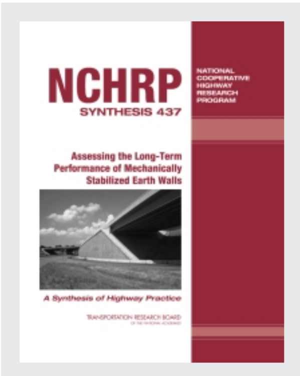

Assessing the Long-Term Performance of Mechanically Stabilized Earth Walls

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Gerber, Travis M.

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NATIONAL
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HIGHWAY
RESEARCH
PROGRAM

Assessing the Long-Term Performance of Mechanically Stabilized Earth Walls

A Synthesis of Highway Practice

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 437

Assessing the Long-Term Performance of Mechanically Stabilized Earth Walls

A Synthesis of Highway Practice

CONSULTANT
Travis M. Gerber
URS Corporation
Salt Lake City, Utah

SUBSCRIBER CATEGORIES
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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The Transportation Research Board of the National Academies was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The project that is the subject of this report was a part of the National Cooperative Highway Research Program, conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council.

The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

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FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice*.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Jon M. Williams
Senior Program Officer
Transportation Research Board

Mechanically stabilized earth (MSE) walls are retaining walls that rely on internal reinforcement embedded in the backfill for stability. This study addresses methods currently used to assess long-term performance of MSE walls, where "long-term" denotes the period of time from approximately one year after the wall is in service until the end of its design life. The focus of the study is on state and federal agency wall inventories, including methods of inspection and assessment of wall conditions.

Information was gathered through a literature review, agency survey, and selected interviews.

Travis M. Gerber, URS Corporation, Salt Lake City, Utah, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

APPENDIX E IS WEB-ONLY AND CAN BE FOUND AT WWW.TRB.ORG, SEARCH ON "NCHRP SYNTHESIS 437."

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

ASSESSING THE LONG-TERM PERFORMANCE OF MECHANICALLY STABILIZED EARTH WALLS

SUMMARY

Mechanically stabilized earth (MSE) walls are an important class of infrastructure assets whose long-term performance depends on various factors. As with most all other classes of assets, MSE walls need periodic inspection and assessment of performance. To date, some agencies have established MSE wall monitoring programs, whereas others are looking for guidance, tools, and funding to establish their own monitoring programs. The objective of this synthesis project is to determine how transportation agencies monitor, assess, and predict the long-term performance of MSE walls.

The information used to develop this synthesis came from a literature review together with a survey and interviews. Of the 52 U.S. and 12 Canadian targeted survey recipients, 39 and five, respectively, responded.

This synthesis reveals that unlike bridges and pavements, MSE walls and retaining walls in general are often overlooked as assets. Fewer than one-quarter of state-level transportation agencies in the United States have developed some type of MSE wall inventory beyond that which may be captured as part of their bridge inventories. Fewer still have the methods and means to populate their inventories with data from ongoing inspections from which assessments of wall performance can be made.

In the United States, there is no widely used, consistently applied system for managing MSE walls. Wall inventory and monitoring practices vary between agencies. This synthesis examines existing practices concerning the nature, scope, and extent of existing MSE wall inventories. It also examines the collection of MSE wall data, including the types of performance data collected, how they are maintained in wall inventories and databases, the frequency of inventory activities, and assessment practices relevant to reinforcement corrosion and degradation. Later parts of this synthesis discuss how MSE wall performance data are assessed, interpreted, and used in asset management decisions.

This synthesis finds that the most well-implemented wall inventory and assessment system in the United States is the Wall Inventory Program developed by FHWA for the National Park Service. However, this system, like some others, uses “condition narratives” in a process that can be somewhat cumbersome and subjective. Other systems use more direct numeric scales to describe wall conditions, and an advantage of such systems is that they are often compatible with those used in assessments of bridges.

As experience with MSE walls accumulates, agencies will likely continue to develop, refine, and better calibrate procedures affecting design, construction, condition assessment, and asset management decisions. One portion of this synthesis is dedicated to summarizing the actions taken thus far by survey respondents to improve the long-term performance of their MSE walls. Many agencies prescribe the use of a pre-approved wall design and/or wall supplier. Other actions or policies frequently focus on drainage-related issues.

Also included as part of this synthesis are statements from survey respondents as to what the most important lesson learned by their agency has been. Although the scope of the

responses is broad, certain topics appear more frequently than others, with the four most frequent being (in order of decreasing frequency) drainage, construction, backfill, and modular block issues.

In examining various reported practices for inventorying and assessing the performance of MSE walls, those appearing to be more effective are: (1) use of inventory and assessment systems with features that are simple to use and as objective as possible; (2) use of rating criteria that are specific to particular wall elements and/or conditions; (3) use of numeric rating scales that correspond to other scales already in use for other asset classes such as bridges; and (4) the incorporation of MSE wall inventory and assessment systems into systems for other asset classes.

An important conclusion of this synthesis is that there exists a need for greater recognition of MSE walls (and retaining walls in general) as important infrastructure assets. In the same vein, a greater number of agencies need to be actively involved in MSE wall inventory and assessment activities, and for greatest benefit there should be greater consistency across agencies relative to the way that these activities are performed. The synthesis also finds that performance assessment methodologies need to be more fully developed; similarly, service life prediction and risk assessment methodologies need to be developed. To realize such goals, it appears that greater funding and allocation of other resources is needed. In follow-up discussions regarding the synthesis survey, multiple participants expressed a hope that such increased awareness and resource allocation can be realized without significant, adverse-performance events such as those that led to the legislative creation and ongoing funding of the nation’s bridge inspection and assessment programs.

CHAPTER ONE

INTRODUCTION

BACKGROUND AND OBJECTIVE

Mechanically stabilized earth (MSE) walls were introduced in the United States about 40 years ago (see Elias et al. 2001). As the technology has improved and gained wider recognition, the number of MSE walls designed and constructed has increased dramatically; however, the long-term performance of these structures depends on various factors, and unfortunately there have been instances of adverse performance. Like every important class of assets, MSE walls need periodic inspection and assessment of performance. To date, some states have established MSE wall monitoring programs, while several others are looking for guidance, tools, and funding to establish their own monitoring programs. This synthesis project is undertaken to determine how state transportation agencies monitor, assess, and predict the long-term performance of MSE walls. This project provides information regarding current methodologies and procedures relating to the following topics:

- Inspection and evaluation of the condition of existing MSE walls along the states' highways;
- Maintenance of design and construction information;
- Recording and applying the results of inspections in each department's centralized database;
- Monitoring corrosion in MSE walls with inextensible steel reinforcement;
- Monitoring degradation of geosynthetics;
- Maintenance of internal and external drainage;
- Assessment of wall performance and evaluation of the consequences of failure based on these inspection and monitoring programs;
- Identification of preservation strategies that can reduce the likelihood of failure of MSE walls;
- Assessment of the key causal factors that affect performance; and
- Use of wall data to make programming decisions.

It is anticipated that this information will lead to better design, construction, monitoring, and maintenance of these important structures. This project can benefit many state agencies by combining the lessons learned from experienced states with the experience and innovative practices of academicians, MSE wall designers, and contractors as presented in technical literature.

For the purposes of this synthesis, the following definitions are used:

- *MSE wall*: Retaining walls that rely on internal reinforcement embedded in the backfill for stability. The reinforcement is attached to the wall's face, which confines the backfill. The reinforcement can be either metallic (strips or meshes) or geosynthetic (fabrics or grids). Soil nail or anchor walls are not considered to be MSE walls for the purposes of this synthesis.
- *Panel MSE wall*: Either one- or two-stage MSE walls that have concrete facing panels; internal soil reinforcement is usually metallic.
- *One-stage MSE wall*: A MSE wall that uses a concrete panel attached to the internal reinforcement to retain the backfill. The panel is in direct contact with the backfill.
- *Two-stage MSE wall*: A MSE wall that uses a metallic mesh or grid and geosynthetic liner attached to the internal reinforcement to retain the backfill. A concrete panel is subsequently attached to the vertical mesh. The panel is not in direct contact with the retained backfill. This wall type is typically used where settlements are expected to be relatively large.
- *Block MSE wall*: A MSE wall that uses a modular block facing attached to the internal soil reinforcement (which is often geosynthetic), and is often referred to as a segmental block wall.

The focus of this synthesis document is the long-term performance of MSE walls, where the term "long-term" nominally refers to the period of time from shortly after construction and acceptance of the MSE wall until the end of the design life, which is typically 75 or 100 years. The term "performance" is used in this report to refer to the behavior as well as the functionality and serviceability of a wall. Poor or adverse performance includes any performance that is less than that intended (e.g., serviceability limits are exceeded) and can structurally be manifest as small to large distortions, cracking, and even collapse.

METHODS OF STUDY

This synthesis project has gathered relevant information through (1) a literature review; (2) a survey of U.S. state and Canadian provincial transportation agencies, as well as other select entities (e.g., FHWA); and (3) interviews with select agencies. The scope of information collected addresses both permanent block and panel types of MSE walls, the latter of which consists of both one- and two-stage varieties. Both extensible and inextensible internal wall reinforcements are also considered.

Although the current body of literature contains many descriptions and references to the monitoring and assessment of MSE walls, much of that literature relates to conditions existing during and immediately after construction. For example, case histories are sometimes presented for particular MSE walls where foundation or geometric conditions are perceived as being particularly adverse or even unique and thus necessitating analytical and/or field studies to validate the adequacy of current design or construction processes (e.g., Reddy et al. 2003; Stuedlein et al. 2010). In other instances, MSE wall performance literature is simply the result of the "observation method" (see Peck 1969) being applied and documented for ordinary wall conditions. One also finds case histories and/or forensic assessments of walls that failed (e.g., Bay et al., 2009; Koerner and Koerner 2009; Holtz 2010). Although indirectly related to long-term performance of MSE walls, the literature also contains construction/inspector manuals (e.g., Passe 2000) as well as guidance for the use and deployment of instrumentation for assessing performance during and soon after construction (e.g., Koerner and Koerner 2011). In examining the literature, one also finds academic studies in which walls are monitored throughout the construction process and immediately thereafter (perhaps a year) with the goal of improving design techniques (e.g., Allen and Bathurst 2001). As stated previously, the focus of this synthesis document is the longer-term performance of MSE walls; hence, discussion of this previously referenced portion of literature is minimal.

In addition to the literature review, U.S. state and Canadian provincial level transportation agencies were surveyed. The survey questionnaire is presented in Appendix A. The survey was web-based and administered through the Internet. The questionnaire was designed to balance comprehensiveness with conciseness to maximize benefit while minimizing response effort, which is essential in achieving a high response rate. Thirty-nine of the 52 U.S. and five of the 12 Canadian targeted recipients responded; they are listed in Appendix B. Follow-up interviews with select agencies were undertaken to provide additional details and insights into survey responses.

ORGANIZATION OF REPORT

This report is organized into six chapters and four appendices. Chapter one presents the background and objectives of this synthesis project, explains the methods used, and outlines the remainder of this document. Drawing on the results of the literature review, survey questionnaire, and select interviews, chapter two describes the state of MSE wall inventory practice with particular emphasis on the nature, scope, and extent of existing inventories. Chapter three discusses the collection of MSE wall data, including the types of performance data collected and maintained in wall inventories and databases, the frequency of inventory activities, and aspects relating to reinforcement corrosion and degradation. Chapter four reviews how MSE wall performance data are assessed, interpreted, and used in asset management decisions. The chapter also discusses practices of estimating design life and risk assessment for MSE walls. Chapter five presents actions reported by transportation agencies and others to improve the long-term performance of MSE walls. This chapter also presents what survey respondents believe is their greatest lesson concerning long-term performance of MSE walls. Finally, in chapter six, a summary of the key findings of this synthesis project is presented, including the state of practice relative to the long-term performance of MSE walls. Other items presented include the direction of the states of practice, effective practices inferred from the literature review and survey respondents, and areas needing improvement and/or research. The appendices include a copy of the survey questionnaire, a list of survey respondents, and examples of existing methodology and tools developed and provided by agencies (e.g., inspection forms, rating or scoring worksheets, and assessment guidelines).

CHAPTER TWO

STATE OF MECHANICALLY STABILIZED EARTH WALL INVENTORY PRACTICE

INTRODUCTION

As with bridges and pavements, retaining walls are an essential component of our transportation infrastructure. However, unlike pavement and bridges, retaining walls (of which MSE walls are a growing subclass) are often overlooked as an asset.

Proper asset management is essential to making informed, cost-effective program decisions and optimizing existing highway resources. The Roadway Data Highway Performance Management System (HPMS) is a national transportation data system that provides detailed data on highway inventory, condition, performance, and operations. It describes functional characteristics, traffic levels, and pavement conditions for all interstate highway system sections. In addition to the HPMS, at least 36 individual state departments of transportation (DOTs) collect basic pavement inventory data, while more than 41 DOTs collect some type of data relative to pavement fatigue and cracking as part of their pavement management systems (Cambridge Systematics et al. 2009).

With respect to bridges, the federal government has mandated the creation and maintenance of the National Bridge Inventory (NBI), which contains data on all bridges and culverts on or over U.S. roads that are greater than 20 ft long. These bridges are also inspected every two years per the National Bridge Inspection Standards (NBIS). In contrast, there is no dedicated management system addressing the whole of the nation's retaining walls, MSE or otherwise. Indeed, although asset management guidance is provided for highway features such as pavements, bridges, culverts, guardrails, and drainage structures in the Asset Management Data Collection Guide developed in conjunction with AASHTO (2006), retaining walls are not addressed—despite there being an estimated 16.3 million square meters of various types of walls along the nation's highways with values ranging from approximately $200 to $2,000 per square meter (DiMaggio 2008). With respect to MSE walls specifically, Berg et al. (2009) indicated that an average of 850,000 square meters of MSE wall with precast facing is built each year in the United States, along with an additional 280,000 square meters of modular block wall. Also, according to Berg et al. (2009), typical total costs for permanent transportation-related MSE walls range from $320 to $650 per square meter of wall face, and modular block walls less than 4.5 m high are less expensive by 10% or more. Elias et al. (2004) placed the cost of MSE walls in the somewhat lower range of $160 to $300 per square meter.

During the preparation of this synthesis, two documents were found to be of particular interest to users of this synthesis, thus meriting specific mention. The first document, *Guide to Asset Management of Earth Retaining Structures*, by Brutus and Tauber (2009), is the product of a study conducted for the AASHTO Standing Committee on Highways, with funding provided through NCHRP Project 20-07. This publication presents methodologies and considerations aimed at helping transportation agencies establish asset management programs for earth retaining structures (of which MSE walls are a component), with particular focus on the development of inventories and inspection programs. The publication also presents the results of a survey similar to the one performed for this synthesis regarding the inventory, inspection, and asset management activities of transportation agencies concerning their earth retaining structures. The second document is *National Park Service Retaining Wall Inventory Program* (*WIP*)*—Procedures Manual,* by DeMarco et al. (2010b). This document represents the efforts of the FHWA Office of Federal Lands Highway, working with the National Park Service (NPS), to develop and implement a retaining wall inventory and condition assessment program [collectively referred to as the Wall Inventory Program (WIP)]. The document describes in detail the data collection and management processes, wall attribute and element definitions, and team member responsibilities for conducting retaining wall inventories and condition assessments as derived from experiences involving nearly 3,500 walls. Although MSE walls constitute only a small fraction of the walls involved in the development of the FHWA's WIP, much of the material in this document is applicable and/or transferable to matters associated with the long-term performance of MSE walls.

PARTIES WITH RESPONSIBLE CHARGE FOR MECHANICALLY STABILIZED EARTH WALLS

MSE walls are multidisciplinary in nature, having both structural and geotechnical components. Once constructed, maintenance concerns are introduced. To develop and maintain an effective inventory, some party must first take responsibility

TABLE 1
PARTY HAVING RESPONSIBLE CHARGE FOR MSE WALLS ONCE THE WALLS ARE CONSTRUCTED AND ACCEPTED (most representative response)

Response	Number	Percent
Structural engineer(s) or similar at an agency-wide level	3	7
Structural engineer(s) or similar at a regional or district level	3	7
Geotechnical engineer or similar at an agency-wide level	3	7
Geotechnical engineer(s) or similar at a regional or district level	0	0
Maintenance engineer or similar at an agency-wide level	4	9
Maintenance engineer(s) or similar at a regional or district level	18	41
No one has this charge	6	14
Other (specify)	7	16

for the walls. As shown in Table 1, when queried regarding who has responsible charge for MSE walls once the walls are constructed and accepted, 41% of survey respondents noted it was a maintenance engineer at a regional or district level. Those who responded "other" generally indicated a mixed or shared responsibility among the various structural (i.e., "bridge"), geotechnical, and maintenance professionals. Approximately 14% of respondents indicated that no one in their agencies has responsibility for MSE walls after construction and acceptance.

AGENCIES HAVING INVENTORIES

Several questions of the survey for this synthesis project focused on the nature and extent of transportation agencies' MSE wall inventories. Thirty (more than two-thirds) of survey respondents indicated that they do not maintain a specific MSE wall inventory. Of the 14 respondents who do have inventories (listed here), 43% reported that the inventory is partial, limited to specific geographic areas, or constrained in some other way. (Although not survey respondents, the states of Ohio, Pennsylvania, and Washington also appear to have at least partial MSE wall inventories. Alberta, Canada, reports "defined problem sites" as a type of wall inventory.)

- Alberta, Canada
- California
- Colorado
- Kansas
- Minnesota
- Missouri
- Nebraska
- New York
- North Carolina
- North Dakota
- Ontario, Canada
- Tennessee
- Utah
- Wisconsin.

In reporting what types of MSE walls are included in their inventories, 100%, 71%, and 86% named one-stage panel walls, two-stage panel walls, and block walls, respectively. The majority of panel walls possess metallic reinforcement. Some wall inventories are also maintained by city-level agencies. The cities of Cincinnati, Ohio; New York City, New York; and Seattle, Washington, all maintain retaining wall inventories, including MSE walls. FHWA has developed a wall inventory and database for the National Park Service listing more than 3,500 walls, some of which are MSE walls.

Although a minority of agencies appear to maintain well-defined MSE wall databases (and fewer still have regular inspections to inform the database beyond the basic identifying information), some limited MSE wall inventory and performance data are apparently maintained by some agencies. Additionally, some MSE wall inventory and performance data are inherently contained in the NBI and are accessible in software database applications such as PONTIS or other agency-maintained databases. These "overlooked" MSE walls would typically be those that serve as bridge abutments or are considered integral to the performance of the bridge structure. These databases contain basic wall information such as spatial dimensions, construction date, and some type of performance rating of bridge support, but greater detail may be lacking. Once recognized, bridge inventory data may be a starting point for developing MSE wall inventories and performance assessments.

NATURE AND SCOPE OF INVENTORIES

Agencies that have established MSE wall inventories appear to own between 100 and 1,000 MSE walls (with mean and median values of 508 and 400, respectively). However, as explained by Gerber et al. (2008), wall counts can be problematic. Single wall segments at a bridge abutment might be treated as an individual wall, whereas at other times one abutment and two adjoining wing-wall segments might be designated as a single wall.

> Consequently, at a bridge abutment with one MSE wall segment beneath the bridge and two MSE wall segments serving as wing-walls on either side, one could count either one or three walls. If one considers a similar configuration for the other abutment,

one could assign one, three, or six wall numbers to the MSE wall segments present at a bridge site. (There could be even more than six if additional walls segments were used to support the exterior sides of ramps.)

In the literature, there appears to be little consensus regarding methodologies for individual wall designations. However, several sources suggest that whatever system is used to identify and count walls, physically tagging the walls with identifiers is a helpful practice.

Different agencies use different criteria when determining what MSE walls to count and/or include in their inventory/database. Brutus and Tauber (2009) provide extended discussion of various possible criteria, which commonly include wall height, proximity to the roadway, batter or face slope, wall ownership, structural type, and proximity to bridges or culverts. The main criteria used by FHWA's WIP are related to jurisdiction (e.g., is the wall along a qualifying road?), proximity of wall relative to roadway, wall height, wall embedment, and wall face angle. [The WIP uses a wall face angle criterion of 45 degrees or greater so that some rockeries and slope protection buttressing are included in the inventory, whereas FHWA (see Berg et al. 2009) typically defines a retaining wall as having an internal face angle greater than or equal to 70 degrees to differentiate walls from reinforced slopes.] The FHWA program also advises that when wall acceptance based on the aforementioned criteria is marginal or difficult to discern, "include the wall in the inventory, particularly where the intent is to support and/or protect the roadway or parking area and where failure would significantly impact the roadway or parking area and/or require replacement with a similar structure." Based on synthesis survey results shown in Table 2, most inventories include only those walls owned by the agency. Only 57% include walls not associated with a specific bridge or culvert. When a wall height criterion is used, 1.2 or 2 m are the most frequent threshold values.

In evaluating the comprehensiveness of inventory databases they currently maintain, transportation agencies report that between 10% and 100% (mean and median of 70% and 78%, respectively) of the walls that satisfy their inclusion criteria are accounted for (Table 11 subsequently shows this information by agency). The particular content contained in each respective database varies and is discussed in the next chapter. As mentioned previously, some MSE wall inventory information and performance data are inherently contained in the NBI. These MSE walls would typically be those that serve as bridge abutments or are considered integral to the performance of the bridge structure. Generally, walls that are not within the vertical projection of the bridge deck and are not constructed integrally with either wing-walls or abutments are not included in bridge assessment activities.

Table 3 summarizes who in an agency principally manages/maintains its inventory of MSE walls. Most frequently it is a geotechnical engineer or similar person at an agency-wide level. This may be inconsistent as Table 1 indicates that maintenance engineers at a regional or district level are the individuals who have responsibility for MSE walls once they are built. It thus appears that there may be a disconnect between those considered responsible for MSE walls and those actually doing the work of asset management. However, such an arrangement need not be problematic; multiple parties can be involved in MSE wall management provided there is a clear understanding that responsibility for the asset may lie in a place other than the location of the data or even the expertise used to collect and/or evaluate the data. Communication and understanding of individual responsibilities would obviously be essential for an effective inventory and assessment program.

Inventories can be maintained in various formats and manipulated using various tools. The current state of practice is summarized in Table 4, which lists the variety of

TABLE 2
CRITERIA USED TO DETERMINE WHAT MSE WALLS TO INCLUDE IN INVENTORY
(multiple responses possible)

Response	Number	Percent
Wall owned by my agency	14	100
Wall owned by others but adjacent to facilities for which my agency is responsible	4	29
Wall owned by others but may negatively impact adjacent facilities for which my agency is responsible	1	7
Wall is associated with a bridge structure	12	86
Wall is associated with a culvert	7	50
Wall is not associated with a bridge or culvert	8	57
Minimum wall height	6	43
Minimum height of retained earth	2	14
Minimum wall length	1	7
Minimum wall area	0	0
Other (specify)	2	14

TABLE 3
PARTY WHO PRINCIPALLY MANAGES/MAINTAINS INVENTORY OF MSE WALLS
(most representative response)

Response	Number	Percent
Structural engineer(s) or similar at an agency-wide level	4	29
Structural engineer(s) or similar at a regional or district level	0	0
Geotechnical engineer or similar at an agency-wide level	5	36
Geotechnical engineer(s) or similar at a regional or district level	0	0
Maintenance engineer or similar at an agency-wide level	0	0
Maintenance engineer(s) or similar at a regional or district level	3	21
Other (specify)	2	14

methods used to manage MSE wall inventories, with preferences given to simple spreadsheets or MS access-type databases.

The potential range of information maintained as part of an MSE wall inventory is broad. Data regarding wall location and geometry are perhaps the most common elements, but depending on the use of the inventory/database, other information might be maintained, including wall features, construction data, and inspection information. Brutus and Tauber (2009) suggest that information such as dates of construction and repairs, geometric wall dimensions, wall materials including backfill type, specific element types and manufacturers, as-built and shop drawings, specifications, quality control test data, and inspection reports be included. They also suggest that a wall database should include basic traffic-volume data. Hearn (2003) offers similar suggestions.

Table 5 summarizes the frequency at which different types of information is collected and/or maintained by surveyed agencies as part of their wall inventories. The most frequently tracked metrics are wall location by route/milepost and wall type. These metrics are followed by date constructed, reinforcement type, and shop drawings. Given that degradation and/or corrosion of reinforcement is a primary concern of agencies (as revealed in a subsequent section of this report), it is logical that these two particular and apparently coupled metrics are among the more frequently tracked items. Information regarding maintenance does not appear to be systematically maintained by any party.

CONSTRAINTS ON INVENTORY DEVELOPMENT AND ASSET MANAGEMENT ACTIVITIES

During oral interviews with select survey participants, the participants frequently identified the lack of a government/legislative directive along with the lack of allocated funding as significant impediments either to initially developing their MSE wall inventory or subsequently populating it with performance data from inspection activities. Although some increasing awareness and impetus toward asset management for retaining walls appears to have existed in the early to mid-2000s (partially characterized by the development and distribution of informational brochure “Earth Retaining Structures and Asset Management,” developed by FHWA (2008), it appears that the economic downturn of 2008 through the present has largely halted those efforts. In Colorado, for example, a plan for implementing a state-wide monitoring program for all types of retaining walls and sound walls was developed for the state DOT (Hearn 2003). Although the feasibility report concluded that “no impediment [was] found to full development of standard data and procedures for walls and sound barriers,” little progress toward implementation has been made as yet because of funding constraints. DOTs in Oregon (see Turner 2008), Nebraska, Ohio, and Utah have simi-

TABLE 4
PRIMARY TOOL USED AS AN ASSET MANAGEMENT SYSTEM FOR MSE WALL INVENTORY (most representative response)

Response	Number	Percent
File boxes/cabinets	3	21
Spreadsheet	4	29
MS Access database without GIS support	3	21
Oracle database without GIS support	1	7
PONTIS	1	7
Other non-GIS supported database (specify)	2	14
GIS-based software (specify)	0	0

TABLE 5
TYPES OF DATA AGENCIES GENERALLY COLLECTED OR MAINTAINED FOR MSE WALLS (multiple responses possible)

Response	Number	Percent
Location by Street Address	3	21
Location by Latitude/Longitude	4	29
Location by Route, Milepost	7	50
Location by State Plane Coordinates	1	7
Wall Type	6	43
Wall Function	3	21
Wall Geometrics—Maximum Wall Height	4	29
Wall Geometrics—Average Wall Height	4	29
Wall Geometrics—Wall Length	4	29
Wall Geometrics—Slope in Front of Wall	2	14
Wall Geometrics—Slope Behind Wall	2	14
Wall Geometrics—Road/Traffic Offset	3	21
Date Constructed	5	36
Manufacturer	4	29
Contractor/Installer	1	7
Reinforcement Type	5	36
Drainage Conditions—Proximity of External Water Sources	0	0
Drainage Conditions—Location and Condition of Drainage Points	2	14
Nature of Adjacent Facilities Owned by Agency	1	7
Nature of Adjacent Facilities or Utilities Owned by Others (e.g., railroad)	0	0
Characterization of Adjacent Roadway Traffic	2	14
Design Data	1	7
Construction Data—Plans	4	29
Construction Data—Specifications	2	14
Construction Data—Shop Drawings/Submittals	5	36
Construction Data—Inspection Documentation	2	14
Construction Data—As-Builts	4	29
Post-construction Modifications	1	7
Photographs	4	29
Condition of Structure—External Inspection Data	3	21
Condition of Structure—Internal (e.g., corrosion) Inspection Data	0	0
Maintenance Activities	0	0
Other (specify)	1	7

larly reported that initially developed and/or implemented plans could not be sustained. In the mid-1980s, California's DOT (Caltrans) established procedures and responsibilities for monitoring, sampling, and testing the MSE wall structures; however, in 1997, budgetary constraints eliminated the program. Some MSE wall inspections continue, but the process is not systematic. New York State's DOT is an exception to this trend; its inventory and assessment efforts date to 1985, when the state began an initial field evaluation and inventory of its MSE walls out of corrosion concerns (Wheeler 2002).

In follow-up discussions regarding the synthesis survey, many respondents expressed hope that increased awareness and resource allocation could be achieved before any significant, adverse events such as those that led to the creation and ongoing support of the nation's bridge inspection and assessment programs.

CHAPTER THREE

COLLECTION OF MECHANICALLY STABILIZED EARTH WALL DATA

At perhaps its most basic level, effective asset management consists of three components: (1) data collection; (2) data assessment and interpretation; and (3) taking action consistent with asset performance goals. Each of these three components is constrained by available resources. This chapter will focus on the data collection component.

TYPES OF DATA CONTAINED IN WALL INVENTORIES/DATABASES

Not all data are helpful in meeting asset management goals. Rather, the appropriate data must be collected—data that can be reliably quantified and assessed so that meaningful conclusions regarding performance can be drawn. In practice, data collection often focuses on potential symptoms of adverse performance and is obtained during field investigations and inspections. Alzamora and Anderson (2009) provide a review of MSE wall performance issues based on their experience with FHWA. They particularly identified geometry/wall layout, obstructions, wall embedment, surface drainage, backfill placement and compaction, panel joints, leveling pad, and durability of facing as potential problem areas. Consistent with their findings, most data collection efforts currently undertaken relate to the condition and performance of these particular elements.

Several agencies have developed guidance manuals and/or inspection forms for gathering post-construction wall performance data. Examples of some of these materials developed by FHWA (DeMarco et al. 2010b), Nebraska (Jensen and Arthur 2009; Nebraska Department of Roads 2009), Ohio (Ohio Department of Transportation 2007), and Utah (Bay et al. 2009) are provided as examples in web-only Appendix E. There are also MSE wall inspection manuals that focus on installation/construction issues (e.g., New York State Department of Transportation 2007), but these usually do not explicitly address long-term wall performance.

A feature common to several of the above-cited manuals is the use of photographs illustrating the nature of a particular feature needing identification (such as a sand cone in front of a wall joint, indicative of backfill migration) and/or quantification of its severity (minor verses major amounts of concrete degradation). The picture and the manuals themselves serve a calibration purpose when multiple individuals are involved in data collection; without a common baseline, data scatter can be excessive, particularly when the metric is subjectively quantified (i.e., not directly measurable).

Perhaps the best documented, large wall inventory program in the United States is FHWA's Wall Inventory Program (WIP). Extensive guidance and discussion concerning data collection methods are presented in the WIP *Procedures Manual* (DeMarco et al. 2010b). The WIP *Procedures Manual* emphasizes that "collected wall data must be accurate, concise and descriptive." Photographic documentation during data collection efforts is also encouraged. For MSE wall types, data collection and rating focuses on the following primary wall elements: wire/geosynthetic facing, concrete panels, manufactured block, wall foundation materials, and wall drains. Applicable secondary wall elements include road/shoulders, upslope, downslope, and lateral slope. Rather than being numeric in nature or measurement-based, the condition data collected for each wall element consist of a written "condition narrative," which is "a concise, descriptive narrative of element condition sufficient to characterize severity, extent, and urgency of element distresses" (DeMarco et al. 2010a). To help ensure consistency, these narratives use terminology and definitions consistent with the types of potential distress described in Figure 1.

As seen in this figure, element ratings reflect observational wall condition data relative to four distress categories: corrosion/weathering, cracking/breaking, distortion/deflection, and lost bearing/missing elements. These narratives are later converted to a numerical "condition rating" ranging from 1 to 10 using the descriptions shown in Table 6. This process is subjective, and rating variances among inspectors are reported to be within plus-or-minus two rating points for a given element.

In the FHWA WIP, a general wall performance rating is also determined along with the element condition ratings. This rating scheme is shown in Table 7. Use of the wall performance rating is illustrated using the following example from the WIP procedures manual (DeMarco et al. 2010b, p. 101):

> For example, an MSE wall with a geogrid-wrapped face shows little sign of specific element distress (geogrid and backing geotextile are largely unweathered, drains are working, etc.). However, the wall is differentially settling at one end, as evidenced by a 3- to 6-inch vertical sag extending full-height in the wall face. A tension crack has begun to open at the top of the wall just beyond the estimated length of reinforcements, further indicating a global or external wall failure mechanism is actively

WALL ELEMENT CONDITION RATING GUIDANCE

GOOD TO EXCELLENT
(minor to no distress, minimal to no impact, few to no occurrences)

Corrosion/Weathering
- No evidence of corrosion/staining, contamination, or cracking/spalling due to weathering or chemical attack.
- Compacted, placed or masoned rock, and associated chinking, is dense, angular, fresh, and without post-placement fracturing or chemical degradation.
- No significant weathering/weakening of bedrock, softening of soil, or saturated ground conditions evident.
- No impacts from vegetation noted within the wall or within adjacent elements.

Cracking/Breaking
- No evidence of element cracking, breaking, or construction/post-construction damage, opening of discontinuities in rock, or cracks or gullies in soils.
- Concrete, shotcrete, and mortar is sound, durable, and shows little or no signs of shrinkage cracking or spalling.
- Drains are clearly open (flowing), and in full working order.

Distortion/Deflection
- Wall elements are as constructed, and/or show no signs of significant settlement, bulging, bending, heaving, or distortion/deflection beyond normal prescribed post-construction limits.

Lost Bearing/Missing Elements
- No wall elements are missing.
- Wall elements are fully bearing against retained soil/rock units.
- Foundation soils/rock are more than adequate to support the wall, consistently dense, drained and strong.
- No slope failures have occurred either removing or adding materials from the wall area.

FAIR
(moderate distress, significant to substantial impact, multiple occurrences)

Corrosion/Weathering
- Moderate corrosion/staining, contamination, or cracking/spalling due to weathering or chemical attack.
- Compacted, placed or masoned rock is not fresh or angular, showing significant weathering, post-placement fracturing, chemical degradation, and/or localized loosening.
- Significant weathering/weakening of bedrock rock, softening of soil, or saturated ground conditions evident.
- Moderate impacts from vegetation are evident within the wall or within adjacent elements.

Cracking/Breaking
- Localized element cracking, breaking, abrasion and/or construction/post-construction damage, opening of discontinuities in rock, or cracks or gullies in soils.
- Concrete, shotcrete, and mortar is occasionally soft or drummy, has lost durability, and shows occasional cracking and/or spalling sufficient to intercept reinforcement.
- Drains cannot be clearly determined to be fully operational.

Distortion/Deflection
- Wall elements show significant localized settlement, bulging, bending, heaving, misalignment, distortion, deflection, and/or displacement beyond normal prescribed post-construction limits (e.g., wall face rotation, basket bulging, anchor head displacement, bin displacement).

Lost Bearing/Missing Elements
- Some wall elements are missing (e.g., chinking, lagging, brickwork) or non-functional.
- Wall elements are generally bearing against retained soil/rock units, but localized open voids may exist along the back and top of the wall.
- Foundation soils/rock are adequate to support the wall, but susceptible to shrink-swell, erosion, scour, or vegetation impacts.
- Isolated slope failures have occurred either removing or adding materials from the wall area.

POOR TO CRITICAL
(severe distress, failure is imminent, pervasive occurrences)

Corrosion/Weathering
- Metallic wall elements are corroded and have lost significant section affecting strength.
- Concrete/shotcrete is extensively spalled, cracked, and/or weakened, and may show evidence of widespread aggregate reaction.
- Compacted, placed, or masoned rock is highly weathered, showing extensive post-placement fracturing, chemical degradation, and/or loosening within the placed volume.
- Extensive weathering/weakening of bedrock, softening of soil, or saturated ground conditions evident.
- Severe impacts from vegetation are evident within the wall or within adjacent elements.

Cracking/Breaking
- Extensive severe element cracking, breaking, abrasion or construction/post-construction damage, opening of discontinuities in rock, or cracks or gullies in soils.
- Concrete, shotcrete, and mortar is consistently soft, drummy, or missing, has lost durability and strength, and shows pervasive cracking and/or spalling intercepting corroding/weathering reinforcement.
- Drainage is missing, clearly damaged, and/or obviously clogged and non-functional.

Distortion/Deflection
- Wall elements show extensive settlement, bulging, bending, heaving, distortion, misalignment, deflection, and/or displacement well beyond prescribed post-construction limits, including loss of ground reinforcement and retention.

Lost Bearing/Missing Elements
- Many or key wall elements are missing (e.g., placed wall stone, chinking, lagging) or non-functional.
- Many or key wall elements are no longer bearing against retained soil/rock units, with visible open voids evident behind a large portion of the wall.
- Foundation soils/rock show signs of failure, excessive settlement, scour, erosion, substantial voids, bench failure, slope over-steepening, and/or may be adversely impacted by vegetation.
- Substantial slope failures have occurred either removing or adding materials from the wall area.

FIGURE 1 Element condition narrative guidance (DeMarco et al. 2010b).

TABLE 6
NUMERICAL CONDITION RATING DEFINITIONS FOR WALL ELEMENTS IN FHWA WALL INVENTORY PROGRAM

Rating	Rating Definition
9 to 10 Excellent	No-to-very low extent of very low distress. Defects are minor, are within the normal range for newly constructed or fabricated elements, and may include those resulting from fabrication or construction. In practice, ratings of 9 to 10 are only given to elements with very minor to no distress whatsoever—conditions typically seen only shortly after wall construction or substantial wall repairs.
7 to 8 Good	Low-to-moderate extent of low severity distress. Distress does not significantly compromise the element function, nor is there significant severe distress to major structural components. In practice, ratings of 7 to 8 indicate highly functioning wall elements that are only beginning to show the first signs of distress or weathering. For example, a ten-year-old soldier pile wall may have moderately extensive minor surface corrosion on piles where protective paint has weathered and peeled, and may have wood lagging beginning to split. Distresses are very low overall, present over a modest amount of the wall, and do not require immediate or near-term attention.
5 to 6 Fair	High extent of low severity distress and/or low-to-medium extent of medium to high severity distress. Distress present does not compromise element function, but lack of treatment may lead to impaired function and/or elevated risk of element failure in the near term. In practice, ratings of 5 to 6 indicate functioning wall elements with specific distresses that need to be mitigated in the near-term to avoid significant repairs or element replacement in the longer term. For example, numerous anchor struts holding MSE wire facing elements in place are beginning to break due to corrosion and suspected over-stressing of the connections at the time of construction. Although the overall function of the reinforced earth wall is not in jeopardy, failing wall facing baskets are allowing facing fill to spill out. If several overlying baskets experience this isolated element failure, significant wall face sag and deformation may result at the top of the wall, eventually impacting the overlying guardrail installation. This element should be inspected carefully along the entire wall and repaired as needed to forestall further facing basket deterioration.
3 to 4 Poor	Medium-to-high extent of medium-to-high severity distress. Distress present threatens element function, and strength is obviously compromised and/or structural analysis is warranted. The element condition does not pose an immediate threat to wall stability and closure is not necessary. In practice, a rating of 3 to 4 indicates marginally functioning, severely distressed wall elements in jeopardy of failing without element repair or replacement in the near-term. For example, mortar throughout a historic stone masonry wall is cracked, spalling, highly weathered, and often missing. Individual stone blocks are missing from the wall face, and adjacent blocks show signs of outward displacement. Although not an immediate threat to overall wall stability, stone block replacement and repointing throughout the wall in the near-term are necessary to forestall rapid wall deterioration.
1 to 2 Critical	Medium-to-high extent of high severity distress. Element is no longer serving intended function. Element performance is threatening overall stability of the wall at the time of inspection. In practice, a rating of 1 to 2 indicates a wall that is no longer functioning as intended, and is in danger of failing catastrophically at any time. For example, a 15-ft-tall cast-in-place concrete cantilever wall has a large open horizontal crack running the full length of the wall at the base of the stem. Vertical cracks are also beginning to open up in the wall face. Water is seeping from most wall cracks, and is running from the basal horizontal crack at several locations. The wall face has rotated outward, resulting in a negative batter of several degrees. The overlying guardrail is highly distorted above the wall and the adjacent roadway is showing significant settlement above the retained fill. The wall is in imminent danger of failing catastrophically, requiring the overlying roadway be closed to all traffic until the wall can be replaced or retained soil backslope can be stabilized.

Source: DeMarco et al. (2010b).

developing. The inspecting engineer describes the overall wall performance as 'low,' providing appropriate narrative describing the state of global distress, and rates the wall performance at a '4' per the rating definitions.

As discussed in the next chapter, these element condition ratings combined with the wall performance ratings create an overall wall performance rating ranging from 5 to 100, and these ratings are used in assessment management decisions.

Although not quite as detailed as the FHWA WIP just presented, Brutus and Tauber (2009) have also developed a guide to asset management of earth structures. They indicate that conditions listed here could be indicative of wall stress or deterioration, and recommend that the precise vertical and horizontal locations where these conditions are observed should be documented. Brutus and Tauber also suggest that a severity or priority rating such as (1) low, (2) moderate, (3) high, or (4) urgent be assigned as conditions are assessed in the field.

