Corrosion of Soil Reinforcements

Course Number: GE-02-305

PDH: 9

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CHAPTER 1
INTRODUCTION

1.1 OBJECTIVES OF COURSE

The use of mechanically stabilized earth (MSE) systems for the construction of retaining wall structures and steepened slopes has gained widespread acceptance among owners, as evidenced by the many thousands of completed structures. As usage increased in the 1980s and 1990s there was, however, a desire by owners and the research community to confirm that current methods are valid and that the design models used will ensure that these structures will perform as intended for their full design life. Previous editions of this reference guide proposed test protocols including electrochemical techniques for condition assessment and corrosion monitoring of MSE soil reinforcements. Various researchers, the FHWA and state transportation agencies have implemented these test protocols to collect information and develop performance databases. These techniques are now considered mature technologies that can be implemented for asset management to document performance and practices that contribute to effective use of resources and cost savings to owners.

It is important to consider the performance of MSE structures within the context of Transportation Asset Management (TAM), as slopes and retaining walls are important components of the highway system. Their performance depends on proper selection of materials, details of construction and maintenance. These are important considerations and their impacts on cost and service life affect decisions inherent to TAM.

The design of MSE structures requires that the combination of a select soil and reinforcement be such that the interaction between the two materials produces a composite structural material that combines their best characteristics. The judicious placement of reinforcements in the select soil mass serves to restrain the deformation of the soil in the direction parallel to the reinforcement.

The most commonly used soil-reinforcing for retaining walls on transportation projects has been galvanized steel, either in strip or grid configuration (~80 to 90 percent of applications to date), connected to a precast concrete facing. Polymeric soil reinforcements were introduced in the 1970s and early 1980s. They have been used with increasing frequency in both MSE walls and reinforced soil slopes (RSS) since their introduction. Today, the majority of RSS on transportation projects use geosynthetic soil reinforcements.

A major design concern for MSE structures has been the durability of reinforcements in the soil/water environment in which they are placed. The dual aim of this course is to provide criteria to guide design engineers in evaluating potential corrosion losses when using coated or uncoated steel reinforcements, and degradation losses when evaluating the use of polymeric reinforcements. The other aim is to guide engineers in implementing field evaluation schemes to monitor such corrosion/degradation mechanisms in constructed structures.

The monitoring of corrosion losses in these structures is addressed by implementation of non-destructive field evaluation systems using remote electrochemical measuring equipment capable of determining in-situ corrosion rates of galvanized and base steel and inferring from them the loss of section. The monitoring of degradation losses for polymeric reinforcements is addressed by implementation of retrieval protocols and destructive testing of samples to measure loss of tensile strength and changes in the polymer structure. This course was originally developed (Elias, 1997) in support of a FHWA Demonstration Project on the design, construction and monitoring of MSE walls and slopes. The course was updated in 2000 (Elias, 2000). The principal function of this course is to serve as a reference source for the long-term performance of soil reinforcements used in MSE structures. This current update incorporates the most recent work in this field, the NCHRP 24-28 study (see Section 1.4, below).

The test techniques and procedures described in the course have been researched and developed over the past several decades. These electrochemical test techniques and test protocols are mature technologies, and useful tools for asset management. Another objective of this course is to describe how these tools can be used for asset management. The benefits of performance monitoring and asset management are demonstrated by several examples included in the course.

1.2 SCOPE

The scope of this course includes:

- Description of the corrosion/deterioration mechanism that occurs in reinforced soil structures constructed with metallic reinforcements, leading to design procedure recommendations.
- Description of techniques and instrumentation designed to measure in-situ corrosion rates of steel reinforcements in MSE structures.

- Review of laboratory test methods for the electrochemical analysis of select reinforced fill materials used in MSE structures. Relationships between these test variables and predictions of corrosion/degradation are also discussed.
- Review of criteria to determine survivability of fusion bonded epoxy coatings.
- Identification of degradation mechanisms consistent with in-ground regimes for geosynthetic reinforcements.
- Monitoring methods and evaluation of degradation mechanisms for geosynthetic reinforcements.

1.3 ORGANIZATION

Chapter 2 is devoted to the fundamentals of corrosion of metals in soil, identification of corrosive environments, and details current design approaches to account for in-ground corrosion.

Chapter 3 details monitoring methods for metallic reinforcements and their application to existing and new construction.

Chapter 4 is devoted to the fundamentals of polymer degradation and identification of in-soil regimes that may accelerate degradation.

Chapter 5 details monitoring methods for geosynthetic reinforcements, and their application to existing and new construction.

