for testing. Four half-cell potential readings were taken prior to removal of the bar mat segments. Reference was a copper-copper sulfate half-cell ($CuSO_4$) with the negative pole connected to ground and the positive pole connected to the metal soil reinforcement. The local ground was saturated prior to the test by the addition of water. Readings were extremely low; probable cause was insufficient moisture in the soil to make a proper circuit.

## MARIPOSA (SITE 1) GENERAL WALL AND SITE DATA

| | | |
|---|---|---|
| **Wall Type** | Mechanically Stabilized Embankment (MSE) | |
| Construction date | October 1979 | |
| Inspection and sampling date | July 1985 | |
| | B | A |
| **Soil Data** | lower 2/3 wall | upper 1/3 wall |
| Unified Soil Classification | GM | GC-GM |
| Moisture Content ten samples | 14.8% | NA |
| Plasticity Index eight samples | LL=36%<br>PL=25%<br>PI=11 | LL=29%<br>PL=22%<br>PI=7 |
| pH eight samples | 6.6 median<br>6.1-6.8 range | 6.6 |
| Minimum Resistivity eight samples | 3700 ohm-cm | 3500 ohm-cm |
| Sulfates eight samples | 10 ppm | 9 ppm |
| Chlorides eight samples | 0 ppm | 0 ppm |
| **Steel Data** | | |
| Specified Galvanization | none | none |
| Original Diameter of Soil Reinforcement | 0.374 in. (nominal) | 0.299 in. |
| As-sampled Dimensions | 0.348 in. | 0.295 in. |
| **Electrical Readings** | | |
| Half-cell potential four readings | +0.012 to -0.45 volt range | |

All sample data are shown as mean values unless noted.

SITE 2 - Baxter

District 3
Placer County
Rte. 80 P.M. 48.6

In September 1985, a Caltrans' Mechanically Stabilized Embankment (MSE) retaining wall along Interstate 80, 2.4 miles east of Baxter, was investigated. The wall is located in an area of the Sierra Nevada which recieves an annual precipitation of 53 inches.

Wall heights vary from 4 feet at the ends to 16 feet maximum. The wall retains a horizontal backfill, a portion of which is paved. Pavement extends to within 3 feet of the wall. The wall has a drainage blanket system directly behind the soil reinforcement (see Mariposa section for drainage details).

Three inspection wires were pulled as part of this study. One was located just below the crest and the other two remaining wires near the wall base. Visual inspection of the three wires showed some corrosion for the first 3 feet of the wire below the unpaved fill. The remainder of the wire showed very little corrosion. Soil samples were taken, using a 1-inch diameter sampler. The sampler was driven horizontally through the hole in the wall face through which the inspection wires were pulled. Driving of the soil sampler was very easy for the first 3 feet, with considerable resistance developing from this point back. The increased resistance is believed to be due to higher soil density in the rearward portion of the backfill relative to the front 3 feet. No density tests were obtained to confirm this speculation.

One section of bar mat was exposed by entering through the unpaved backfill of the wall crest. The mat was located 1 foot below the surface. The small section of bar mat wire that was removed showed only slight corrosion and no pitting. Soil adjacent to the removed steel bar mat was taken for testing. Half-cell potential readings were taken prior to removal of all the steel elements and on all inspected wires throughout the wall.

Soil moisture content, soluble salt content and soil gradation were shown to be similar throughout the backfill areas tested.

## BAXTER (SITE 2) GENERAL WALL AND SITE DATA

| | |
|---|---|
| **Wall Type** | Mechanically Stabilized Embankment (MSE) |
| Construction date | November 1982 |
| Inspection and sampling date | September 1985 |
| **Soil Data** | |
| Unified Soil Classification | GM |
| Moisture content three samples | 7% |
| Plasticity Index three samples | Nonplastic |
| pH four samples | 5.2 median<br>4.5-6.0 range |
| Minimum Resistivity four samples | 3300 ohm-cm |
| Sulfates four samples | 48 ppm |
| Chlorides four samples | 90 ppm |
| **Steel Data** | |
| Specified Galvanization | none |
| Original Diameter of Soil Reinforcement | 0.300 inches (nominal) |
| As-sampled Diameter | |
| front 3 feet (site 2A) | 0.293 inches |
| remainder of length (site 2B) | 0.298 inches |
| **Electrical Readings** | |
| Half-cell potential | -0.507 to -0.796 volt range |

All sample data are presented as mean values unless noted.