TABLE 7
WALL PERFORMANCE RATINGS

Rating	Rating Definition
7 to 10 Good to Excellent	No combinations of element distresses are observed indicating unseen problems or creating significant performance problems. No history of remediation or repair to wall or adjacent elements is observed.
5 to 6 Fair	Some observed global distress is not associated with specific elements. Some element distress combinations are observed that indicate wall component problems. Minor work on primary elements or major work on secondary elements has occurred improving overall wall function.
1 to 4 Poor to Critical	Global wall rotation, sliding, settlement, and/or overturning are readily apparent. Combined element distresses clearly indicate serious stability problems with components or global wall stability. Major repairs have occurred to wall structural elements, though functionality has not improved significantly. Severe distresses are apparent on adjoining roadways.

Source: DeMarco et al. (2010b).

- Wall or parts of it out of plumb, tilting, or deflected
- Bulges or distortion in wall facing
- Some elements not fully bearing against load
- Joints between facing units (panels, bricks, etc.) are misaligned
- Joints between panels are too wide or too narrow
- Cracks or spalls in concrete, brick, or stone masonry
- Missing blocks, bricks, or other facing units
- Settlement of wall or visible wall elements
- Settlement behind wall
- Settlement or heaving in front of wall
- Displacement of coping or parapet
- Rust stains or other evidence of corrosion of rebar
- Damage from vehicle impact
- Material from upslope rockfall or landslide adding to load on wall
- Presence of graffiti (slight, moderate, heavy)
- Drainage channels along top of wall not operating properly
- Drainage outlets (pipes/weepholes) not operating properly
- Any excessive ponding of water over backfill
- Any irrigation or watering of landscape plantings above wall
- Root penetration of wall facing
- Trees growing near top of wall.

Another data collection/wall inspection process has been developed by the Nebraska Department of Roads. In this methodology (Nebraska Department of Roads 2009), the MSE wall features that are assessed are:

- Wall tilting
- Structural cracking
- Facial deterioration
- Bowing of the wall
- Panel staining
- Exposure of fabric
- Loss of backfill
- Erosion in front of wall
- Erosion in back of wall
- Joint spacing
- Condition of “v-ditch” (i.e., drainage way at top of wall)
- Coping deterioration
- Drainage runoff
- Drainage at the front of the wall.

A rating scale ranging from zero to 9 (consistent with most bridge assessment procedures) is provided to describe the extent or severity of each feature. For example, with respect to loss of backfill, the following ratings descriptions are used: (zero)—backfill loss has resulted in significant settlement of the v-ditch or roadway or has affected wall inclination or alignment; (3)—significant areas/quantities of backfill loss are visible; (6)—backfill loss is occurring, but only minor areas/quantities of backfill loss are visible; and (9)—no visible evidence of backfill loss. Numeric rating descriptions are unique to each type of feature or condition being assessed and can be found in the materials in Appendix E (web-only).

The MSE wall inspection program in Ohio has focused data collection activities on observed problems, particularly sand leaking from joints, settlement of panels (largely from erosion of underlying support), uncontrolled drainage, and deteriorating panels (Narsavage 2006). The inspection program focuses on 23 potential symptoms (e.g., signs of water flow along the base of the wall) associated with wall joints, wall facing, drainage, and conditions at the top of the wall (see inspection form in web-only Appendix E). Condition ratings consist of simple “yes” or “no” responses. After its first inspection effort completed in 2006, Ohio reported that of the state’s 339 inspected walls, nearly one-third exhibited backfill migrating through wall joints and 13% exhibited some type of erosion problem.

Utah’s MSE wall data collection largely follows the Ohio model. As shown on the inspection form provided in (web-only) Appendix E, data collection efforts focus on features and conditions believed to affect or reflect wall performance; namely, drainage, wall joints, wall facing, conditions at top of wall, foundation conditions and external stability, corrosion and degradation, impact and collision, and miscellaneous issues. As in Ohio, condition ratings consist of simple "yes" or "no" responses; however, the extent of the symptom/issue is quantified as a percentage of the total wall. Some of Utah's inspection queries relate directly to two-stage MSE walls, which are widely used in the state.

The Pennsylvania DOT (PennDOT; see Pennsylvania Department of Transportation 2010) has a well-defined retaining wall inspection program conducted in conjunction with its bridge inspection program. (Bridge and retaining wall data are maintained in the same management system.) The program involves all walls, not just those at bridges. One wall element receiving particular focus in PennDOT's inspection process is a button-head connection present in some first-generation MSE walls, because the cold-formed button head details were found to develop micro-cracks that contributed to the failure of the button head. The following directives relating to MSE walls are specified in the PennDOT inspection manual:

> Mechanically Stabilized Earth (MSE) retaining walls should be inspected for evidence of wall movement.
>
> - Examine barrier and moment slab for evidence of movement as well as the MSE wall for evidence of bulging, bowing, or panel offset.
> - Perform a survey if movement is suspected to compare to initial inspection data to gauge amount of movement.
> - Examine the roadway above MSE walls for indications of failing pavement or tension cracking. These may indicate a loss of fill. For MSE walls in front of sloping backfill, the crest of the embankment should be investigated for soil stress or failure, both of which may indicate settlement or wall movement.
>
> The joints between panels of MSE walls are to be inspected and examined for loss of backfill, change in spacing, and indications of settlement. The specification requirement for joint spacing is a maximum three-quarters of an inch.
>
> - Inspect walls for evidence of backfill loss (piles of aggregate at the base of the wall).
> - Indicate visibility of backfill or fabric behind the panel through joints.
> - Examine for evidence of damage to the geotextile fabric, if visible.
> - Look for variation in joint spacing. Note vegetation growing in joints.
> - Vertical slip (expansion joints) used on long lengths of walls should be investigated similar to panel joints. The initial spacing at the slip joint should be determined from design, shop, or as-built drawings.
>
> Wall panels shall be checked for cracking, spalling, other forms of deterioration, and collision damage.
>
> - Drainage systems through or along MSE walls should be inspected to verify water is free flowing into and out of the appropriate facility.
> - Ensure that weep holes are free draining.
> - Inspect all inlets to verify water is draining into the inlet, and flowing freely to the inlet and out of the outlet. Examine inlets for cracks.
> - Inspect visually or use down hole cameras (as appropriate) for all culverts and pipes contained or having portions in, behind, or above the MSE wall mass and for pipes or culverts which run above, adjacent to, or outlet through the MSE walls to verify pipes are free draining and water is flowing through (and not under or around) the pipe. Examine drainage pipes for cracking or damage with emphasis on areas where water may flow, or is flowing, into the MSE wall soil mass. Inspect outlet ends to verify free drainage or for evidence of migration of fill or other material.
> - Inspect swales above the MSE wall. Verify rock fall or other materials (trees, etc.) are not blocking, redirecting, or restricting the flow of water through the drainage ditch above the MSE wall to the appropriate receptacle.
> - Inspect collection and outlet basins to verify water is draining freely. Look for any signs of infiltration or migration of material which may prevent water from draining from the wall.
> - Identify inappropriate appearance of water along the base of the wall (i.e., if water is appearing when weather conditions have been particularly dry). Note areas where there is inappropriate collection and/or lack of drainage for water along the length of the MSE wall.
> - Note erosion of soil along the base of the wall exposing or undermining the leveling pad.

In the Pennsylvania methodology, observed conditions are then translated into ratings (shown in Table 8) that are assigned to the following MSE wall elements/items:

- Anchorage
- Backfill
- Wall conditions such as bulging, joint conditions, deterioration of face panels, connection of the backs, etc.
- Panels
- Drainage
- Foundation
- Parapets.

Data collection and inspection schemes are inherently rooted in the experience and judgment of their developers. In the city of Seattle, Washington, for example, instances of

TABLE 8
PERFORMANCE RATINGS ASSIGNED TO WALL ELEMENTS IN PENNSYLVANIA INSPECTION/ASSESSMENT PROCESS

Rating	Rating Definition
8	Good condition. No apparent problems.
6	Satisfactory condition. Structural elements sound. Localized drainage problems, settlement, staining, washing of fines from backfill material.
4	Poor condition. Localized buckling, deteriorated face panels, joint problems, major settlement, ice damage.
2	Critical. Major structural defects, components have moved to point of possible collapse.

adverse retaining wall performance were observed to accompany (or even be manifest as) excess wall tilt. Consequently, wall tilt measurements using a digital protractor are a principal component of Seattle's inspection program (Molla 2009). To help ensure comparable and consistent data, tilt measuring stations are permanently established on many walls. Another example of how experience affects data collection activities is the scope and frequency of inspections specified for MSE walls in Pennsylvania. An in-depth inspection including a three-dimensional spatial survey of the wall is required every 10 to 15 years. This requirement arises largely from global stability and creep concerns stemming from local geologic conditions in the state—more particularly along Route 22/322 in Lewistown Narrows, where one of the longest MSE walls in the United States has been constructed. PennDOT has also implemented new technology as part of its data collection efforts. In 2008 and 2009, Lidar technology using a fixed-wing aircraft was used to assess the amount of creep that the Lewiston Narrows wall was experiencing. Unfortunately, the goal of 0.10 ft (30 mm) proved difficult to confirm because of the low altitude required within the canyon. The technology may be retried using a helicopter instead.

Other examples of using new technologies to monitor the performance of MSE walls include the incorporation of fiber-optics into geosynthetic reinforcement (Lostumbo and Artieres 2011). Various structural health monitoring tools now being built into bridges can readily be adapted for retaining walls. New technologies such as these will become increasingly more common in wall performance data collection and assessment efforts.

The general state of practice with respect to which MSE wall features or components are examined during data collection activities, based on survey respondents, is shown in Table 9. Only three of the 17 respondents to the associated survey question reported having some type of inventory. Responses suggest that the wall features or conditions most frequently examined by agencies are wall plumbness, bulging or distortion of the wall facing, and cracking of facing elements. As can be seen subsequently in Table 16, these features/conditions correlate well to those distress/failure modes which are believed most important or significant relative to wall performance. Eight of the 11 responses provided as "other" features were simple declarations that the particular respondent did not collect any such data. Two more

TABLE 9
MSE WALL FEATURES AND/OR CONDITIONS ASSESSED AS PART OF DATA COLLECTION AND MONITORING ACTIVITIES (multiple responses possible)

	Only Agencies with Inventories		All Respondents to Particular Question	
Response	Number	Percent	Number	Percent
Wall plumbness	2	67	5	29
Bulging or distortion of wall facing	2	67	5	29
Alignment and spacing of joints between facing elements	2	67	4	24
Cracking of facing elements	2	67	5	29
Damage to corners of facing elements	2	67	4	24
Damage from vehicular impact	1	33	3	18
Settlement along line of wall	1	33	4	24
Settlement behind wall	1	33	4	24
Distress in ground or pavement in front of wall	1	33	2	12
Distress in ground or pavement behind wall	1	33	3	18
Displacement of coping or parapet	2	67	3	18
Rust stains or other external evidence of corrosion	1	33	3	18
Functionality of drainage/catch basin	1	33	2	12
Functionality of internal drainage features (e.g., weepholes and piping)	1	33	2	12
External erosion	2	67	3	18
Internal erosion of backfill	1	33	2	12
Changes to wall geometry (e.g., excavation at toe, add surcharge load)	1	33	3	18
Vegetation growth	0	0	1	6
Internal corrosion/degradation of reinforcement	1	33	2	12
Other (specify)	0	0	11	65

of these responses indicated that feature assessment was only performed in response to observed wall distress, while the remaining response clarified that wall features were examined as part of their bi-annual bridge inspection activities.

FREQUENCY OF FIELD INSPECTIONS AND MONITORING ACTIVITIES

The condition and performance of MSE walls vary over time. Because of this, it is important that data collection and assessment activities be conducted routinely. According to the NBIS, bridges are inspected at two-year intervals. Some agencies have adopted similar two-year inspection intervals for retaining walls. Other agencies such as New York City require privately owned retaining walls to be inspected every five years. Kansas typically assesses its MSE walls at three-year intervals, whereas Oregon's plan calls for inspection of "good" walls of all types every five years, and "fair" or "poor" walls more often. Between 1986 and 1997, California had established five- to ten-year inspection intervals for MSE wall elements, particularly internal reinforcement elements.

PennDOT takes a tiered approach, with a "routine" wall inspection every five years and an "in-depth" inspection (which includes a three-dimensional survey for MSE walls more than 100 ft long and more than 20 ft high) at either 10- or 15-year intervals. Unscheduled "special" inspections are to be performed after a significant event, such as a vehicular collision, extreme weather, or indication of wall movement. Similarly, the FHWA's WIP directs that all walls should be inspected on a maximum 10-year cycle, and walls having performance issues are subject to more frequent inspection and assessment work, particularly those subject to "qualifying emergency relief events" such as a landslide or flood. PennDOT defines a routine inspection as "a close visual and hands-on examination of retaining walls and their drainage systems without traffic control. Those portions which cannot be accessed safely from beyond the edge of pavement are viewed using binoculars and/or a digital camera." In contrast, an in-depth inspection consists of "a close visual and hands-on examination of retaining walls and their drainage systems. Use of down-hole cameras or visual inspection of larger pipes is required for the drainage system."

Based on their study, Brutus and Tauber recommend a five-year interval for routine inspections (i.e., inspections conducted "in the absence of any special condition or circumstance that makes it prudent to inspect more often"). Selection of an inspection interval for a specific wall involves considerations of any known occurrence of adverse performance; wall age (older walls may require more frequent inspections); presence of questionable backfill (that may lead to settlement or internal corrosion concerns); and occurrence of flooding, earthquake, or vehicle damage. Principles of risk management dictate that walls whose failure would produce significant consequences are candidates for more frequent inspection.

When survey respondents were asked, "Which of the following statements best describes your agency's MSE wall performance monitoring activities?" (as shown in Table 10), the overwhelming response was that such activities were generally in response to specific instances of adverse performance. The remainder indicated that assessments were performed, but not always including all MSE walls in their inventory. This appears to suggest that, contrary to the practices and recommendations previously discussed, the frequency of monitoring activities appears to be largely driven by resource availability and/or in response to incidents of adverse performance.

Table 11 summarizes some interrelationships between those agencies that have reported the establishment of MSE wall inventories, the extent of those inventories, and the nature of their ongoing monitoring activities. As can be seen in this table, more than half of the agencies reporting MSE wall inventories only monitor their walls in response to known incidents of adverse performance. Just over one-quarter of agencies having inventories regularly inspect or assess most or all of those walls. From these data, it appears that once MSE wall inventories are initially developed, additional information relative to ongoing performance is generally either not collected or not assessed for most walls. (As pointed out previously, there is no uniform standard for designating and counting MSE walls).

COLLECTION OF CORROSION AND DEGRADATION DATA

A distinguishing feature of MSE walls relative to other retaining wall types is the reinforcement in the retained soil mass. The stability of the wall depends on the integrity of the reinforce-

TABLE 10
BEST DESCRIPTION OF AGENCY'S MSE WALL PERFORMANCE MONITORING ACTIVITIES

Response	Number	Percent
Reactive to reported incidents of adverse performance	32	73
Irregular inspection/assessment of some MSE walls	3	7
Regular inspection/assessment of some MSE walls	4	9
Irregular inspection/assessment of most or all walls in inventory	1	2
Regular inspection/assessment of most or all walls in inventory	4	9

TABLE 11
RELATIONSHIPS BETWEEN THOSE AGENCIES WITH MSE WALL INVENTORIES, THE SCOPE OF THOSE INVENTORIES, AND NATURE OF ONGOING MONITORING ACTIVITIES

Agency	Number of Walls	Percent Walls in Inventory	Best Description of Monitoring Activities
Alberta, Canada	300	10	Reactive to reported incidents of adverse performance
California	400	75	Reactive to reported incidents of adverse performance
Colorado	800	60	Reactive to reported incidents of adverse performance
Kansas	300	50	Regular inspection/assessment of most or all walls in inventory
Minnesota	300	60	Reactive to reported incidents of adverse performance
Missouri	899	100	Reactive to reported incidents of adverse performance
Nebraska	—[1]	10	Regular inspection/assessment of most or all walls in inventory
New York	635	100	Regular inspection/assessment of most or all walls in inventory
North Carolina	275	97	Regular inspection/assessment of most or all walls in inventory
North Dakota	100	100	Irregular inspection/assessment of most or all walls in inventory
Ontario, Canada	500	100	Regular inspection/assessment of some MSE walls
Tennessee	1000	50	Reactive to reported incidents of adverse performance
Utah	700	80	Reactive to reported incidents of adverse performance
Wisconsin	400	85	Reactive to reported incidents of adverse performance

[1]Data missing.

ment, which can be either relatively extensible geosynthetic materials or inextensible metallic straps or meshes. Because of the reinforcement's criticality, many MSE performance assessments focus on the reinforcement, which can be challenging since the reinforcement is buried and not directly observable. Also problematic is corrosion, which is a rate process affected by multiple factors. If certain other factors are assumed, wall age might serve as a proxy parameter for corrosion and remaining service life. However, premature failures illustrate potential shortcomings of relying on such assumptions.

Several U.S. state agencies have undertaken reinforcement corrosion studies. Table 12 presents a brief summary, slightly expanded from that prepared and presented by Fishman and Withiam (2011) of these various efforts. It can be noted that the corrosion issues reported in Nevada resulted from a now-outdated backfill specification rather than current AASHTO backfill specifications, and care must be taken when interpreting adverse performance of walls constructed using early design methods. Detailed descriptions of the corrosion monitoring activities of California, Florida, New York, and North Carolina are presented in Elias et al. (2009). It is interesting to note the correlation between agencies that have developed MSE wall inventories and those that have experienced MSE wall corrosion issues (and have subsequently developed monitoring programs).

Corrosion monitoring of steel reinforcement is typically accomplished by either retrieval of buried coupons or nondestructive electrochemical methods. With exhumed coupons, corrosion can be assessed by determining weight and section thickness loss, as well as decreases in tensile strength. With electrochemical methods, potential and polarization resistance measurements are made and correlated with dimensions of the reinforcement. In *Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes*, a principal reference in the United States regarding the degradation and corrosion of MSE wall reinforcement, Elias et al. (2009) advise that "given the advantages, utilization of remote electrochemical methods is highly recommended with at least some coupons buried for retrievals to confirm results." Their provided rule of thumb regarding installation is two locations spaced at least 200 ft (60 m) apart for MSE walls 800 ft (250 m) or less in length and three locations for longer walls. At each location, corrosion should be monitored at a minimum of two depths. For extractible coupons (i.e., inspection wires), Caltrans has developed a typical layout of 18 clustered coupons to be periodically extracted (see appendix in Fishman and Withiam 2011). Caltrans has also developed a set of extraction guidelines (California Department of Transportation 2004).

With respect to frequency of assessing corrosion, Elias et al. (2009) recommend that potential and polarization resistance measurements (owing to their sensitive nature) be made monthly for the first three months, bi-monthly for the next nine months, and annually thereafter. This recommended frequency is significantly greater than the frequency at which other wall inspection and data collection activities occur (as described in the previous section). Extractible coupons are typically removed at five- to 15-year intervals, depending on the number of coupons installed. In California's typical

TABLE 12
SUMMARY OF US STATE MSE WALL CORROSION ASSESSMENT PROGRAMS

State	Description
California	Has been installing inspection elements with new construction since 1987, and has been performing tensile strength tests on extracted elements. Some electrochemical testing of in-service reinforcements and coupons has also been performed. Linear polarization resistance (LPR) and EIS tests were performed on inspection elements at selected sites as part of NCHRP Project 24-28 and results compared with direct physical observations on extracted elements.
Florida	Program focused on evaluating the impact of saltwater intrusion, including laboratory testing and field studies. Coupons were installed and reinforcements were wired for electrochemical testing and corrosion monitoring at 10 MSE walls. Monitoring has continued since 1996.
Georgia	Began evaluating MSE walls in 1979 in response to observations of poor performance at one site located in a very aggressive marine environment incorporating an early application of MSE technology. Exhumed reinforcement samples for visual examination and laboratory testing. Some in situ corrosion monitoring of in-service reinforcements and coupons at 12 selected sites using electrochemical test techniques was also performed.
Kentucky	Developed an inventory and performance database for MSE walls. Performed corrosion monitoring including electrochemical testing of in-service reinforcements and coupons at five selected sites.
Nevada	Condition assessments and corrosion monitoring of three walls at a site with aggressive reinforced fill and site conditions. Exhumed reinforcements for visual examination and laboratory testing; performed electrochemical testing on in-service reinforcements and coupons. A total of 12 monitoring stations were dispersed throughout the site providing a very good sample distribution.
New York	Screened inventory and established priorities for condition assessment and corrosion monitoring based on suspect reinforced fills. Two walls with reinforced fill known to meet department specifications for MSE construction are also included in program as a basis for comparison. Corrosion monitoring uses electrochemical tests on coupons and in-service reinforcements.
North Carolina	Initiated a corrosion evaluation program for MSE structures in 1992. Screened inventory and six walls were selected for electrochemical testing including measurement of half-cell potential and LPR. This initial study included in-service reinforcements, but coupons were not installed. Subsequent to the initial study, NCDOT has installed coupons and wired in-service reinforcements for measurement of half-cell potential on MSE walls and embankments constructed since 1992. LPR testing was also performed at approximately 30 sites in cooperation with NCHRP Project 24-28.
Ohio	Concerned about the impact of their highway and bridge de-icing programs on the service life of metal reinforcements. Performed laboratory testing on samples of reinforced fill but did not sample reinforcements or make in situ corrosion rate measurements.
Oregon	Preliminary study including (1) a review of methods for estimating and measuring deterioration of structural reinforcing elements, (2) a selected history of design specifications and utilization of metallic reinforcements, and (3) listing of MSE walls that can be identified in the ODOT system.
Utah	Extracted 22 wire coupons from one- and two-stage MSE walls all approximately 11 to 12 years old. Galvanization thickness was found to still be greater than initial specified values. Data to provide baselines for future assessments.

After Fishman and Withiam (2011).

TABLE 13
METHOD(S) CURRENTLY USED BY AGENCIES TO ASSESS DEGRADATION/CORROSION OF REINFORCEMENT (multiple responses possible)

	Only Agencies with Inventories		All Respondents to Particular Question	
Response	Number	Percent	Number	Percent
Do not currently assess	2	67	12	86
Linear polarization resistance (LPR) for metallic	0	0	1	7
Extractible coupons for metallic	1	33	2	14
Exhumation for geosynthetic	0	0	0	0
Other (specify)	0	0	0	0

installation, coupons are removed and inspected after five, ten, 20, 30, 40, and 50 years.

For geosynthetic reinforcement, the primary performance issue is polymer degradation. At present, the only effective means of assessment is retrieval of buried specimens. The assessment process involves successive retrieval and testing of samples to determine both mechanical and chemical properties. Strength and elongation (i.e., creep) properties can then be extrapolated to predict future performance. Elias et al. (2009) recommend that sampling and testing occur at five- to seven-year intervals for a minimum of four retrievals, or one-third the expected life of the facility.

The state of practice for assessing degradation and corrosion in MSE walls, as indicated by 14 survey participants who provided specific responses, is shown in Table 13. Three of these respondents indicated that they have their own MSE wall inventories. Based on the information presented in this table and in Table 12, it appears that a minority of agencies assesses corrosion of metallic MSE wall reinforcement, and none systematically assess degradation of geosynthetic reinforcement.

CHAPTER FOUR

ASSESSMENT AND USE OF MECHANICALLY STABILIZED EARTH WALL DATA

After wall condition and performance data have been collected, assessments can be performed to determine how well MSE walls are meeting their performance objective(s). Assessments can also be performed to prioritize maintenance and replacement functions. [As a reference, FHWA (1999) has developed a basic primer regarding assessment management concepts while Bernhardt et al. (2003) have discussed application of these concepts to "geotechnical infrastructure" assets.] Such assessments commonly involve some type of numerical scale or standard set of terms. These scales or terms can be used in quantitative rating algorithms and/or more subjective, qualitative expressions of wall performance. Ideally, these scales ultimately link current wall performance with the wall's position within its design life cycle. This chapter will discuss how wall performance data are assessed and then used for asset management.

ASSESSMENT AND INTERPRETATION OF DATA

Referring again to the established and tested FHWA's WIP, the wall element and performance data collected (as discussed in the previous chapter) are combined with factors measuring the relative importance of each element to establish a final overall wall condition rating, which ranges from 5 to 100. Conversion of this numeric rating to a qualitative description can be approximately achieved by dividing the rating by 10 and comparing it to the element and wall performance rating definitions shown in Table 6 and Table 7, respectively.

Although their origin is not explicitly stated, it appears that the weighting factors used in the WIP were established by some type of consensus of experienced persons. The procedure manual states, "these element weightings have been determined to sufficiently discern element impacts on wall performance. However, as more wall inventory data are collected, weightings will be re-evaluated for appropriateness, and altered as needed to provide meaningful and consistent wall condition ratings."

The FHWA WIP wall condition rating was also cited by Brutus and Tauber (2009) in their consideration of how to quantify wall performance. They also provided the five-point rating scale in Table 14 as another possible sample rating system. In some numeric schemes, adverse performance is indicated by a low rating, whereas in others a low score is desirable. Some MSE wall assessments do not incorporate a type of condition rating, numeric or otherwise. For example, state agencies in Utah and Ohio currently document only the existence of certain adverse conditions.

As part of this synthesis, 44 survey participants provided feedback regarding how important they thought particular wall features and conditions are in assessing the long-term performance of MSE walls. These beliefs are in large measure representative of the relative importance of specific wall condition data and might function similarly to the FHWA WIP weighting factors in a current assessment or prediction of future wall performance. In the survey, relative importance was distinguished using a numerical rating scale where 1 = not important, 2 = mildly important, 3 = moderately important, 4 = very important, and 5 = most important. The results in terms of average rating are shown in Table 15. Also shown is the variance for each feature from the overall mean rating, helping indicate each feature's perceived importance relative to the others.

As can be seen in the table, features associated with drainage (both external and internal) typically are considered to be among the most important. Changes to wall geometry resulting from excavation or addition of surcharge load that would affect global stability are also viewed as being relatively important. Most important, however, is corrosion and degradation of internal reinforcement. This result appears to be consistent with the impetus for the initial establishment of many existing MSE wall inventories—concerns relative to, or premature failures stemming from, corrosion of MSE wall reinforcement. Interestingly, a small panel of MSE wall experts convened by the Utah DOT judged that drainage issues are the most significant issues during the first 15 years or so of wall life, after which corrosion issues become the most important (Bay et al. 2009).

Perhaps most surprisingly, the survey indicated that wall height is considered among the least important—surprising because this parameter is among the more frequently included parameters in wall inventories. This also appears inconsistent with the assessment of Brutus and Tauber (2009) that the most important component contributing to risk stemming from wall failure is the height of the wall. Also surprising is that wall age (as implied from date constructed) is rated as being below average in importance because internal corrosion (the most important factor) is itself a function of age.

TABLE 14
SAMPLE RATING SYSTEM FOR WALL PERFORMANCE

Rating	Description
Excellent	No significant indication of distress or deterioration.
Good	Some indications of distress or deterioration, but wall is performing as designed.
Fair	Moderate or multiple indications of distress or deterioration affecting wall performance.
Poor	Significant distress or deterioration with potential for wall failure.
Critical	Severe distress or deterioration. Indications of imminent wall failure.

Source: Brutus and Tauber (2009).

TABLE 15
RELATIVE IMPORTANCE OF WALL FEATURES/CONDITIONS IN ASSESSING THE LONG-TERM PERFORMANCE OF MSE WALLS

Response	Mean	Variance
Internal corrosion/degradation of reinforcement	4.4	+0.9
Internal erosion of backfill	4.1	+0.7
Wall geometry changes (e.g., excavation at toe, added surcharge load)	4.1	+0.6
Functionality of internal drainage features (e.g., weepholes and piping)	4.0	+0.6
Drainage conditions	4.0	+0.6
Proximity of external water sources (e.g., river, sprinklers, etc.)	3.9	+0.4
Distress in ground or pavement behind wall	3.8	+0.4
Functionality of drainage/catch basins	3.8	+0.3
Bulging or distortion of wall facing	3.7	+0.2
Maximum wall height	3.7	+0.2
Cracking of facing elements	3.6	+0.2
Settlement behind wall	3.6	+0.2
Reinforcement type	3.6	+0.1
Location and condition of drainage discharge points	3.5	+0.1
Rust stains or other external evidence of corrosion	3.5	+0.1
Distress in ground or pavement in front of wall	3.5	+0.1
External erosion	3.5	+0.1
Embedment of wall	3.5	+0.0
Post-construction modifications	3.5	+0.0
Settlement along line of wall	3.5	+0.0
Slope behind wall	3.4	+0.0
Damage from vehicular impact	3.4	+0.0
Slope in front of wall	3.3	–0.1
Alignment and spacing of joints between facing elements	3.3	–0.1
Wall plumbness	3.3	–0.2
Wall type	3.3	–0.2
Damage to corners of facing elements	3.2	–0.3
Presence of bench at toe of wall founded on slope	3.2	–0.3
Road/traffic offset	3.1	–0.3
Displacement of coping or parapet	3.0	–0.4
Date constructed	3.0	–0.5
Manufacturer	2.7	–0.7
Vegetation growth	2.7	–0.7
Average wall height	2.6	–0.8
Wall length	2.3	–1.2

TABLE 16
RELATIVE SIGNIFICANCE OF POTENTIAL FAILURE/DISTRESS MODES IN LONG-TERM PERFORMANCE OF MSE WALLS

Response	Mean	Variance
Global stability	4.3	+0.4
Reinforcement rupture	4.3	+0.4
Reinforcement pullout	4.2	+0.3
Loss of foundation support due to erosion	4.0	+0.1
Loss of foundation support to bearing capacity failure	4.0	+0.1
Excessive settlement	3.8	–0.1
Sliding	3.6	–0.3
Overturning	3.5	–0.4
Facing failure	3.3	–0.6

In addition to the relative importance of certain wall features and conditions, survey participants were also asked to rate how significant they thought certain potential failure/distress modes were relative to the long-term performance of MSE walls. The failure/distress modes were those typically considered in wall design procedures. Significance was rated on a scale of 1 = not significant, 2 = mildly significant, 3 = moderately significant, 4 = very significant, and 5 = most significant. The results, shown in Table 16, indicate that most agencies believe that global stability and reinforcement rupture are the most likely failure modes for MSE walls in the long term. The term “reinforcement rupture” was not specifically defined, but is believed to have been interpreted to include failures resulting from both section loss and subsequent overstressing as well as overstressing of the initial section. The data also suggest that agencies believe overturning and facing failure are the least likely failure modes. This information is important in that these beliefs constitute a type of expert opinion that can be used in MSE wall service life prediction methods as well as in wall failure risk assessments. Both of these activities currently appear to be in their naissance, as discussed later in this chapter.

USE OF PERFORMANCE ASSESSMENTS IN DECISION MAKING

Once wall conditions are assessed and its condition quantified on some basis (such as the FHWA WIP wall condition rating), the assigned rating can be used in more than one way for programming decisions. In some systems, the numeric value can be directly related to a specified action level (e.g., walls rated below 40 must be repaired). In other systems, the numeric value is used for ranking, and resources for items such as maintenance or repair are allocated accordingly (e.g., there is $100,000 in the budget for repairs, which walls do we start with?). In yet other systems, such as the FHWA WIP, the final overall rating is only one of several factors used to make programming decisions. The rating by itself is not directly related to a particular action. Rather, four additional items/questions are considered in the FHWA WIP: (1) are additional investigations required (how reliable is our assessment); (2) what design criteria may have been used in planning the structure (was the structure engineered); (3) what aspects of the wall structure are historic or contribute to the cultural context of the road asset; and (4) what are the consequences of wall failure. These items are subjectively assessed by the person rating the wall with few objectively defined criteria; hence, programming decisions, to which wall condition ratings only partially contribute, are largely subjective in the FHWA WIP.

As stated previously, some MSE wall assessments do not incorporate any condition ratings; therefore, some alternate means of decision making is required. On a comparative wall-to-wall basis, one can tally the number of adverse occurrences per wall and then rank the tallies to establish a type of priority list. Swenson (2010) used the Utah wall inventory data and attempted to improve the ranking processes by associating particular conditions/issues with particular failure modes and then assigning weights to indicate criticality. Unfortunately, the expert input/consensus usually required to link conditions, failure modes, and consequences was limited.

When asked about a specific methodology for assessing long-term performance of existing MSE walls, no survey respondent answered affirmatively beyond citing regular inspections or several corrosion assessment studies. These items appear to be contributing components to a methodology, but no fully developed methods were identified. From the responses gathered and review of available literature, it does appear that some agencies may rely largely on pre-approval product processes and compliance with Highway Innovative Technology Center criteria (see Highway Innovative Technology Center 1998) for assurance that MSE walls will perform adequately. Although such measures should improve the likelihood of good, long-term performance, failure case histories suggest that they are not failsafe.

Estimation of Service Life

In their study, Brutus and Tauber (2009) concluded that “there is no data available in technical literature on the estimate of designed service life or on construction or maintenance operations on old retaining walls built somewhere between 50 to 100 years ago.” MSE walls in the United States are newer than this, yet this statement also appears to apply to those

TABLE 17
SAMPLE RATING SYSTEM FOR CONSEQUENCES OF FAILURE

Rating	Description
Severe	High likelihood of injuries or death from debris falling on a heavily traveled roadway, on other heavily used adjacent areas, or from collapse of structures near top of wall. High likelihood of extensive or total-loss damage to vehicles or structures. Complete closure of a heavily traveled roadway requiring lengthy detours.
Significant	Low probability of injury to persons but likelihood of any of the following: (a) substantial property damage, (b) interruption of water or other utility service to a large area, (c) lengthy blockage of access to business properties or public facilities, (d) long-term damage to environmental or cultural resources, (e) closure of two or more lanes of a heavily traveled roadway, (f) full closure of any roadway with no alternative access or requiring lengthy detours.
Minor	Low probability of injury to persons or of damage to vehicles or non-highway property or facilities. Full roadway closures where alternative access is available. Closure of a single lane on a heavily traveled roadway.

Source: Brutus and Tauber (2009).

newer MSE walls that have intended design lives of 75 to 100 years. As reported in the previous section, none of the agencies surveyed had a specific methodology for assessing long-term performance of existing MSE walls, let alone a method for estimating design life.

Brutus and Tauber do however suggest two approaches that might be used to estimate the remaining service life of walls. One approach is to perform repeated inspections and "chart escalating maintenance and repair costs to project a remaining service life . . . using some criterion such as when the repair and maintenance costs exceed more than 50% of the replacement cost." The other approach is to assess the performance of similar walls (e.g., same construction standards) built over a long period of time and use the observed performance to forecast the performance of newer walls. However, care must be taken when interpreting adverse performance of walls constructed using different, older design methods that may not be representative of newer walls. Elements of these approaches are now beginning to be implemented with the development of MSE wall inventories and the collection of data as described in the previous chapters. As pointed out previously, the development of initial inventories appears to be progressing much more rapidly than regular ongoing performance data collection.

Risk Assessment

Tied closely to the assessment of wall performance is the assessment of risk. Sometimes, risk assessment is not explicitly undertaken, particularly if wall performance appears more than adequate. Ultimately however, it is questions of risk and consequence of adverse performance that drive many asset management activities. Potential consequences of failure that are considered in the performance of risk assessments include (Brutus and Tauber 2009):

- Death or injury to persons, including facility users and those on adjacent properties or facilities;
- Damage to property including vehicles, highway property or facilities, and adjacent property or facilities;
- Disruption of highway operations, including full or partial closure of the roadway, or appurtenant facilities;
- Disruption of adjacent utility lines, such as water mains or electrical conduits;
- Environmental consequences, such as damage to a significant wildlife habitat or blockage of a watercourse; and
- Damage to cultural assets or sensitive land uses.

Again, as outlined by Brutus and Tauber, the consequences of adverse wall performance or failure can be affected by:

- The volume of earth retained by and otherwise contained in the wall, which in turn is most frequently reflected by the height of the wall;
- The proximity of the wall ERS to the roadway or other potentially affected facilities or structures;
- The intensity of usage of potentially affected facilities, such as traffic volume on a roadway or occupancy of a building;
- The structural robustness of adjacent buildings and facilities; and
- The vulnerability of occupants and/or users.

Often the consequence of failure (either functional or structural) is also quantified or expressed in terms of some type of scale. Possible metrics include monetary losses, injuries or fatalities, and/or decrease in levels of serviceability. Brutus and Tauber suggest use of a three-level rating system such as that shown in Table 17.

Performance of risk assessments for MSE walls at present appears to be problematic. Risk assessments (particularly probabilistic ones) typically require the use of "expert opinion" or "expert consensus"; however, being expert requires being experienced. As agencies continue to monitor wall performance, they will gain further experience, and with this increased experience, their ability to assess risk will improve; hence it is in this manner that methods for risk assessment are likely to evolve. Wall function as reflected in inventory inclusion criteria such as that shown in Table 2 would be of particular importance when executing risk assessments.

CHAPTER FIVE

OUTCOMES AND LESSONS LEARNED

As MSE wall performance is monitored, assessments can be made regarding the adequacy of the wall's design, construction, and maintenance. These assessments can in turn be used to change practices and policies with the intent of improving wall performance, particularly for future walls. The feedback loop thus established becomes a means of continual improvement. One example of this process is the development and recent release of *NCHRP Report 675, LRFD Metal Loss and Service-Life Strength Reduction Factors for Metal-Reinforced Systems* (Fishman and Withiam 2011), in which the accumulation of reinforcement corrosion data over time has led to the development of more accurate metal loss models. This chapter discusses actions taken by survey respondents to improve the long-term performance of their MSE walls. These actions reflect lessons learned relative to design, construction, and maintenance. Ideally, these actions will lead to a decreased likelihood of failure or adverse performance of MSE walls in the long term.

POLICIES AND PRACTICES DEVELOPED TO IMPROVE PERFORMANCE OF MECHANICALLY STABILIZED EARTH WALLS

Survey participants were asked to respond regarding any approaches, besides monitoring, that their agency may have developed or implemented to improve the long-term performance of their MSE walls. Specific responses were sought relative to the following categories:

- Regularly scheduled cleanout/maintenance of catch basins
- Different requirements for backfill immediately behind wall face as compared with remainder of reinforced backfill
- Developed special drainage details at ends of MSE walls
- Developed special drainage details behind MSE walls
- Specified vertical and horizontal distances for discharge points and water sources
- Increased wall embedment
- Other design specifications
- Contractor/installer qualifications
- Construction inspection
- Post-construction inspection
- Other.

Typically, fewer than half of survey respondents provided feedback in any one category. The responses provided are generally summarized in the following paragraphs.

With respect to regularly scheduled cleanout and maintenance of catch basins, respondents reported no special actions being taken in this regard. The responses offered suggest that performance of this activity varies significantly between agencies, ranging from its being "done as a matter of course," and being done routinely, to "hit and miss if they actually do it."

With respect to different requirements for backfill immediately behind wall face as compared with remainder of reinforced backfill, seven agencies specifically specified use of open-graded, free-draining aggregate or rock immediately behind the wall face.

With respect to developing special drainage details at ends of MSE walls, agency improvements included turning the wall ends into the slope, concrete headwalls being used (presumably at culvert openings), "plating all drainage surfaces above and around wall; insuring drainage does not enter and saturate reinforced backfill," and use of waterproofing membranes together with weep drains and dedicated drainage collection systems. In the related query regarding specification of vertical and horizontal distances for discharge points and water sources, one agency reports using 100-ft intervals and another emphasized assuring that drainage below and above wall is on concrete inverts and concrete aprons.

With respect to developing special drainage details behind MSE walls, multiple respondents indicated they require some type of underdrain located at the wall face and/or in back of the reinforced soil zone. One respondent emphasized that non-frost-susceptible aggregate and drain pipes should be extended to a depth below frost penetration. Other practices include using a drain gutter, lined swale, or concrete plating at the top of the wall. Most responses referred to needs for direct water away from the wall and to a lower elevation. A couple of respondents indicated that they had added weep drains and/or strip drains at the wall–soil interface rather than relying on drainage through panel or block joints. Texas reports that it has developed an inlet standard to "best accommodate inlets . . . and also convey the water out of the wall in the quickest fashion."

With respect to increased wall embedment, most participants who provided a response in this category indicated that their practice involves embedding the wall foundation below the frost line or at least some minimum depth (the value of which is most frequently 0.6 m, but appears to range up to 1.2 and 1.5 m in northern states such as Minnesota and New Hampshire). Some agencies reported using increased embedment for walls founded on slope, with minimum depths conforming to AASHTO design specifications or as needed to satisfy global stability requirements. Although not reported in the survey, recent inspection of Utah DOT MSE walls indicates that the 1.2-m-wide horizontal bench required by AASHTO to be placed at the base of MSE walls founded on slopes is frequently absent. A proposed alternative to the bench suggested that embedment depth be increased to produce the same amount of distance from the buried base of the wall to the face of the slope had the bench been installed. New Brunswick reported that maintaining such benches was one of its most important lessons learned. Elsewhere in the survey, Texas reported that it strongly encourages that walls not be perched on slopes, and if a slope is to exist at the base of wall that the slope be limited to 6:1 or flatter in combination with an increased wall embedment.