Greater detail on topics discussed in Chapters 2 and 3 are detailed fully in FHWA RD 89-186 *Durability/Corrosion of Soil Reinforced Structures* (Elias, 1990), a primary source document for this course.

Greater detail on topics discussed in chapters 4 and 5 are detailed fully in FHWA RD-97-144, *Testing Protocols for Oxidation and Hydrolysis of Geosynthetics* (Elias et al., 1997).

1.4 PROJECT NCHRP 24-28 "LRFD Metal Loss and Service Life Strength Reduction Factors for Metal Reinforced Systems in Geotechnical Applications."

NCHRP 24-28 aims to: (1) assess and improve the predictive capabilities of existing models for corrosion potential, and for estimating metal loss and service life of earth reinforcements, and (2) to develop methodology that incorporates the improved predictive models into an

LRFD approach for the design of MSE. The project scope includes collecting data on the performance of metallic reinforcements used in the construction of MSE, developing a database for archiving performance data, statistical analysis of performance data, and reliability analysis of metal loss estimates used to ensure the specified design life. The test techniques and protocols for condition assessment and corrosion monitoring described in this reference course were used in pursuit of performance data for NCHRP 24-28.

We expect the final report for NCHRP 24-28 to be issued for distribution before September 2010. Anticipated products from NCHRP Project 24-28 include:

1. A performance database documenting the attributes and metal loss observed from in-service MSE reinforcements.
2. Updated metal loss models considering targeted levels of confidence and various site conditions.
3. Recommended resistance factors for use in LRFD designs that account for the estimated metal loss over the service life of the structure.
4. A recommended practice that specifically addresses issues related to metal loss from corrosion including required sampling and testing, example design procedure, and commentary.

The field experience, performance data, and insights into factors affecting metal loss gained from NCHRP 24-28 contribute to information included in this course. Retaining walls and slopes are important components of the highway system, and the database and test protocols resulting from NCHRP 24-28 serve as important tools for asset management. These data incorporate effects of climate, soil environment and site conditions, which are significant factors in terms of service-life. A major contribution from NCHRP 24-28 is to evaluate effects from reinforced fill quality, site conditions, maintenance operations and climatic factors on variance, and hence uncertainty, with respect to corrosion and anticipated metal loss.

Changes to the current AASHTO metal loss model are not anticipated; however, confidence and model reliability are assessed. The current AASHTO model only applies to galvanized reinforcements and reinforced fill meeting stringent electrochemical requirements. Data from reinforced fills that don't necessarily meet all of these requirements (e.g., $\rho < 3000$ Ω-cm) were also collected during the fieldwork for NCHRP Project 24-28. These data will be used to evaluate parameters and other adjustments needed to estimate the impacts of marginal quality fills on service life.

CHAPTER 2
CORROSION OF METALLIC REINFORCEMENTS

The current design approach to account for potential corrosion losses is to add to the required structural thickness a sacrificial thickness equal to the projected section loss over the design life of the structure. To minimize the sacrificial thickness and reduce uncertainties, a select fill with controlled electrochemical properties is specified for the reinforced zone. This chapter is intended to provide a background in the fundamentals of corrosion, the identification of corrosive environments by electrochemical testing and a review of the basis for the currently used design corrosion loss rates.

2.1 FUNDAMENTALS OF CORROSION OF METALS IN SOIL

Accelerated or unanticipated corrosion of the reinforcements could cause sudden and catastrophic failure of MSE structures, generally along a nearly vertical plane of maximum tensile stresses in the reinforcements. This plane is located at a distance varying from 0 to 0.3H from the facing where H is the height of the structure. Few instances of advanced corrosion that have compromised service life of MSE structures have been documented in the United States, Europe and South Africa (Blight and Dane, 1989; Elias, 1990; Fishman et al., 1986; Frondistou-Yannis, 1985; Armour et al., 2004; Gladstone et al, 2006; McGee, 1985; Raeburn et al., 2008).

Corrosion is the deterioration or dissolution of metal or its properties by chemical or electrochemical reaction with the environment. When a large surface is affected, it can be viewed as general corrosion and approximated by an assumed average, uniform rate of corrosion per year. If confined to small points so that definite indentations form in the metal surface, it is referred to as pitting corrosion and generally reported as maximum pit depth per year.

Corrosion is fundamentally a return of metals to their native state as oxides and salts. Only the more noble metals (platinum, gold, etc.) and copper exist in nature in their metallic state and are resistant to corrosion. Other metals are refined by applying energy in the form of heat. Unless protected from the environment, these metals revert by the corrosion process, which is irreversible, from their temporary state to a more natural state.

Although most chemical elements and their compounds are present in soil, only a limited number exert an important influence on corrosion. In areas of high rainfall, the passage of