SITES 3 and 5 - Dunsmuir

District 2
Siskiyou County
I-5, P.M. 3.0

Two retaining walls in Dunsmuir, California were investigated in October, 1985. One was a Caltrans' Mechanically Stabilized Embankment (MSE) (Site 3) wall and the other a Reinforced Earth (RE) concrete face wall (Site 5). Both walls are located on Interstate 5 approximately 50 miles north of Redding, California. Precipitation in this area is 50 inches per year.

Both walls vary in height from 6 to 20 feet. The RE wall retains a horizontal backfill, of which the nearest 11 feet to the wall face is unpaved. The MSE wall retains a 4:1 unpaved backslope. Both walls have a drainage blanket behind the soil reinforcement (see Mariposa section for details of drainage system).

Two areas were excavated at the RE wall. One excavation occurred near the wall's southern end, 3 feet behind the face and 21 inches from the top. Three strips were uncovered for inspection and of those, one was removed. The removed strip was the only one that had signs of corrosion; over 50% of the galvanization was depleted on its top side but only a slight amount of corrosion of the steel (as evidenced by slight rusting) had taken place. (Photo 14). The second area was excavated near the central portion of the wall. This location was hand excavated down 21 inches to expose three strips. None were removed. The strips uncovered at this location showed little or no zinc loss by visual inspection. Half-cell readings were taken on all strips and soil samples were taken from the area adjacent to the steel strips.

Two locations were excavated at the crest of the MSE wall.

The first location was near the wall's southern end at 2 feet behind the wall face. Two bar mat sections were removed from the topmost reinforcement level at the 1 foot depth. They showed by visual inspection only slight corrosion. Digging continued to the second level of reinforcement at the 3 foot depth and revealed similar steel condition to that above. Soil samples were removed adjacent to the steel at the upper level.

The second excavation was located at about the middle of the wall length and was 2 feet behind the wall face. Two levels of reinforcement were uncovered; one at the 1 foot depth, and a second at the 2-1/2 foot depth. Visual inspection showed only slight corrosion. One bar mat section was removed for this site. Half-cell potential readings were taken on the exposed soil reinforcement at both locations.

## DUNSMUIR (SITE 3) GENERAL WALL AND SITE DATA

| | |
|---|---|
| **Wall Type** | Mechanically Stabilized Embankment (MSE) |
| Construction date | October 1976 |
| Inspection and sampling date | October 1985 |
| **Soil Data** | |
| Unified Soil Classification | GM |
| Moisture Content | 18% |
| Plasticity Index | Nonplastic |
| pH | 6.5 |
| Minimum Resistivity | 14,300 ohm-cm |
| Sulfates | 5 ppm |
| Chlorides | 0 ppm |
| **Steel Data** | |
| Specified Galvanization | none |
| Original Diameter of Soil Reinforcement | 0.380 inches (nominal) |
| As-sampled Diameter | 0.376 inches |
| **Electrical Readings** | |
| Half-cell potential | -0.098 to -0.130 volt range |

## DUNSMUIR (SITE 5) GENERAL WALL AND SITE DATA

| | |
|---|---|
| **Wall Type** | Reinforced Earth (RE) |
| Construction date | September 1974 |
| Inspection and sampling date | October 1985 |
| **Soil Data** | |
| Unified Soil Classification | SM |
| Moisture Content | 22% |
| Plasticity Index | Nonplastic |
| pH three samples | 6.4 median<br>5.7-6.5 range |
| Minimum Resistivity three samples | 19,900 ohm-cm |
| Sulfates three samples | 7 ppm |
| Chlorides three samples | 0 ppm |
| **Steel Data** | |
| Specified Galvanization | 0.80 oz/sf |
| Remaining Galvanization | 1.20 oz/sf * |
| Original Dimensions of Soil Reinforcement | 0.118 x 2.36 inches |
| As-sampled Dimensions | as above |
| **Electrical Readings** | |
| Half-cell potential | -0.502 to -0.670 volt range |

* see text

All data are presented as mean values unless noted.