With respect to other design specifications, responses varied greatly. Several respondents indicated that they were in the process of revising or had recently improved their specifications but did not provide details, although one respondent implied that the presence of regular specification and design manual updates in and of itself is a beneficial practice. The most frequently reported focus is on being more restrictive in specifying backfill, particularly with respect to gradation, fines content, and physiochemical-electrical properties. (Interestingly, current research being performed by W.A. Marr as NCHRP Project 24-22, "Selecting Backfill Materials for MSE Retaining Walls," aims to broaden current FHWA specifications for MSE wall backfills.) One respondent indicated an improved practice in using concrete level pads at the base of the wall. Although not reported in the survey, owing to some instances of adverse wall performance, some states (e.g., Ohio) discourage the use of acute corners for its MSE walls.

Nearly all responses to the question of contractor/installer qualifications (11 out of 12) indicate that agencies use an approved (or pre-approved) list of products and/or vendors. However, only two respondents (Colorado and Oregon) explicitly indicated that their specifications require wall system vendors to provide contractor training or that the contractor possess some type of previous training.

Sixteen agencies responded with comments regarding construction inspection; only one indicated that it does not do construction inspection on a regular basis. Four of the responding agencies (Colorado, Minnesota, New York, and Texas) have developed manuals and/or provide specific training for MSE wall construction. Four agencies (Massachusetts, Michigan, Montana, and Nova Scotia) indicated that they require wall supplier/vendor/manufacturer personnel on-site at least some time during construction. One agency (Nevada) reports now requiring production testing of MSE backfill stockpiles on-site rather than just at the material source.

With respect to post-construction inspection, no new developments were reported beyond a few agencies that now make a complete inspection of the wall at the end of construction routine. One responding agency indicated having a three-year warranty period for its MSE walls. Two agencies (Kansas and New York) reported that they retain construction quality control/quality assurance data and point out that retaining such data has the potential to diagnose future problems if they arise.

While not being a practice unique to agencies responding to this survey, use of an impervious membrane above the entire reinforced soil mass to prevent the migration of aggressive materials (such as salts used to de-ice the overlying pavement) was cited by several respondents as a means of protecting the reinforcement from corrosion/degradation.

MOST IMPORTANT "LESSON LEARNED"

As part of the survey conducted for this synthesis project, recipients were asked to give their opinion as to what is the most significant lesson learned by their agency with respect to the long-term performance of MSE walls. Responses varied from design and backfill specification to construction practices and post-construction drainage maintenance. Given the potential significance of these responses—being the most important thing(s) learned—all responses are presented in Appendix C in their entirety.

Although the scope of the responses was broad, certain topics appeared more frequently than others. The four most frequent topics (in order of decreasing frequency) mentioned were drainage, construction, backfill, and modular block issues.

Approximately one-fourth of respondents indicated that the most important lesson learned by their agency was drainage-related—as two respondents put it: "Drainage; drainage; drainage," and "W-a-t-e-r: from any and all directions and sources." Although these particular responses lack specificity, it is readily apparent that the two respondents believe that drainage is essential to the successful performance of MSE walls. Another respondent suggested that the most important lesson was "providing a sound and firm foundation for support of the wall; and providing proper drainage within the wall system and adjacent to the wall geometry."

Approximately one-fifth of respondents reported that the most important lesson they learned was construction-related. One pointed out that "the systems can last forever but must be designed and built correctly." Similarly, another noted, "For the most part [my agency] has had very few problems with MSE structures. We do know that great care must be taken in constructing these structures. If you start wrong in the beginning you'll always be seeing problems in the walls."

Lessons involving either MSE wall backfill or modular blocks accounted for about 14% and 10% of responses, respectively. With respect to backfill, one respondent replied, “Use of fine grained select fill has resulted in the migration of material out from behind walls. We have thousands of square foot of wall that was backfilled with this type of material. Many walls have shown distress as a result. We have coarsened up the gradation of select fill to lessen the potential of fill migration.” When modular blocks were mentioned, it was usually in the context of durability and degradation because of roadway de-icing activities. According to one respondent, “By having a formal wall approval process we have limited the use of modular block wall systems and the deterioration of these facing elements due to deicing chemicals.”

One of the more extensive commentaries provided by a survey respondent related to the deformation-tolerance of MSE walls, and has bearing on wall inspection activities:

> The outside may get ugly [but] it’s the inside that matters. We had an MSE ride a landslide downslope 32 ft back in the 1970s. It deformed significantly, but is still in service today. We have had several lose foundation support, but as long as they were able to move and readjust the stresses through deformation, with no loss of backfill, they have all been able to stay in service—some for decades. However, excessive consolidation settlement and internal drainage failures have led to issues with cavities and retainment loss. These MSE failed within months and had to be replaced. Amazing[ly] flexible, but only up to a limit. It’s what’s inside that counts.

Although different agencies appear to have had varying experiences with MSE walls, the “most important lessons learned” do tend to focus on the topics of drainage, construction, backfill, and modular block issues. Considering the importance given these topics by survey respondents, those issues could be important focal points in the development of future MSE wall assessment and/or management activities.

CHAPTER SIX

CONCLUSIONS

Combining a literature review with a survey and interviews, this synthesis project has attempted to determine:

- The current state of practice in assessing the performance of mechanically stabilized earth (MSE) walls, particularly in the long term;
- The direction of the state of practice;
- What the current and effective practices are; and
- What areas need improvement and/or research.

Key findings and conclusions regarding each of these items have been summarized and are presented below.

CURRENT STATE OF PRACTICE

MSE walls are important infrastructure assets. However, unlike bridges and pavements, they are often overlooked. The current state of practice with respect to the management of MSE walls as assets can be characterized thusly:

- There is no widely used, consistently applied system for managing MSE wall assets.
- Fewer than one-quarter of state-level transportation agencies have developed any type of MSE wall inventory data beyond that which may be captured as part of their bridge inventories.
- Still fewer agencies have the methods and/or means to support their inventories with data from ongoing inspections from which assessments of wall performance can be made.
- Some previously established wall inventory and inspection activities have ceased because of lack of resources and funding.

Regarding the inventory and gathering of MSE wall-related data once the walls are constructed and accepted, current practice can be generally described as follows:

- Responsibility for MSE walls after their construction usually rests with maintenance personnel operating in a decentralized structure, while most inventories are managed by a geotechnical engineer or similar person at an agency-wide level. However, in 20% of agencies, no one has end responsibility for MSE walls.
- Various types of data are collected and maintained in order to assess wall performance. Most frequently, the data consist of ratings that describe the observed condition of wall features.
- The manner in which wall features are observed and assessed varies between agencies, as do the rating criteria themselves.
- Rating criteria are usually more subjective than objective.
- When scheduled, the frequency of data collection varies from two to 15 years, although wall performance monitoring activities are most often (i.e., two-thirds of the time) simply reactive to reported incidents of adverse performance.

Once asset data have been collected, they must be assessed to predict future performance and determine maintenance and management activities. With respect to MSE walls, current practice in the area of assessment can be basically described this way:

- Agencies believe that drainage, global stability, and corrosion/degradation of internal reinforcement are the most important issues affecting the long-term performance of MSE walls.
- Wall performance is sometimes only one factor used in making asset-management decisions.
- No state transportation agency has a specific methodology for assessing long-term performance of existing MSE walls.
- Similarly, there appears to be no specific methodology for accurately predicting the remaining service life of an MSE wall.

DIRECTION OF STATE OF PRACTICE

As walls have aged and adverse performance (whether age-related or not) has occurred, more agencies are becoming aware of a need for long-term performance monitoring of MSE walls. An opinion voiced by some survey respondents is that there is insufficient attention given to long-term performance of MSE walls despite the potential for poor performance of this important asset. One reason is that, while other assets such as pavements and bridge structures are subject to formal inspection and reporting requirements, there are no such requirements for retaining walls, and in particular MSE walls. Without such requirements, respondents noted difficulty in obtaining funding for wall inspection and management. Consequently, it appears that the direction of practice is largely limited to the status quo, with relatively few agencies performing inspections or conducting assessments. However, it is anticipated that as experience with MSE walls accumulates, those that are able to secure funding and resources will continue to develop, refine, and better calibrate procedures regarding design, construction, condition assessment, and asset management decision making.

EFFECTIVE PRACTICES

Although wall inventory and monitoring practices vary between agencies, effective practices can be extracted from systems currently in use. The most well-implemented and developed wall inventory and assessment system in the United States appears to be the Wall Inventory Program developed by the FHWA for the National Park Service. The system uses "conditions narratives" (the preparation of which is illustrated by only general guidance, thus making them fairly subjective) to describe the conditions of certain wall elements, and then these narratives are converted to a numeric rating. Although the multiple steps in the rating process increase the effort required to use the system, an inherent strength is that it can be applied to many wall types (not just MSE walls).

Other wall inventory and assessment systems such as those used by Pennsylvania and Nebraska are relatively simple to use and appear to be less interpretive. Such characteristics typically lead to greater consistency in data interpretation and broader use. Without consistency in collected datasets, broadly applicable conclusions are more difficult to reach, and methodologies developed from inconsistent data are inherently less robust. The numeric ratings associated with these two particular systems are also compatible with the 0 (worst) to 9 (best) scale already used by many in the assessment of bridges, thus facilitating the development of readily accessible MSE wall assessment tools and methods within the domain of asset management already occupied by other asset types.

Other desirable practices include that reflected in the Nebraska system, in which rating criteria are specific to each element or wall condition rather than being generic. This specificity avoids vagueness and contributes to greater consistency. For example, a rating of 6 is assigned "when less than 25% of the wall area shows deterioration," and a rating of 5 is assigned "when wall panels have bowed outward to where connectors between panels are visible and deforming." This would be in contrast to a system in which a rating of 3 is assigned if "the wall exhibits 'extensive' distress."

The wall inventory and assessment system employed in Pennsylvania reflects another apparently effective practice, in that it actively and regularly inspects all of its retaining walls (inclusive of MSE types) and manages its inventory within the same framework as it does its bridges. In this manner, overlaps and gaps in inventory are minimized, and data and assessments are kept current.

Although individual experiences and beliefs regarding practices that improve wall performance vary, most agencies agree that the use of a pre-approved wall design and/or wall supplier helps ensure better wall performance. Similarly, based on the "most important lessons learned," many agencies believe that providing adequate drainage, both internal and external, is an essential practice in realizing good MSE wall performance.

In summary, current effective practices for inventorying and assessing the performance of MSE walls include:

- Use of inventory and assessment systems with features that are as simple to use and as objective as reasonably possible
- Use of rating criteria that are specific to particular wall elements and/or conditions
- Use of numeric rating scales that correspond to other scales already in use for other asset classes such as bridges
- Incorporation of MSE wall inventory and assessment systems together with systems for other asset classes.

Current effective practices for improving the performance of MSE walls include:

- Use of pre-approval process for wall design and/or wall supplier
- Provision of adequate internal and external drainage.

AREAS NEEDING IMPROVEMENT AND/OR RESEARCH

Today there are many millions of square meters of MSE walls with typical design lives of 75 to 100 years. The oldest of these walls are about 40 years old. Instances of MSE wall failures and poor performance are expected to increase as walls age. To better assess the performance of MSE walls, the following practices would be beneficial:

- Greater recognition of MSE walls and retaining walls in general as important infrastructure assets
- Increased availability of funding and other resources for inventory and assessment activities
- Active involvement of a larger number of agencies in MSE wall inventory and assessment activities
- Greater consistency across agencies relative to the way that inventory and assessment activities are performed
- Greater use of bridge and other existing asset inventory data for MSE wall inventories.

To move beyond current inventory and the data baselines now being established, repeated observations and performance predictions will be needed, as will specific decision-making methodologies. To this end, research relative to the following topics would be helpful:

- Improved ability to evaluate the integrity of existing MSE reinforcement systems using methods that are economically and logistically effective
- Standards for performance data baselines and data collection activities
- Predictive models for remaining MSE wall service life
- Methods of risk assessment specifically for MSE walls and, more generally, for various types of retaining walls.

A potential research problem statement for predictive models for remaining MSE wall service life is presented in Appendix D. The statement is adaptable to the other identified research needs.

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APPENDIX A

Survey Questionnaire

NCHRP Synthesis Survey: Long-term Performance of Mechanically Stabilized Earth (MSE) Walls

Introduction Page

Dear Recipient:

The Transportation Research Board (TRB) is preparing a synthesis on Long-term Performance of Mechanically Stabilized Earth (MSE) Walls. This is being done for the National Cooperative Highway Research Project (NCHRP), under the sponsorship of the American Association of State Highway and Transportation Officials, in cooperation with the U.S. Federal Highway Administration.

Mechanically Stabilized Earth (MSE) walls were introduced in North America about 40 years ago. As the technology has improved and gained wider recognition, the number of MSE walls designed and constructed has increased dramatically. The long-term performance of these structures depends on various factors, and unfortunately there have been instances of adverse performance. Multiple states have established MSE wall monitoring programs, while several others are looking for guidance, tools, and funding to establish their own monitoring program. This project will study how state transportation agencies monitor, assess, and predict the long-term performance of MSE walls. It is anticipated that synthesis of this information will lead to better design, construction, monitoring, and maintenance of these important structures.

This survey is being sent to all state and provincial transportation agencies in the US and Canada. Your cooperation in completing the questionnaire will ensure the success of this effort. If you are not the appropriate person at your agency to complete this survey, please forward it to the correct person.

Please compete and submit this survey by Friday, MARCH 11, 2011. This survey is dynamic in nature, and the total number of questions asked and time to complete will depend upon your level of experience with MSE walls and your responses. Some agencies will be able to provide more feedback than others. The number of questions will be a minimum of 12 (taking approximately 20 minutes) and a maximum of 20. Whatever your experience is relative to the long-term performance of MSE walls, reporting that experience is valuable in determining current practices and realizing the objectives of this synthesis project. If you have any questions, please contact our principal investigator, Travis M. Gerber (email: tgerber@byu.edu; phone: 801.422.1349). Any supporting materials can be sent directly to Dr. Gerber by e-mail or at the postal address shown at the end of the survey.

Confidentiality: All answers provided by survey respondents will be treated as confidential and aggregated with other responses in the reporting. Survey respondents will receive a link to the synthesis report when it is published.

SURVEY/QUESTIONNAIRE INSTRUCTIONS

To view and print the entire questionnaire, Click on this link, and print using "control p".
To save your partial answers, or to forward a partially completed questionnaire to another party, click on the "Save and Continue Later" link in the upper right hand corner of your screen. A link to the partial survey will be e-mailed to you or a colleague.
To view and print your answers before submitting the survey, click forward to the page following question K1. Print using "control p".
To submit the survey, click on "Submit" on the last page.

The following definitions are used in this questionnaire:

- MSE wall: Retaining walls which rely on internal reinforcement for stability. The reinforcement can be either metallic strips or meshes, or geosynthetic fabrics or grids. Soil nail or anchor walls are not considered to be MSE walls for the purposes of this Synthesis.

- Panel MSE wall: Either one- or two-stage MSE walls that having concrete facing panels; internal soil reinforcement is usually metallic

- One stage MSE wall: A MSE wall which uses a concrete panel attached to the internal reinforcement to retain the backfill

- Two-stage MSE wall: A MSE wall which uses a metallic mesh and geosynthetic liner face attached to the internal reinforcement to retain the backfill. A concrete panel is subsequently attached to the vertical mesh. This wall type is typically used where settlements are expected to be relatively large.

- Block MSE wall: A MSE wall which uses a modular block facing attached to the internal soil reinforcement; also referred to as a segmental block wall and the reinforcement is often geosynthetic.

Please enter the date (MM/DD/YYYY). (Required)

Please enter your contact information.

First Name (Required)

Last Name (Required)

Title (Required)

Agency/Organization (Required)

Street Address (Required)

Suite

NCHRP Synthesis Survey: Long-term Performance of Mechanically Stabilized Earth (MSE) Walls

City (Required)

State (Required)

Zip Code (Required)

Country (Required)

Email Address (Required)

Phone Number (Required)

Do You Have an MSE Wall Inventory?

1. A1. Who in your agency typically has responsible charge for MSE walls once the walls are constructed and accepted? (select most representative response) (Required)

- A. Structural engineer(s) or similar at an agency-wide level
- B. Structural engineer(s) or similar at a regional or district level
- C. Geotechnical engineer or similar at an agency-wide level
- D. Geotechnical engineer(s) or similar at a regional or district level
- E. Maintenance engineer or similar at an agency-wide level
- F. Maintenance engineer(s) or similar at a regional or district level
- G. No one has this charge
- H. Other (specify [don't forget to select button at left when entering response in following text box])

2. A2. Does you agency maintain an inventory of your MSE walls? (select most representative response) (Required)

- A. No
- B. Yes
- C. Yes, but inventory is limited to (specify limitation such as specific geographic areas, wall types, etc [don't forget to select button at left when entering response in following text box]):

NCHRP Synthesis Survey: Long-term Performance of Mechanically Stabilized Earth (MSE) Walls

Aspects of Your MSE Wall Inventory

3. B1. What types of permanent MSE walls does your agency include in your inventory? (select as many as applicable) (Required)

- ☐ A. One-stage panel walls
- ☐ B. Two-stage panel walls
- ☐ C. Block walls

4. B2. What criteria OR partial criteria does your agency use to determine what MSE walls to include in your inventory? (select as many as applicable)

- ☐ A. Wall owned by my agency
- ☐ B. Walls owned by others but adjacent to facilities for which my agency is responsible
- ☐ C. Wall owned by others but may negatively impact adjacent facilities for which my agency is responsible
- ☐ D. Wall is associated with a bridge structure
- ☐ E. Wall is associated with a culvert
- ☐ F. Walls is not associated with a bridge or culvert
- ☐ G. Minimum wall height (specify height, in meters [don't forget to select checkbox at left when entering response in following text box])
- ☐ H. Minimum height of retained earth (specify height, in meters [don't forget to select checkbox at left when entering response in following text box])
- ☐ I. Minimum wall length (specify length, in meters [don't forget to select checkbox at left when entering response in following text box])
- ☐ J. Minimum wall area (specify area, in square meters [don't forget to select checkbox at left when entering response in following text box])
- ☐ K. Other (specify [don't forget to select checkbox at left when entering response in following text box])

5. B3. Approximately how many MSE walls does your agency have? (indicate number)

6. B4. Approximately what percentage of the MSE walls that your agency has, which also satisfy your previously identified inclusion criteria, are currently in your inventory database? (indicate percentage, expressed as a decimal)

Type of Information in Your MSE Wall Inventory

7. C1. What types of data does your agency generally collect or maintain in your inventory for each MSE wall? (select as many as applicable)

- ☐ Aa. Location by Street Address
- ☐ Ab. Location by Lat / Long
- ☐ Ac. Location by Route, Milepost
- ☐ Ad. Location by State Plane Coordinates
- ☐ B. Wall Type
- ☐ C. Wall Function
- ☐ Da. Wall Geometrics - Max Wall Height
- ☐ Db. Wall Geometrics - Average Wall Height
- ☐ Dc. Wall Geometrics - Wall Length
- ☐ Dd. Wall Geometrics - Slope in Front of Wall
- ☐ De. Wall Geometrics - Slope Behind Wall
- ☐ Df. Wall Geometrics - Road/traffic offset
- ☐ E. Date Constructed
- ☐ F. Manufacturer
- ☐ G. Contractor / Installer
- ☐ H. Reinforcement Type
- ☐ Ia. Drainage Conditions - Proximity of external water sources (e.g., river, sprinklers, etc)
- ☐ Ib. Drainage Conditions - Location and condition of drainage discharge points
- ☐ J. Nature of adjacent facilities owned by agency
- ☐ K. Nature of adjacent facilities or utilities owned by others (e.g., railroad)
- ☐ L. Characterization of adjacent roadway traffic
- ☐ M. Design Data
- ☐ Na. Construction Data - Plans
- ☐ Nb. Construction Data - Specifications
- ☐ Nc. Construction Data - Shop drawings / submittals
- ☐ Nd. Construction Data - Inspection documentation
- ☐ Ne. Construction Data - As-builts
- ☐ O. Post-construction modifications
- ☐ P. Photographs
- ☐ Qa. Condition of Structure - External inspection data (components to be specified in a subsequent survey question)
- ☐ Qb. Condition of Structure - Internal inspection data (e.g., corrosion / degradation assessment)
- ☐ R. Maintenance activities
- ☐ S. Other (specify [don't forget to select button at left when entering response in following text box])

Asset Management System (AMS) User and Tools

8. D1. Who in your agency principally manages/maintains your inventory of MSE walls? (select most representative response) (Required)
- A. Structural engineer(s) or similar at an agency-wide level
- B. Structural engineer(s) or similar at a regional or district level
- C. Geotechnical engineer or similar at an agency-wide level
- D. Geotechnical engineer(s) or similar at a regional or district level
- E. Maintenance engineer or similar at an agency-wide level
- F. Maintenance engineer(s) or similar at a regional or district level
- G. Other (specify [don't forget to select button at left when entering response in following text box])

9. D2. What primary tool does this person use as an asset management system (AMS) for your MSE wall inventory? (select most representative response) (Required)
- A. File boxes/cabinets
- B. Spreadsheet
- C. MS Access database without GIS support
- D. Oracle database without GIS support
- E. PONTIS
- F. Other non-GIS supported database (specify [don't forget to select button at left when entering response in following text box])
- G. GIS-based software (specify [don't forget to select button at left when entering response in following text box])

Aspects of MSE Wall Monitoring

10. E1. Which of the following statements best describes your agency's MSE wall performance monitoring activities? (select most representative response) (Required)
- A. Reactive to reported incidents of adverse performance
- B. Irregular inspection/assessment of some MSE walls
- C. Regular inspection/assessment of some MSE walls
- D. Irregular inspection/assessment of most or all walls in inventory
- E. Regular inspection/assessment of most or all walls in inventory

Aspects of MSE Wall Monitoring - Features and Conditions

11. E2. What MSE wall features and/or conditions does your agency assess as part of your monitoring? (select as many as applicable)

- ☐ A. Wall plumbness
- ☐ B. Bulging or distortion of wall facing
- ☐ C. Alignment and spacing of joints between facing elements
- ☐ D. Cracking of facing elements
- ☐ E. Damage to corners of facing elements
- ☐ F. Damage from vehicular impact
- ☐ G. Settlement along line of wall
- ☐ H. Settlement behind wall
- ☐ I. Distress in ground or pavement in front of wall
- ☐ J. Distress in ground or pavement behind wall
- ☐ K. Displacement of coping or parapet
- ☐ L. Rust stains or other external evidence of corrosion
- ☐ M. Functionality of drainage/catch basin
- ☐ N. Functionality of internal drainage features (e.g., weepholes and piping)
- ☐ O. External erosion
- ☐ P. Internal erosion of backfill
- ☐ Q. Changes to wall geometry (e.g., excavation at toe, addition of surcharge load)
- ☐ R. Vegetation growth
- ☐ S. Internal corrosion / degradation of reinforcement
- ☐ T. Other (specify [don't forget to select checkbox at left when entering response in following text box])

12. E3. For internal reinforcement, what methods of corrosion / degradation assessment does your agency generally use? (select as many as applicable [don't forget to select checkbox at left when entering response in following text box])

- ☐ A. Do not currently assess
- ☐ B. Linear polarization resistance (LPR) for metallic (specify assessment interval)
- ☐ C. Extractible coupons for metallic (specify assessment interval)
- ☐ D. Exhumation for geosynthetic (specify assessment interval)
- ☐ E. Other (specify)

Reinforcement Monitoring Site Description/Criteria

13. E4. Explain the nature and criteria your agency uses for establishing corrosion/degradation monitoring sites.

Approaches Developed to Improve MSE Wall Performance

14. F1. Besides monitoring, what particular approach(es) has your agency developed/implemented to improve the long-term performance of MSE walls? (select as many as applicable [don't forget to select checkbox at left when entering response in following text box])

- ☐ A. Regularly scheduled cleanout/maintenance of catch basins (please elaborate)
- ☐ B. Different requirements for backfill immediately behind wall face as compared to remainder of reinforced backfill (please elaborate)
- ☐ C. Developed special drainage details at ends of MSE walls (please elaborate)
- ☐ D. Developed special drainage details behind MSE walls (please elaborate)
- ☐ E. Specified vertical and horizontal distances for discharge points and water sources (please elaborate)
- ☐ F. Increased wall embedment (please elaborate)
- ☐ G. Other design specifications (please elaborate)
- ☐ H. Contractor/installer qualifications (please elaborate)
- ☐ I. Construction inspection (please elaborate)
- ☐ J. Post-construction inspection (please elaborate)
- ☐ K. Other (specify)

Specific Assessment Methodology for MSE Wall Performance

15. G1. Does your agency have a specific methodology for assessing long-term performance of existing MSE walls? Please explain the methodology in the text box below (consider using cut/ paste); alternatively, use the next query to attach an external file and leave the following text box blank.

17. G2. Does your agency have a specific methodology for assessing risk from adverse, long-term performance of MSE walls? If so, identify which of the following features are part of your methodology (select as many as applicable). Please use the next query to attach any pertinent file.

- ☐ A. Do not have specific methodology
- ☐ B. Quantitative assessment of failure potential
- ☐ C. Qualitative assessment of failure potential
- ☐ D. Quantitative assessment of life-safety impacts
- ☐ E. Qualitative assessment of life-safety impacts
- ☐ F. Quantitative assessment of economic loss of service costs
- ☐ G. Qualitative assessment of economic loss of service costs
- ☐ H. Quantitative assessment of economic repair/remediation costs
- ☐ I. Qualitative assessment of economic repair/remediation costs
- ☐ J. Explicit use of wall geometrics
- ☐ K. Explicit use of inspection or wall condition data
- ☐ L. Explicit use of wall age
- ☐ M. Explicit use of MSE wall type
- ☐ N. Largely based on subjective judgment with limited input from asset management system (AMS)

Causal Features and Conditions Affecting MSE Wall Performance

19. H1. How important do you think that each of the following wall features/conditions are in assessing the long-term performance of MSE walls?

		Not important (1)	Mildly important (2)	Moderately important (3)	Very important (4)	Most important (5)
A.	Wall type					
B.	Maximum wall height					
C.	Average wall height					
D.	Wall length					
E.	Slope in front of wall					
F.	Slope behind wall					
G.	Presence of bench at toe of wall founded on slope					
H.	Embedment of wall					
I.	Road/traffic offset					
J.	Date constructed					
K.	Manufacturer					
L.	Reinforcement type					
M.	Post-construction modifications					
N.	Drainage conditions					
O.	Proximity of external water sources (e.g., river, sprinklers, etc)					
P.	Location and condition of drainage discharge points					
Q.	Wall plumbness					
R.	Bulging or distortion of wall facing					
S.	Alignment and spacing of joints between facing elements					
T.	Cracking of facing elements					
U.	Damage to corners of facing elements					
V.	Damage from vehicular impact					
W.	Settlement along line of wall					
X.	Settlement behind wall					
Y.	Distress in ground or pavement in front of wall					
Z.	Distress in ground or pavement behind wall					
AA.	Displacement of coping or parapet					
AB.	Rust stains or other external evidence of corrosion					
AC.	Functionality of drainage/catch basins					
AD.	Functionality of internal drainage features (e.g., weepholes and piping)					
AE.	External erosion					
AF.	Internal erosion of backfill					
AG.	Changes to wall geometry (e.g., excavation at toe, addition of surcharge load)					
AH.	Vegetation growth					
AI.	Internal corrosion / degradation of reinforcement					

NCHRP Synthesis Survey: Long-term Performance of Mechanically Stabilized Earth (MSE) Walls

Distress Mechanisms for MSE Walls

20. I1. How significant do you think each of the following potential failure/distress modes are relative to the long-term performance of MSE walls?

	Not significant (1)	Mildly significant (2)	Moderately significant (3)	Very significant (4)	Most significant (5)
A. Facing failure	○	○	○	○	○
B. Reinforcement rupture	○	○	○	○	○
C. Reinforcement pullout	○	○	○	○	○
D. Sliding	○	○	○	○	○
E. Overturning	○	○	○	○	○
F. Loss of foundation support due to erosion	○	○	○	○	○
G. Loss of foundation support to bearing capacity failure	○	○	○	○	○
H. Global stability	○	○	○	○	○
I. Excessive settlement	○	○	○	○	○

Lesson Learned

21. J1. In your opinion, what is the most significant "lesson learned" by your agency with respect to the long-term performance of MSE walls? If desired, use the next query to attach an external file and leave the following text box blank.

Additional Person to Contact

23. K1. Is there someone else within your agency that we should contact for additional information relative to this synthesis topic? (Required)

○ No
○ Yes

NCHRP Synthesis Survey: Long-term Performance of Mechanically Stabilized Earth (MSE) Walls

Additional Person to Contact - Details

Complete this section only if: "K1. Is there someone else within your agency that we should contact for additional information relative to this synthesis topic?" matches: 'Y'

24. K1a. Please provide contact information for another individual in your agency who might be able to provide additional information relative to the completion of this survey.

First Name

Last Name

Title

Company Name

Street Address

Apt/Suite/Office

City

State

Postal Code

Country

Email Address

Phone Number

APPENDIX B

List of Survey Respondents

SURVEY RESPONDENTS (BY INDIVIDUAL)

Ahmad, Ken; Foundation Engineer; Ontario, Ministry of Transportation (Ontario, Canada)
Annable, Jonathan; Assistant Division Head—Materials; Arkansas State Highway and Transportation Department (Arkansas)
Arndorfer, Robert; Foundation and Pavement Engineering Supervisor; Wisconsin DOT (Wisconsin)
Bart, Bradley; Kentucky Transportation Cabinet (Kentucky)
Benda, Christopher; Soils and Foundations Engineer; Vermont Agency of Transportation (Vermont)
Brennan, James; Assistant Geotechnical Engineer; Kansas DOT (Kansas)
Buu, Tri; Geotechnical Engineer; Idaho Transportation Department (Idaho)
Chlak, Byron; Bridge Preservation Specialist; Alberta Transportation (Alberta, Canada)
Connors, Peter; Geotechnical Engineer; Massachusetts DOT (Massachusetts)
Davis, Kaye; Geotechnical Engineer; Alabama DOT (Alabama)
Dickson, Todd; Civil Engineer 2; New York State DOT Geotechnical Engineering Bureau (New York)
Dusseault, Chuck; Geotechnical Section Chief; New Hampshire DOT (New Hampshire)
Endres, Richard; Supervising Engineer of Geotechnical Services; Michigan DOT (Michigan)
Falk, Mark; Assistant Chief Engineering Geologist; Wyoming DOT (Wyoming)
Fisher, James; Lab Coordinator; West Virginia DOT (West Virginia)
Fontaine, Leo; Transportation Principal Engineer; Connecticut DOT (Connecticut)
Griese, Kevin; Geotechnical Engineer; South Dakota DOT (South Dakota)
Griswell, Kathryn; Earth Retaining Systems Specialist; Caltrans (California)
Guido, Jonathan; Senior Geotechnical Engineer; Oregon DOT (Oregon)
Higbee, Jim; Geotechnical Engineer; Utah DOT (Utah)
Hoyt, James; Assistant Director Materials Research and Environment; New Brunswick DOT (New Brunswick, Canada)
Hunter, Brian; Chemical Testing Engineer; North Carolina DOT Materials and Tests (North Carolina)
Jackson, Jeff; Geotechnical Engineer; Montana DOT (Montana)
Ketterling, Jon; NDDOT Geotechnical Engineer; North Dakota DOT (North Dakota)
Kramer, Bill; Foundations Engineer; Illinois DOT (Illinois)
Krusinski, Laura; Senior Geotechnical Engineer; Maine DOT (Maine)
Lawler, Ashton; State Program Manager for Geotechnical Design of Structures; Virginia DOT (Virginia)
Lindemann, Mark; Soil Mechanics Engineer; Nebraska Department of Roads (Nebraska)
MacAskill, Wayne; Contract Administrator; Nova Scotia Transportation and Infrastructure Renewal (Nova Scotia, Canada)
Marcus, Galvan; State Geotechnical Engineer; Texas DOT (Texas)
McLain, Kevin; Geotechnical Engineer; Missouri DOT (Missouri)
Meyers, Robert; NMDOT State Geotechnical Engineer; New Mexico DOT (New Mexico)
Nelson, Blake; Geotechnologies Engineer; Minnesota DOT (Minnesota)
Oliver, Len; Civil Engineering Manager 2; Tennessee DOT (Tennessee)
Romero, Ricardo; Acting Chief, Soils Engineering Office; Puerto Rico Highway Authority (Puerto Rico)
Salazar, John; Chief Geotechnical Engineer; Nevada DOT—Materials Division~Geotechnical Engineering Branch (Nevada)
Scruggs, Thomas; State Geotechnical Engineer; Georgia DOT (Georgia)
Sizemore, Jeff; Geotechnical Design Support Engineer; South Carolina DOT (South Carolina)
Smadi, Malek; Supervisor, Geotechnical Operations; Indiana DOT (Indiana)
Stanley, Robert; Soils Design Engineer; Iowa DOT (Iowa)
Tsai, Ching; Senior Geotechnical Specialist; Louisiana Department of Transportation and Development (Louisiana)
Wang, Trever; Supervising Professional Engineer; Colorado DOT (Colorado)
Wetz, Norman; Geotechnical Design Engineer; Arizona DOT (Arizona)
Yea, Howard; Director, Bridge Standards; Saskatchewan Ministry of Highways and Infrastructure (Saskatchewan, Canada)

SURVEY RESPONDENTS (BY AGENCY LOCATION)

Alabama
Arizona
Arkansas
California
Colorado
Connecticut
Georgia
Idaho
Illinois
Indiana
Iowa
Kansas
Kentucky
Louisiana
Maine
Massachusetts
Michigan
Minnesota

Missouri
Montana
Nebraska
Nevada
New Hampshire
New Mexico
New York
North Carolina
North Dakota
Oregon
Puerto Rico
South Carolina
South Dakota
Tennessee
Texas
Utah
Vermont
Virginia
West Virginia
Wisconsin
Wyoming
Alberta, Canada
New Brunswick, Canada
Nova Scotia, Canada
Ontario, Canada
Saskatchewan, Canada

APPENDIX C

"Most Signficant Lesson(s) Learned" as Reported by Agencies

- "Use the right technology for the right application. For example, consider need and possibility to achieve various settlement/rigidity constraints and match service level to appropriate cost for application."
- "Providing a sound and firm foundation for support of the wall; and providing proper drainage within the wall system and adjacent to the wall geometry."
- "Performance depends on quality of construction and quality of retained backfill materials."
- "Make sure the contractor is using the specified reinforced fill material and is constructing according to plans."
- "By having a formal wall approval process we have limited the use of modular block wall systems and the deterioration of these facing elements due to deicing chemicals."
- "The systems can last forever but must be designed and built correctly."
- "Electrochemical property requirements for backfill material were not specified for one wall built in the late 70s. As a result, the wall failed due to corrosion of the steel reinforcements when it was about 25 years old."
- "You need to have an inventory and know where all the walls are that you own."
- "For the most part, NYSDOT has had very few problems with MSE Structures. We do know that great care must be taken in constructing these structures. If you start wrong in the beginning you'll always be seeing problems in the walls."
- "The inadequate durability of modular block MSE wall facings in locations affected by winter roadway salt application."
- "Prevent surface runoff or other external water sources from inundating reinforced zone."
- "I think we are so conservative in our designs that we have not had any problems with our long term stability of our MSE walls."
- "This is an issue which has not been addressed by the agency."
- "Lesson(s) learned—'The outside may get ugly—it's the inside that matters.' We had an MSE ride a landslide downslope 32 ft back in the 1970's. It deformed significantly, but is still in service today. We have had several lose foundation support. But as long as they were able to move and readjust the stresses through deformation, with no loss of backfill, they have all been able to stay in service, some for decades. However, excessive consolidation settlement and internal drainage failures have lead to issues with cavities and retainment loss. These MSE failed within months and had to be replaced. Amazing[ly] flexible, but only up to a limit. It's what's inside that counts."
- "Quality of construction. Drainage, drainage, drainage (including erosion). Corrosion of metallic reinforcement."
- "Ensure corrosion monitor readings are performed at a regular inspection rate. If a failure occurs then notify appropriate subsection."
- "We don't have a lot of MSE walls relative to other states, so this question is difficult to answer. We have not had problems that I am aware of with our MSE walls."
- "Put tight requirements on the modular blocks. Make sure the wall is well drained internally and externally."
- "So far have performed very well."
- "Proper drainage within the wall and proper external drainage behind and in front of the wall."
- "Use of fine-grained select fill has resulted in the migration of material out from behind walls. We have thousands of square foot of wall that was backfilled with this type of material. Many walls have shown distress as a result. We have coarsened up the gradation of select fill to lessen the potential of fill migration."
- "We have had some failures and problems that have shown the need for an assessment, inventory, and inspection program."
- "Drainage, drainage, drainage."
- "W-a-t-e-r: from any and all directions and sources."
- "Following proper construction procedures and following material specifications."
- "Performing and adequate geotechnical subsurface investigation."
- "Settlement."
- "Investigate and address identified problems quickly."
- "The recognition that most MSE wall problems are almost always related to a combination of deficiencies, hardly ever just one single issue. The 'devil is always in the details,' so to speak. It is important to keep in mind that most walls are categorized as a Series Engineering System, as opposed to a Parallel Engineering System with respect to external and global stability considerations. Using 'averaged' shear strengths along a Linear/Series Wall System can actually cause a real stability failure within a known weak design reach . . . as the weakest link will most assuredly show up as a stability issue on any shallow wall foundation. There is typically no benefit from a redundant parallel system as in most other structure types. Also, we have learned the hard way that MSE Wall reinforcing details around obstructions must be identified early-on in the design phase, as it is always a hassle to deal with during construction. And last, but certainly not the least, wall drainage is a huge component in any MSE Wall project, both during construction and throughout the lifetime of the structure. In summary . . . external/global stability, internal reinforcing details and drainage should be high on any engineer's checklist of important considerations necessary for the successful performance of any MSE Wall Project."
- "Freeze and thaw of block wall, surface run-off seep into the wall."
- "Improve Specifications, Approved Products List, Inspector and contractor training."

- "[Our agency] has been using MSE walls for over 30 years with great success. Our only problems have been poor construction practices which are found and corrected before walls are accepted from the Contractor. We attribute our success to good geotechnical design, quality backfill required and only using pre-approved walls systems that meet AASHTO requirements."
- "To make sure the ends of the wall where the access trails to build the wall are properly compacted."
- "We have to get beyond our reactive mentality and be proactive in monitoring these walls."
- "None of our installations have reached an age where failure would be anticipated. To date, no significant performance issues have been identified."
- "[. . . N]eed to model to predict the life of the reinforcement."
- "Performance of nearby drainage culverts can have significant impacts on wall performance. In our case, a collapsed culvert resulted in local groundwater table above the height of the wall. Other lessons: the bench at the base of the MSE wall is important to maintain."

APPENDIX D

Research Problem Statement

PROBLEM TITLE

Prediction of Remaining Service Life for Mechanically Stabilized Earth (MSE) Walls

RESEARCH PROBLEM STATEMENT

There are an estimated 16.3 million square meters of various types of walls along the nation's highways (DiMaggio 2008), with an average of 850,000 square meters of mechanically stabilized earth (MSE) wall with precast facing now being built each year in the United States at a cost of $160 to $650 per square meter (Elias et al. 2004; Berg et al. 2009). However, unlike bridges and pavements, MSE walls and retaining walls in general are often overlooked as assets. While the U.S. federal government has fostered the development of the National Bridge Inventory System (NBIS) that involves inspection of the nation's bridges every two years, there is no existing, dedicated management system addressing the whole of the nation's retaining walls, MSE or otherwise. The long-term performance of MSE walls depends on various factors, and unfortunately there have been instances of adverse performance. Like every important class of assets, MSE walls need periodic inspection, assessment, and management. To date, some states have established MSE wall monitoring programs, while several others are looking for guidance, tools, and funding to establish their own monitoring program (Gerber 2012).

During the development of NCHRP Project 20-05, Synthesis Topic 42-05, Assessing the Long-Term Performance of Mechanically Stabilized Earth (MSE) Walls, it was determined that less than a quarter of state-level transportation agencies in the United States have developed some type of MSE wall inventory beyond that which may be captured as part of their bridge inventories (Gerber 2012). Fewer still have the methods and means to populate their inventories with data from ongoing inspections from which assessments of wall performance could be made. The synthesis project determined that in order to "move beyond current inventorying activities and the data baselines now being established, repeated observations and performance predictions will be needed, as will rational decision-making methodologies" (Gerber 2012). To make this leap in asset management practice, research relative to the following topics is needed:

- "Improved ability to evaluate the integrity of existing MSE reinforcement systems using methods that are economically and logistically effective.
- Standards for performance data baselines and data collection activities.
- Predictive models for remaining MSE wall service life.
- Methods of risk assessment specifically for MSE walls and more generally for various types of retaining walls."

LITERATURE SEARCH SUMMARY

As part of NCHRP Project 20-07, Task 259, Brutus and Tauber (2009), concluded that there was/is no data or methods available in technical literature for the estimation of design/service life of existing retaining walls. Based on a survey of transportation agencies, a similar conclusion was reached by Gerber (2012)—no transportation agency currently has a well-established methodology for predicting future MSE wall performance or remaining design life. Certainly some agencies are monitoring corrosion in some walls (see Fishman and Withiam 2011), but a systematic procedure for determining remaining wall life with consideration of all other parameters believed to be important to performance (such as drainage) was not identified. Additionally, methods for risk assessment for MSE walls were found to largely be absent, although nascent efforts can be found in work reported by Bernhardt et al. (2003), Bay et al. (2009), and DeMarco et al. (2010). Consequently both methods for design life prediction and risk assessment are needed. Also needed are well-developed tools for gathering wall performance data that will be needed as input and/or calibration parameters for such methods. Again, some efforts in the area are underway (see Fishman and Withiam 2011 regarding corrosion monitoring, Lostumbo and Artieres 2011 regarding in-situ stress monitoring of reinforcement), but greater progress is needed. Recent technological advances in structural health monitoring present promising avenues of research and progress in asset management.

References

Bay, J.A., L.R. Anderson, T.M. Gerber, and R.B. Maw, *An Inspection, Assessment, and Database of UDOT MSE Walls,* Report Number UT- 09.21, Utah Department of Transportation, Salt Lake City, 2009.

Berg, R.R., B.R. Christopher, and N.C. Samtani, *Design of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes*, Volume 1, Report FHWA-NHI-10-024, Federal Highway Administration, Washington, D.C., 2009, 306 pp.

Bernhardt, K.L.S., J.E. Loehr, and D. Huaco, "Asset Management Framework for Geotechnical Infrastructure," *Journal of Infrastructure Systems*, Vol. 9, No. 3, 2003, pp. 107–116.

Brutus, O. and G. Tauber, *Guide to Asset Management of Earth Retaining Structures*, prepared as part of NCHRP Project 20-07, Task 259, Transportation Research Board of the National Academies, Washington, D.C., Oct. 2009, 120 pp.

DeMarco, M.J., R.J. Barrows, and S. Lewis, "NPS Retaining Wall Inventory and Assessment Program (WIP): 3,500 Walls Later," *Proceeding of Earth Retention Conference 3,* Bellevue, Wash., Aug. 1–4, 2010a, pp. 870–877.

DiMaggio, J.A., "Geotechnical Engineering Assets and Liabilities on Surface Transportation Facilities," presented at National Workshop on Highway Asset Management and Data Collection, Durham, N.C., Sep. 25, 2008.

Elias, V., J. Welsh, J. Warren, R. Lukas, J.G. Collin, and R.R. Berg, Ground Improvement Methods, Participant Notebook, NHI Course 132034, FHWA NHI-04-001, National Highway Institute, Federal Highway Administration, Washington, D.C., 2004, 1,022 pp.

Fishman, K.L. and J.L.Withiam, *NCHRP Report 675: LRFD Metal Loss and Service-Life Strength Reduction Factors for Metal-Reinforced Systems*, Transportation Research Board of the National Academies, Washington, D.C., 2011, 116 pp.

Gerber, T.M., Assessing the Long-term Performance of Mechanically Stabilized Earth (MSE) Walls, NCHRP Project 20-05, Synthesis Topic 42-05, Transportation Research Board of the National Academies, Washington, D.C., 2012.

Lostumbo, J.M. and O. Artieres, "Geosynthetic Enabled with Fiber Optic Sensors for MSE Bridge Abutment Supporting Shallow Bridge Foundations," *Proceedings of GeoFrontiers 2011*, Dallas, Tex., Mar. 13–16, 2011, pp. 3497–3504.

RESEARCH OBJECTIVE

The primary objective of this research effort is to establish a methodology for predicting the remaining service life of MSE walls. To meet this objective, the following tasks are proposed.

Task 1: Review literature for information regarding methods for predicting service life of engineered structures other than retaining walls (such as pavements and bridges). From this review, identify key parameters and/or approach concepts that can be applied to MSE walls. Also part of this task will be the collection of case history data for subsequent calibration and verification activities.

Task 2: Develop an initial methodology based on the results of Task 1. While corrosion rate is anticipated to play a major role in the method, other parameters such as drainage are also anticipated to be important. It is anticipated that the method will tie wall features and performance observations to particular distress mechanisms. Because of this, particular consideration will be given to the nature and robustness of the analytical model's input parameters. The parameters selected for the model will influence future standards for MSE wall performance data baselines and data collection activities.

Task 3: Apply the method in order to both calibrate and verify it against case histories and/or known performance data for particular groups of MSE walls. It is recognized that a rigorous assessment of the method's predictive ability by comparison with existing wall inventories will be limited by the availability of performance data as well as the ages of walls in our existing MSE wall inventories.

Task 4: Publish and disseminate results.

ESTIMATE OF PROBLEM FUNDING AND RESEARCH PERIOD

Recommended Funding:

$XXX,XXX.XX

Research Period:

XX Months

URGENCY, PAYOFF POTENTIAL, AND IMPLEMENTATION

MSE walls are being constructed at an ever-increasing rate. The oldest walls in the U.S. inventory are about 40 years old, and most walls have an intended design life of 75 to 100 years. However, the age-related performance of the technology has not been fully assessed, and more instances of adverse performance are expected with time. Some agencies are now gathering performance data, but predictive models for remaining MSE wall service life are needed so that appropriate management and maintenance and/or replacement decisions can be made. The initial availability of predictive tools would assist agencies in determining whether and/or how much to invest in MSE wall inventory and assessment systems. By facilitating broader participation and greater consistency in methods and practice, greater improvements in asset management and service-life predictive models will be realized. Without the initial investment represented by this development of a remaining service life model, needed progress will continue to go unrealized.

APPENDIX E

EXAMPLES OF EXISTING METHODOLOGY AND TOOLS DEVELOPED AND PROVIDED BY AGENCIES

Materials from FHWA's Wall Inventory Program

Field Inspection Form (Front Page)

-NPS RETAINING WALL INVENTORY PROGRAM (WIP) FIELD FORM-

NPS Park Name		Route/Parking No.		Wall Start Milepoint	
Inspected By		Route/Parking Name		Wall End Milepoint	
Inspection Date		Side of Centerline	(R/L/P# #)	Visidata Event Milepoint	

WALL FUNCTION, DIMENSIONS, and DESCRIPTION

Wall Function		Primary Wall Type		Architectural Facings	
Approx. Year Built		Secondary Wall Types		Surface Treatments	

Wall General Description Notes: *(e.g., wall purpose, setting, construction, consequence of failure, special design, etc.)*

Wall Length (ft)		Wall Face Area (ft²)		Wall Start Offset (ft)	
Max. Wall Height (ft)		Vertical Offset (+/- ft)		Wall End Offset (ft)	

Photo Description/No. *(e.g., approach, elevation, wall top, alignment, face detail, deficiencies, etc.)*

Face Angle (deg)	

Park Designated Wall ID	

REPAIR /REPLACE RECOMMENDATIONS AND WORK ORDER

Wall Condition Rating		Design Criteria		Failure Consequence	
Investigation Req'd?	(Y/N)	Cultural Concern?	(Y/N)	Action	

Brief Work Order Description *(5-10 word maximum, key work elements)*

Repair/Replace Recommendations *(itemized description of wall repairs, methods, estimated quantities, and costs per repair item, including consideration of constructability issues such as access, traffic control, staging, safety hazards, etc.)*

Repair/Replace COST:	

Rev. 07-10-2007

Field Inspection Form (Back Page)

Element	Condition Narrative	Condition Rating x	Weighting Factor =	Condition Score	Data Reliability
Primary Wall Elements					
Piles and Shafts		1-10	8		1-3
Lagging		1-10	8		1-3
Anchor Heads		1-10	8		1-3
Wire/Geosynthetic Facing Elements		1-10	8		1-3
Bin or Crib		1-10	8		1-3
Concrete		1-10	8		1-3
Shotcrete		1-10	8		1-3
Mortar		1-10	8		1-3
Manufactured Block/Brick		1-10	8		1-3
Placed Stone		1-10	8		1-3
Stone Masonry		1-10	8		1-3
Wall Foundation Material		1-10	8		1-3
Other Primary Wall Element		1-10	8		1-3
Secondary Wall Elements (WF=0.5 for CR=8-10/ WF=1.0 for CR=4-7/WF=5 for CR=1-3)					
Wall Drains		1-10	0.5-5		1-3
Architectural Facing		1-10	0.5-5		1-3
Traffic Barrier/Fence		1-10	0.5-5		1-3
Road/Sidewalk/ Shoulder		1-10	0.5-5		1-3
Upslope		1-10	0.5-5		1-3
Downslope		1-10	0.5-5		1-3
Lateral Slope		1-10	0.5-5		1-3
Vegetation		1-10	0.5-5		1-3
Culvert		1-10	0.5-5		1-3
Curb/Berm/Ditch		1-10	0.5-5		1-3
Other Secondary Wall Elements		1-10	0.5-5		1-3
Wall Performance					
Performance		1-10	8		
WALL RATING	Weighting Factor (x10) and Condition Score Totals				
	Wall Condition Rating (= [Condition Score Total/Weighting Factor Total (x10)] X 100)				

Materials from Nebraska Department of Roads

RETAINING WALL INSPECTION MANUAL

NDOR
Nebraska Department of Roads

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Glossary

Coping

The coping is used at the top of the wall panels to provide an aesthetic finish to the wall top. Coping can be cast-in-place or prefabricated.

Geotextile Fabric (Filter)

Geotextile fabric (filter) is used to cover the joints between panels. It is placed on the backside of the wall panels. Fabric keeps soil from moving through the joints while allowing any excess water to drain.

Base Pad

The base pad is a non-reinforced concrete pad used to provide a level, consistent surface at the proper elevation.

Random Backfill

Random backfill is material derived from excavation during construction of the MSE wall.

Select Backfill

Select backfill is fill that meets gradation, corrosion, unit weight, internal friction angle and/or other requirements for a specific MSE wall.

Reinforcement

Soil reinforcement holds the wall facing in position and reinforces the soil directly behind the panels. Soil reinforcement can be strips, grids, or mesh. Reinforcement can be steel (inextensible) or polymers (extensible).

Spacers

Wall panel spacers are typically ribbed elastomeric or polymeric pads. They are inserted between panels to create proper spacing. Proper spacing keeps the panels from having point contact and spawling the concrete. Some walls are constructed without spacers.

Wall Facing Panels

Wall facing panels are used to hold the soil in position at the face of the wall. The panels are typically concrete but they can be metal, wood, block, mesh or other materials.

Introduction

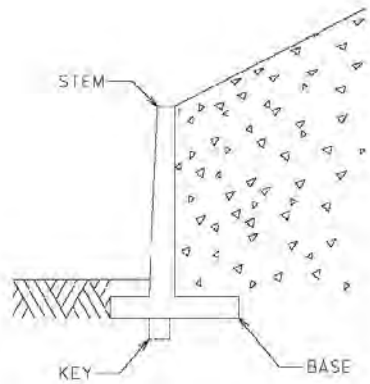
The Nebraska Department of Roads has numerous retaining walls throughout the state. The definition of a retaining wall is a structure designed and constructed to resist the lateral pressure of soil when there is a desired change in ground elevation that exceeds the angle of repose of the soil. Besides the wall itself, key components that determine a wall's performance are the foundation soil (soil below the wall), the soil being retained, drainage of surface water and water in the soil, and any additional loads placed behind the load (such as traffic or buildings). Because over time one or more of these components can change, it can affect how the wall performs. As a result, an inspection program and database has been developed to; 1) locate all of the current retaining walls that are on NDOR right-of-way, 2) inspect the condition of each wall, 3) review wall conditions, and 4) determine if repairs or replacements are needed. This manual is intended to provide guidance on how the walls are located, the inspections of the walls, and procedures for using the database.

Wall Types

There are several types of retaining walls used on NDOR right-of-way. Below is a list of types currently used along with a brief definition and examples of each:

Conventional Cast-in-Place (CIP) Wall

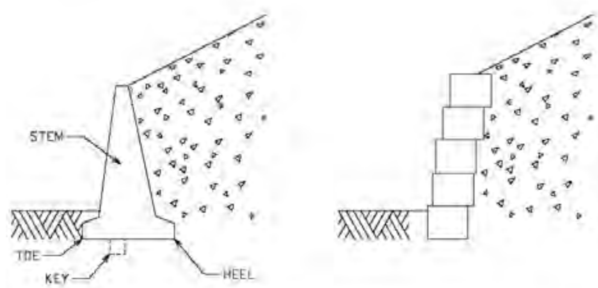
Cast-in-Place walls or cantilever walls are made of reinforced concrete that consists of a thin stem and a base slab and is economically up to heights of 25 feet. A key can be added at the base to resist sliding.



CIP Cantilever Wall

Gravity Wall

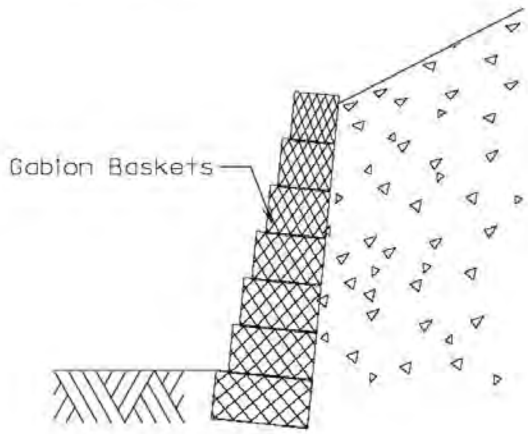
Gravity walls are constructed with plain concrete or stone masonry and rely on their own weight and any soil resting on the wall for stability. Gravity walls are not used in high walls.



Typical Gravity Walls, concrete or block.

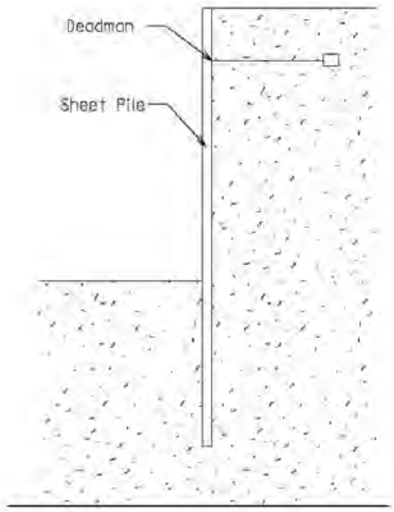
Gabion Walls

Gabion Walls are retaining walls made of rectangular containers (baskets) fabricated of heavily galvanized wire, which are filled with stone and stacked on one another, usually in tiers that step back with the slope rather than vertically. The gabions are essentially designed in the same manner as a gravity wall. Gabions are typically used in water environments such as along streams.



Sheet Pile Walls

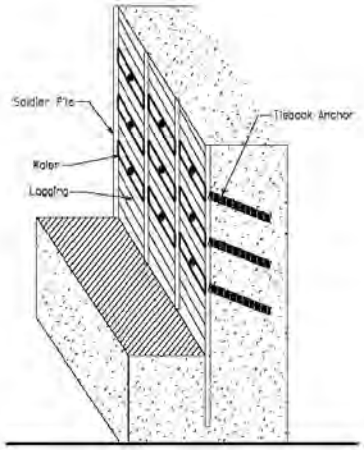
Sheet pile walls are made out of steel, vinyl or wood planks which are driven into the ground and are connected together. Sheet piles are often used for temporary structures or braced cuts, but can be used as permanent structures. Taller sheet pile walls require a tie-back anchor, or "dead-man" placed in the soil a distance behind the face of the wall, that is tied to the wall, usually by a cable or a rod to prevent excessive movement of the top of the wall.



Sheet Pile Wall with Deadman

Soldier Pile Tieback Walls

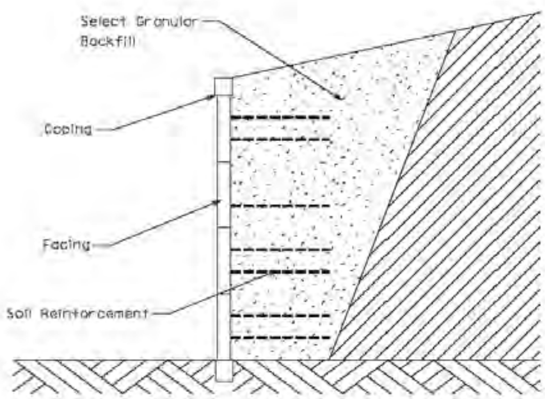
For Soldier Pile Tieback Walls, piles (steel, timber, concrete) are either driven or placed in augured holes along wall lines to the eventual depth of the excavation. If placed in a drilled hole, the piling is lowered into the augured hole and backfilled with concrete. Once the line of soldier piles have been installed, excavation proceeds in lifts, with each level lagged as it is uncovered. The lagging typically consists of hard wood timbers which are placed between the soldier beam spans to support the earth on the unexcavated side of the line. In permanent situations often reinforced concrete is cast-in-place in lieu of timber lagging. The excavation and lagging installation continues downward to depth required. During excavation and lagging operations tiebacks are installed to withstand the horizontal pressures exerted by the surrounding soil. Typically tiebacks are drilled into the surrounding soil or rock, placed, and grouted at angles to withstand these pressures. Tieback rods are placed into the drilled angled holes, then grouted and tested for strength. External whalers or chair anchors are attached to the outside of the soldier pile and lagging wall. The resulting wall forms a secure, open environment for all subsequent foundation operations.



Soldier Pile Tie-back Wall

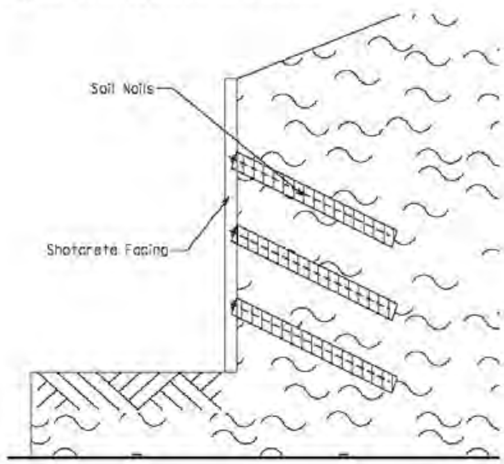
Mechanically Stabilized Earth (MSE) Walls

MSE Walls have become one of the primary walls used on NDOR projects, especially along the interstate and viaducts. MSE Walls incorporate layers of reinforcement materials high in tensile strength within the granular backfill behind the wall, which increases the strength of the backfill materials significantly. The reinforcement can consist of steel strips or mesh, or geosynthetic grid materials. The facing is typically a pre-cast panel or modular block, whose sole purpose is to prevent loss of the granular backfill. The granular backfill used in the reinforcement is called "Select Granular Backfill" and has specific engineering requirements it must meet before it can be approved for use. For further information refer to Section 714 or 715 of the Standard Specifications.



Soil Nail Wall

Soil nailing is a technique in which a retaining wall is reinforced by the insertion of relatively slender steel reinforcing bar. The bars are usually installed into a pre-drilled hole and then grouted into place or drilled and grouted simultaneously and installed at a slight downward inclination. A shotcrete facing or a cast-in-place facing is then constructed over the nail heads. They are similar to a Soldier Pile Tie-back wall, except no piling or lagging is used and the reinforcing bar is not placed in tension.



Inspection

Locating the Desired Wall

The first step in starting the inspection program is identifying all the walls. Each District will be responsible for locating all the walls in each their District. Once a wall is located it will need to be given an identification number, much like that of bridge structures in the state. The first letter of each wall ID will start with the letter "M", followed by a series of numbers that identify the highway, reference post, and the last letter indicates either left (L) or right (R) of the highway when facing in the direction of ascending reference posts. Some walls will not be left or right, as an instance of a viaduct over a railroad. In this instance the last letter will not be given. Even though they are virtually in the same location, each wall will have its own ID number. See the example below for a sample Wall Number:

Retaining Wall ID Numbering Convention

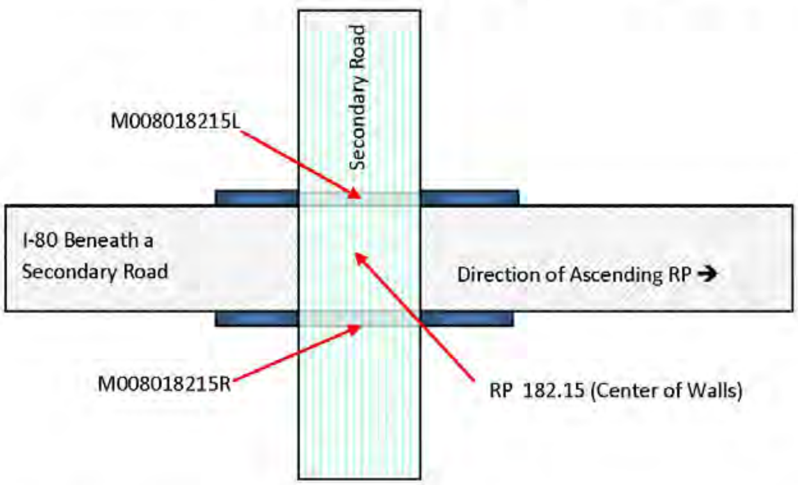
M008018215L

1. 2. 3. 4.

1. Indicates the type of wall present. "M" indicates a MSE wall, while "R" indicates a retaining or gravity wall.
2. Indicates the highway number associated with a specific wall. The MSE wall(s) form(s) one lateral boundary of this highway. Four spaces are required. If the highway number is a 2 digit number, add two "0's" as placeholders before the highway number (as illustrated above for I-80).
3. These five digits indicate the Reference Post location closest to the center of the wall.
4. The last letter is used to designate which side of the highway the wall is located on when the inspector is facing in the direction of ascending reference posts.

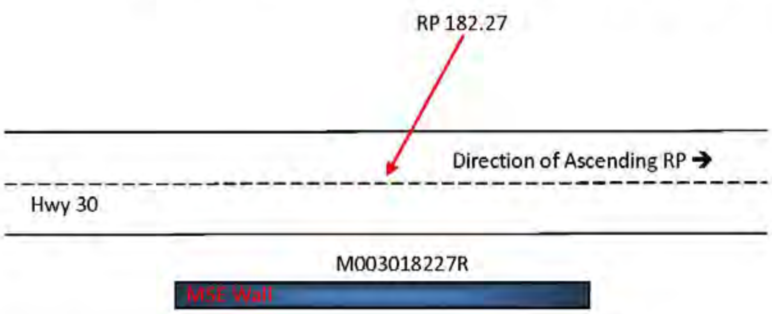
There are many difference scenarios where MSE or retaining walls are present. The following examples describe some of the most common scenarios. Instructions on how to assign ID numbers to specific walls are shown for each scenario.

Scenario 1 - Secondary Road Bridge Over a Highway or Interstate



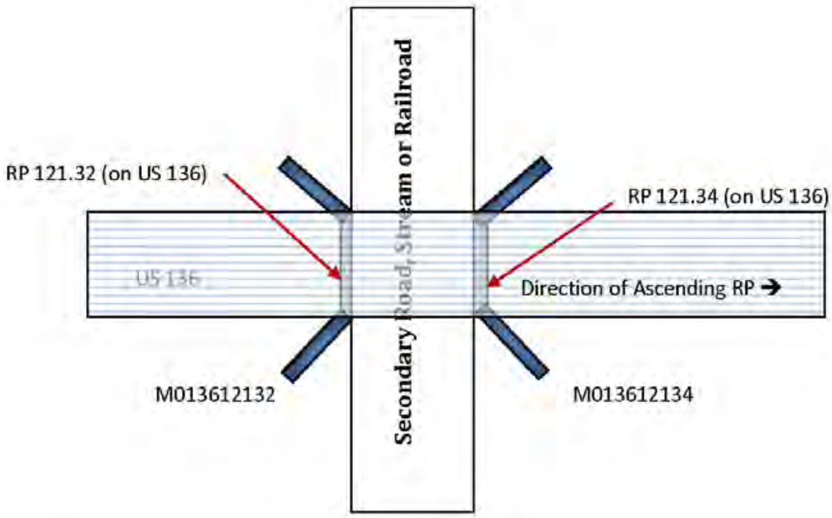
This figure shows a situation where a county bridge passes over an interstate highway. The center of both walls is located at approximately RP 182.15 on Interstate 80. In this situation, the wall identification number is the same, except for the last digit (R or L), which indicates whether the specific wall is to the left or right when facing in the direction of ascending RP numbers.

Scenario 2 – Stand-Alone Wall Along a Highway



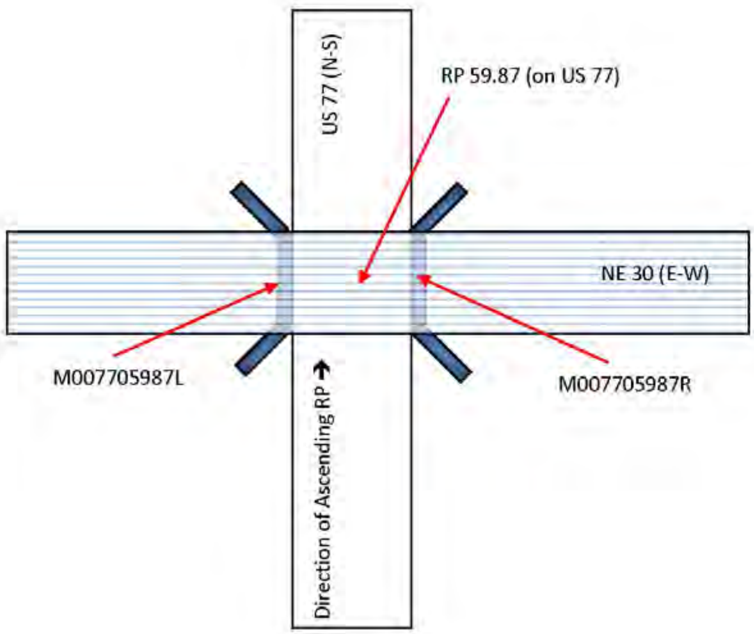
This figure shows a stand-alone wall along one side of a highway. The center of the wall is located nearest RP 182.27 and the wall is to the right when facing in the direction of ascending reference post numbers. If the wall was a retaining wall instead of a MSE wall, the first character would be R in lieu of M and the nomenclature would read R003018227R.

Scenario 3 – Highway Over a Secondary Road, Stream or Railroad



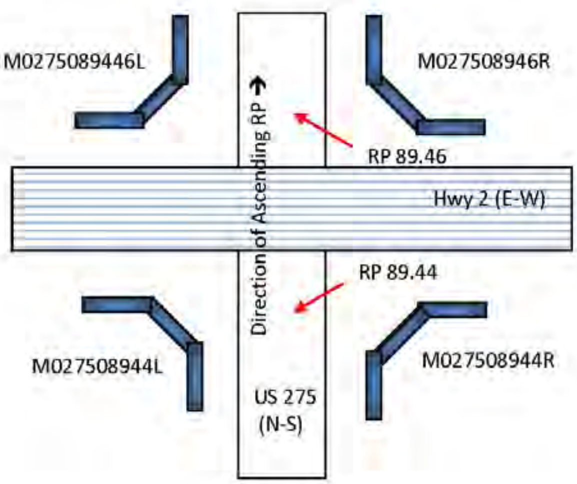
This figure shows a situation where a highway passes over a secondary road, stream or railroad. The center of one wall is located near RP 121.32 (on US 136) while the center of the other wall is located near RP 121.34 (on US 136). In this situation, the wall identification number corresponds to the location of each specific wall's center with regard to reference posts along the numbered highway. R and L are not used. Wing walls, which may be MSE or retaining walls, are considered to be components of each primary wall.

Scenario 4 – Two Highways Crossing



This figure shows a situation where two highways cross. The center of both walls is located at approximately RP 59.87 on US 77. In this situation, the North-South highway is the basis for wall nomenclature. The wall identification number is the same, except for the last digit (R or L), which indicates whether that specific wall is to the left or to the right when facing in the direction of ascending RP numbers along the North-South highway.

Scenario 5 – Multiple Walls Where Highways Cross/Merge



This figure shows a situation where two highways cross or merge. The center of one set of walls is located near RP 89.44 on US 275. The center of the other set of walls is located near RP 89.46 on US 275. In this situation, the North-South highway is again the basis for wall nomenclature. The wall identification number within each set of walls is the same, except for the last digit (R or L), which indicates whether that specific wall is to the left or right when facing in the direction of ascending RP numbers along the North-South highway.

Once a wall ID has been created, it should be written down on the Wall Inspection Checklist Sheet provided. This will be the wall's permanent ID and should not be changed from inspection to inspection. M&R currently has records of existing and new MSE walls constructed after the year 2000 and a Wall ID for such walls may already be entered into the database.

Wall Inspection Rating System

All wall inspections shall be recorded on the provided Wall Inspection Checklist either from the Wall Inspection Manual or from the NDOR website. The checklist gives guidance on how what to inspect and how to rate each criteria. The database will then use the numbers from each inspection to create a Wall Performance Index (WPI) that allows NDOR to "Rate" how each retaining wall is performing. Appendix A has a copy of the Wall Inspection Checklist.

It is important that the inspectors are familiar with the different elements of the walls being inspected as well as the criteria by which each wall will be rated. The following descriptions explain each criterion with definitions and examples.

Wall Tilting

A panel wall showing a positive tilt.

Definition:

Panel Walls:

Inclination of the wall face from vertical or from its original inclination.

Modular Block & Gravity Walls:

Modular block walls often exhibit negative tilt (tilt towards the back of the wall) due to the setback of each successive layer of blocks. Gravity walls are generally constructed with a slight negative tilt.

Wall Tilting

Panel Walls:

- 0– A section of or the entire wall has failed due to tilting.
- 1 – A section of or the entire wall is inclined to the extent that separation is beginning in the wall face.
- 3 – A section of or the entire wall is inclined outward at 10° (2 inches Horizontal: 12 inches Vertical) to 15° (3 inches Horizontal: 12 inches Vertical).
- 5 – A section of or the entire wall is inclined outward at 5° (1 inch Horizontal: 12 inches Vertical) to 10° (2 inches Horizontal: 12 inches Vertical).
- 7 – A section of or the entire wall is inclined outward at 0°-5° (1 inch Horizontal: 12 inches Vertical).
- 9 – There is no change in wall inclination from construction specifications.

Block Walls:

- 0-Block wall has positive inclination.
- 5- Block wall is vertical (it has no tilt).
- 9-Block wall has negative inclination.

Structural Cracking

Separation of the corner on precast panel as a result of structural cracking.

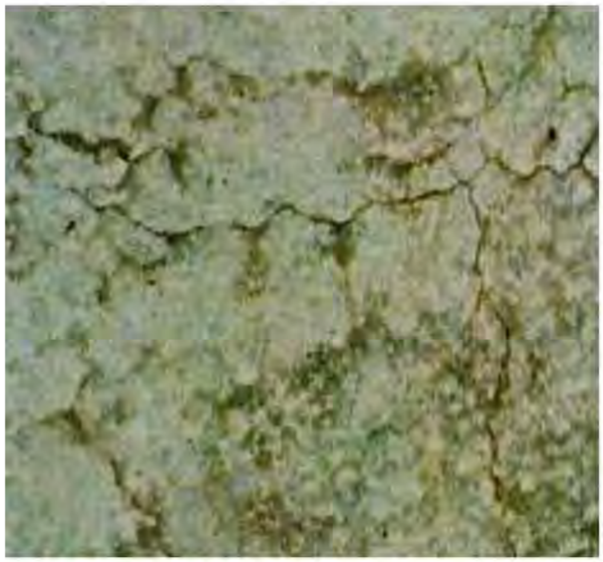
Definition:

Structural cracking is characterized by a separation which penetrates through the entire depth of the wall face. A crack which does not extend through the entire thickness of the wall face should be characterized as facial deterioration.

Structural Cracking

- 0 - More than 50% of wall area shows structural cracking.
- 1 - Between 33 - 50% of wall area shows structural cracking.
- 3 – Between 20 - 33% of wall area shows structural cracking.
- 5 – Between 10- 20% of wall area shows structural cracking.
- 7 - Less than 10% of wall area shows structural cracking.
- 9 - None or only an insignificantly small area shows structural cracking.

Facial Deterioration



Discoloration and/or nonstructural cracking of a wall surface.

Definition:

Impairment of the quality, appearance or function of a wall face. Facial deterioration can be characterized by spawling, nonstructural cracking, deterioration of facing materials or other phenomena. Cracks which do not extend through the total depth of the wall face should be characterized as facial deterioration.

Facial Deterioration

- 0 - More than 50% of the wall area shows facial deterioration.
- 3 – Between 50% and 25% of the wall area shows deterioration.
- 6 – Less than 25% of the wall area shows deterioration.
- 9 - None or only an insignificantly small area of the wall shows facial deterioration.

Bowing of the Wall

Bowing caused by failure of adjacent reinforcement connections.

Definition:

An outward bend or curve in the horizontal or vertical direction (or both) in a wall face. Bowing results from embedment pullout or broken connections between reinforcement and facing on adjacent panels.

Bowing of the Wall

- 0 – Wall panels have bowed outward to the point where backfill loss is occurring through joints.
- 3 – Wall panels have bowed outward to the point where filter fabric is visible at the joints; connectors between panels have broken.
- 5 – Wall panels have bowed outward to where connectors between panels are visible and deforming.
- 7 – Wall panels have bowed outward to the point where bowing is visible standing directly in front of the wall.
- 9 – No indication of bowing anywhere on the wall face.

Panel Staining

Discoloration of wall face due to water flowing through cracks or joints.

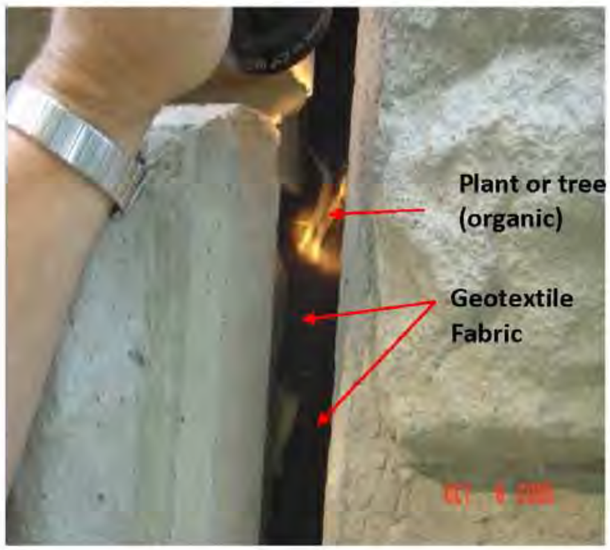
Definition:

A discoloration or change in the appearance of the surface for one or more panels or blocks. Staining is caused by water containing minerals moving through wall joints or cracks.

Panel Staining

- 0 - More than 50% of the wall surface is stained.
- 5- Less than 25% of the wall surface is stained.
- 9 - None or only an insignificantly small area of the wall surface is stained.

Exposure of Fabric at Joints



Organic material exposed outside of filter fabric (behind the wall face).

Definition:

Joints in the wall face can be deformed to the point where geotextile fabric behind the wall face becomes visible or protrudes through the joint. Filter fabric decomposes within a few months once exposed to sunlight.

Exposure of Fabric at Joints

- 0- Greater than 10% of the joints allow fabric to be exposed to sunlight.
- 3 - Fewer than 5% of joints allow fabric to be exposed to sunlight.
- 6 - No fabric is currently exposed at joints, but some joints appear to be increasing in width, which may allow fabric behind to become visible.
- 9 - Joints appear to be stable; no fabric is currently exposed.

Loss of Backfill

Loss of select backfill through joints.

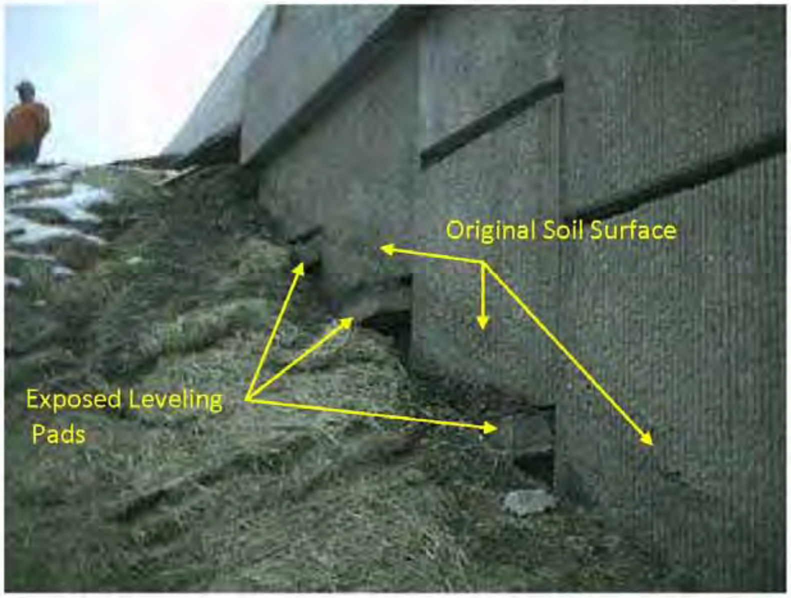
Definition:

Backfill moving from its original location down the wall's back slope or outward through wall joints.

Loss of Backfill

- 0 - Backfill loss has resulted in significant settlement of the v-ditch or roadway or has degraded wall inclination or alignment.
- 3 – Significant areas/quantities of backfill loss are visible.
- 6 – Backfill loss is occurring, but only minor areas/quantities of backfill loss are visible.
- 9 - No visible evidence of backfill loss.

Erosion- Front of Wall



The soil surface along this wall is being eroded, which exposed the leveling pads.

Definition:

Materials covering the leveling pad are being eroded. Uncorrected erosion results in exposure of the leveling pad (subsurface panel face or concrete footing) and, if not brought under control, can remove material beneath the wall.

Erosion- Front of Wall

- NA – Area in front of the wall is paved.
- 0 - Erosion has exposed more than 50% of the wall base.
- 3 - Erosion has exposed more than 25% of the wall base.
- 5 – Erosion has exposed less than 25% of the wall base.
- 7 – Erosion is occurring but the wall base remains covered.
- 9- No evidence of erosion in front of the wall.

Erosion- Back of Wall

Washout (showing lateral reinforcement exposed).

Definition:

Loss of backfill material through erosion behind the wall face. Severe erosion of backfill is indicated by significant washouts and exposure of wall lateral reinforcement.

Erosion- Back of Wall

- 0 - Wall reinforcement is visible in several locations.
- 3 - Wall reinforcement is being exposed at two or more locations.
- 5 - Effects of erosion are visible but no wall reinforcement has been exposed.
- 7 - Minor effects of erosion are visible; plant roots may be exposed or higher original soil levels on concrete structures may be indicative of erosion.
- 9 - There is no visual evidence that erosion is occurring behind the wall.

Joint Spacing

Two adjacent sections of this wall are bowing outward,
causing excessive joint spacing between adjacent panels.

Definition:

Even spacing between panels or blocks is desirable for wall function and for esthetic considerations. Vertical and horizontal joints should be consistent and of uniform size across the entire wall face.

Joint Spacing

- NA – Wall is not a panel wall; wall has no joints.
- 0 – Joint width appears almost totally irregular and random.
- 3 - Joint width varies widely across the wall face.
- 5 - Joint width appears marginally regular, but considerable variation exists in different areas or at different heights along the wall.
- 7 – Joint width appears generally uniform with the exception of some discrepancies in localized areas.
- 9 - Joint width appears generally uniform across the entire wall.

Condition of V-Ditch

Loss of backfill has caused a complete break in this V-Ditch as well as its separation from the wall.

Definition:

The V-Ditch is a continuous structure that intercepts runoff and transports it away from the wall. Where the V-Ditch has failed, runoff may cascade downward over the wall's face or drain downward through the wall along its back face.

Condition of V-Ditch

- NA – The wall has no V-Ditch.
- 0 - The V-Ditch is nonfunctional due to backfill movement, cracking, etc.
- 3 - The V-Ditch has separated from the wall face; extensive cracking or breakup of the V-Ditch has rendered it almost nonfunctional.
- 5 - The V-Ditch is still attached to wall, but large cracks are developing in the V-ditch at several locations. The V-Ditch can transport less water than intended.
- 7 - The V-Ditch is still attached to the wall, but minor cracks are developing; ability of V-Ditch to transport water has not been affected.
- 9 - No cracks in the V-Ditch; no separation of the V-Ditch from the wall. The V-Ditch is functioning as intended.

Coping Deterioration

The coping covering the top of this wall is in excellent condition.