## SITE 4 - Santa Barbara

District 5
Santa Barbara County
Rte. 192 P.M. 5.2

In December 1985, an investigation of a plywood-faced bar-mat reinforced soil retaining wall along Route 192 took place. The site is located just north of Santa Barbara, California. Annual average precipitation is 15 inches.

Maximum wall height is 11 feet near the center. No drainage blanket system was installed in the backfill. Fill behind the wall crest was placed on a 1-1/2:1 unpaved slope for 9 feet horizontally, then it levels to meet the highway grade.

Field work consisted of exhuming a bar mat section near the center of the wall. The mat was 2 feet below the surface and 1-1/2 feet behind the wall face. A section of mat and part of the connecting plate were removed. Half-cell potential readings were taken prior to removal of the bar mat and soil samples taken.

After surface cleaning, the steel wire and plate were visually judged to be in good condition. Some minor pitting was apparent on the plate only.

## SANTA BARBARA (SITE 4) GENERAL WALL AND SITE DATA

| | |
|---|---|
| **Wall Type** | Mechanically Stabilized Embankment (MSE) |
| Construction date | October 1978 |
| Inspection and sampling date | December 1985 |
| **Soil Data** | |
| Unified Soil Classification | SM |
| Moisture Content two samples | 14% |
| Plasticity Index | Nonplastic |
| pH | 7.4 |
| Minimum Resistivity | 800 ohm-cm |
| Sulfates | 1,650 ppm |
| Chlorides | 0 |
| **Steel Data** | |
| Specified Galvanization | none |
| Original Diameter of Soil Reinforcement | 0.252 inches (nominal) |
| As-sampled Dimension | 0.249 inches |
| **Electrical Readings** | |
| Half-cell potential four readings | -0.574 to -0.693 volt range |

SITE 6 - Los Angeles, Route 39

District 7
L. A. County
Rte. 39 P.M. 43.9

In September 1985, a Reinforced Earth (RE) steel-faced retaining wall on Route 39 in the San Gabriel Mountains was investigated. Annual average precipitation for this area is 27 inches.

This wall was the first RE wall built in the U.S.A. Wall height varies from 8 feet at the southern end to 55 feet near the center. At the wall crest the fill remains unpaved for approximately 8 to 10 feet before pavement begins. The unpaved area has a gravel cover which allows water to infiltrate into the soil reinforcement region. The wall system has a drainage blanket behind the soil reinforcement (see Mariposa section for details of the drainage system).

Four separate locations were inspected; two at the wall crest and two at the base. Two strips from each location were retrieved.

To achieve retrieval of the strips at the base, the steel facing panel was torch-cut and backfill hand excavated. The strips, when exposed, had water droplets on their bottom side signifying no soil contact on the bottom of the strap at this location.

The strips were in good condition with almost all of the strip still galvanized and only slight corrosion near the edges.

Soil adjacent to the removed steel at every location was collected for testing. Half-cell potential readings were taken prior to removal of the steel elements.

## LOS ANGELES ROUTE 39 (SITE 6) GENERAL WALL AND SITE DATA

| | |
|---|---|
| **Wall Type** | Reinforced Earth (RE) |
| Construction date | October 1972 |
| Inspection and sampling date | September 1985 |
| **Soil Data** | |
| Unified Soil Classification | SW |
| Moisture Content | 12% |
| Plasticity Index | Nonplastic |
| pH four samples | 8.2 median<br>7.9-8.4 range |
| Minimum Resistivity four samples | 13,800 ohm-cm |
| Sulfates four samples | 1 ppm |
| Chlorides four samples | 0 ppm |
| **Steel Data** | |
| Specified Galvanization | 0.80 oz/sf |
| Remaining Galvanization | 0.38 oz/sf |
| Original Dimensions of Soil Reinforcement | 0.118 x 3.15 inches (nominal) |
| As-sampled Dimensions | as above |
| **Electrical Readings** | |
| Half-cell potential | -0.670 to -0.772 volt range |

All sample data are presented as mean values unless noted.