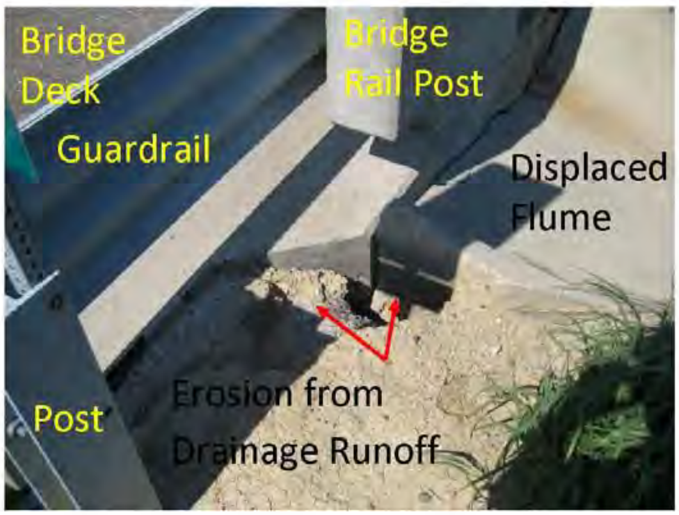
Definition:

Coping is the cap (often concrete) that covers the top panels along a wall face. Coping should not be confused with railing, which serves as a safety mechanism.

Coping Deterioration

- NA – This wall has no coping.
- 0 - More than 25% of the coping shows signs of severe cracking, has become detached or is spawling.
- 5 – Less than 25% of the coping shows signs of severe cracking, has become detached or is spalling.
- 9 – There are no signs of coping deterioration.

Drainage Runoff



Improper drainage runoff from the roadway caused undermining of this road and displacement of the flume .

Definition:

Drainage pathways should move runoff from the upper roadway away from the wall without adversely affecting the wall function or traffic movement. Indicators of problems include and are not limited to: misalignment on tilting of guardrails and erosion beneath the guardrail or adjacent to the road.

Drainage Runoff

- NA- No structure above wall to cause drainage runoff.
- 0 - Erosion runoff is actively moving significant quantities of backfill material from its original location.
- 3 - Indications of erosion runoff are present; quantity of backfill material being moved appears significant.
- 6 - Indications of erosion runoff are present but there is no indication that the quantity of backfill material being moved is significant.
- 9 - No signs of erosion due to drainage runoff.

Drainage at the Front of the Wall

Problematic drainage is causing ponding at the front of this wall.

Definition:

Drainage along the front of the wall should remove water without allowing inundation of the structure's base or adjacent traffic paths.

Drainage at the Front of the Wall

- 0 – Signs of water ponding consistently in front of the wall (Cattails growing, stain lines left from standing water on the wall, etc.).
- 5 – Water seldom ponds in front of the wall or only during periods of intense precipitation.
- 9 - Front of the wall is well drained; no ponding occurs.

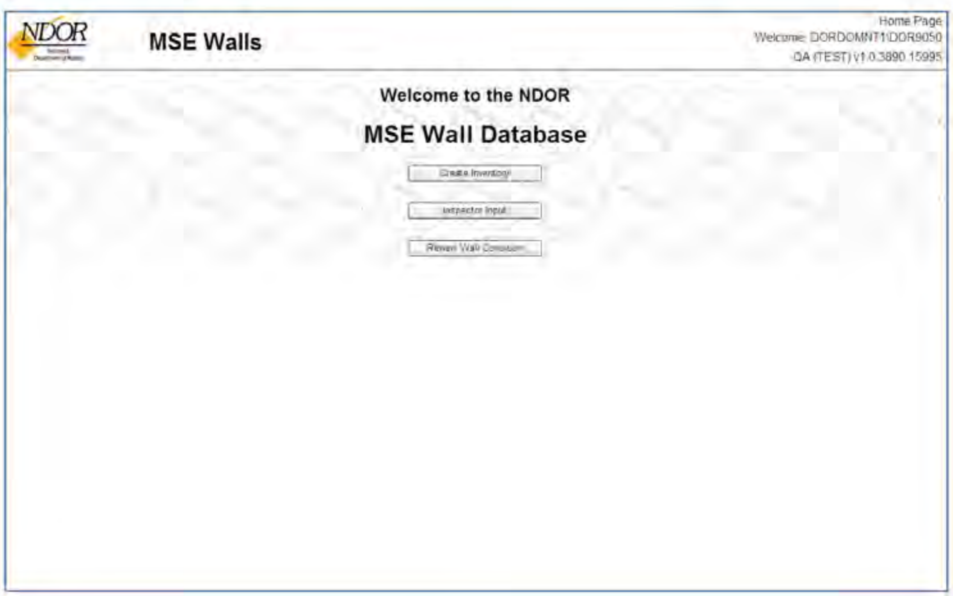
MSE Wall Database

The purpose of the data base will be to establish the number of walls and wall types and provide a way to keep track of the condition of each wall. There are three main inputs into the MSE Wall data base: 1) Entering Wall Data, 2) Inspector Input, and 3) Review wall data. The "Enter Wall Data" input consists of establishing the location, type, size, date constructed, and any shop plans. This data will be entered by the Geotechnical Section. The "Inspector Input" data will consist of the wall condition rating survey that is conducted by the District inspectors. Besides the wall rating criteria, photos taken at the time of the survey can also be added. The inspector input data can only be entered for walls of an inspector's District. The "Review Wall Data" allows anyone to review the condition of any wall in the state that is in the database. This feature will be helpful to the Districts & the Geotechnical Section to monitor the conditions of walls and if repairs are required.

The following is a step-by step procedure for entering inspector input and reviewing wall data:

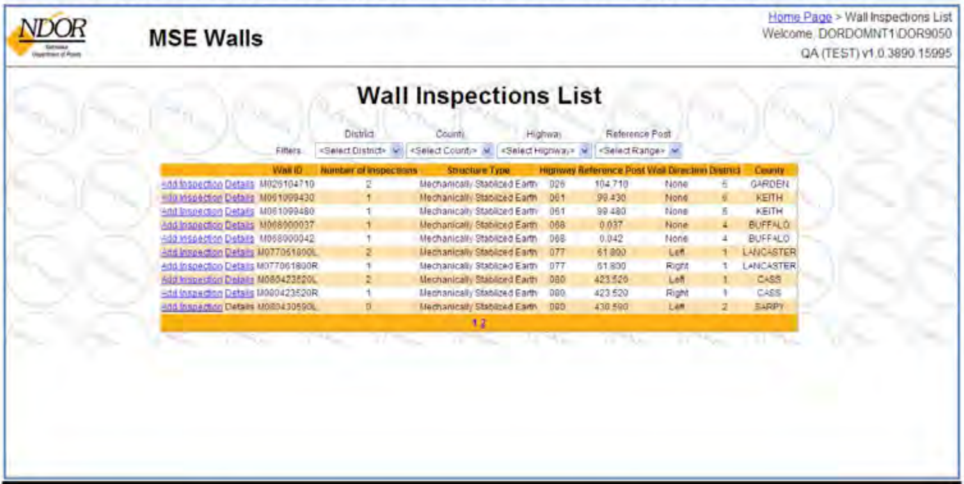
Go to the link: http://www2.dor.state.ne.us/MSEwall

This will pull up the MSE Wall Database program and show the Main Screen Page below.



INSPECTOR INPUT

The Create Inventory button is only used by NDOR administrators and will not be active for District Personnel. To add a new inspection entry click on the "Inspector Input" button.



	Wall ID	Number of Inspections	Structure Type	Highway	Reference Post	Wall Direction	District	County
Add Inspection Details	M026104710	2	Mechanically Stabilized Earth	026	104.710	None	5	GARDEN
Add Inspection Details	M061099430	1	Mechanically Stabilized Earth	061	99.430	None	6	KEITH
Add Inspection Details	M061099480	1	Mechanically Stabilized Earth	061	99.480	None	5	KEITH
Add Inspection Details	M068000037	1	Mechanically Stabilized Earth	068	0.037	None	4	BUFFALO
Add Inspection Details	M068000042	1	Mechanically Stabilized Earth	068	0.042	None	4	BUFFALO
Add Inspection Details	M077061800L	2	Mechanically Stabilized Earth	077	61.800	Left	1	LANCASTER
Add Inspection Details	M077061800R	1	Mechanically Stabilized Earth	077	61.800	Right	1	LANCASTER
Add Inspection Details	M080423520L	2	Mechanically Stabilized Earth	080	423.520	Left	1	CASS
Add Inspection Details	M080423520R	1	Mechanically Stabilized Earth	080	423.520	Right	1	CASS
Add Inspection Details	M080430590L	0	Mechanically Stabilized Earth	080	430.590	Left	2	SARPY

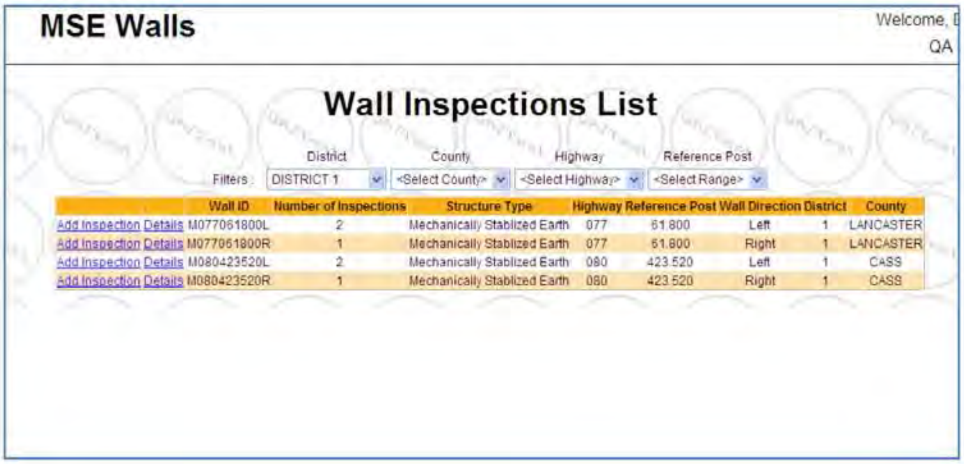
1 2

To find the correct Wall ID you inspected you can either manually search and each ID and click on the page numbers to continue to search the data base.

FILTER SEARCH

You can also filter your search by selecting the appropriate District, County, Highway and Reference Post Range. You can search using one, several, or all of the filter criteria.

DISTRICT



	Wall ID	Number of Inspections	Structure Type	Highway	Reference Post	Wall Direction	District	County
Add Inspection Details	M077061800L	2	Mechanically Stablized Earth	077	61.800	Left	1	LANCASTER
Add Inspection Details	M077061800R	1	Mechanically Stablized Earth	077	61.800	Right	1	LANCASTER
Add Inspection Details	M080423520L	2	Mechanically Stablized Earth	080	423.520	Left	1	CASS
Add Inspection Details	M080423520R	1	Mechanically Stablized Earth	080	423.520	Right	1	CASS

DISTRICT & COUNTY

	Wall ID	Number of Inspections	Structure Type	Highway	Reference Post	Wall Direction	District	County
Add Inspection Details	M077061800L	2	Mechanically Stablized Earth	077	61.800	Left	1	LANCASTER
Add Inspection Details	M077061800R	1	Mechanically Stablized Earth	077	61.800	Right	1	LANCASTER

DISTRICT, COUNTY, & HIGHWAY

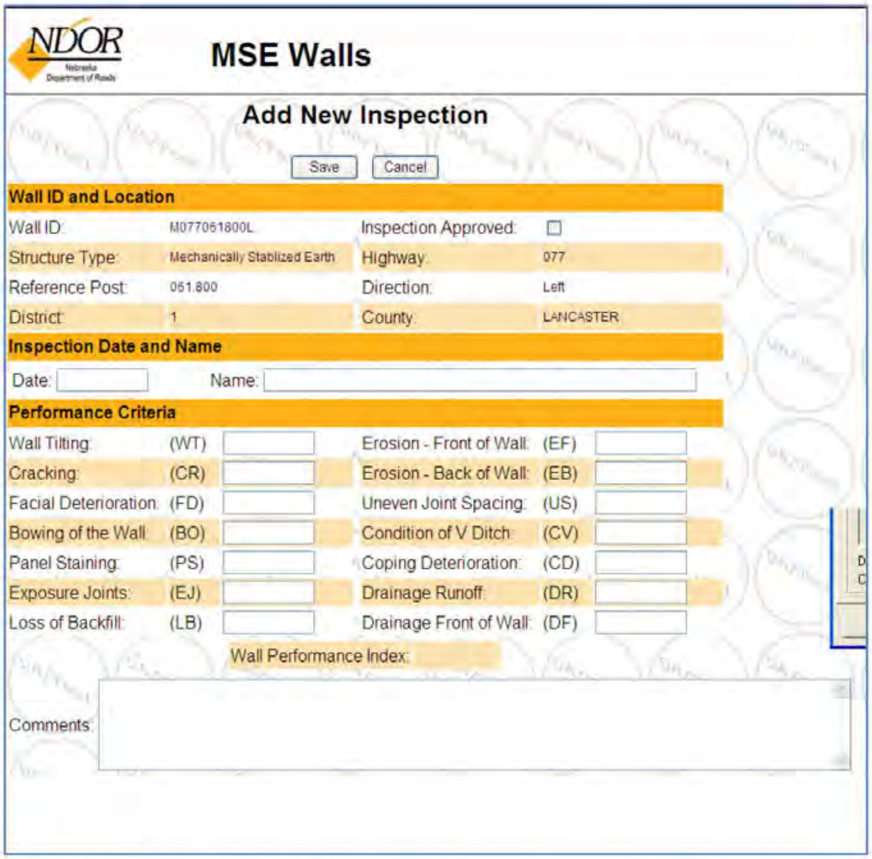
DISTRICT, COUNTY, HIGHWAY, & R.P.

ADDING A NEW INSPECTION

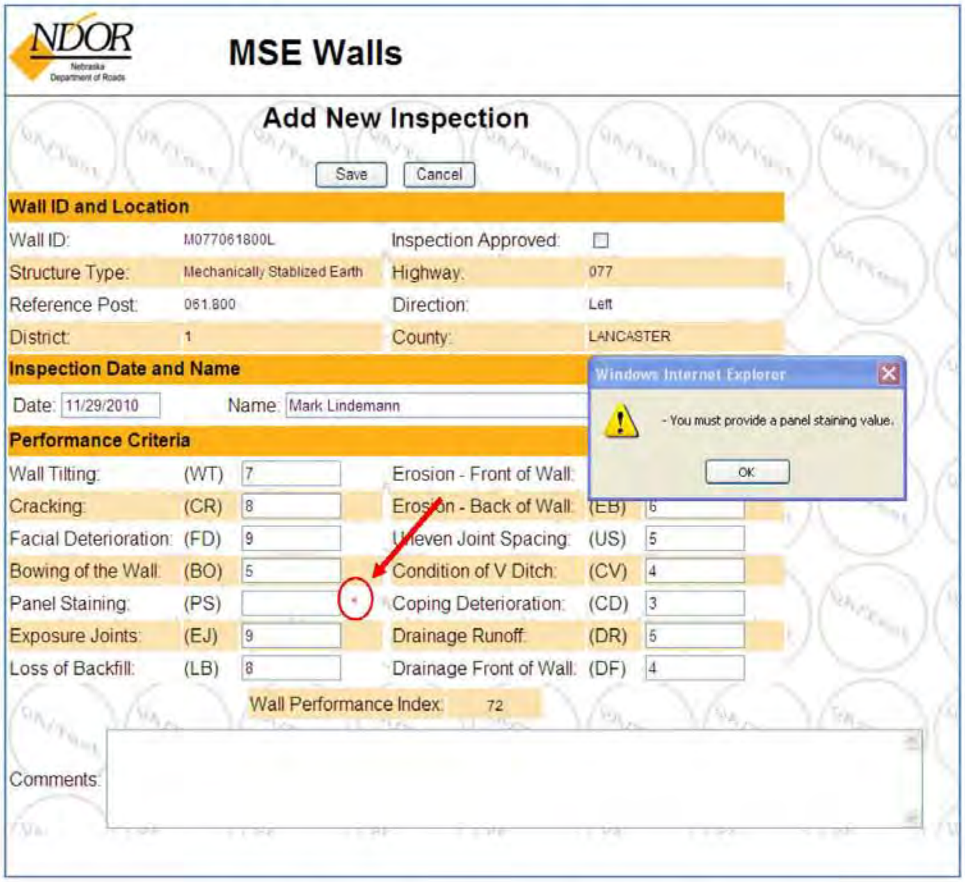
To review the information about the wall you can click on the highlighted word "Details". To add a new inspection click on "Add Inspection".

		Wall ID	Number of Inspections	Structure Type	Highway	Reference Post	Wall Direction	District	County
Add Inspection	Details	M077061800L	2	Mechanically Stablized Earth	077	61.800	Left	1	LANCASTER
Add Inspection	Details	M077061800R	1	Mechanically Stablized Earth	077	61.800	Right	1	LANCASTER

The "Add New Inspection" screen will appear. Make note that you have selected the proper wall paying special attention that it is the correct direction (Left or Right of Centerline or Centerline).



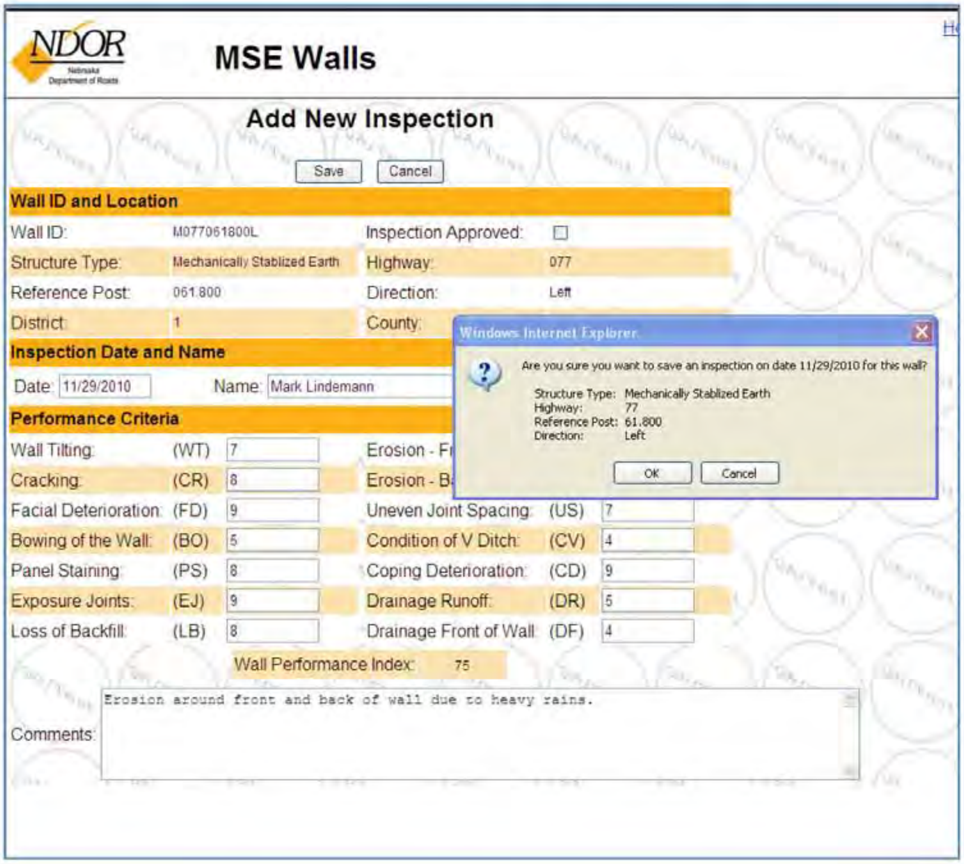
If you selected the wrong wall, simply click on the "Cancel" button and you will return to the Wall Inspection List page. If you have the correct Wall ID, begin entering the inspection data for the wall. Note that if not all the required blanks are not filled out you will receive an error message when trying to save the inspection. The error message will describe the error and a red asterisk will be shown next to the error category.



Note that there is an additional box for any comments noted during the inspection that could be helpful describing any problems.

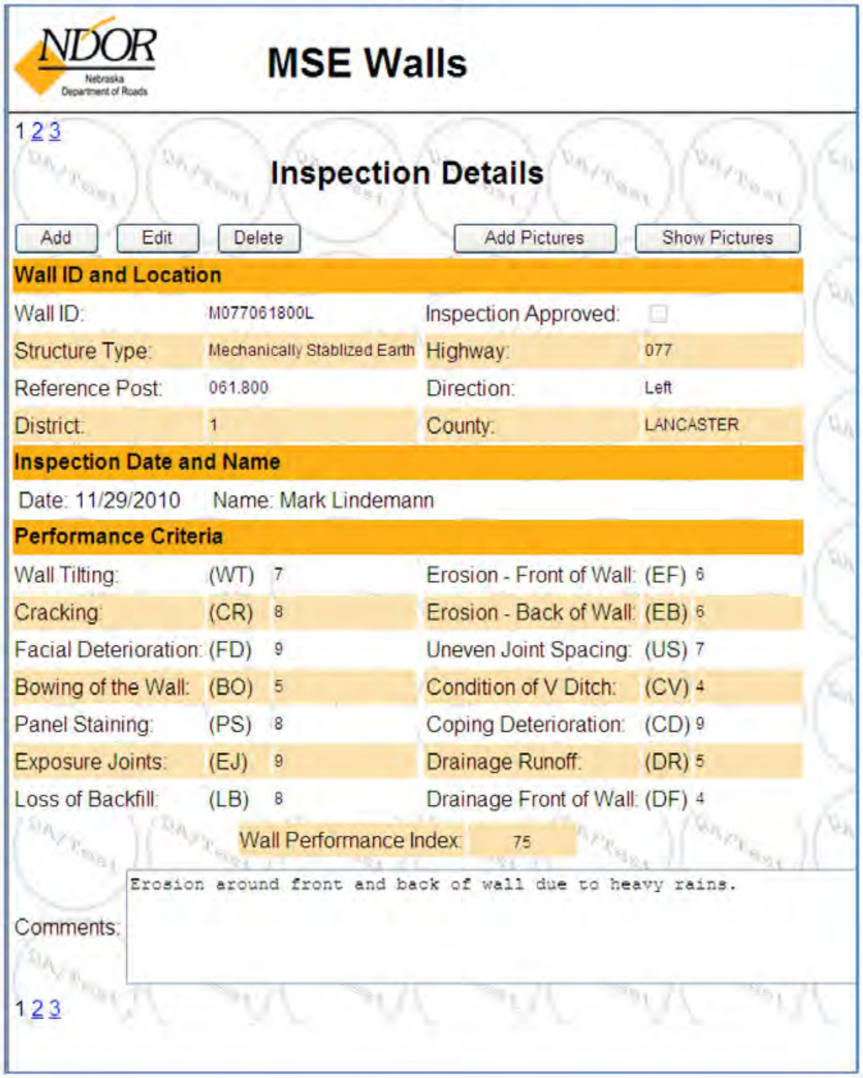
SAVING AN INSPECTION

Once all the data has been entered click the "Save" button. A prompt will come up asking if you are sure you want to save for the selected data. If everything is correct, select "OK".



EDITING AN INSPECTION

Once the file is saved the "Inspection Details" screen appears. This screen allows the inspector to edit or delete the recently saved inspection and also adds the ability to add inspection Pictures and also view the pictures. To edit the existing data click on the "Edit" button, change the data, and click on "Save". To delete the whole inspection file click the "Delete" button and select "OK".



NDOR Nebraska Department of Roads

MSE Walls

1 2 3

Inspection Details

Add | Edit | Delete | Add Pictures | Show Pictures

Wall ID and Location

Wall ID:	M077061800L	Inspection Approved:	☐
Structure Type:	Mechanically Stablized Earth	Highway:	077
Reference Post:	061.800	Direction:	Left
District:	1	County:	LANCASTER

Inspection Date and Name

Date: 11/29/2010 Name: Mark Lindemann

Performance Criteria

Wall Tilting:	(WT)	7	Erosion - Front of Wall:	(EF)	6
Cracking:	(CR)	8	Erosion - Back of Wall:	(EB)	6
Facial Deterioration:	(FD)	9	Uneven Joint Spacing:	(US)	7
Bowing of the Wall:	(BO)	5	Condition of V Ditch:	(CV)	4
Panel Staining:	(PS)	8	Coping Deterioration:	(CD)	9
Exposure Joints:	(EJ)	9	Drainage Runoff:	(DR)	5
Loss of Backfill:	(LB)	8	Drainage Front of Wall:	(DF)	4

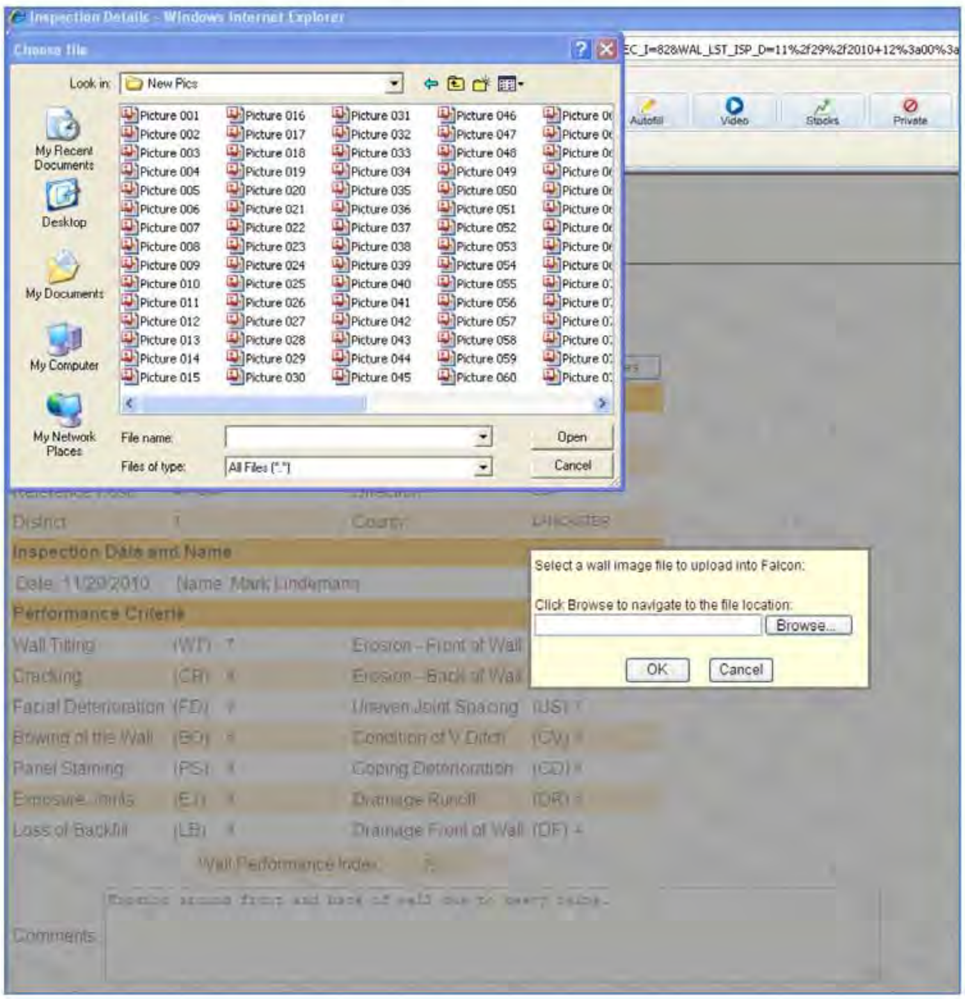
Wall Performance Index: 75

Comments: Erosion around front and back of wall due to heavy rains.

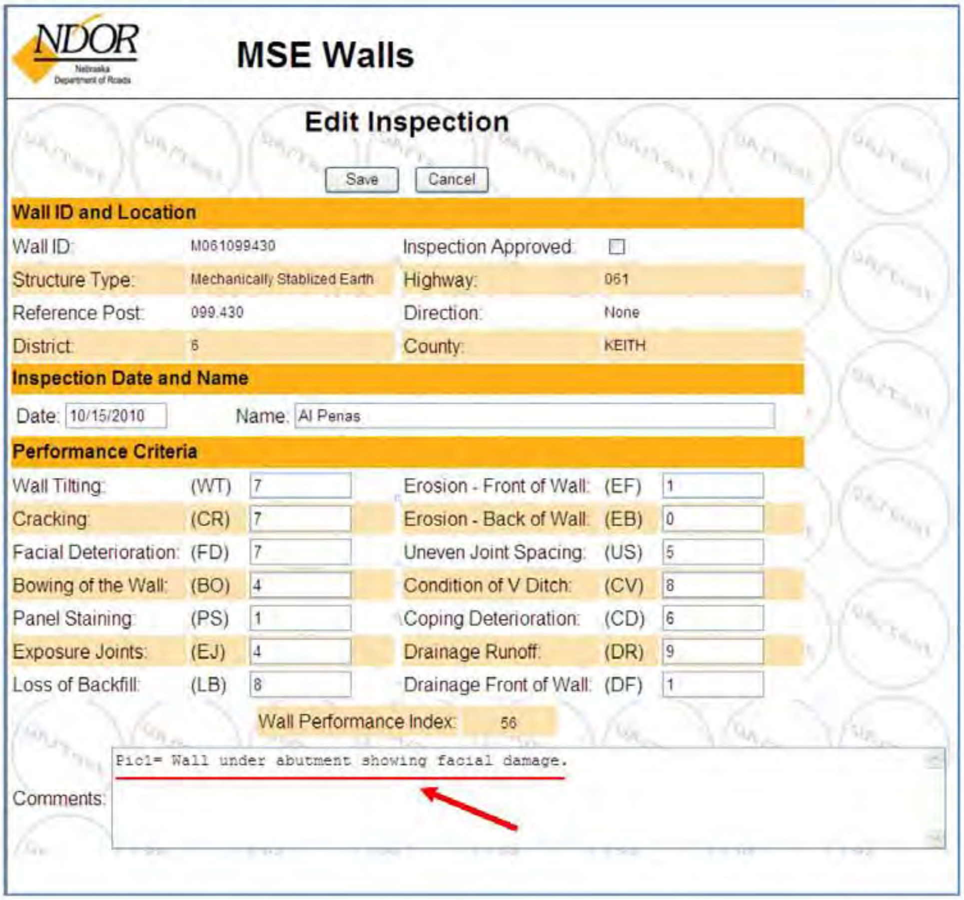
1 2 3

ADDING/VIEWING PICTURES

To add pictures click on the "Add Pictures" button. You will be prompted to browse your computer for the picture file you want to add. Find the picture you want and double click on it to select it and then select "OK" to complete the task.



Please add a brief description of each picture in the comments section below for each picture added by using the edit feature.


NDOR Nebraska Department of Roads

MSE Walls

Edit Inspection

Save Cancel

Wall ID and Location			
Wall ID:	M061099430	Inspection Approved:	☐
Structure Type:	Mechanically Stablized Earth	Highway:	061
Reference Post:	099.430	Direction:	None
District:	6	County:	KEITH

Inspection Date and Name

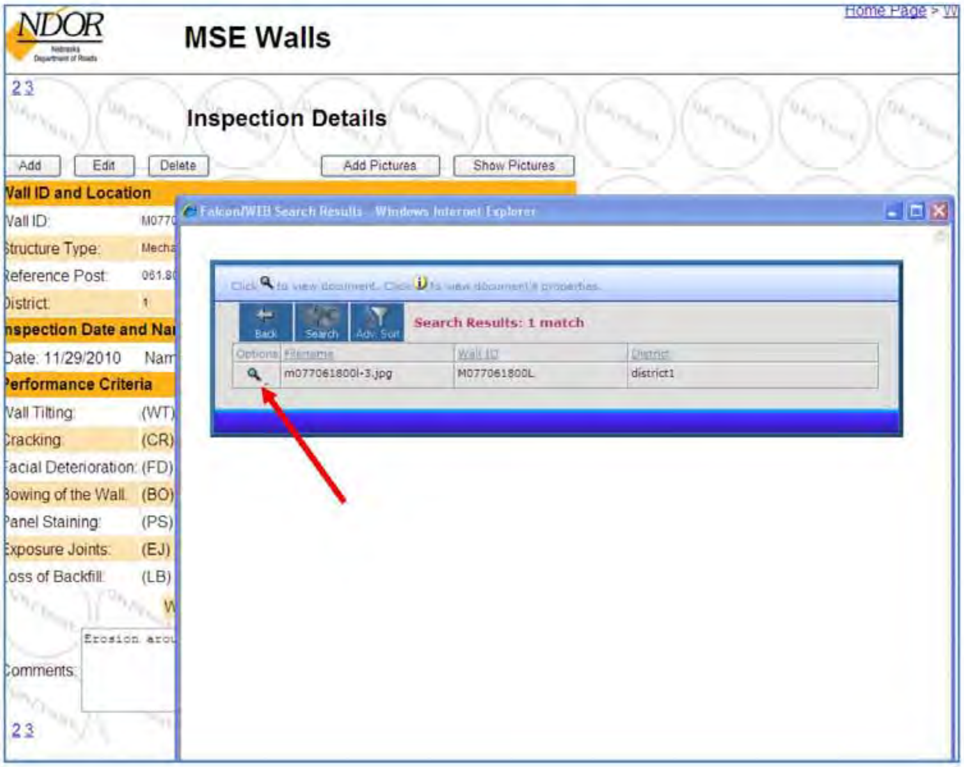
Date: 10/15/2010 Name: Al Penas

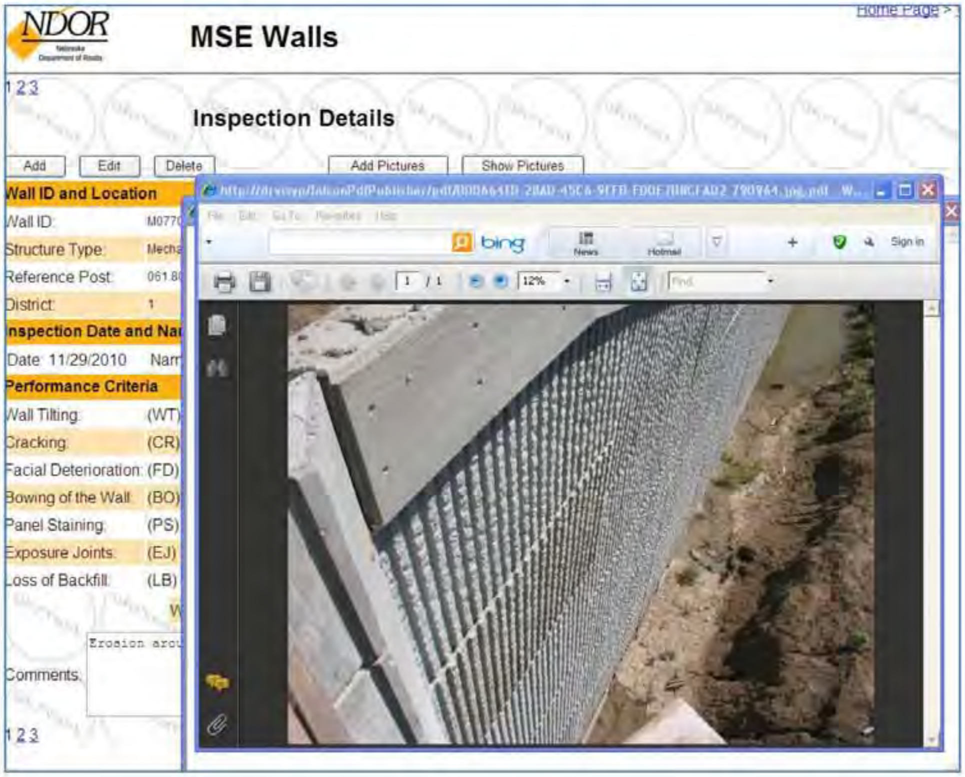
Performance Criteria					
Wall Tilting:	(WT)	7	Erosion - Front of Wall:	(EF)	1
Cracking:	(CR)	7	Erosion - Back of Wall:	(EB)	0
Facial Deterioration:	(FD)	7	Uneven Joint Spacing:	(US)	5
Bowing of the Wall:	(BO)	4	Condition of V Ditch:	(CV)	8
Panel Staining:	(PS)	1	Coping Deterioration:	(CD)	6
Exposure Joints:	(EJ)	4	Drainage Runoff:	(DR)	9
Loss of Backfill:	(LB)	8	Drainage Front of Wall:	(DF)	1

Wall Performance Index: 56

Comments: Pic1= Wall under abutment showing facial damage.

To view the pictures added click on the "Show Pictures" button. Each picture is labeled by Wall ID and picture #1 (the order in which they were added). To view a picture, click on the magnifying glass on the left of the picture name.


NDOR
MSE Walls
Home Page
Inspection Details
Add
Edit
Delete
Add Pictures
Show Pictures
Wall ID and Location
Wall ID:
Structure Type:
Reference Post:
District:
Inspection Date and Na
Date: 11/29/2010
Performance Criteria
Wall Tilting: (WT)
Cracking: (CR)
Facial Deterioration: (FD)
Bowing of the Wall: (BO)
Panel Staining: (PS)
Exposure Joints: (EJ)
Loss of Backfill: (LB)
Comments:
FalconWEB Search Results - Windows Internet Explorer
Search Results: 1 match
Back
Search
Adv. Sort
m077061800l-3.jpg
M077061800L
district1



EXITING INSPECTOR INPUT

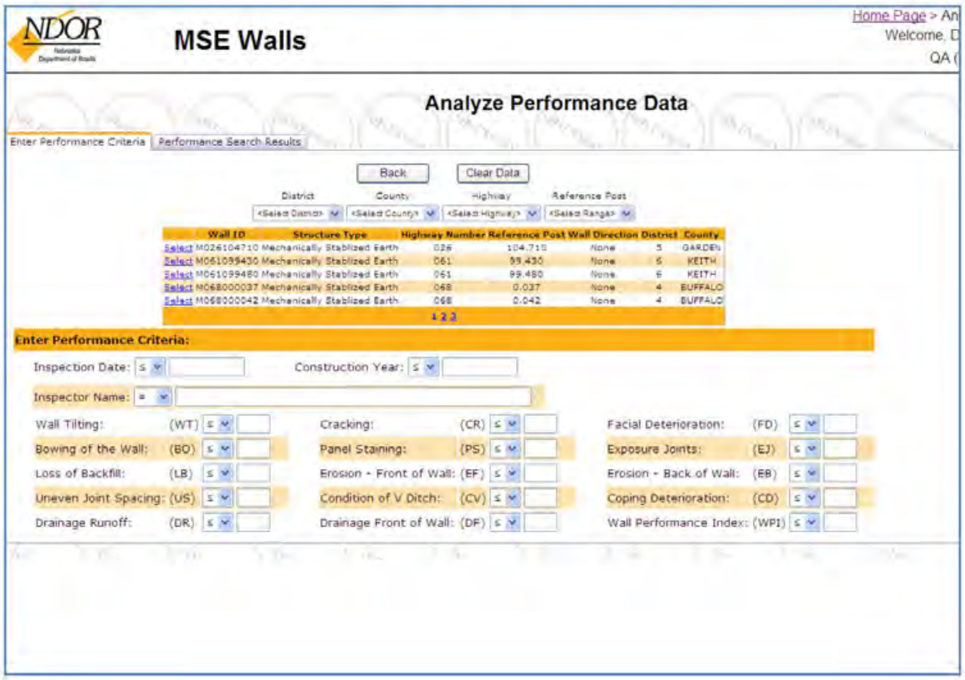
To exit from the viewing pictures click on the "X" on the top right corner of each window. When you are finished editing and adding pictures go to the top of the screen and click on the words "Home Page". This will take you to the Main Screen. If you are finished you can close the program by either selecting "File" and "Exit" or by clicking on the "X" at the upper right hand of the window screen..

REVIEW WALL CONDITION

To view the conditions of a wall or a group of walls, you again start at the Main Screen. Select the "Review Wall Condition" to begin.

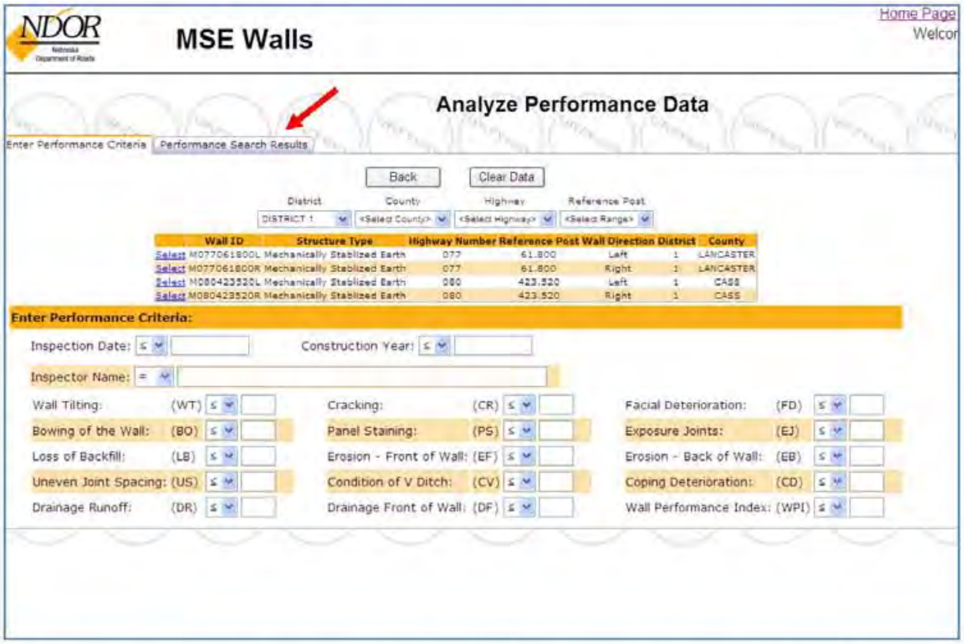
FILTERED SEARCH FOR ANALYSIS

A screen titled "Analyze Performance Data" appears. This screen is much like the Inspector Input screen in that you can filter walls based on District, Highway, and R.P. In addition, you can also filter data based on Inspection Date, Construction Year, or Performance Criteria. Again, you can customize your search using the any combination of the filters provided.

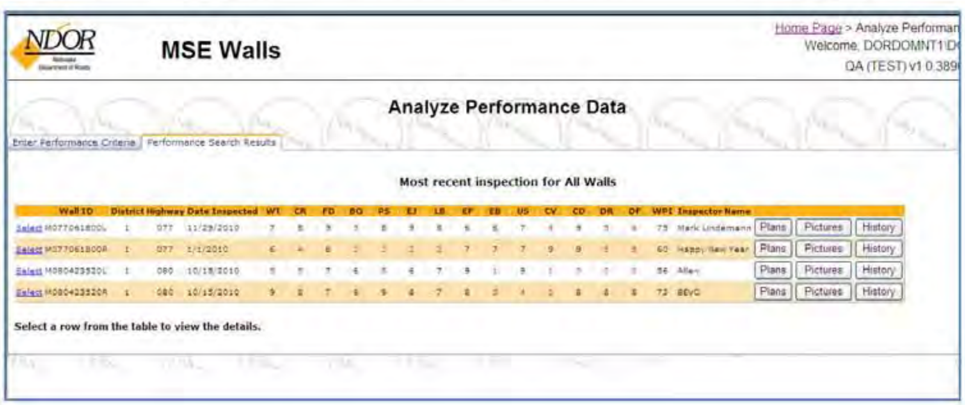


REVIEW OF PERFORMANCE DATA

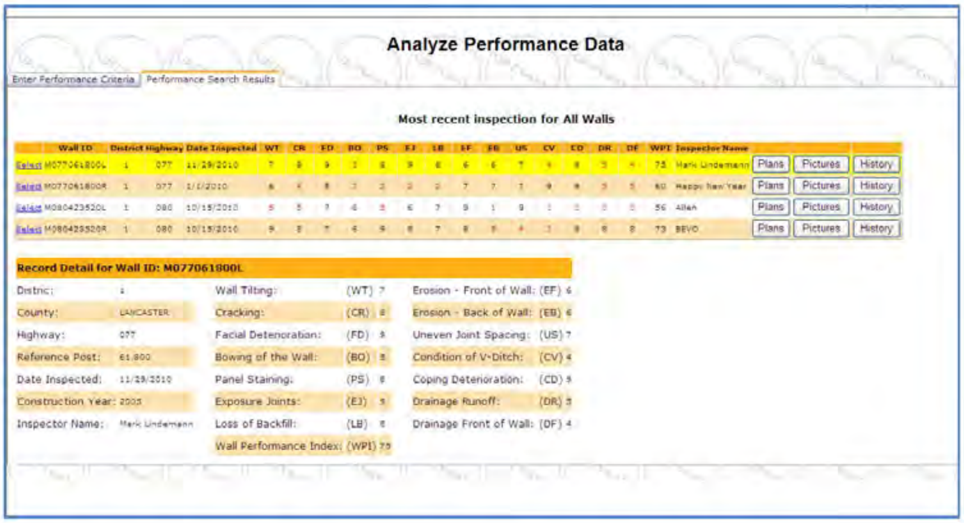
Once you have filtered the data, click on the Performance Search Results tab.



Once the Performance Results tab is select, the data that meets the filter criteria is shown.

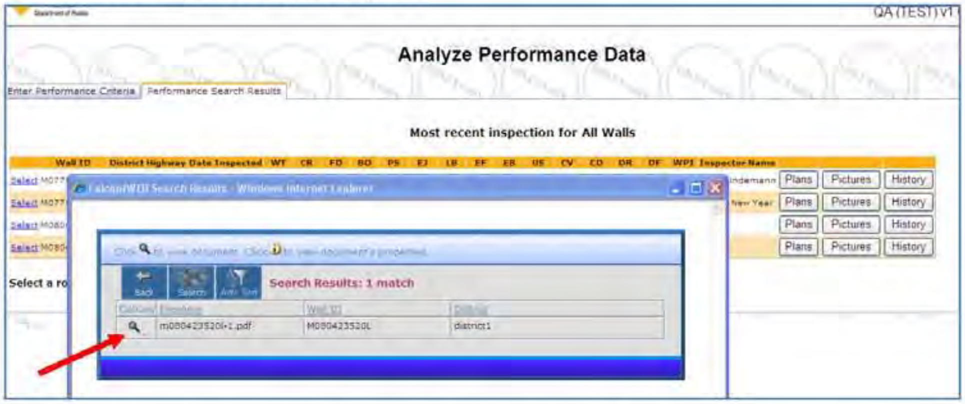


To view a single wall, click on "<u>Select</u>" to the left of the Wall ID. The entire line of the selected wall is highlighted in yellow and the performance results are shown in an enlarged format towards the bottom of the page.

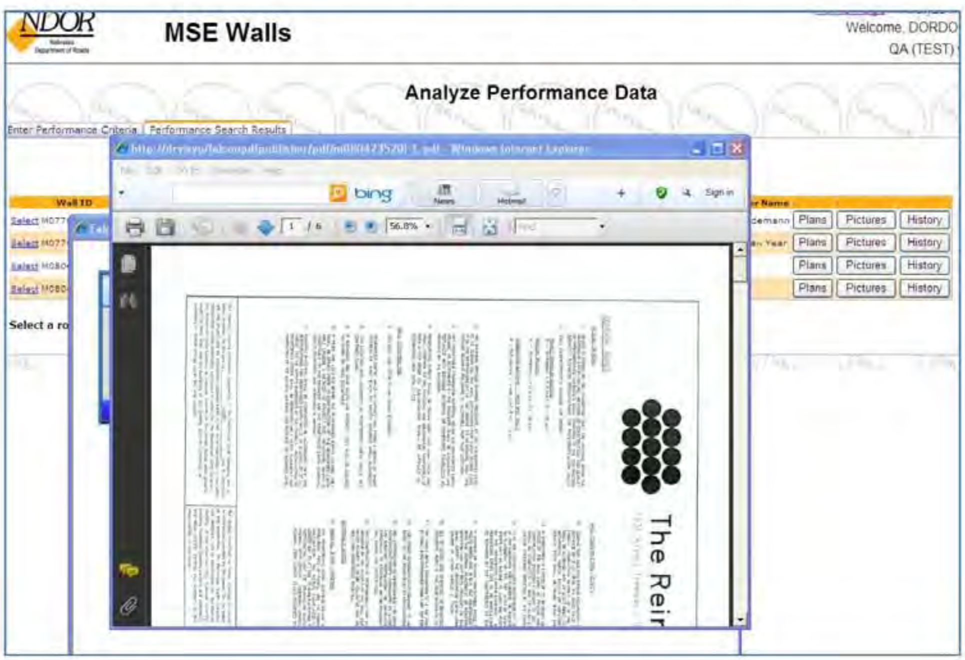


There are three buttons that are used to view the wall plans, pictures, and the previous wall inspections performed for each individual wall.

To view the plans for a particular Wall ID, select the "Plans" button. A screen will appear much like that of the Show Pictures option in the Inspector Input menu. Click on the magnifying glass to the left of the Wall ID to view the plans.

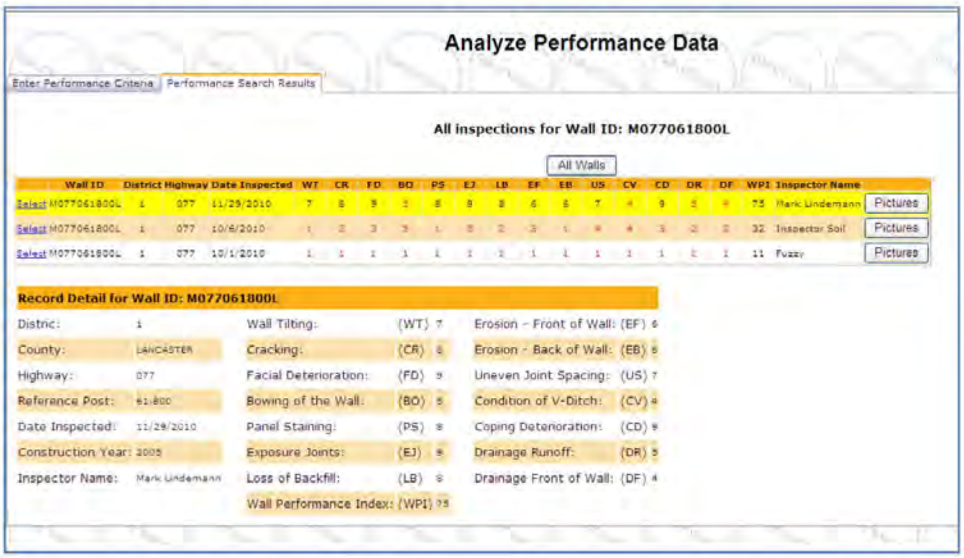


Another window will open which allows you to view the plans for the wall.



To view pictures, click on the "Pictures" button in the same line as the Wall ID of interest. Follow the same procedures for viewing the pictures.

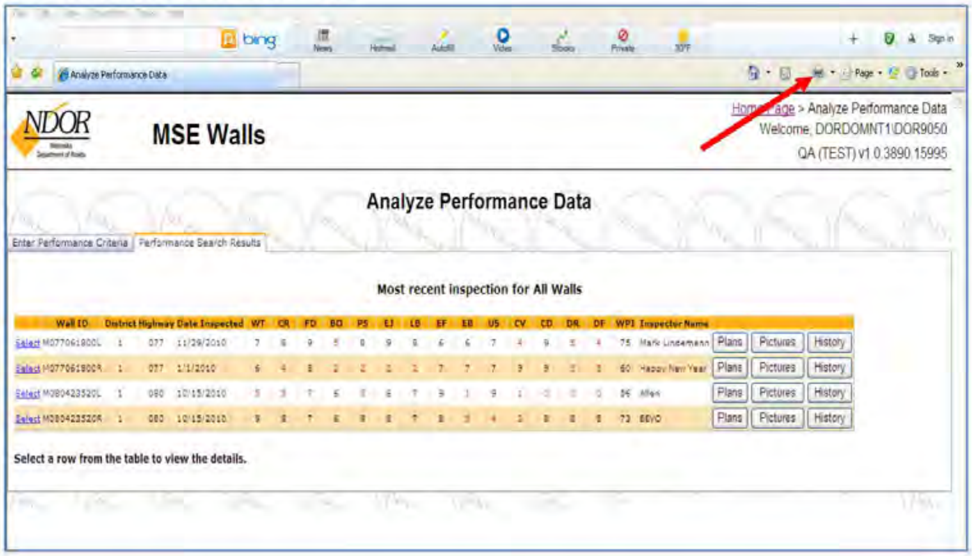
To view the all the inspections for an individual Wall ID select the "History" button. A screen will appear that shows all the inspections for that Wall ID. To view an individual inspection click on "Select" on the same line as that inspection date. The individual inspection is highlighted in yellow and the inspection details are shown towards the bottom of the screen. In this screen you can also view pictures from each inspection date by clicking on the "Pictures" button corresponding to each inspection.



To return to the filtered search of all the walls you selected, click on the "All Walls" button.

PRINTING DATA

If you would like to print the data from a search, go to the toolbar at the top of the windows screen and click on the Printer Icon.



NEW SEARCH OR EXIT DATABASE

To perform another search click on the “Enter Performance Criteria” tab and you can revise your search. If you are finished viewing performance data click on “Home Page” at the top of the screen and then select either “File” and “Exit” or click on the “X” at the upper right hand of the window screen.

APPENDIX A

Wall ID# ________________ Date Inspected ______________ Inspector's Initials ______

Directions: Fill the line next to each parameter with a number between zero and nine or N/A (if applicable). A zero indicates immediate attention to this parameter is needed while a nine indicates the wall appears to meet original construction specifications with regard to this parameter. All parameters are shown with explanations corresponding to numbers. N/A should be used only when that option is listed for a specific parameter.

____ **Wall Tilting** (Panel Wall)

- 0- A section of the entire wall has failed due to tilting.
- 1 – A section of or the entire wall is inclined to the extent that separation is beginning in the wall face.
- 3 – A section of or the entire wall is inclined outward at 10° (2 inches Horizontal: 12 inches Vertical) to 15° (3 inches Horizontal: 12 inches Vertical).
- 5 – A section of or the entire wall is inclined outward at 5° (1 inch Horizontal: 12 inches Vertical) to 10° (2 inches Horizontal: 12 inches Vertical).
- 7 – A section of or the entire wall is inclined outward at 0°-5° (1 inch Horizontal: 12 inches Vertical).
- 9- There is no change in wall inclination from construction specifications.

____ **Structural Cracking**

- 0- More than 50% of wall area shows structural cracking.
- 1 - Between 33 - 50% of wall area shows structural cracking.
- 3 – Between 20 - 33% of wall area shows structural cracking.
- 5 – Between 10- 20% of wall area shows structural cracking.
- 7 – Less than 10% of wall area shows structural cracking.
- 9- None or only an insignificantly small area shows structural cracking.

____ **Facial Deterioration**

- 0 - More than 50% of wall area shows facial deterioration.
- 3 – Between 50% and 25% of the wall area shows deterioration.
- 6 – Less than 25% of the wall area shows deterioration.
- 9- None or only an insignificantly small area shows facial deterioration.

____ **Bowing of the Wall**

- 0- Wall panels have bowed outward to the point where backfill loss is evident.
- 3 – Wall panels have bowed outward to the point where filter fabric is visible at the joints; connectors between panels have broken.
- 5 – Wall panels have bowed outward to where connectors between panels are visible and deforming.
- 7 – Wall panels have bowed outward to the point where bowing is visible standing directly in front of the wall.
- 9- No signs of bowing in wall face.

____ **Panel Staining**

- 0- More than 50% of wall area is stained.
- 5- Less than 25% of the wall surface is stained.
- 9-None or only an insignificantly small area of the wall is stained.

____ **Exposure of Fabric at Joints**

- 0- Greater than 10% of the joints allow fabric to be exposed to sunlight.
- 3 - Fewer than 5% of joints allow fabric to be exposed to sunlight.
- 6 - No fabric is currently exposed at joints, but some joints appear to be increasing in width, which may allow fabric behind to become visible.
- 9- Joints appear to be stable; no fabric is currently exposed.

____ **Loss of Backfill**

- 0- Backfill loss has resulted in significant settlement of the V-Ditch or roadway or has affected wall inclination or alignment.
- 3 – Significant areas/quantities of backfill loss are visible.
- 6 – Backfill loss is occurring, but only minor areas/quantities of backfill loss are visible.
- 9- No visual evidence of backfill loss.

____ **Erosion: Front of Wall**

- N/A- Area in front of wall is paved.
- 0- Erosion has exposed more than 50% of the wall base.
- 3 - Erosion has exposed more than 25% of the wall base.
- 5 – Erosion has exposed less than 25% of the wall base.
- 7 – Erosion is occurring but the wall base remains covered.
- 9- No evidence of erosion in front of the wall.

____ **Erosion: Back of Wall**

- 0- Wall reinforcement is visible in several locations.
- 3 - Wall reinforcement is being exposed at two or more locations.
- 5 - Effects of erosion are visible but no wall reinforcement has been exposed.
- 7 - Minor effects of erosion are visible; plant roots may be exposed or higher original soil levels on concrete structures may be indicative of erosion.
- 9- There is no visual evidence that erosion is occurring behind the wall.

____ **Joint Spacing**

- N/A- Wall is not a panel wall; wall has no joints.
- 0- Joint width appears almost totally irregular and random.
- 3 - Joint width varies widely across the wall face.
- 5 - Joint width appears marginally regular, but considerable variation exists in different areas or at different heights along the wall.
- 7 – Joint width appears generally uniform with the exception of some discrepancies in localized areas.
- 9- Joint width appears uniform across the entire wall.

____ **Condition of V-Ditch**

- N/A- The wall has no V-Ditch.
- 0- The V-Ditch is nonfunctional due to backfill movement, cracking, etc.
- 3 – The V-Ditch has separated from the wall face; extensive cracking or breakup of the V-Ditch has rendered it almost nonfunctional.
- 5 - The V-Ditch is still attached to wall, but large cracks are developing in the V-ditch at several locations. The V-Ditch can transport less water than intended.
- 7 - The V-Ditch is still attached to the wall, but minor cracks are developing; the ability of the V-ditch to transport water has not been affected.
- 9- No cracks in the V-Ditch; no separation of the V-Ditch from the wall. The V-Ditch is functioning as intended.

_____ **Coping Deterioration**

- N/A- The wall has no coping.
- 0- More than 25% of the coping shows signs of severe cracking, has become detached, or is spawling.
- 5 – Less than 25% of the coping shows signs of severe cracking, has become detached or is spawling.
- 9- Coping shows no sign of cracking, spawling or other signs of deterioration.

_____ **Drainage Runoff**

- N/A- No structure above wall to cause drainage runoff.
- 0- Erosion is actively moving significant quantities of backfill material from the backfill to other locations
- 3 - Indications of erosion runoff are present; quantity of backfill material being moved appears significant.
- 6 - Indications of erosion runoff are present but there is no indication that the quantity of backfill material being moved is significant.
- 9- No signs of erosion due to drainage runoff.

_____ **Drainage Front of the Wall**

- 0- Signs of water ponding consistently in front of the wall.
- 5 – Water seldom ponds in front of the wall or only during periods of intense precipitation.
- 9- Front of wall is well drained; no ponding occurs.

Comments:

Materials from Ohio Department of Transpportation

STATE OF OHIO DEPARTMENT OF TRANSPORTATION

MSE WALL INSPECTION CHECKLIST

District [ ] Date Inspected [ ] Name of Inspector [ ]

Is MSE wall at a bridge? (Y/N) [ ] County [ ] Route [ ] Section [ ] L/R [ ] RA/FA [ ] End Sec. [ ]

Instructions are on the 2nd page.

Yes No N/A		Measure-ment
	Joints	
○ Y ○ N ○ X	1. Is sand or gravel coming out of joints or are there piles of sand or gravel at the base of the wall? (Photos 2 & 3)	
○ Y ○ N ○ X	2. Is sand or gravel visible in the horizontal joints? (Photo 4)	
○ Y ○ N ○ X	3. Are the joints wide enough to see the sand, gravel or fabric behind the panels when looking perpendicular to the wall face using a flashlight? (Photo 5) If yes, record the approximate maximum joint width, in inches.	
○ Y ○ N ○ X	4. If fabric is visible in the joints, is it torn? IMPORTANT - DO NOT POKE OR CUT THE FABRIC.	
○ Y ○ N ○ X	5. Do the joints have a nonuniform size, or are some joints noticeably wider than others? (Photo 6)	
○ Y ○ N ○ X	6. Are the panels offset at the joints either in or out of the wall? (Photo 7) If yes, record the approximate maximum offset.	
○ Y ○ N ○ X	7. Is there vegetation growing in the joints? (Photo 8)	
	Wall Facing	
○ Y ○ N ○ X	8. Are there cracks in more than two facing panels? (Photos 9 & 10) If yes, record the approximate number of panels that are cracked.	
○ Y ○ N ○ X	9. Is the face of the wall bowed or bulged? (Photo 11)	
	Drainage	
○ Y ○ N ○ X	10. Are there any signs of water flow along the base of the wall?	
○ Y ○ N ○ X	11. Is there erosion of the embankment at the base of the wall? (Photo 12)	
○ Y ○ N ○ X	12. If there is erosion, is the leveling pad exposed at the base of the wall? (Photo 13)	
○ Y ○ N ○ X	13. Are the catch basins or the catch basin outlets near the wall blocked? (Photo 14)	
○ Y ○ N ○ X	14. Is the roadway drainage system above the wall malfunctioning?	
○ Y ○ N ○ X	15. Does water at the top of the wall collect behind the concrete coping?	
	Top of Wall	
○ Y ○ N ○ X	16. Is there settlement at the top of the wall?	
○ Y ○ N ○ X	17. Are there any open cracks in the concrete coping (not hairline cracks)? If yes, record the approximate maximum crack width.	
○ Y ○ N ○ X	18. Have the construction joints in the concrete coping opened up? (Photo 6) If yes, record the approximate maximum joint width.	
○ Y ○ N ○ X	19. Is there a gap larger than 1 inch between the approach slab and the approach pavement? (Photo 15) If yes, record the approx. max. gap size.	
○ Y ○ N ○ X	20. At abutments, has the joint between the wall coping and the abutment opened up more than two inches? (Photo 16)	

Revised 12/15/2005

STATE OF OHIO DEPARTMENT OF TRANSPORTATION

MSE WALL INSPECTION CHECKLIST

District [ ] [ ] Date Inspected [ ] Name of Inspector

Is MSE wall at a bridge? (Y/N) [ ] [ ] County [ ] Route [ ] Section [ ] L/R [ ] RA/FA [ ] End Sec.

Instructions are on the 2nd page.

Comments

Instructions

1. Enter the District, date inspected, and the name of the inspector.

2. Identify the MSE wall location.
   For MSE walls at bridges, use the section for the bridge in the C/R/S. For twin bridges with separate MSE walls, identify if the MSE wall is on the left or right. Identify if the MSE wall is at the rear or forward abutment.
   For MSE walls away from bridges, use the section at the beginning of the wall in the C/R/S. Identify if the wall is on the left or right of the roadway. Fill in the section for the end of the MSE wall.

3. Inspect the wall and answer the 20 questions. Refer to the example photos to identify the parts of an MSE wall and for guidance as to what to look for. A "Yes" answer to any of the questions may indicate a potential problem with the wall. When required, take an approximate measurement and record it in the box to the right of the question.

4. Take photos showing the entire height of the wall. For long walls, take multiple photos to show the entire length of the wall. For walls at bridges, take one photo of each section of wall.

5. For each "Yes" answer to a question, take a photo that shows the relevant item in sufficient detail to understand the reason for the "Yes" answer.

Necessary equipment

Digital camera, ruler, and flashlight.

STATE OF OHIO DEPARTMENT OF TRANSPORTATION

MSE WALL INSPECTION CHECKLIST
Example Photos

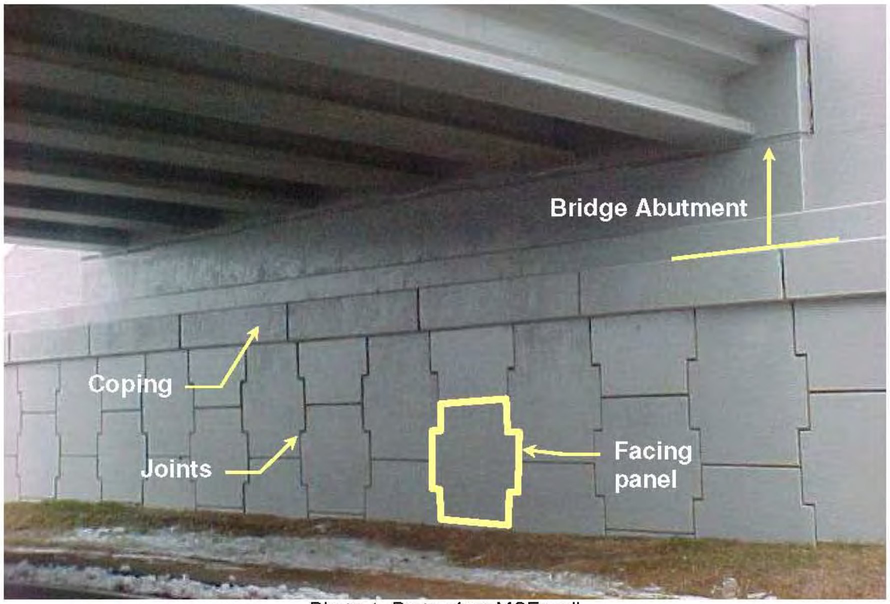


Photo 1. Parts of an MSE wall

Photo 2. Pile of sand at base of slip joint

STATE OF OHIO DEPARTMENT OF TRANSPORTATION
MSE WALL INSPECTION CHECKLIST
Example Photos

Photo 3. Pile of sand at base of wall

Photo 4. Sand in horizontal joint

STATE OF OHIO DEPARTMENT OF TRANSPORTATION

MSE WALL INSPECTION CHECKLIST

Example Photos

Photo 5. Filter fabric visible in joint

Photo 6. Nonuniform joint sizes and open joints in coping

STATE OF OHIO DEPARTMENT OF TRANSPORTATION
MSE WALL INSPECTION CHECKLIST
Example Photos

Photo 7. Panels offset at the joint

Photo 8. Vegetation growing in the joints

STATE OF OHIO DEPARTMENT OF TRANSPORTATION

MSE WALL INSPECTION CHECKLIST

Example Photos

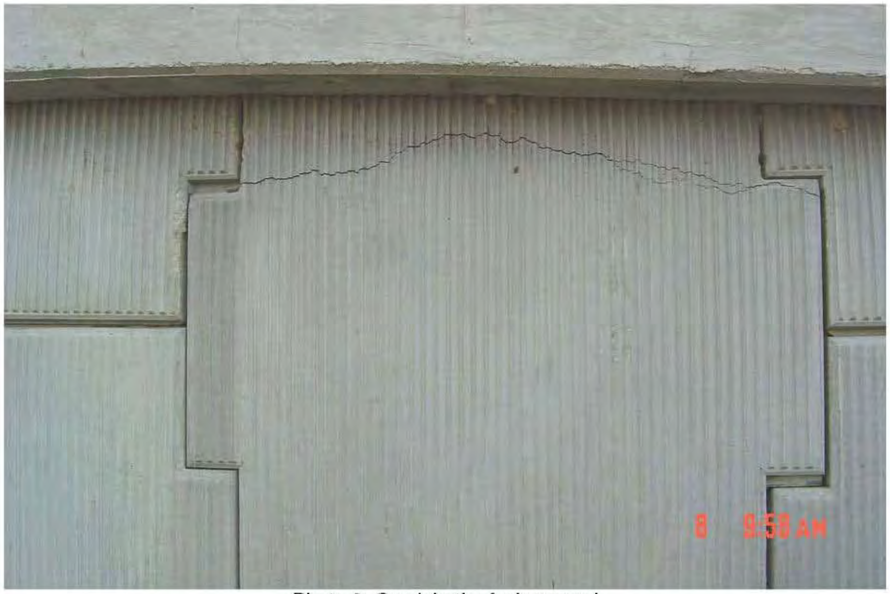


Photo 9. Crack in the facing panel


Photo 10. Cracks in the facing panel

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MSE WALL INSPECTION CHECKLIST

Example Photos

Photo 11. Bowed wall face

Photo 12. Severe erosion along the wall

STATE OF OHIO DEPARTMENT OF TRANSPORTATION
MSE WALL INSPECTION CHECKLIST
Example Photos

Photo 13. Leveling pad has been exposed by erosion

STATE OF OHIO DEPARTMENT OF TRANSPORTATION
MSE WALL INSPECTION CHECKLIST
Example Photos

Photo 14. Blocked catch basin outlet

STATE OF OHIO DEPARTMENT OF TRANSPORTATION

MSE WALL INSPECTION CHECKLIST

Example Photos

Photo 15. Large gaps at the approach slab

Photo 16. Opened joint between coping and abutment

Materials from Utah Department of Transportation

Example MSE Wall Evaluation Form (Plan/Drainage View and Cross-Section sheets not shown)

STATE OF UTAH MSE WALL INSPECTION FORM

Compiled as Part of Research for the Utah Department of Transportation

Instructions:

1-Fill out required sections for MSE Wall Inspector and Wall Characteristics.

2-Inspect the wall using the attached form. Questions that require a 'Yes' answer should be documented by noting the extent of the problem in the right most column and photo documentation Photo documentation should consist of or bridge number. nature of problem, date, photo number for wall, and a size reference, which should be indicated in the photo (white board/paper). Photos taken should be placed on the Top View layout and indicated with the appropriate number. Note should be taken by the inspector that often anomalies are due to construction and should be distinguished from those that are a result of post-construction. If it is observable that they existed at the time of construction note should be taken in the space provided for drawings.

3- Shoot digital photos of the entire wall. This may require the use of a variety of shots and angles on each wall to cover the wall in its entirety.

4- Indicate Layout of MSE Wall in respect to major intersections, roadways, potential hazards, irrigation, vegetation, locations of conditions for which 'Yes' was marked, etc. in space provided below. Also Indicate approximate GPS Coordinates of Site of Interest in space provided below

Inspector Information

Inspection Date		**Names Of Inspectors**	
Region		**Identifying Road/Intersection**	

MSE WALL CHARACTERISTICS

MSE Wall at Bridge	**Y N**	**Bridge Number if applicable:**		**Wall Number**	
Surrounding Structures			Maximum Height of Wall (ft)		
Distance to Each Structure			One Stage, Two Stage or Block Wall		
State Route Number			Estimated Max Length of Wall Abutment		
Approximate Mile Marker			Max Slope of Ground in front of wall		
GPS Datum	WGS/84, NAD/83, or NAD/27		Max Height of wall burial line above surrounding level ground		
MSE Wall GPS Coordinates (Location of Measurement shown on plan view)			Please draw rough layout of panel with approximate dimensions in space provided below:		
If known, Panel or System Manufacturer					
Are there coupons availabe for this wall? If so, how many?					

Summary of Key Observations:

SPECIFIC WALL CHARACTERISTICS

DRAINAGE

Required Tools: Nylon Mallet-Water Bottle-Camera-Tape Measure

Yes	No	N/A	UKN	Issue	Measurement / Explanation (if applicable)	Percentage of Wall Affected / Extent of Problem / Photo #
Y	N	N/A	UKN	Is there an active water source near the toe of the wall (is the wall near a body of water with scour potential?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	If applicable, are the catch basins at the base of the wall blocked?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Are there culverts protruding through the wall?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Are there vertical drains that travel through the backfill?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there erosion at the base of the wall or leveling pad?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there erosion along the wing walls?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Are there any signs of water flow along the base of the wall?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there less than 14 feet between irrigation sprinklers and wall?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Does the backfill or joint fabric appear to be saturated?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there vegetation growing in panel joints?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Are the deck drains and outlets at the top of the wall blocked?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Can water enter the wall between coping and slab (i.e.. Drain appropriately)?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there evidence at discharge point of fill washing through drain pipes?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%

MSE WALL JOINTS

Required Tools: Long Level-String-Camera-Tape Measure

Yes	No	N/A	UKN	Issue	Measurement / Explanation (if applicable)	Percentage of Wall Affected / Extent of Problem / Photo #
Y	N	N/A	UKN	Is backfill coming out of joints or are there piles of backfill at the base of the wall?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Are the joints wide enough to see fabric or backfill behind panels when looking into joints? If yes, record the approximate maximum joint width in inches.		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is exposed backfill visible in the horizontal joints?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Are there visible tears in the fabric?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there evidence of backfill or water leaking through tears in fabric behind panels? (Do not induce additional damage to fabric)		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Do the joints have a non-uniform horizontal spacing/size? (I,e. Are some horizontal joints larger/smaller than others?)		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Do the joints have a non-uniform vertical spacing/size? (I,e. Are some horizontal joints larger/smaller than others?)		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum offset.		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Does the fabric appear brittle, or appear as if it has undergone excessive UV exposure?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%

SPECIFIC WALL CHARACTERISTICS

WALL FACING

Required Tools: Long Level-String-Camera-Crack Gauge-Tape Measure

Yes	No	N/A	UKN	Issue	Measurement / Explanation (if applicable)	Percentage of Wall Affected / Extent of Problem / Photo #									
Y	N	N/A	UKN	Were the panels built using "Tilt-Up" construction? Is there excessive cracking in the panels?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Is there excessive cracking in panels?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are there cracks that continue vertically through adjacent panels?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are there cracks that continue horizontally through adjacent panels?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are the panel corners making contact with each other?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are the panel corners "popped-off" or chipped from contact with adjacent panel(s)?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Does crack spacing suggest differential settlement?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Does the overlying coping exhibit vertical offset?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are the coping and parapets loose or detaching?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are the panels in danger of falling off?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Do the panels exhibit bulging? If so, record maximum deformation from accessible coping to leveling pad.		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Is there 'tipping' at the top or bottom of the wall? (Record maximum degree of tipping from azimuth using vertical level).		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Is there excessive degradation of wall panels?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%

MSE TOP OF WALL

Required Tools: Long Level-Crack Gauge-Camera-Tape Measure

Yes	No	N/A	UKN	Issue	Measurement / Explanation (if applicable)	Percentage of Wall Affected / Extent of Problem / Photo #									
Y	N	N/A	UKN	Is there evidence of settlement at the top of the wall (pavement cracking, etc)?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are there any non-hairline cracks in the concrete coping? If yes, record the approximate maximum crack width.		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Have the construction joints in the concreting coping opened up? If yes, record the maximum joint width.		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Is there a large gap between the approach slab and pavement? If yes, record the approximate maximum gap size.		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	At the abutments, has the joint between the wall coping and abutment opened up significantly? If so record maximum distance		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Is the coping wall pulling away from pavement and roadway section? Please record maximum displacement for wall.		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%

SPECIFIC WALL CHARACTERISTICS

FOUNDATION CONDITIONS AND EXTERNAL STABILITY

Required Tools: Shovel. GEO-Probe-Tape Measure

Yes	No	N/A	UKN	Issue	Measurement / Explanation (if applicable)	Percentage of Wall Affected / Extent of Problem / Photo #
Y	N	N/A	UKN	What is the burial depth of leveling pad? (push geo-probe into ground 2-in from wall face to minimum depth of wall embedment)		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is the leveling pad exposed?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there cracking in the leveling pad? If so, record maximum crack size with gage.		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there a four foot bench (level slope) along the base of the wall before the slope changes? If not record width of bench?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there a slope steeper than H: 1.5 to V:1 behind the wall? Please record slope		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there a slope greater than V 1.5 to H:1 below in front of the wall? Please record slope.		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%

CORROSION

Required Tools: Nylon Mallet-Camera-Zip Lock Bag-Trowel-Tape Measure

Yes	No	N/A	UKN	Issue	Measurement / Explanation (if applicable)	Percentage of Wall Affected / Extent of Problem / Photo #
Y	N	N/A	UKN	Is there excessive corrosion on guardrails or other exposed metal that might indicate corrosive conditions?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Are there significant rust stains on face of the wall? Along joints?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Are any internal straps exposed?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	If exposed, does there appear to be corrosion on straps?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Was a resistivity sample taken of soil? If so, please indicate depth taken in inches.		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there indication of rebar corrosion (i.e, swelling bars, rust, exposed metal inside epoxy coating)?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%

SPECIFIC WALL CHARACTERISTICS

IMPACT AND COLLISION

Required Tools: Camera

Yes	No	N/A	UKN	Issue	Measurement / Explanation (if applicable)	Percentage of Wall Affected / Extent of Problem / Photo #									
Y	N	N/A	UKN	Are guardrails wall protections in place at the base of the wall (to protect it from potential traffic hazards)?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Does it appear that the wall has been involved in an accident (replaced panel, recent dings in the wall)?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Does it appear the walls functionality and integrity has been compromised by a collision or accident?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%

MISCELLANEOUS

Required Tools: Available drawings-Camera-Tape Measure

Yes	No	N/A	UKN	Issue	Measurement / Explanation (if applicable)	Percentage of Wall Affected / Extent of Problem / Photo #									
Y	N	N/A	UKN	Are there acute wall angles (_90)?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are there available drawings for the wall? Please indicate type (Situation and Layout, Design, As Built, etc.)		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Is the layout in general accordance with drawings?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are the panels CIP (Cast in Place)?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Was Geofoam used in the construction of the wall?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are there any structures on or near wall that were not included in initial drawings?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are there any irrigation, utilities, or intrusions that are not part of the initial drawings?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Have there been any excavations or evidence of excavations near the wall?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Have local property owners changed the dynamics of the wall (additional structures, irrigation, vegetation, etc.)?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are there piles or other bridge support systems located in the wall (bridge abutment)?		0/No	1%	5%	10%	25%	50%	75%	90%	95%	100%

Abbreviations used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 437

Assessing the Long-Term Performance of Mechanically Stabilized Earth Walls

A Synthesis of Highway Practice

CONSULTANT
Travis M. Gerber
URS Corporation
Salt Lake City, Utah

SUBSCRIBER CATEGORIES
Bridges and Other Structures • Highways • Maintenance and Preservation • Railroads

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TRANSPORTATION RESEARCH BOARD

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Academies was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP SYNTHESIS 437

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NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program, conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council.

The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

The opinions and conclusions expressed or implied in this report are those of the researchers who performed the research and are not necessarily those of the Transportation Research Board, the National Research Council, or the program sponsors.

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FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice*.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Jon M. Williams
Senior Program Officer
Transportation Research Board

Mechanically stabilized earth (MSE) walls are retaining walls that rely on internal reinforcement embedded in the backfill for stability. This study addresses methods currently used to assess long-term performance of MSE walls, where "long-term" denotes the period of time from approximately one year after the wall is in service until the end of its design life. The focus of the study is on state and federal agency wall inventories, including methods of inspection and assessment of wall conditions.

Information was gathered through a literature review, agency survey, and selected interviews.

Travis M. Gerber, URS Corporation, Salt Lake City, Utah, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

APPENDIX E IS WEB-ONLY AND CAN BE FOUND AT WWW.TRB.ORG, SEARCH ON “NCHRP SYNTHESIS 437.”

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

ASSESSING THE LONG-TERM PERFORMANCE OF MECHANICALLY STABILIZED EARTH WALLS

SUMMARY

Mechanically stabilized earth (MSE) walls are an important class of infrastructure assets whose long-term performance depends on various factors. As with most all other classes of assets, MSE walls need periodic inspection and assessment of performance. To date, some agencies have established MSE wall monitoring programs, whereas others are looking for guidance, tools, and funding to establish their own monitoring programs. The objective of this synthesis project is to determine how transportation agencies monitor, assess, and predict the long-term performance of MSE walls.

The information used to develop this synthesis came from a literature review together with a survey and interviews. Of the 52 U.S. and 12 Canadian targeted survey recipients, 39 and five, respectively, responded.

This synthesis reveals that unlike bridges and pavements, MSE walls and retaining walls in general are often overlooked as assets. Fewer than one-quarter of state-level transportation agencies in the United States have developed some type of MSE wall inventory beyond that which may be captured as part of their bridge inventories. Fewer still have the methods and means to populate their inventories with data from ongoing inspections from which assessments of wall performance can be made.

In the United States, there is no widely used, consistently applied system for managing MSE walls. Wall inventory and monitoring practices vary between agencies. This synthesis examines existing practices concerning the nature, scope, and extent of existing MSE wall inventories. It also examines the collection of MSE wall data, including the types of performance data collected, how they are maintained in wall inventories and databases, the frequency of inventory activities, and assessment practices relevant to reinforcement corrosion and degradation. Later parts of this synthesis discuss how MSE wall performance data are assessed, interpreted, and used in asset management decisions.

This synthesis finds that the most well-implemented wall inventory and assessment system in the United States is the Wall Inventory Program developed by FHWA for the National Park Service. However, this system, like some others, uses “condition narratives” in a process that can be somewhat cumbersome and subjective. Other systems use more direct numeric scales to describe wall conditions, and an advantage of such systems is that they are often compatible with those used in assessments of bridges.

As experience with MSE walls accumulates, agencies will likely continue to develop, refine, and better calibrate procedures affecting design, construction, condition assessment, and asset management decisions. One portion of this synthesis is dedicated to summarizing the actions taken thus far by survey respondents to improve the long-term performance of their MSE walls. Many agencies prescribe the use of a pre-approved wall design and/or wall supplier. Other actions or policies frequently focus on drainage-related issues.

Also included as part of this synthesis are statements from survey respondents as to what the most important lesson learned by their agency has been. Although the scope of the

responses is broad, certain topics appear more frequently than others, with the four most frequent being (in order of decreasing frequency) drainage, construction, backfill, and modular block issues.

In examining various reported practices for inventorying and assessing the performance of MSE walls, those appearing to be more effective are: (1) use of inventory and assessment systems with features that are simple to use and as objective as possible; (2) use of rating criteria that are specific to particular wall elements and/or conditions; (3) use of numeric rating scales that correspond to other scales already in use for other asset classes such as bridges; and (4) the incorporation of MSE wall inventory and assessment systems into systems for other asset classes.