## SITE 7 - Mammoth

District 9
Mono County
Rte. 203 P.M. 5.9

In July 1985, two Tire Anchor Timber (TAT) retaining walls along Route 203 to Mammoth Lakes were investigated; the data is collectively labeled as from a single site. The walls are located in the Sierra Nevada; annual precipitation averages 16 inches of rain and 10 feet of snow. In winter months during roadway clearing operations, snow is blown onto the wall crest. Some salt is used during clearing operations.

Wall heights vary from 3 to 12 feet. The walls retain an unpaved backfill slope of 1-1/2:1. No drainage blankets were installed at either wall; backfill gradation allows for adequate drainage.

Field work included retrieving one anchor bar assembly from each wall. Soil samples and half-cell potentials readings were taken.

Two anchor bar assemblies (see photo) were removed from the soil reinforcement; they were located approximately 1-1/2 feet below the surface and 3 feet behind the face.

## MAMMOTH (SITE 7) GENERAL WALL AND SITE DATA

| | |
|---|---|
| <u>Wall Type</u> | Tire Anchored Timber (TAT) |
| Construction date | September 1981 |
| Inspection and sampling date | July 1985 |
| <u>Soil Data</u> | |
| Unified Soil Classification | SW |
| Moisture Content | 1% |
| Plasticity Index, four samples | Nonplastic |
| pH, four samples | 7.6 median<br>7.2-7.7 range |
| Minimum Resistivity, four samples | 9,500 ohm-cm |
| Sulfates, four samples | 0 ppm |
| Chlorides, four samples | 0 ppm |
| <u>Steel Data</u> | |
| Specified Galvanization | 2.0 oz/sf |
| Remaining Galvanization | 2.97 oz/sf |
| Original Diameter of Soil Reinforcement | 0.625 inches (nominal) |
| As-sampled Diameter | as above |
| <u>Electrical Readings</u> | |
| Half-cell potential | -0.675 to -1.018 volt range |

All sample data are presented as mean values unless noted.

SITE 8 - Mar Monte

District 4
Santa Cruz County
Rte. 1 P.M. 6.6

In September 1985, a Tire Anchor Timber Wall (TAT) just off Route 1 was investigated. The wall is located west of the Santa Cruz Mountains and south of the city of Santa Cruz. Precipitation averages 25 inches annually.

Wall height varies from 3 feet at the ends to 14 feet near the center. The wall is backed by a drainage blanket (see Mariposa section for details of the drainage system). A 2 foot-thick clay cap was placed over the reinforced backfill. Fill behind the wall is on a 2:1 slope to meet the existing ground. A concrete gutter is located directly behind the wall crest for the entire wall length to channelize surface runoff into a catch basin.

Field work consisted of retrieval of an anchor bar assembly (rebar and cross arm) at one end of the wall and a short rebar section near the midpoint of the wall. The two elements were located approximately 2 feet below the surface and 3 feet behind the face.

Soil adjacent to the removed steel was collected for testing. Half-cell potential readings were taken prior to removal of the steel elements.

## MAR MONTE (SITE 8) GENERAL WALL AND SITE DATA

| | |
|---|---|
| **Wall Type** | Tire Anchored Timber (TAT) |
| Construction date | September 1982 |
| Inspection and sampling date | September 1985 |
| **Soil Data** | |
| Unified Soil Classification | SM |
| Moisture Content two samples | 11% |
| Plasticity Index two samples | Nonplastic |
| pH two samples | 7.7 median<br>7.6-7.7 range |
| Minimum Resistivity two samples | 2,400 ohm-cm |
| Sulfates two samples | 43 ppm |
| Chlorides two samples | 7 ppm |
| **Steel Data** | |
| Specified Galvanization | 2.0 oz/sf |
| Remaining Galvanization | 3.85 oz/sf |
| Original Diameter of Soil Reinforcement | 0.750 inches (nominal) |
| As-sampled Diameter | as above |
| **Electrical Readings** | |
| Half-cell potential | -0.671 to -0.966 volt range |

All sample data are presented as mean values unless noted.

SITE 9 - Waldo

District 4
Marin County
Rte. 101 P.M. 1.4

Investigation of a Tire Anchor Timber (TAT) wall took place in November 1985. Precipitation in the area averages 36 inches per year. These walls are near the base of a hill that supports an embankment for U.S. Highway 101 in southern Marin County.

The three walls at this site were built in a stepped fashion. Walls heights vary from 6 feet for the lower wall to 17 feet for the upper wall. The walls were considered as a single site for investigative purposes. Behind the top wall a drainage blanket system is provided behind and underneath the soil reinforcement.

Field investigation consisted of retrieval of one anchor bar assembly and visual inspection of a second assembly. The two elements were located approximately 1-1/2 feet below the surface and 3 feet behind the wall face of the topmost wall.

Soil adjacent to the removed element was collected for testing. Half-cell potential readings were taken prior to removal of the steel elements.

## WALDO (SITE 9) GENERAL WALL AND SITE DATA

| | |
|---|---|
| **Wall Type** | Tire Anchored Timber (TAT) |
| Construction date | August 1983 |
| Inspection and sampling date | November 1985 |
| **Soil Data** | |
| Unified Soil Classification | GM |
| Moisture Content | 14% |
| Plasticity Index | LL=36%<br>PL=27%<br>PI=9 |
| pH<br>two samples | 6.2 median<br>5.9-6.4 range |
| Minimum Resistivity<br>two samples | 2,900 ohm-cm |
| Sulfates<br>two samples | 85 ppm |
| Chlorides<br>two samples | 0 ppm |
| **Steel Data** | |
| Specified Galvanization | 2.0 oz/sf |
| Remaining Galvanization | 4.50 oz/sf |
| Original Diameter of Soil Reinforcement | 0.875 inches (nominal) |
| As-sampled Diameter | as above |
| **Electrical Readings** | |
| Half-cell potential | -0.607 to -0.980 volt range |

All sample data are presented as mean values unless noted.

## SITE 10 - Los Angeles Route 2

District 7
L.A. County
Rte. 2 P.M. 63.1

In September 1985, a Hilfiker Welded Wire retaining wall was investigated. The wall is located in the San Gabriel Mountains on a now-closed section of Route 2. Precipitation for this area is an average of 27 inches annually.

The wall varies in height from 3 to 14 feet and retains a 5 foot high 1-1/2:1 unpaved slope which then levels to meet the highway grade. No drainage blanket was installed; backfill gradation allows for adequate drainage.

Field work consisted of retrieval of two inspection wires. Both wires were 10 feet long, 9 gauge smooth wire. The wires were situated near the wall crest, one at the wall midpoint and the other at the north end of the wall.

Half-cell potential readings were taken on the inspection wire only.

Soil samples were taken from the top surface (not adjacent to the inspection wires).

## LOS ANGELES ROUTE 2 (SITE 10) GENERAL WALL AND SITE DATA

| | |
|---|---|
| **Wall Type** | Welded Wire Wall |
| Construction date | July 1983 |
| Inspection and sampling date | September 1985 |
| **Soil Data** | |
| Unified Soil Classification | GW |
| Moisture Content | trace |
| Plasticity Index | Nonplastic |
| pH | 7.5 |
| Minimum Resistivity | 10,300 ohm-cm |
| Sulfates | 0 ppm |
| Chlorides | 0 ppm |
| **Steel Data** | |
| Specified Galvanization | 0.8 oz/sf |
| Remaining Galvanization | 5.7 oz/sf |
| Original Diameter of Soil Reinforcement | 0.148 inches (nominal) |
| As-sampled Diameter | as above |
| **Electrical Readings** | |
| Half-cell potential four readings | -0.676 to -0.904 volt range |

## SITE 11 - Lake

District 1
Lake County
Rte. 20 P.M. 1.5

In October 1985, a Hilfiker Welded Wire retaining wall along State Route 20 was investigated. This site is on the banks of the Upper Blue Lake near Ukiah, California. Average precipitation for this area is 40 inches annually.

Wall height varies from 12 feet at the ends to 22.5 feet near the center. The wall retains a 5 foot wide, gravel-covered 2:1 backslope which levels to meet the highway pavement. A pea-gravel backfill was installed directly behind the wall face for a distance of about 3 feet.