An important conclusion of this synthesis is that there exists a need for greater recognition of MSE walls (and retaining walls in general) as important infrastructure assets. In the same vein, a greater number of agencies need to be actively involved in MSE wall inventory and assessment activities, and for greatest benefit there should be greater consistency across agencies relative to the way that these activities are performed. The synthesis also finds that performance assessment methodologies need to be more fully developed; similarly, service life prediction and risk assessment methodologies need to be developed. To realize such goals, it appears that greater funding and allocation of other resources is needed. In follow-up discussions regarding the synthesis survey, multiple participants expressed a hope that such increased awareness and resource allocation can be realized without significant, adverse-performance events such as those that led to the legislative creation and ongoing funding of the nation’s bridge inspection and assessment programs.

CHAPTER ONE

INTRODUCTION

BACKGROUND AND OBJECTIVE

Mechanically stabilized earth (MSE) walls were introduced in the United States about 40 years ago (see Elias et al. 2001). As the technology has improved and gained wider recognition, the number of MSE walls designed and constructed has increased dramatically; however, the long-term performance of these structures depends on various factors, and unfortunately there have been instances of adverse performance. Like every important class of assets, MSE walls need periodic inspection and assessment of performance. To date, some states have established MSE wall monitoring programs, while several others are looking for guidance, tools, and funding to establish their own monitoring programs. This synthesis project is undertaken to determine how state transportation agencies monitor, assess, and predict the long-term performance of MSE walls. This project provides information regarding current methodologies and procedures relating to the following topics:

- Inspection and evaluation of the condition of existing MSE walls along the states' highways;
- Maintenance of design and construction information;
- Recording and applying the results of inspections in each department's centralized database;
- Monitoring corrosion in MSE walls with inextensible steel reinforcement;
- Monitoring degradation of geosynthetics;
- Maintenance of internal and external drainage;
- Assessment of wall performance and evaluation of the consequences of failure based on these inspection and monitoring programs;
- Identification of preservation strategies that can reduce the likelihood of failure of MSE walls;
- Assessment of the key causal factors that affect performance; and
- Use of wall data to make programming decisions.

It is anticipated that this information will lead to better design, construction, monitoring, and maintenance of these important structures. This project can benefit many state agencies by combining the lessons learned from experienced states with the experience and innovative practices of academicians, MSE wall designers, and contractors as presented in technical literature.

For the purposes of this synthesis, the following definitions are used:

- *MSE wall*: Retaining walls that rely on internal reinforcement embedded in the backfill for stability. The reinforcement is attached to the wall's face, which confines the backfill. The reinforcement can be either metallic (strips or meshes) or geosynthetic (fabrics or grids). Soil nail or anchor walls are not considered to be MSE walls for the purposes of this synthesis.
- *Panel MSE wall*: Either one- or two-stage MSE walls that have concrete facing panels; internal soil reinforcement is usually metallic.
- *One-stage MSE wall*: A MSE wall that uses a concrete panel attached to the internal reinforcement to retain the backfill. The panel is in direct contact with the backfill.
- *Two-stage MSE wall*: A MSE wall that uses a metallic mesh or grid and geosynthetic liner attached to the internal reinforcement to retain the backfill. A concrete panel is subsequently attached to the vertical mesh. The panel is not in direct contact with the retained backfill. This wall type is typically used where settlements are expected to be relatively large.
- *Block MSE wall*: A MSE wall that uses a modular block facing attached to the internal soil reinforcement (which is often geosynthetic), and is often referred to as a segmental block wall.

The focus of this synthesis document is the long-term performance of MSE walls, where the term "long-term" nominally refers to the period of time from shortly after construction and acceptance of the MSE wall until the end of the design life, which is typically 75 or 100 years. The term "performance" is used in this report to refer to the behavior as well as the functionality and serviceability of a wall. Poor or adverse performance includes any performance that is less than that intended (e.g., serviceability limits are exceeded) and can structurally be manifest as small to large distortions, cracking, and even collapse.

METHODS OF STUDY

This synthesis project has gathered relevant information through (1) a literature review; (2) a survey of U.S. state and Canadian provincial transportation agencies, as well as other select entities (e.g., FHWA); and (3) interviews with select agencies. The scope of information collected addresses both permanent block and panel types of MSE walls, the latter of which consists of both one- and two-stage varieties. Both extensible and inextensible internal wall reinforcements are also considered.

Although the current body of literature contains many descriptions and references to the monitoring and assessment of MSE walls, much of that literature relates to conditions existing during and immediately after construction. For example, case histories are sometimes presented for particular MSE walls where foundation or geometric conditions are perceived as being particularly adverse or even unique and thus necessitating analytical and/or field studies to validate the adequacy of current design or construction processes (e.g., Reddy et al. 2003; Stuedlein et al. 2010). In other instances, MSE wall performance literature is simply the result of the "observation method" (see Peck 1969) being applied and documented for ordinary wall conditions. One also finds case histories and/or forensic assessments of walls that failed (e.g., Bay et al., 2009; Koerner and Koerner 2009; Holtz 2010). Although indirectly related to long-term performance of MSE walls, the literature also contains construction/inspector manuals (e.g., Passe 2000) as well as guidance for the use and deployment of instrumentation for assessing performance during and soon after construction (e.g., Koerner and Koerner 2011). In examining the literature, one also finds academic studies in which walls are monitored throughout the construction process and immediately thereafter (perhaps a year) with the goal of improving design techniques (e.g., Allen and Bathurst 2001). As stated previously, the focus of this synthesis document is the longer-term performance of MSE walls; hence, discussion of this previously referenced portion of literature is minimal.

In addition to the literature review, U.S. state and Canadian provincial level transportation agencies were surveyed. The survey questionnaire is presented in Appendix A. The survey was web-based and administered through the Internet. The questionnaire was designed to balance comprehensiveness with conciseness to maximize benefit while minimizing response effort, which is essential in achieving a high response rate. Thirty-nine of the 52 U.S. and five of the 12 Canadian targeted recipients responded; they are listed in Appendix B. Follow-up interviews with select agencies were undertaken to provide additional details and insights into survey responses.

ORGANIZATION OF REPORT

This report is organized into six chapters and four appendices. Chapter one presents the background and objectives of this synthesis project, explains the methods used, and outlines the remainder of this document. Drawing on the results of the literature review, survey questionnaire, and select interviews, chapter two describes the state of MSE wall inventory practice with particular emphasis on the nature, scope, and extent of existing inventories. Chapter three discusses the collection of MSE wall data, including the types of performance data collected and maintained in wall inventories and databases, the frequency of inventory activities, and aspects relating to reinforcement corrosion and degradation. Chapter four reviews how MSE wall performance data are assessed, interpreted, and used in asset management decisions. The chapter also discusses practices of estimating design life and risk assessment for MSE walls. Chapter five presents actions reported by transportation agencies and others to improve the long-term performance of MSE walls. This chapter also presents what survey respondents believe is their greatest lesson concerning long-term performance of MSE walls. Finally, in chapter six, a summary of the key findings of this synthesis project is presented, including the state of practice relative to the long-term performance of MSE walls. Other items presented include the direction of the states of practice, effective practices inferred from the literature review and survey respondents, and areas needing improvement and/or research. The appendices include a copy of the survey questionnaire, a list of survey respondents, and examples of existing methodology and tools developed and provided by agencies (e.g., inspection forms, rating or scoring worksheets, and assessment guidelines).

CHAPTER TWO

STATE OF MECHANICALLY STABILIZED EARTH WALL INVENTORY PRACTICE

INTRODUCTION

As with bridges and pavements, retaining walls are an essential component of our transportation infrastructure. However, unlike pavement and bridges, retaining walls (of which MSE walls are a growing subclass) are often overlooked as an asset.

Proper asset management is essential to making informed, cost-effective program decisions and optimizing existing highway resources. The Roadway Data Highway Performance Management System (HPMS) is a national transportation data system that provides detailed data on highway inventory, condition, performance, and operations. It describes functional characteristics, traffic levels, and pavement conditions for all interstate highway system sections. In addition to the HPMS, at least 36 individual state departments of transportation (DOTs) collect basic pavement inventory data, while more than 41 DOTs collect some type of data relative to pavement fatigue and cracking as part of their pavement management systems (Cambridge Systematics et al. 2009).

With respect to bridges, the federal government has mandated the creation and maintenance of the National Bridge Inventory (NBI), which contains data on all bridges and culverts on or over U.S. roads that are greater than 20 ft long. These bridges are also inspected every two years per the National Bridge Inspection Standards (NBIS). In contrast, there is no dedicated management system addressing the whole of the nation's retaining walls, MSE or otherwise. Indeed, although asset management guidance is provided for highway features such as pavements, bridges, culverts, guardrails, and drainage structures in the Asset Management Data Collection Guide developed in conjunction with AASHTO (2006), retaining walls are not addressed—despite there being an estimated 16.3 million square meters of various types of walls along the nation's highways with values ranging from approximately $200 to $2,000 per square meter (DiMaggio 2008). With respect to MSE walls specifically, Berg et al. (2009) indicated that an average of 850,000 square meters of MSE wall with precast facing is built each year in the United States, along with an additional 280,000 square meters of modular block wall. Also, according to Berg et al. (2009), typical total costs for permanent transportation-related MSE walls range from $320 to $650 per square meter of wall face, and modular block walls less than 4.5 m high are less expensive by 10% or more. Elias et al. (2004) placed the cost of MSE walls in the somewhat lower range of $160 to $300 per square meter.

During the preparation of this synthesis, two documents were found to be of particular interest to users of this synthesis, thus meriting specific mention. The first document, *Guide to Asset Management of Earth Retaining Structures*, by Brutus and Tauber (2009), is the product of a study conducted for the AASHTO Standing Committee on Highways, with funding provided through NCHRP Project 20-07. This publication presents methodologies and considerations aimed at helping transportation agencies establish asset management programs for earth retaining structures (of which MSE walls are a component), with particular focus on the development of inventories and inspection programs. The publication also presents the results of a survey similar to the one performed for this synthesis regarding the inventory, inspection, and asset management activities of transportation agencies concerning their earth retaining structures. The second document is *National Park Service Retaining Wall Inventory Program* (*WIP*)*—Procedures Manual,* by DeMarco et al. (2010b). This document represents the efforts of the FHWA Office of Federal Lands Highway, working with the National Park Service (NPS), to develop and implement a retaining wall inventory and condition assessment program [collectively referred to as the Wall Inventory Program (WIP)]. The document describes in detail the data collection and management processes, wall attribute and element definitions, and team member responsibilities for conducting retaining wall inventories and condition assessments as derived from experiences involving nearly 3,500 walls. Although MSE walls constitute only a small fraction of the walls involved in the development of the FHWA's WIP, much of the material in this document is applicable and/or transferable to matters associated with the long-term performance of MSE walls.

PARTIES WITH RESPONSIBLE CHARGE FOR MECHANICALLY STABILIZED EARTH WALLS

MSE walls are multidisciplinary in nature, having both structural and geotechnical components. Once constructed, maintenance concerns are introduced. To develop and maintain an effective inventory, some party must first take responsibility

TABLE 1
PARTY HAVING RESPONSIBLE CHARGE FOR MSE WALLS ONCE THE WALLS ARE CONSTRUCTED AND ACCEPTED (most representative response)

Response	Number	Percent
Structural engineer(s) or similar at an agency-wide level	3	7
Structural engineer(s) or similar at a regional or district level	3	7
Geotechnical engineer or similar at an agency-wide level	3	7
Geotechnical engineer(s) or similar at a regional or district level	0	0
Maintenance engineer or similar at an agency-wide level	4	9
Maintenance engineer(s) or similar at a regional or district level	18	41
No one has this charge	6	14
Other (specify)	7	16

for the walls. As shown in Table 1, when queried regarding who has responsible charge for MSE walls once the walls are constructed and accepted, 41% of survey respondents noted it was a maintenance engineer at a regional or district level. Those who responded "other" generally indicated a mixed or shared responsibility among the various structural (i.e., "bridge"), geotechnical, and maintenance professionals. Approximately 14% of respondents indicated that no one in their agencies has responsibility for MSE walls after construction and acceptance.

AGENCIES HAVING INVENTORIES

Several questions of the survey for this synthesis project focused on the nature and extent of transportation agencies' MSE wall inventories. Thirty (more than two-thirds) of survey respondents indicated that they do not maintain a specific MSE wall inventory. Of the 14 respondents who do have inventories (listed here), 43% reported that the inventory is partial, limited to specific geographic areas, or constrained in some other way. (Although not survey respondents, the states of Ohio, Pennsylvania, and Washington also appear to have at least partial MSE wall inventories. Alberta, Canada, reports "defined problem sites" as a type of wall inventory.)

- Alberta, Canada
- California
- Colorado
- Kansas
- Minnesota
- Missouri
- Nebraska
- New York
- North Carolina
- North Dakota
- Ontario, Canada
- Tennessee
- Utah
- Wisconsin.

In reporting what types of MSE walls are included in their inventories, 100%, 71%, and 86% named one-stage panel walls, two-stage panel walls, and block walls, respectively. The majority of panel walls possess metallic reinforcement. Some wall inventories are also maintained by city-level agencies. The cities of Cincinnati, Ohio; New York City, New York; and Seattle, Washington, all maintain retaining wall inventories, including MSE walls. FHWA has developed a wall inventory and database for the National Park Service listing more than 3,500 walls, some of which are MSE walls.

Although a minority of agencies appear to maintain well-defined MSE wall databases (and fewer still have regular inspections to inform the database beyond the basic identifying information), some limited MSE wall inventory and performance data are apparently maintained by some agencies. Additionally, some MSE wall inventory and performance data are inherently contained in the NBI and are accessible in software database applications such as PONTIS or other agency-maintained databases. These "overlooked" MSE walls would typically be those that serve as bridge abutments or are considered integral to the performance of the bridge structure. These databases contain basic wall information such as spatial dimensions, construction date, and some type of performance rating of bridge support, but greater detail may be lacking. Once recognized, bridge inventory data may be a starting point for developing MSE wall inventories and performance assessments.

NATURE AND SCOPE OF INVENTORIES

Agencies that have established MSE wall inventories appear to own between 100 and 1,000 MSE walls (with mean and median values of 508 and 400, respectively). However, as explained by Gerber et al. (2008), wall counts can be problematic. Single wall segments at a bridge abutment might be treated as an individual wall, whereas at other times one abutment and two adjoining wing-wall segments might be designated as a single wall.

> Consequently, at a bridge abutment with one MSE wall segment beneath the bridge and two MSE wall segments serving as wing-walls on either side, one could count either one or three walls. If one considers a similar configuration for the other abutment,

one could assign one, three, or six wall numbers to the MSE wall segments present at a bridge site. (There could be even more than six if additional walls segments were used to support the exterior sides of ramps.)

In the literature, there appears to be little consensus regarding methodologies for individual wall designations. However, several sources suggest that whatever system is used to identify and count walls, physically tagging the walls with identifiers is a helpful practice.

Different agencies use different criteria when determining what MSE walls to count and/or include in their inventory/database. Brutus and Tauber (2009) provide extended discussion of various possible criteria, which commonly include wall height, proximity to the roadway, batter or face slope, wall ownership, structural type, and proximity to bridges or culverts. The main criteria used by FHWA's WIP are related to jurisdiction (e.g., is the wall along a qualifying road?), proximity of wall relative to roadway, wall height, wall embedment, and wall face angle. [The WIP uses a wall face angle criterion of 45 degrees or greater so that some rockeries and slope protection buttressing are included in the inventory, whereas FHWA (see Berg et al. 2009) typically defines a retaining wall as having an internal face angle greater than or equal to 70 degrees to differentiate walls from reinforced slopes.] The FHWA program also advises that when wall acceptance based on the aforementioned criteria is marginal or difficult to discern, "include the wall in the inventory, particularly where the intent is to support and/or protect the roadway or parking area and where failure would significantly impact the roadway or parking area and/or require replacement with a similar structure." Based on synthesis survey results shown in Table 2, most inventories include only those walls owned by the agency. Only 57% include walls not associated with a specific bridge or culvert. When a wall height criterion is used, 1.2 or 2 m are the most frequent threshold values.

In evaluating the comprehensiveness of inventory databases they currently maintain, transportation agencies report that between 10% and 100% (mean and median of 70% and 78%, respectively) of the walls that satisfy their inclusion criteria are accounted for (Table 11 subsequently shows this information by agency). The particular content contained in each respective database varies and is discussed in the next chapter. As mentioned previously, some MSE wall inventory information and performance data are inherently contained in the NBI. These MSE walls would typically be those that serve as bridge abutments or are considered integral to the performance of the bridge structure. Generally, walls that are not within the vertical projection of the bridge deck and are not constructed integrally with either wing-walls or abutments are not included in bridge assessment activities.

Table 3 summarizes who in an agency principally manages/maintains its inventory of MSE walls. Most frequently it is a geotechnical engineer or similar person at an agency-wide level. This may be inconsistent as Table 1 indicates that maintenance engineers at a regional or district level are the individuals who have responsibility for MSE walls once they are built. It thus appears that there may be a disconnect between those considered responsible for MSE walls and those actually doing the work of asset management. However, such an arrangement need not be problematic; multiple parties can be involved in MSE wall management provided there is a clear understanding that responsibility for the asset may lie in a place other than the location of the data or even the expertise used to collect and/or evaluate the data. Communication and understanding of individual responsibilities would obviously be essential for an effective inventory and assessment program.

Inventories can be maintained in various formats and manipulated using various tools. The current state of practice is summarized in Table 4, which lists the variety of

TABLE 2
CRITERIA USED TO DETERMINE WHAT MSE WALLS TO INCLUDE IN INVENTORY
(multiple responses possible)

Response	Number	Percent
Wall owned by my agency	14	100
Wall owned by others but adjacent to facilities for which my agency is responsible	4	29
Wall owned by others but may negatively impact adjacent facilities for which my agency is responsible	1	7
Wall is associated with a bridge structure	12	86
Wall is associated with a culvert	7	50
Wall is not associated with a bridge or culvert	8	57
Minimum wall height	6	43
Minimum height of retained earth	2	14
Minimum wall length	1	7
Minimum wall area	0	0
Other (specify)	2	14

TABLE 3
PARTY WHO PRINCIPALLY MANAGES/MAINTAINS INVENTORY OF MSE WALLS
(most representative response)

Response	Number	Percent
Structural engineer(s) or similar at an agency-wide level	4	29
Structural engineer(s) or similar at a regional or district level	0	0
Geotechnical engineer or similar at an agency-wide level	5	36
Geotechnical engineer(s) or similar at a regional or district level	0	0
Maintenance engineer or similar at an agency-wide level	0	0
Maintenance engineer(s) or similar at a regional or district level	3	21
Other (specify)	2	14

methods used to manage MSE wall inventories, with preferences given to simple spreadsheets or MS access-type databases.

The potential range of information maintained as part of an MSE wall inventory is broad. Data regarding wall location and geometry are perhaps the most common elements, but depending on the use of the inventory/database, other information might be maintained, including wall features, construction data, and inspection information. Brutus and Tauber (2009) suggest that information such as dates of construction and repairs, geometric wall dimensions, wall materials including backfill type, specific element types and manufacturers, as-built and shop drawings, specifications, quality control test data, and inspection reports be included. They also suggest that a wall database should include basic traffic-volume data. Hearn (2003) offers similar suggestions.

Table 5 summarizes the frequency at which different types of information is collected and/or maintained by surveyed agencies as part of their wall inventories. The most frequently tracked metrics are wall location by route/milepost and wall type. These metrics are followed by date constructed, reinforcement type, and shop drawings. Given that degradation and/or corrosion of reinforcement is a primary concern of agencies (as revealed in a subsequent section of this report), it is logical that these two particular and apparently coupled metrics are among the more frequently tracked items. Information regarding maintenance does not appear to be systematically maintained by any party.

CONSTRAINTS ON INVENTORY DEVELOPMENT AND ASSET MANAGEMENT ACTIVITIES

During oral interviews with select survey participants, the participants frequently identified the lack of a government/legislative directive along with the lack of allocated funding as significant impediments either to initially developing their MSE wall inventory or subsequently populating it with performance data from inspection activities. Although some increasing awareness and impetus toward asset management for retaining walls appears to have existed in the early to mid-2000s (partially characterized by the development and distribution of informational brochure "Earth Retaining Structures and Asset Management," developed by FHWA (2008), it appears that the economic downturn of 2008 through the present has largely halted those efforts. In Colorado, for example, a plan for implementing a state-wide monitoring program for all types of retaining walls and sound walls was developed for the state DOT (Hearn 2003). Although the feasibility report concluded that "no impediment [was] found to full development of standard data and procedures for walls and sound barriers," little progress toward implementation has been made as yet because of funding constraints. DOTs in Oregon (see Turner 2008), Nebraska, Ohio, and Utah have simi-

TABLE 4
PRIMARY TOOL USED AS AN ASSET MANAGEMENT SYSTEM FOR MSE WALL INVENTORY (most representative response)

Response	Number	Percent
File boxes/cabinets	3	21
Spreadsheet	4	29
MS Access database without GIS support	3	21
Oracle database without GIS support	1	7
PONTIS	1	7
Other non-GIS supported database (specify)	2	14
GIS-based software (specify)	0	0

TABLE 5
TYPES OF DATA AGENCIES GENERALLY COLLECTED OR MAINTAINED FOR MSE WALLS (multiple responses possible)

Response	Number	Percent
Location by Street Address	3	21
Location by Latitude/Longitude	4	29
Location by Route, Milepost	7	50
Location by State Plane Coordinates	1	7
Wall Type	6	43
Wall Function	3	21
Wall Geometrics—Maximum Wall Height	4	29
Wall Geometrics—Average Wall Height	4	29
Wall Geometrics—Wall Length	4	29
Wall Geometrics—Slope in Front of Wall	2	14
Wall Geometrics—Slope Behind Wall	2	14
Wall Geometrics—Road/Traffic Offset	3	21
Date Constructed	5	36
Manufacturer	4	29
Contractor/Installer	1	7
Reinforcement Type	5	36
Drainage Conditions—Proximity of External Water Sources	0	0
Drainage Conditions—Location and Condition of Drainage Points	2	14
Nature of Adjacent Facilities Owned by Agency	1	7
Nature of Adjacent Facilities or Utilities Owned by Others (e.g., railroad)	0	0
Characterization of Adjacent Roadway Traffic	2	14
Design Data	1	7
Construction Data—Plans	4	29
Construction Data—Specifications	2	14
Construction Data—Shop Drawings/Submittals	5	36
Construction Data—Inspection Documentation	2	14
Construction Data—As-Builts	4	29
Post-construction Modifications	1	7
Photographs	4	29
Condition of Structure—External Inspection Data	3	21
Condition of Structure—Internal (e.g., corrosion) Inspection Data	0	0
Maintenance Activities	0	0
Other (specify)	1	7

larly reported that initially developed and/or implemented plans could not be sustained. In the mid-1980s, California's DOT (Caltrans) established procedures and responsibilities for monitoring, sampling, and testing the MSE wall structures; however, in 1997, budgetary constraints eliminated the program. Some MSE wall inspections continue, but the process is not systematic. New York State's DOT is an exception to this trend; its inventory and assessment efforts date to 1985, when the state began an initial field evaluation and inventory of its MSE walls out of corrosion concerns (Wheeler 2002).

In follow-up discussions regarding the synthesis survey, many respondents expressed hope that increased awareness and resource allocation could be achieved before any significant, adverse events such as those that led to the creation and ongoing support of the nation's bridge inspection and assessment programs.

CHAPTER THREE

COLLECTION OF MECHANICALLY STABILIZED EARTH WALL DATA

At perhaps its most basic level, effective asset management consists of three components: (1) data collection; (2) data assessment and interpretation; and (3) taking action consistent with asset performance goals. Each of these three components is constrained by available resources. This chapter will focus on the data collection component.

TYPES OF DATA CONTAINED IN WALL INVENTORIES/DATABASES

Not all data are helpful in meeting asset management goals. Rather, the appropriate data must be collected—data that can be reliably quantified and assessed so that meaningful conclusions regarding performance can be drawn. In practice, data collection often focuses on potential symptoms of adverse performance and is obtained during field investigations and inspections. Alzamora and Anderson (2009) provide a review of MSE wall performance issues based on their experience with FHWA. They particularly identified geometry/wall layout, obstructions, wall embedment, surface drainage, backfill placement and compaction, panel joints, leveling pad, and durability of facing as potential problem areas. Consistent with their findings, most data collection efforts currently undertaken relate to the condition and performance of these particular elements.

Several agencies have developed guidance manuals and/or inspection forms for gathering post-construction wall performance data. Examples of some of these materials developed by FHWA (DeMarco et al. 2010b), Nebraska (Jensen and Arthur 2009; Nebraska Department of Roads 2009), Ohio (Ohio Department of Transportation 2007), and Utah (Bay et al. 2009) are provided as examples in web-only Appendix E. There are also MSE wall inspection manuals that focus on installation/construction issues (e.g., New York State Department of Transportation 2007), but these usually do not explicitly address long-term wall performance.

A feature common to several of the above-cited manuals is the use of photographs illustrating the nature of a particular feature needing identification (such as a sand cone in front of a wall joint, indicative of backfill migration) and/or quantification of its severity (minor verses major amounts of concrete degradation). The picture and the manuals themselves serve a calibration purpose when multiple individuals are involved in data collection; without a common baseline, data scatter can be excessive, particularly when the metric is subjectively quantified (i.e., not directly measurable).

Perhaps the best documented, large wall inventory program in the United States is FHWA's Wall Inventory Program (WIP). Extensive guidance and discussion concerning data collection methods are presented in the WIP *Procedures Manual* (DeMarco et al. 2010b). The WIP *Procedures Manual* emphasizes that "collected wall data must be accurate, concise and descriptive." Photographic documentation during data collection efforts is also encouraged. For MSE wall types, data collection and rating focuses on the following primary wall elements: wire/geosynthetic facing, concrete panels, manufactured block, wall foundation materials, and wall drains. Applicable secondary wall elements include road/shoulders, upslope, downslope, and lateral slope. Rather than being numeric in nature or measurement-based, the condition data collected for each wall element consist of a written "condition narrative," which is "a concise, descriptive narrative of element condition sufficient to characterize severity, extent, and urgency of element distresses" (DeMarco et al. 2010a). To help ensure consistency, these narratives use terminology and definitions consistent with the types of potential distress described in Figure 1.

As seen in this figure, element ratings reflect observational wall condition data relative to four distress categories: corrosion/weathering, cracking/breaking, distortion/deflection, and lost bearing/missing elements. These narratives are later converted to a numerical "condition rating" ranging from 1 to 10 using the descriptions shown in Table 6. This process is subjective, and rating variances among inspectors are reported to be within plus-or-minus two rating points for a given element.

In the FHWA WIP, a general wall performance rating is also determined along with the element condition ratings. This rating scheme is shown in Table 7. Use of the wall performance rating is illustrated using the following example from the WIP procedures manual (DeMarco et al. 2010b, p. 101):

> For example, an MSE wall with a geogrid-wrapped face shows little sign of specific element distress (geogrid and backing geotextile are largely unweathered, drains are working, etc.). However, the wall is differentially settling at one end, as evidenced by a 3- to 6-inch vertical sag extending full-height in the wall face. A tension crack has begun to open at the top of the wall just beyond the estimated length of reinforcements, further indicating a global or external wall failure mechanism is actively

WALL ELEMENT CONDITION RATING GUIDANCE

GOOD TO EXCELLENT
(minor to no distress, minimal to no impact, few to no occurrences)

Corrosion/Weathering
- No evidence of corrosion/staining, contamination, or cracking/spalling due to weathering or chemical attack.
- Compacted, placed or masoned rock, and associated chinking, is dense, angular, fresh, and without post-placement fracturing or chemical degradation.
- No significant weathering/weakening of bedrock, softening of soil, or saturated ground conditions evident.
- No impacts from vegetation noted within the wall or within adjacent elements.

Cracking/Breaking
- No evidence of element cracking, breaking, or construction/post-construction damage, opening of discontinuities in rock, or cracks or gullies in soils.
- Concrete, shotcrete, and mortar is sound, durable, and shows little or no signs of shrinkage cracking or spalling.
- Drains are clearly open (flowing), and in full working order.

Distortion/Deflection
- Wall elements are as constructed, and/or show no signs of significant settlement, bulging, bending, heaving, or distortion/deflection beyond normal prescribed post-construction limits.

Lost Bearing/Missing Elements
- No wall elements are missing.
- Wall elements are fully bearing against retained soil/rock units.
- Foundation soils/rock are more than adequate to support the wall, consistently dense, drained and strong.
- No slope failures have occurred either removing or adding materials from the wall area.

FAIR
(moderate distress, significant to substantial impact, multiple occurrences)

Corrosion/Weathering
- Moderate corrosion/staining, contamination, or cracking/spalling due to weathering or chemical attack.
- Compacted, placed or masoned rock is not fresh or angular, showing significant weathering, post-placement fracturing, chemical degradation, and/or localized loosening.
- Significant weathering/weakening of bedrock rock, softening of soil, or saturated ground conditions evident.
- Moderate impacts from vegetation are evident within the wall or within adjacent elements.

Cracking/Breaking
- Localized element cracking, breaking, abrasion and/or construction/post-construction damage, opening of discontinuities in rock, or cracks or gullies in soils.
- Concrete, shotcrete, and mortar is occasionally soft or drummy, has lost durability, and shows occasional cracking and/or spalling sufficient to intercept reinforcement.
- Drains cannot be clearly determined to be fully operational.

Distortion/Deflection
- Wall elements show significant localized settlement, bulging, bending, heaving, misalignment, distortion, deflection, and/or displacement beyond normal prescribed post-construction limits (e.g., wall face rotation, basket bulging, anchor head displacement, bin displacement).

Lost Bearing/Missing Elements
- Some wall elements are missing (e.g., chinking, lagging, brickwork) or non-functional.
- Wall elements are generally bearing against retained soil/rock units, but localized open voids may exist along the back and top of the wall.
- Foundation soils/rock are adequate to support the wall, but susceptible to shrink-swell, erosion, scour, or vegetation impacts.
- Isolated slope failures have occurred either removing or adding materials from the wall area.

POOR TO CRITICAL
(severe distress, failure is imminent, pervasive occurrences)

Corrosion/Weathering
- Metallic wall elements are corroded and have lost significant section affecting strength.
- Concrete/shotcrete is extensively spalled, cracked, and/or weakened, and may show evidence of widespread aggregate reaction.
- Compacted, placed, or masoned rock is highly weathered, showing extensive post-placement fracturing, chemical degradation, and/or loosening within the placed volume.
- Extensive weathering/weakening of bedrock, softening of soil, or saturated ground conditions evident.
- Severe impacts from vegetation are evident within the wall or within adjacent elements.

Cracking/Breaking
- Extensive severe element cracking, breaking, abrasion or construction/post-construction damage, opening of discontinuities in rock, or cracks or gullies in soils.
- Concrete, shotcrete, and mortar is consistently soft, drummy, or missing, has lost durability and strength, and shows pervasive cracking and/or spalling intercepting corroding/weathering reinforcement.
- Drainage is missing, clearly damaged, and/or obviously clogged and non-functional.

Distortion/Deflection
- Wall elements show extensive settlement, bulging, bending, heaving, distortion, misalignment, deflection, and/or displacement well beyond prescribed post-construction limits, including loss of ground reinforcement and retention.

Lost Bearing/Missing Elements
- Many or key wall elements are missing (e.g., placed wall stone, chinking, lagging) or non-functional.
- Many or key wall elements are no longer bearing against retained soil/rock units, with visible open voids evident behind a large portion of the wall.
- Foundation soils/rock show signs of failure, excessive settlement, scour, erosion, substantial voids, bench failure, slope over-steepening, and/or may be adversely impacted by vegetation.
- Substantial slope failures have occurred either removing or adding materials from the wall area.

FIGURE 1 Element condition narrative guidance (DeMarco et al. 2010b).

TABLE 6
NUMERICAL CONDITION RATING DEFINITIONS FOR WALL ELEMENTS IN FHWA WALL INVENTORY PROGRAM

Rating	Rating Definition
9 to 10 Excellent	No-to-very low extent of very low distress. Defects are minor, are within the normal range for newly constructed or fabricated elements, and may include those resulting from fabrication or construction. In practice, ratings of 9 to 10 are only given to elements with very minor to no distress whatsoever—conditions typically seen only shortly after wall construction or substantial wall repairs.
7 to 8 Good	Low-to-moderate extent of low severity distress. Distress does not significantly compromise the element function, nor is there significant severe distress to major structural components. In practice, ratings of 7 to 8 indicate highly functioning wall elements that are only beginning to show the first signs of distress or weathering. For example, a ten-year-old soldier pile wall may have moderately extensive minor surface corrosion on piles where protective paint has weathered and peeled, and may have wood lagging beginning to split. Distresses are very low overall, present over a modest amount of the wall, and do not require immediate or near-term attention.
5 to 6 Fair	High extent of low severity distress and/or low-to-medium extent of medium to high severity distress. Distress present does not compromise element function, but lack of treatment may lead to impaired function and/or elevated risk of element failure in the near term. In practice, ratings of 5 to 6 indicate functioning wall elements with specific distresses that need to be mitigated in the near-term to avoid significant repairs or element replacement in the longer term. For example, numerous anchor struts holding MSE wire facing elements in place are beginning to break due to corrosion and suspected over-stressing of the connections at the time of construction. Although the overall function of the reinforced earth wall is not in jeopardy, failing wall facing baskets are allowing facing fill to spill out. If several overlying baskets experience this isolated element failure, significant wall face sag and deformation may result at the top of the wall, eventually impacting the overlying guardrail installation. This element should be inspected carefully along the entire wall and repaired as needed to forestall further facing basket deterioration.
3 to 4 Poor	Medium-to-high extent of medium-to-high severity distress. Distress present threatens element function, and strength is obviously compromised and/or structural analysis is warranted. The element condition does not pose an immediate threat to wall stability and closure is not necessary. In practice, a rating of 3 to 4 indicates marginally functioning, severely distressed wall elements in jeopardy of failing without element repair or replacement in the near-term. For example, mortar throughout a historic stone masonry wall is cracked, spalling, highly weathered, and often missing. Individual stone blocks are missing from the wall face, and adjacent blocks show signs of outward displacement. Although not an immediate threat to overall wall stability, stone block replacement and repointing throughout the wall in the near-term are necessary to forestall rapid wall deterioration.
1 to 2 Critical	Medium-to-high extent of high severity distress. Element is no longer serving intended function. Element performance is threatening overall stability of the wall at the time of inspection. In practice, a rating of 1 to 2 indicates a wall that is no longer functioning as intended, and is in danger of failing catastrophically at any time. For example, a 15-ft-tall cast-in-place concrete cantilever wall has a large open horizontal crack running the full length of the wall at the base of the stem. Vertical cracks are also beginning to open up in the wall face. Water is seeping from most wall cracks, and is running from the basal horizontal crack at several locations. The wall face has rotated outward, resulting in a negative batter of several degrees. The overlying guardrail is highly distorted above the wall and the adjacent roadway is showing significant settlement above the retained fill. The wall is in imminent danger of failing catastrophically, requiring the overlying roadway be closed to all traffic until the wall can be replaced or retained soil backslope can be stabilized.

Source: DeMarco et al. (2010b).

developing. The inspecting engineer describes the overall wall performance as 'low,' providing appropriate narrative describing the state of global distress, and rates the wall performance at a '4' per the rating definitions.

As discussed in the next chapter, these element condition ratings combined with the wall performance ratings create an overall wall performance rating ranging from 5 to 100, and these ratings are used in assessment management decisions.

Although not quite as detailed as the FHWA WIP just presented, Brutus and Tauber (2009) have also developed a guide to asset management of earth structures. They indicate that conditions listed here could be indicative of wall stress or deterioration, and recommend that the precise vertical and horizontal locations where these conditions are observed should be documented. Brutus and Tauber also suggest that a severity or priority rating such as (1) low, (2) moderate, (3) high, or (4) urgent be assigned as conditions are assessed in the field.

TABLE 7
WALL PERFORMANCE RATINGS

Rating	Rating Definition
7 to 10 Good to Excellent	No combinations of element distresses are observed indicating unseen problems or creating significant performance problems. No history of remediation or repair to wall or adjacent elements is observed.
5 to 6 Fair	Some observed global distress is not associated with specific elements. Some element distress combinations are observed that indicate wall component problems. Minor work on primary elements or major work on secondary elements has occurred improving overall wall function.
1 to 4 Poor to Critical	Global wall rotation, sliding, settlement, and/or overturning are readily apparent. Combined element distresses clearly indicate serious stability problems with components or global wall stability. Major repairs have occurred to wall structural elements, though functionality has not improved significantly. Severe distresses are apparent on adjoining roadways.

Source: DeMarco et al. (2010b).

- Wall or parts of it out of plumb, tilting, or deflected
- Bulges or distortion in wall facing
- Some elements not fully bearing against load
- Joints between facing units (panels, bricks, etc.) are misaligned
- Joints between panels are too wide or too narrow
- Cracks or spalls in concrete, brick, or stone masonry
- Missing blocks, bricks, or other facing units
- Settlement of wall or visible wall elements
- Settlement behind wall
- Settlement or heaving in front of wall
- Displacement of coping or parapet
- Rust stains or other evidence of corrosion of rebar
- Damage from vehicle impact
- Material from upslope rockfall or landslide adding to load on wall
- Presence of graffiti (slight, moderate, heavy)
- Drainage channels along top of wall not operating properly
- Drainage outlets (pipes/weepholes) not operating properly
- Any excessive ponding of water over backfill
- Any irrigation or watering of landscape plantings above wall
- Root penetration of wall facing
- Trees growing near top of wall.

Another data collection/wall inspection process has been developed by the Nebraska Department of Roads. In this methodology (Nebraska Department of Roads 2009), the MSE wall features that are assessed are:

- Wall tilting
- Structural cracking
- Facial deterioration
- Bowing of the wall
- Panel staining
- Exposure of fabric
- Loss of backfill
- Erosion in front of wall
- Erosion in back of wall
- Joint spacing
- Condition of "v-ditch" (i.e., drainage way at top of wall)
- Coping deterioration
- Drainage runoff
- Drainage at the front of the wall.

A rating scale ranging from zero to 9 (consistent with most bridge assessment procedures) is provided to describe the extent or severity of each feature. For example, with respect to loss of backfill, the following ratings descriptions are used: (zero)—backfill loss has resulted in significant settlement of the v-ditch or roadway or has affected wall inclination or alignment; (3)—significant areas/quantities of backfill loss are visible; (6)—backfill loss is occurring, but only minor areas/quantities of backfill loss are visible; and (9)—no visible evidence of backfill loss. Numeric rating descriptions are unique to each type of feature or condition being assessed and can be found in the materials in Appendix E (web-only).

The MSE wall inspection program in Ohio has focused data collection activities on observed problems, particularly sand leaking from joints, settlement of panels (largely from erosion of underlying support), uncontrolled drainage, and deteriorating panels (Narsavage 2006). The inspection program focuses on 23 potential symptoms (e.g., signs of water flow along the base of the wall) associated with wall joints, wall facing, drainage, and conditions at the top of the wall (see inspection form in web-only Appendix E). Condition ratings consist of simple "yes" or "no" responses. After its first inspection effort completed in 2006, Ohio reported that of the state's 339 inspected walls, nearly one-third exhibited backfill migrating through wall joints and 13% exhibited some type of erosion problem.

Utah's MSE wall data collection largely follows the Ohio model. As shown on the inspection form provided in (web-only) Appendix E, data collection efforts focus on features and conditions believed to affect or reflect wall performance; namely, drainage, wall joints, wall facing, conditions at top of wall, foundation conditions and external stability, corrosion and degradation, impact and collision, and miscellaneous issues. As in Ohio, condition ratings consist of simple “yes” or “no” responses; however, the extent of the symptom/issue is quantified as a percentage of the total wall. Some of Utah’s inspection queries relate directly to two-stage MSE walls, which are widely used in the state.