Field work required two visits to the wall. The first trip involved opening two locations at the wall crest. Wire mats at both locations were exposed for 2 feet from the wall face. Steel mat was taken from one location only. Soil samples were taken and half-cell potential readings were taken at both locations.

On the second trip, an inspection wire at the eastern end was retrieved near the wall base along with a portion of the actual soil reinforcement. Half-cell potential readings were taken on the wire and the mat. Soil samples were taken of the backfill material.

## LAKE ROUTE 20 (SITE 11) GENERAL WALL AND SITE DATA

| | |
|---|---|
| **Wall Type** | Welded Wire Wall |
| Construction date | December 1982 |
| Inspection and sampling date | October 1985 |
| **Soil Data** | |
| Unified Soil Classification | SC |
| Moisture Content | 14% |
| Plasticity Index | LL=30%<br>PL=22%<br>PI=8 |
| pH two samples | 7.7 |
| Minimum Resistivity two samples | 3,250 ohm-cm |
| Sulfates two samples | 20 ppm |
| Chlorides two samples | 0 ppm |
| **Steel Data** | |
| Specified Galvanization | 0.8 oz/sf |
| Remaining Galvanization | 2.95 oz/sf |
| Original Diameter of Soil Reinforcement | 0.148 inches (nominal) |
| As-sampled Diameter | as above |
| **Electrical Readings** | |
| Half-cell potential four readings | -0.688 to -0.940 volt range |

All sample data are presented as mean values unless noted.

SITE 12- Trinity

District 2
Trinity County
Rte. 299 P.M. 36.7

Investigation of a Hilfiker Welded Wire retaining wall took place in October, 1985. This location is approximately 60 miles west of Redding, California along Route 299 adjacent to the Trinity River. Average annual precipitation in this area is 40 inches.

The wall height varies from 3 to 17 feet. The wall retains a 1-1/2:1 gravel slope for 3 feet which levels to meet the highway grade. No drainage blanket was installed. Backfill gradation allows for adequate drainage.

Field work consisted of retrieval of a section of welded wire mat from the topmost layer of soil reinforcement. The mat was retrieved from a point 2 feet below the surface and 4 feet behind the wall face near the eastern end of the wall. All exposed steel showed little or no zinc loss. Soil samples adjacent to the removed wire mat were taken for testing. Half-cell potential readings were taken on the exposed steel. Readings were also taken on all the inspection wires which projected through the wall face.

A second location was also investigated at the west end of the wall. A soil sample was taken just behind the wall crest and forty inches of wire was cut from the 10 foot long inspection strand. (Removal of two inspection wires by pulling was unsuccessful due to the pull load breaking the wires). Visual inspection revealed water droplets were present on the inspection wires and the adjacent soil reinforcement mat. No loss of galvanization was seen on any of the exposed or retrieved steel.

## TRINITY ROUTE 299 (SITE 12) GENERAL WALL AND SITE DATA

| | |
|---|---|
| **Wall Type** | Welded Wire Wall |
| Construction date | July 1983 |
| Inspection and sampling date | October 1985 |
| **Soil Data** | |
| Unified Soil Classification | GW |
| Moisture Content | 6% |
| Plasticity Index | Nonplastic |
| pH three samples | 3.1 median<br>2.9-3.1 range |
| Minimum Resistivity three samples | 1,500 ohm-cm |
| Sulfates three samples | 680 ppm |
| Chlorides three samples | 0 ppm |
| **Steel Data** | |
| Specified Galvanization | 2.2 oz/sf |
| Remaining Galvanization | 1.32 oz/sf |
| Original Diameter of Soil Reinforcement | 0.177 inches (nominal) |
| As-sampled Diameter | as above |
| **Electrical Readings** | |
| Half-cell potential four readings | -0.976 to -1.054 volt range |

All data presented as mean values unless noted.

## SITE 13 - Castro Valley

District 4
Alameda County
Rte. 580 P.M. 25.9

In November, 1985 a Hilfiker Welded Wire retaining wall was investigated. Located along Interstate Route 580 in the northeast Alameda County, the wall was designed as a temporary system. Average precipitation in this area is 14 inches annually.

Maximum wall height is approximately 29 feet. The wall retains a 1-1/2:1 slope to the new bridge abutment.

Field work consisted of exhuming soil reinforcement wire mats at two locations. Both location sites were opened through the wall face. At one location approximately 9 feet below the wall crest, portions of the mat were exhumed to a point 5 feet behind the face. A section of mat was removed, after half-cell readings and soil samples were taken.

The second location, approximately 12 feet below the wall crest, was exposed to 7 feet behind the wall face. A portion of wire mat was removed, after half-cell readings and samples were taken. The mat was originally galvanized with a commercial coating of about 0.3 $oz/ft^2$. The retrieved mat sections had signs of galvanization loss, but overall, were in good condition.

At the second location, moisture content was measured as increasing with distance from the wall face. Corrosion was evident on the mat and also increased with the distance from the wall face. An estimated 30% of the surface galvanization had corroded.

This wall will be buried under a fill during the fall of 1986 and will be inaccessible to future study.

## CASTRO VALLEY (SITE 13) GENERAL WALL AND SITE DATA

| | |
|---|---|
| **Wall Type** | Welded Wire Wall |
| Construction Date | October 1982 |
| Inspection Date and sampling date | November 1985 |
| **Soil Data** | |
| Unified Soil Classifiectiona | SC-CL |
| Moisture Content | 14% |
| Plasticity Index | LL=31%<br>PL=22%<br>PI=9 |
| pH<br>two samples | 7.7 median<br>7.6-7.7 range |
| Resistivity<br>two samples | 1,300 ohm-cm |
| Sulfates<br>two samples | 140 ppm |
| Chlorides<br>two samples | 35 ppm |
| **Steel Data** | |
| Specified Galvanization | 0.32 oz/sf |
| Remaining Galvanization | 0.28 oz/sf |
| Original Diameter of Soil Reinforcement | 0.177 inches (nominal) |
| As-sampled Diameter | as above |
| **Electrical Readings** | |
| Half-cell potential<br>four readings | Not available |

All data presented as a mean value unless noted.

SITE 14 - Ventura

District 7
Ventura County
Rte. 101 P.M. 4.3

In December 1985, a Salvaged Guard Rail (SGR) retaining wall was investigated. The wall is located in coastal southern California along Highway 101. Precipitation averages 14 inches annually.

Wall height varies from 9 feet at the ends to 15 feet near the center. Fill behind the wall is placed at a 1:1 slope for 3 feet then levels for 8 feet to meet the highway grade. The wall was placed with a drainage blanket (see Mariposa section for details of the drainage system.

Field work consisted of opening the steel facing member to exhume the soil reinforcement. The opening was located near the northern end of the wall and 6 feet below the wall crest. Half-cell readings were taken and a small section of reinforcement was removed. Soil adjacent to the sample was collected for testing.

Visual inspection of the steel reinforcement showed little or no galvanization loss. The face element was kept for testing and a patch was attached to the wall face. Some corrosion was present on the fill side of the face element; however, when measured, average remaining galvanization thickness exceeded original specifications.

## VENTURA ROUTE 101 (SITE 14) GENERAL WALL AND SITE DATA

| | |
|---|---|
| **Wall Type** | Salvage Guard Rail (SGR) |
| Construction date | August 1981 |
| Inspection and sampling date | December 1985 |
| **Soil Data** | |
| Unified Soil Classification | SP |
| Moisture Content | 8% |
| Plasticity Index two samples | Nonplastic |
| pH | 8.1 |
| Resistivity | 10,700 ohm-cm |
| Sulfates | 3 ppm |
| Chlorides | 0 ppm |
| **Steel Data** | |
| Specified Galvanization | 1.8 oz/sf |
| Remaining Galvanization | When averaged over entire surface, remaining galvanization exceeded specifications even though an estimated 30% of surface exhibited total zinc depletion. |
| Original Dimensions of Soil Reinforcement | 0.14 x 5.13 inches (nominal) |
| As-sampled Dimensions | as above |
| **Electrical Readings** | |
| Half-cell potential | -0.651 to -0.857 volt range |