The Pennsylvania DOT (PennDOT; see Pennsylvania Department of Transportation 2010) has a well-defined retaining wall inspection program conducted in conjunction with its bridge inspection program. (Bridge and retaining wall data are maintained in the same management system.) The program involves all walls, not just those at bridges. One wall element receiving particular focus in PennDOT’s inspection process is a button-head connection present in some first-generation MSE walls, because the cold-formed button head details were found to develop micro-cracks that contributed to the failure of the button head. The following directives relating to MSE walls are specified in the PennDOT inspection manual:

> Mechanically Stabilized Earth (MSE) retaining walls should be inspected for evidence of wall movement.
>
> - Examine barrier and moment slab for evidence of movement as well as the MSE wall for evidence of bulging, bowing, or panel offset.
> - Perform a survey if movement is suspected to compare to initial inspection data to gauge amount of movement.
> - Examine the roadway above MSE walls for indications of failing pavement or tension cracking. These may indicate a loss of fill. For MSE walls in front of sloping backfill, the crest of the embankment should be investigated for soil stress or failure, both of which may indicate settlement or wall movement.
>
> The joints between panels of MSE walls are to be inspected and examined for loss of backfill, change in spacing, and indications of settlement. The specification requirement for joint spacing is a maximum three-quarters of an inch.
>
> - Inspect walls for evidence of backfill loss (piles of aggregate at the base of the wall).
> - Indicate visibility of backfill or fabric behind the panel through joints.
> - Examine for evidence of damage to the geotextile fabric, if visible.
> - Look for variation in joint spacing. Note vegetation growing in joints.
> - Vertical slip (expansion joints) used on long lengths of walls should be investigated similar to panel joints. The initial spacing at the slip joint should be determined from design, shop, or as-built drawings.
>
> Wall panels shall be checked for cracking, spalling, other forms of deterioration, and collision damage.
>
> - Drainage systems through or along MSE walls should be inspected to verify water is free flowing into and out of the appropriate facility.
> - Ensure that weep holes are free draining.
> - Inspect all inlets to verify water is draining into the inlet, and flowing freely to the inlet and out of the outlet. Examine inlets for cracks.
> - Inspect visually or use down hole cameras (as appropriate) for all culverts and pipes contained or having portions in, behind, or above the MSE wall mass and for pipes or culverts which run above, adjacent to, or outlet through the MSE walls to verify pipes are free draining and water is flowing through (and not under or around) the pipe. Examine drainage pipes for cracking or damage with emphasis on areas where water may flow, or is flowing, into the MSE wall soil mass. Inspect outlet ends to verify free drainage or for evidence of migration of fill or other material.
> - Inspect swales above the MSE wall. Verify rock fall or other materials (trees, etc.) are not blocking, redirecting, or restricting the flow of water through the drainage ditch above the MSE wall to the appropriate receptacle.
> - Inspect collection and outlet basins to verify water is draining freely. Look for any signs of infiltration or migration of material which may prevent water from draining from the wall.
> - Identify inappropriate appearance of water along the base of the wall (i.e., if water is appearing when weather conditions have been particularly dry). Note areas where there is inappropriate collection and/or lack of drainage for water along the length of the MSE wall.
> - Note erosion of soil along the base of the wall exposing or undermining the leveling pad.

In the Pennsylvania methodology, observed conditions are then translated into ratings (shown in Table 8) that are assigned to the following MSE wall elements/items:

- Anchorage
- Backfill
- Wall conditions such as bulging, joint conditions, deterioration of face panels, connection of the backs, etc.
- Panels
- Drainage
- Foundation
- Parapets.

Data collection and inspection schemes are inherently rooted in the experience and judgment of their developers. In the city of Seattle, Washington, for example, instances of

TABLE 8
PERFORMANCE RATINGS ASSIGNED TO WALL ELEMENTS IN PENNSYLVANIA INSPECTION/ASSESSMENT PROCESS

Rating	Rating Definition
8	Good condition. No apparent problems.
6	Satisfactory condition. Structural elements sound. Localized drainage problems, settlement, staining, washing of fines from backfill material.
4	Poor condition. Localized buckling, deteriorated face panels, joint problems, major settlement, ice damage.
2	Critical. Major structural defects, components have moved to point of possible collapse.

adverse retaining wall performance were observed to accompany (or even be manifest as) excess wall tilt. Consequently, wall tilt measurements using a digital protractor are a principal component of Seattle's inspection program (Molla 2009). To help ensure comparable and consistent data, tilt measuring stations are permanently established on many walls. Another example of how experience affects data collection activities is the scope and frequency of inspections specified for MSE walls in Pennsylvania. An in-depth inspection including a three-dimensional spatial survey of the wall is required every 10 to 15 years. This requirement arises largely from global stability and creep concerns stemming from local geologic conditions in the state—more particularly along Route 22/322 in Lewistown Narrows, where one of the longest MSE walls in the United States has been constructed. PennDOT has also implemented new technology as part of its data collection efforts. In 2008 and 2009, Lidar technology using a fixed-wing aircraft was used to assess the amount of creep that the Lewiston Narrows wall was experiencing. Unfortunately, the goal of 0.10 ft (30 mm) proved difficult to confirm because of the low altitude required within the canyon. The technology may be retried using a helicopter instead.

Other examples of using new technologies to monitor the performance of MSE walls include the incorporation of fiber-optics into geosynthetic reinforcement (Lostumbo and Artieres 2011). Various structural health monitoring tools now being built into bridges can readily be adapted for retaining walls. New technologies such as these will become increasingly more common in wall performance data collection and assessment efforts.

The general state of practice with respect to which MSE wall features or components are examined during data collection activities, based on survey respondents, is shown in Table 9. Only three of the 17 respondents to the associated survey question reported having some type of inventory. Responses suggest that the wall features or conditions most frequently examined by agencies are wall plumbness, bulging or distortion of the wall facing, and cracking of facing elements. As can be seen subsequently in Table 16, these features/conditions correlate well to those distress/failure modes which are believed most important or significant relative to wall performance. Eight of the 11 responses provided as "other" features were simple declarations that the particular respondent did not collect any such data. Two more

TABLE 9
MSE WALL FEATURES AND/OR CONDITIONS ASSESSED AS PART OF DATA COLLECTION AND MONITORING ACTIVITIES (multiple responses possible)

	Only Agencies with Inventories		All Respondents to Particular Question	
Response	Number	Percent	Number	Percent
Wall plumbness	2	67	5	29
Bulging or distortion of wall facing	2	67	5	29
Alignment and spacing of joints between facing elements	2	67	4	24
Cracking of facing elements	2	67	5	29
Damage to corners of facing elements	2	67	4	24
Damage from vehicular impact	1	33	3	18
Settlement along line of wall	1	33	4	24
Settlement behind wall	1	33	4	24
Distress in ground or pavement in front of wall	1	33	2	12
Distress in ground or pavement behind wall	1	33	3	18
Displacement of coping or parapet	2	67	3	18
Rust stains or other external evidence of corrosion	1	33	3	18
Functionality of drainage/catch basin	1	33	2	12
Functionality of internal drainage features (e.g., weepholes and piping)	1	33	2	12
External erosion	2	67	3	18
Internal erosion of backfill	1	33	2	12
Changes to wall geometry (e.g., excavation at toe, add surcharge load)	1	33	3	18
Vegetation growth	0	0	1	6
Internal corrosion/degradation of reinforcement	1	33	2	12
Other (specify)	0	0	11	65

of these responses indicated that feature assessment was only performed in response to observed wall distress, while the remaining response clarified that wall features were examined as part of their bi-annual bridge inspection activities.

FREQUENCY OF FIELD INSPECTIONS AND MONITORING ACTIVITIES

The condition and performance of MSE walls vary over time. Because of this, it is important that data collection and assessment activities be conducted routinely. According to the NBIS, bridges are inspected at two-year intervals. Some agencies have adopted similar two-year inspection intervals for retaining walls. Other agencies such as New York City require privately owned retaining walls to be inspected every five years. Kansas typically assesses its MSE walls at three-year intervals, whereas Oregon's plan calls for inspection of "good" walls of all types every five years, and "fair" or "poor" walls more often. Between 1986 and 1997, California had established five- to ten-year inspection intervals for MSE wall elements, particularly internal reinforcement elements.

PennDOT takes a tiered approach, with a "routine" wall inspection every five years and an "in-depth" inspection (which includes a three-dimensional survey for MSE walls more than 100 ft long and more than 20 ft high) at either 10- or 15-year intervals. Unscheduled "special" inspections are to be performed after a significant event, such as a vehicular collision, extreme weather, or indication of wall movement. Similarly, the FHWA's WIP directs that all walls should be inspected on a maximum 10-year cycle, and walls having performance issues are subject to more frequent inspection and assessment work, particularly those subject to "qualifying emergency relief events" such as a landslide or flood. PennDOT defines a routine inspection as "a close visual and hands-on examination of retaining walls and their drainage systems without traffic control. Those portions which cannot be accessed safely from beyond the edge of pavement are viewed using binoculars and/or a digital camera." In contrast, an in-depth inspection consists of "a close visual and hands-on examination of retaining walls and their drainage systems. Use of down-hole cameras or visual inspection of larger pipes is required for the drainage system."

Based on their study, Brutus and Tauber recommend a five-year interval for routine inspections (i.e., inspections conducted "in the absence of any special condition or circumstance that makes it prudent to inspect more often"). Selection of an inspection interval for a specific wall involves considerations of any known occurrence of adverse performance; wall age (older walls may require more frequent inspections); presence of questionable backfill (that may lead to settlement or internal corrosion concerns); and occurrence of flooding, earthquake, or vehicle damage. Principles of risk management dictate that walls whose failure would produce significant consequences are candidates for more frequent inspection.

When survey respondents were asked, "Which of the following statements best describes your agency's MSE wall performance monitoring activities?" (as shown in Table 10), the overwhelming response was that such activities were generally in response to specific instances of adverse performance. The remainder indicated that assessments were performed, but not always including all MSE walls in their inventory. This appears to suggest that, contrary to the practices and recommendations previously discussed, the frequency of monitoring activities appears to be largely driven by resource availability and/or in response to incidents of adverse performance.

Table 11 summarizes some interrelationships between those agencies that have reported the establishment of MSE wall inventories, the extent of those inventories, and the nature of their ongoing monitoring activities. As can be seen in this table, more than half of the agencies reporting MSE wall inventories only monitor their walls in response to known incidents of adverse performance. Just over one-quarter of agencies having inventories regularly inspect or assess most or all of those walls. From these data, it appears that once MSE wall inventories are initially developed, additional information relative to ongoing performance is generally either not collected or not assessed for most walls. (As pointed out previously, there is no uniform standard for designating and counting MSE walls).

COLLECTION OF CORROSION AND DEGRADATION DATA

A distinguishing feature of MSE walls relative to other retaining wall types is the reinforcement in the retained soil mass. The stability of the wall depends on the integrity of the reinforce-

TABLE 10
BEST DESCRIPTION OF AGENCY'S MSE WALL PERFORMANCE MONITORING ACTIVITIES

Response	Number	Percent
Reactive to reported incidents of adverse performance	32	73
Irregular inspection/assessment of some MSE walls	3	7
Regular inspection/assessment of some MSE walls	4	9
Irregular inspection/assessment of most or all walls in inventory	1	2
Regular inspection/assessment of most or all walls in inventory	4	9

TABLE 11
RELATIONSHIPS BETWEEN THOSE AGENCIES WITH MSE WALL INVENTORIES, THE SCOPE OF THOSE INVENTORIES, AND NATURE OF ONGOING MONITORING ACTIVITIES

Agency	Number of Walls	Percent Walls in Inventory	Best Description of Monitoring Activities
Alberta, Canada	300	10	Reactive to reported incidents of adverse performance
California	400	75	Reactive to reported incidents of adverse performance
Colorado	800	60	Reactive to reported incidents of adverse performance
Kansas	300	50	Regular inspection/assessment of most or all walls in inventory
Minnesota	300	60	Reactive to reported incidents of adverse performance
Missouri	899	100	Reactive to reported incidents of adverse performance
Nebraska	—[1]	10	Regular inspection/assessment of most or all walls in inventory
New York	635	100	Regular inspection/assessment of most or all walls in inventory
North Carolina	275	97	Regular inspection/assessment of most or all walls in inventory
North Dakota	100	100	Irregular inspection/assessment of most or all walls in inventory
Ontario, Canada	500	100	Regular inspection/assessment of some MSE walls
Tennessee	1000	50	Reactive to reported incidents of adverse performance
Utah	700	80	Reactive to reported incidents of adverse performance
Wisconsin	400	85	Reactive to reported incidents of adverse performance

[1]Data missing.

ment, which can be either relatively extensible geosynthetic materials or inextensible metallic straps or meshes. Because of the reinforcement's criticality, many MSE performance assessments focus on the reinforcement, which can be challenging since the reinforcement is buried and not directly observable. Also problematic is corrosion, which is a rate process affected by multiple factors. If certain other factors are assumed, wall age might serve as a proxy parameter for corrosion and remaining service life. However, premature failures illustrate potential shortcomings of relying on such assumptions.

Several U.S. state agencies have undertaken reinforcement corrosion studies. Table 12 presents a brief summary, slightly expanded from that prepared and presented by Fishman and Withiam (2011) of these various efforts. It can be noted that the corrosion issues reported in Nevada resulted from a now-outdated backfill specification rather than current AASHTO backfill specifications, and care must be taken when interpreting adverse performance of walls constructed using early design methods. Detailed descriptions of the corrosion monitoring activities of California, Florida, New York, and North Carolina are presented in Elias et al. (2009). It is interesting to note the correlation between agencies that have developed MSE wall inventories and those that have experienced MSE wall corrosion issues (and have subsequently developed monitoring programs).

Corrosion monitoring of steel reinforcement is typically accomplished by either retrieval of buried coupons or nondestructive electrochemical methods. With exhumed coupons, corrosion can be assessed by determining weight and section thickness loss, as well as decreases in tensile strength. With electrochemical methods, potential and polarization resistance measurements are made and correlated with dimensions of the reinforcement. In *Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes*, a principal reference in the United States regarding the degradation and corrosion of MSE wall reinforcement, Elias et al. (2009) advise that "given the advantages, utilization of remote electrochemical methods is highly recommended with at least some coupons buried for retrievals to confirm results." Their provided rule of thumb regarding installation is two locations spaced at least 200 ft (60 m) apart for MSE walls 800 ft (250 m) or less in length and three locations for longer walls. At each location, corrosion should be monitored at a minimum of two depths. For extractible coupons (i.e., inspection wires), Caltrans has developed a typical layout of 18 clustered coupons to be periodically extracted (see appendix in Fishman and Withiam 2011). Caltrans has also developed a set of extraction guidelines (California Department of Transportation 2004).

With respect to frequency of assessing corrosion, Elias et al. (2009) recommend that potential and polarization resistance measurements (owing to their sensitive nature) be made monthly for the first three months, bi-monthly for the next nine months, and annually thereafter. This recommended frequency is significantly greater than the frequency at which other wall inspection and data collection activities occur (as described in the previous section). Extractible coupons are typically removed at five- to 15-year intervals, depending on the number of coupons installed. In California's typical

TABLE 12
SUMMARY OF US STATE MSE WALL CORROSION ASSESSMENT PROGRAMS

State	Description
California	Has been installing inspection elements with new construction since 1987, and has been performing tensile strength tests on extracted elements. Some electrochemical testing of in-service reinforcements and coupons has also been performed. Linear polarization resistance (LPR) and EIS tests were performed on inspection elements at selected sites as part of NCHRP Project 24-28 and results compared with direct physical observations on extracted elements.
Florida	Program focused on evaluating the impact of saltwater intrusion, including laboratory testing and field studies. Coupons were installed and reinforcements were wired for electrochemical testing and corrosion monitoring at 10 MSE walls. Monitoring has continued since 1996.
Georgia	Began evaluating MSE walls in 1979 in response to observations of poor performance at one site located in a very aggressive marine environment incorporating an early application of MSE technology. Exhumed reinforcement samples for visual examination and laboratory testing. Some in situ corrosion monitoring of in-service reinforcements and coupons at 12 selected sites using electrochemical test techniques was also performed.
Kentucky	Developed an inventory and performance database for MSE walls. Performed corrosion monitoring including electrochemical testing of in-service reinforcements and coupons at five selected sites.
Nevada	Condition assessments and corrosion monitoring of three walls at a site with aggressive reinforced fill and site conditions. Exhumed reinforcements for visual examination and laboratory testing; performed electrochemical testing on in-service reinforcements and coupons. A total of 12 monitoring stations were dispersed throughout the site providing a very good sample distribution.
New York	Screened inventory and established priorities for condition assessment and corrosion monitoring based on suspect reinforced fills. Two walls with reinforced fill known to meet department specifications for MSE construction are also included in program as a basis for comparison. Corrosion monitoring uses electrochemical tests on coupons and in-service reinforcements.
North Carolina	Initiated a corrosion evaluation program for MSE structures in 1992. Screened inventory and six walls were selected for electrochemical testing including measurement of half-cell potential and LPR. This initial study included in-service reinforcements, but coupons were not installed. Subsequent to the initial study, NCDOT has installed coupons and wired in-service reinforcements for measurement of half-cell potential on MSE walls and embankments constructed since 1992. LPR testing was also performed at approximately 30 sites in cooperation with NCHRP Project 24-28.
Ohio	Concerned about the impact of their highway and bridge de-icing programs on the service life of metal reinforcements. Performed laboratory testing on samples of reinforced fill but did not sample reinforcements or make in situ corrosion rate measurements.
Oregon	Preliminary study including (1) a review of methods for estimating and measuring deterioration of structural reinforcing elements, (2) a selected history of design specifications and utilization of metallic reinforcements, and (3) listing of MSE walls that can be identified in the ODOT system.
Utah	Extracted 22 wire coupons from one- and two-stage MSE walls all approximately 11 to 12 years old. Galvanization thickness was found to still be greater than initial specified values. Data to provide baselines for future assessments.

After Fishman and Withiam (2011).

TABLE 13
METHOD(S) CURRENTLY USED BY AGENCIES TO ASSESS DEGRADATION/CORROSION OF REINFORCEMENT (multiple responses possible)

	Only Agencies with Inventories		All Respondents to Particular Question	
Response	Number	Percent	Number	Percent
Do not currently assess	2	67	12	86
Linear polarization resistance (LPR) for metallic	0	0	1	7
Extractible coupons for metallic	1	33	2	14
Exhumation for geosynthetic	0	0	0	0
Other (specify)	0	0	0	0

installation, coupons are removed and inspected after five, ten, 20, 30, 40, and 50 years.

For geosynthetic reinforcement, the primary performance issue is polymer degradation. At present, the only effective means of assessment is retrieval of buried specimens. The assessment process involves successive retrieval and testing of samples to determine both mechanical and chemical properties. Strength and elongation (i.e., creep) properties can then be extrapolated to predict future performance. Elias et al. (2009) recommend that sampling and testing occur at five- to seven-year intervals for a minimum of four retrievals, or one-third the expected life of the facility.

The state of practice for assessing degradation and corrosion in MSE walls, as indicated by 14 survey participants who provided specific responses, is shown in Table 13. Three of these respondents indicated that they have their own MSE wall inventories. Based on the information presented in this table and in Table 12, it appears that a minority of agencies assesses corrosion of metallic MSE wall reinforcement, and none systematically assess degradation of geosynthetic reinforcement.

CHAPTER FOUR

ASSESSMENT AND USE OF MECHANICALLY STABILIZED EARTH WALL DATA

After wall condition and performance data have been collected, assessments can be performed to determine how well MSE walls are meeting their performance objective(s). Assessments can also be performed to prioritize maintenance and replacement functions. [As a reference, FHWA (1999) has developed a basic primer regarding assessment management concepts while Bernhardt et al. (2003) have discussed application of these concepts to "geotechnical infrastructure" assets.] Such assessments commonly involve some type of numerical scale or standard set of terms. These scales or terms can be used in quantitative rating algorithms and/or more subjective, qualitative expressions of wall performance. Ideally, these scales ultimately link current wall performance with the wall's position within its design life cycle. This chapter will discuss how wall performance data are assessed and then used for asset management.

ASSESSMENT AND INTERPRETATION OF DATA

Referring again to the established and tested FHWA's WIP, the wall element and performance data collected (as discussed in the previous chapter) are combined with factors measuring the relative importance of each element to establish a final overall wall condition rating, which ranges from 5 to 100. Conversion of this numeric rating to a qualitative description can be approximately achieved by dividing the rating by 10 and comparing it to the element and wall performance rating definitions shown in Table 6 and Table 7, respectively.

Although their origin is not explicitly stated, it appears that the weighting factors used in the WIP were established by some type of consensus of experienced persons. The procedure manual states, "these element weightings have been determined to sufficiently discern element impacts on wall performance. However, as more wall inventory data are collected, weightings will be re-evaluated for appropriateness, and altered as needed to provide meaningful and consistent wall condition ratings."

The FHWA WIP wall condition rating was also cited by Brutus and Tauber (2009) in their consideration of how to quantify wall performance. They also provided the five-point rating scale in Table 14 as another possible sample rating system. In some numeric schemes, adverse performance is indicated by a low rating, whereas in others a low score is desirable. Some MSE wall assessments do not incorporate a type of condition rating, numeric or otherwise. For example, state agencies in Utah and Ohio currently document only the existence of certain adverse conditions.

As part of this synthesis, 44 survey participants provided feedback regarding how important they thought particular wall features and conditions are in assessing the long-term performance of MSE walls. These beliefs are in large measure representative of the relative importance of specific wall condition data and might function similarly to the FHWA WIP weighting factors in a current assessment or prediction of future wall performance. In the survey, relative importance was distinguished using a numerical rating scale where 1 = not important, 2 = mildly important, 3 = moderately important, 4 = very important, and 5 = most important. The results in terms of average rating are shown in Table 15. Also shown is the variance for each feature from the overall mean rating, helping indicate each feature's perceived importance relative to the others.

As can be seen in the table, features associated with drainage (both external and internal) typically are considered to be among the most important. Changes to wall geometry resulting from excavation or addition of surcharge load that would affect global stability are also viewed as being relatively important. Most important, however, is corrosion and degradation of internal reinforcement. This result appears to be consistent with the impetus for the initial establishment of many existing MSE wall inventories—concerns relative to, or premature failures stemming from, corrosion of MSE wall reinforcement. Interestingly, a small panel of MSE wall experts convened by the Utah DOT judged that drainage issues are the most significant issues during the first 15 years or so of wall life, after which corrosion issues become the most important (Bay et al. 2009).

Perhaps most surprisingly, the survey indicated that wall height is considered among the least important—surprising because this parameter is among the more frequently included parameters in wall inventories. This also appears inconsistent with the assessment of Brutus and Tauber (2009) that the most important component contributing to risk stemming from wall failure is the height of the wall. Also surprising is that wall age (as implied from date constructed) is rated as being below average in importance because internal corrosion (the most important factor) is itself a function of age.

TABLE 14
SAMPLE RATING SYSTEM FOR WALL PERFORMANCE

Rating	Description
Excellent	No significant indication of distress or deterioration.
Good	Some indications of distress or deterioration, but wall is performing as designed.
Fair	Moderate or multiple indications of distress or deterioration affecting wall performance.
Poor	Significant distress or deterioration with potential for wall failure.
Critical	Severe distress or deterioration. Indications of imminent wall failure.

Source: Brutus and Tauber (2009).

TABLE 15
RELATIVE IMPORTANCE OF WALL FEATURES/CONDITIONS IN ASSESSING THE LONG-TERM PERFORMANCE OF MSE WALLS

Response	Mean	Variance
Internal corrosion/degradation of reinforcement	4.4	+0.9
Internal erosion of backfill	4.1	+0.7
Wall geometry changes (e.g., excavation at toe, added surcharge load)	4.1	+0.6
Functionality of internal drainage features (e.g., weepholes and piping)	4.0	+0.6
Drainage conditions	4.0	+0.6
Proximity of external water sources (e.g., river, sprinklers, etc.)	3.9	+0.4
Distress in ground or pavement behind wall	3.8	+0.4
Functionality of drainage/catch basins	3.8	+0.3
Bulging or distortion of wall facing	3.7	+0.2
Maximum wall height	3.7	+0.2
Cracking of facing elements	3.6	+0.2
Settlement behind wall	3.6	+0.2
Reinforcement type	3.6	+0.1
Location and condition of drainage discharge points	3.5	+0.1
Rust stains or other external evidence of corrosion	3.5	+0.1
Distress in ground or pavement in front of wall	3.5	+0.1
External erosion	3.5	+0.1
Embedment of wall	3.5	+0.0
Post-construction modifications	3.5	+0.0
Settlement along line of wall	3.5	+0.0
Slope behind wall	3.4	+0.0
Damage from vehicular impact	3.4	+0.0
Slope in front of wall	3.3	–0.1
Alignment and spacing of joints between facing elements	3.3	–0.1
Wall plumbness	3.3	–0.2
Wall type	3.3	–0.2
Damage to corners of facing elements	3.2	–0.3
Presence of bench at toe of wall founded on slope	3.2	–0.3
Road/traffic offset	3.1	–0.3
Displacement of coping or parapet	3.0	–0.4
Date constructed	3.0	–0.5
Manufacturer	2.7	–0.7
Vegetation growth	2.7	–0.7
Average wall height	2.6	–0.8
Wall length	2.3	–1.2

TABLE 16
RELATIVE SIGNIFICANCE OF POTENTIAL FAILURE/DISTRESS MODES IN LONG-TERM PERFORMANCE OF MSE WALLS

Response	Mean	Variance
Global stability	4.3	+0.4
Reinforcement rupture	4.3	+0.4
Reinforcement pullout	4.2	+0.3
Loss of foundation support due to erosion	4.0	+0.1
Loss of foundation support to bearing capacity failure	4.0	+0.1
Excessive settlement	3.8	–0.1
Sliding	3.6	–0.3
Overturning	3.5	–0.4
Facing failure	3.3	–0.6

In addition to the relative importance of certain wall features and conditions, survey participants were also asked to rate how significant they thought certain potential failure/distress modes were relative to the long-term performance of MSE walls. The failure/distress modes were those typically considered in wall design procedures. Significance was rated on a scale of 1 = not significant, 2 = mildly significant, 3 = moderately significant, 4 = very significant, and 5 = most significant. The results, shown in Table 16, indicate that most agencies believe that global stability and reinforcement rupture are the most likely failure modes for MSE walls in the long term. The term “reinforcement rupture” was not specifically defined, but is believed to have been interpreted to include failures resulting from both section loss and subsequent overstressing as well as overstressing of the initial section. The data also suggest that agencies believe overturning and facing failure are the least likely failure modes. This information is important in that these beliefs constitute a type of expert opinion that can be used in MSE wall service life prediction methods as well as in wall failure risk assessments. Both of these activities currently appear to be in their naissance, as discussed later in this chapter.

USE OF PERFORMANCE ASSESSMENTS IN DECISION MAKING

Once wall conditions are assessed and its condition quantified on some basis (such as the FHWA WIP wall condition rating), the assigned rating can be used in more than one way for programming decisions. In some systems, the numeric value can be directly related to a specified action level (e.g., walls rated below 40 must be repaired). In other systems, the numeric value is used for ranking, and resources for items such as maintenance or repair are allocated accordingly (e.g., there is $100,000 in the budget for repairs, which walls do we start with?). In yet other systems, such as the FHWA WIP, the final overall rating is only one of several factors used to make programming decisions. The rating by itself is not directly related to a particular action. Rather, four additional items/questions are considered in the FHWA WIP: (1) are additional investigations required (how reliable is our assessment); (2) what design criteria may have been used in planning the structure (was the structure engineered); (3) what aspects of the wall structure are historic or contribute to the cultural context of the road asset; and (4) what are the consequences of wall failure. These items are subjectively assessed by the person rating the wall with few objectively defined criteria; hence, programming decisions, to which wall condition ratings only partially contribute, are largely subjective in the FHWA WIP.

As stated previously, some MSE wall assessments do not incorporate any condition ratings; therefore, some alternate means of decision making is required. On a comparative wall-to-wall basis, one can tally the number of adverse occurrences per wall and then rank the tallies to establish a type of priority list. Swenson (2010) used the Utah wall inventory data and attempted to improve the ranking processes by associating particular conditions/issues with particular failure modes and then assigning weights to indicate criticality. Unfortunately, the expert input/consensus usually required to link conditions, failure modes, and consequences was limited.

When asked about a specific methodology for assessing long-term performance of existing MSE walls, no survey respondent answered affirmatively beyond citing regular inspections or several corrosion assessment studies. These items appear to be contributing components to a methodology, but no fully developed methods were identified. From the responses gathered and review of available literature, it does appear that some agencies may rely largely on pre-approval product processes and compliance with Highway Innovative Technology Center criteria (see Highway Innovative Technology Center 1998) for assurance that MSE walls will perform adequately. Although such measures should improve the likelihood of good, long-term performance, failure case histories suggest that they are not failsafe.

Estimation of Service Life

In their study, Brutus and Tauber (2009) concluded that “there is no data available in technical literature on the estimate of designed service life or on construction or maintenance operations on old retaining walls built somewhere between 50 to 100 years ago.” MSE walls in the United States are newer than this, yet this statement also appears to apply to those

TABLE 17
SAMPLE RATING SYSTEM FOR CONSEQUENCES OF FAILURE

Rating	Description
Severe	High likelihood of injuries or death from debris falling on a heavily traveled roadway, on other heavily used adjacent areas, or from collapse of structures near top of wall. High likelihood of extensive or total-loss damage to vehicles or structures. Complete closure of a heavily traveled roadway requiring lengthy detours.
Significant	Low probability of injury to persons but likelihood of any of the following: (a) substantial property damage, (b) interruption of water or other utility service to a large area, (c) lengthy blockage of access to business properties or public facilities, (d) long-term damage to environmental or cultural resources, (e) closure of two or more lanes of a heavily traveled roadway, (f) full closure of any roadway with no alternative access or requiring lengthy detours.
Minor	Low probability of injury to persons or of damage to vehicles or non-highway property or facilities. Full roadway closures where alternative access is available. Closure of a single lane on a heavily traveled roadway.

Source: Brutus and Tauber (2009).

newer MSE walls that have intended design lives of 75 to 100 years. As reported in the previous section, none of the agencies surveyed had a specific methodology for assessing long-term performance of existing MSE walls, let alone a method for estimating design life.

Brutus and Tauber do however suggest two approaches that might be used to estimate the remaining service life of walls. One approach is to perform repeated inspections and "chart escalating maintenance and repair costs to project a remaining service life . . . using some criterion such as when the repair and maintenance costs exceed more than 50% of the replacement cost." The other approach is to assess the performance of similar walls (e.g., same construction standards) built over a long period of time and use the observed performance to forecast the performance of newer walls. However, care must be taken when interpreting adverse performance of walls constructed using different, older design methods that may not be representative of newer walls. Elements of these approaches are now beginning to be implemented with the development of MSE wall inventories and the collection of data as described in the previous chapters. As pointed out previously, the development of initial inventories appears to be progressing much more rapidly than regular ongoing performance data collection.

Risk Assessment

Tied closely to the assessment of wall performance is the assessment of risk. Sometimes, risk assessment is not explicitly undertaken, particularly if wall performance appears more than adequate. Ultimately however, it is questions of risk and consequence of adverse performance that drive many asset management activities. Potential consequences of failure that are considered in the performance of risk assessments include (Brutus and Tauber 2009):

- Death or injury to persons, including facility users and those on adjacent properties or facilities;
- Damage to property including vehicles, highway property or facilities, and adjacent property or facilities;
- Disruption of highway operations, including full or partial closure of the roadway, or appurtenant facilities;
- Disruption of adjacent utility lines, such as water mains or electrical conduits;
- Environmental consequences, such as damage to a significant wildlife habitat or blockage of a watercourse; and
- Damage to cultural assets or sensitive land uses.

Again, as outlined by Brutus and Tauber, the consequences of adverse wall performance or failure can be affected by:

- The volume of earth retained by and otherwise contained in the wall, which in turn is most frequently reflected by the height of the wall;
- The proximity of the wall ERS to the roadway or other potentially affected facilities or structures;
- The intensity of usage of potentially affected facilities, such as traffic volume on a roadway or occupancy of a building;
- The structural robustness of adjacent buildings and facilities; and
- The vulnerability of occupants and/or users.

Often the consequence of failure (either functional or structural) is also quantified or expressed in terms of some type of scale. Possible metrics include monetary losses, injuries or fatalities, and/or decrease in levels of serviceability. Brutus and Tauber suggest use of a three-level rating system such as that shown in Table 17.

Performance of risk assessments for MSE walls at present appears to be problematic. Risk assessments (particularly probabilistic ones) typically require the use of "expert opinion" or "expert consensus"; however, being expert requires being experienced. As agencies continue to monitor wall performance, they will gain further experience, and with this increased experience, their ability to assess risk will improve; hence it is in this manner that methods for risk assessment are likely to evolve. Wall function as reflected in inventory inclusion criteria such as that shown in Table 2 would be of particular importance when executing risk assessments.

CHAPTER FIVE

OUTCOMES AND LESSONS LEARNED

As MSE wall performance is monitored, assessments can be made regarding the adequacy of the wall's design, construction, and maintenance. These assessments can in turn be used to change practices and policies with the intent of improving wall performance, particularly for future walls. The feedback loop thus established becomes a means of continual improvement. One example of this process is the development and recent release of *NCHRP Report 675, LRFD Metal Loss and Service-Life Strength Reduction Factors for Metal-Reinforced Systems* (Fishman and Withiam 2011), in which the accumulation of reinforcement corrosion data over time has led to the development of more accurate metal loss models. This chapter discusses actions taken by survey respondents to improve the long-term performance of their MSE walls. These actions reflect lessons learned relative to design, construction, and maintenance. Ideally, these actions will lead to a decreased likelihood of failure or adverse performance of MSE walls in the long term.

POLICIES AND PRACTICES DEVELOPED TO IMPROVE PERFORMANCE OF MECHANICALLY STABILIZED EARTH WALLS

Survey participants were asked to respond regarding any approaches, besides monitoring, that their agency may have developed or implemented to improve the long-term performance of their MSE walls. Specific responses were sought relative to the following categories:

- Regularly scheduled cleanout/maintenance of catch basins
- Different requirements for backfill immediately behind wall face as compared with remainder of reinforced backfill
- Developed special drainage details at ends of MSE walls
- Developed special drainage details behind MSE walls
- Specified vertical and horizontal distances for discharge points and water sources
- Increased wall embedment
- Other design specifications
- Contractor/installer qualifications
- Construction inspection
- Post-construction inspection
- Other.

Typically, fewer than half of survey respondents provided feedback in any one category. The responses provided are generally summarized in the following paragraphs.

With respect to regularly scheduled cleanout and maintenance of catch basins, respondents reported no special actions being taken in this regard. The responses offered suggest that performance of this activity varies significantly between agencies, ranging from its being "done as a matter of course," and being done routinely, to "hit and miss if they actually do it."

With respect to different requirements for backfill immediately behind wall face as compared with remainder of reinforced backfill, seven agencies specifically specified use of open-graded, free-draining aggregate or rock immediately behind the wall face.

With respect to developing special drainage details at ends of MSE walls, agency improvements included turning the wall ends into the slope, concrete headwalls being used (presumably at culvert openings), "plating all drainage surfaces above and around wall; insuring drainage does not enter and saturate reinforced backfill," and use of waterproofing membranes together with weep drains and dedicated drainage collection systems. In the related query regarding specification of vertical and horizontal distances for discharge points and water sources, one agency reports using 100-ft intervals and another emphasized assuring that drainage below and above wall is on concrete inverts and concrete aprons.

With respect to developing special drainage details behind MSE walls, multiple respondents indicated they require some type of underdrain located at the wall face and/or in back of the reinforced soil zone. One respondent emphasized that non-frost-susceptible aggregate and drain pipes should be extended to a depth below frost penetration. Other practices include using a drain gutter, lined swale, or concrete plating at the top of the wall. Most responses referred to needs for direct water away from the wall and to a lower elevation. A couple of respondents indicated that they had added weep drains and/or strip drains at the wall–soil interface rather than relying on drainage through panel or block joints. Texas reports that it has developed an inlet standard to "best accommodate inlets . . . and also convey the water out of the wall in the quickest fashion."

With respect to increased wall embedment, most participants who provided a response in this category indicated that their practice involves embedding the wall foundation below the frost line or at least some minimum depth (the value of which is most frequently 0.6 m, but appears to range up to 1.2 and 1.5 m in northern states such as Minnesota and New Hampshire). Some agencies reported using increased embedment for walls founded on slope, with minimum depths conforming to AASHTO design specifications or as needed to satisfy global stability requirements. Although not reported in the survey, recent inspection of Utah DOT MSE walls indicates that the 1.2-m-wide horizontal bench required by AASHTO to be placed at the base of MSE walls founded on slopes is frequently absent. A proposed alternative to the bench suggested that embedment depth be increased to produce the same amount of distance from the buried base of the wall to the face of the slope had the bench been installed. New Brunswick reported that maintaining such benches was one of its most important lessons learned. Elsewhere in the survey, Texas reported that it strongly encourages that walls not be perched on slopes, and if a slope is to exist at the base of wall that the slope be limited to 6:1 or flatter in combination with an increased wall embedment.

With respect to other design specifications, responses varied greatly. Several respondents indicated that they were in the process of revising or had recently improved their specifications but did not provide details, although one respondent implied that the presence of regular specification and design manual updates in and of itself is a beneficial practice. The most frequently reported focus is on being more restrictive in specifying backfill, particularly with respect to gradation, fines content, and physiochemical-electrical properties. (Interestingly, current research being performed by W.A. Marr as NCHRP Project 24-22, “Selecting Backfill Materials for MSE Retaining Walls,” aims to broaden current FHWA specifications for MSE wall backfills.) One respondent indicated an improved practice in using concrete level pads at the base of the wall. Although not reported in the survey, owing to some instances of adverse wall performance, some states (e.g., Ohio) discourage the use of acute corners for its MSE walls.

Nearly all responses to the question of contractor/installer qualifications (11 out of 12) indicate that agencies use an approved (or pre-approved) list of products and/or vendors. However, only two respondents (Colorado and Oregon) explicitly indicated that their specifications require wall system vendors to provide contractor training or that the contractor possess some type of previous training.

Sixteen agencies responded with comments regarding construction inspection; only one indicated that it does not do construction inspection on a regular basis. Four of the responding agencies (Colorado, Minnesota, New York, and Texas) have developed manuals and/or provide specific training for MSE wall construction. Four agencies (Massachusetts, Michigan, Montana, and Nova Scotia) indicated that they require wall supplier/vendor/manufacturer personnel on-site at least some time during construction. One agency (Nevada) reports now requiring production testing of MSE backfill stockpiles on-site rather than just at the material source.

With respect to post-construction inspection, no new developments were reported beyond a few agencies that now make a complete inspection of the wall at the end of construction routine. One responding agency indicated having a three-year warranty period for its MSE walls. Two agencies (Kansas and New York) reported that they retain construction quality control/quality assurance data and point out that retaining such data has the potential to diagnose future problems if they arise.

While not being a practice unique to agencies responding to this survey, use of an impervious membrane above the entire reinforced soil mass to prevent the migration of aggressive materials (such as salts used to de-ice the overlying pavement) was cited by several respondents as a means of protecting the reinforcement from corrosion/degradation.

MOST IMPORTANT “LESSON LEARNED”

As part of the survey conducted for this synthesis project, recipients were asked to give their opinion as to what is the most significant lesson learned by their agency with respect to the long-term performance of MSE walls. Responses varied from design and backfill specification to construction practices and post-construction drainage maintenance. Given the potential significance of these responses—being the most important thing(s) learned—all responses are presented in Appendix C in their entirety.

Although the scope of the responses was broad, certain topics appeared more frequently than others. The four most frequent topics (in order of decreasing frequency) mentioned were drainage, construction, backfill, and modular block issues.

Approximately one-fourth of respondents indicated that the most important lesson learned by their agency was drainage-related—as two respondents put it: “Drainage; drainage; drainage,” and “W-a-t-e-r: from any and all directions and sources.” Although these particular responses lack specificity, it is readily apparent that the two respondents believe that drainage is essential to the successful performance of MSE walls. Another respondent suggested that the most important lesson was “providing a sound and firm foundation for support of the wall; and providing proper drainage within the wall system and adjacent to the wall geometry.”

Approximately one-fifth of respondents reported that the most important lesson they learned was construction-related. One pointed out that “the systems can last forever but must be designed and built correctly.” Similarly, another noted, “For the most part [my agency] has had very few problems with MSE structures. We do know that great care must be taken in constructing these structures. If you start wrong in the beginning you’ll always be seeing problems in the walls.”

Lessons involving either MSE wall backfill or modular blocks accounted for about 14% and 10% of responses, respectively. With respect to backfill, one respondent replied, “Use of fine grained select fill has resulted in the migration of material out from behind walls. We have thousands of square foot of wall that was backfilled with this type of material. Many walls have shown distress as a result. We have coarsened up the gradation of select fill to lessen the potential of fill migration.” When modular blocks were mentioned, it was usually in the context of durability and degradation because of roadway de-icing activities. According to one respondent, “By having a formal wall approval process we have limited the use of modular block wall systems and the deterioration of these facing elements due to deicing chemicals.”

One of the more extensive commentaries provided by a survey respondent related to the deformation-tolerance of MSE walls, and has bearing on wall inspection activities:

> The outside may get ugly [but] it’s the inside that matters. We had an MSE ride a landslide downslope 32 ft back in the 1970s. It deformed significantly, but is still in service today. We have had several lose foundation support, but as long as they were able to move and readjust the stresses through deformation, with no loss of backfill, they have all been able to stay in service—some for decades. However, excessive consolidation settlement and internal drainage failures have led to issues with cavities and retainment loss. These MSE failed within months and had to be replaced. Amazing[ly] flexible, but only up to a limit. It’s what’s inside that counts.

Although different agencies appear to have had varying experiences with MSE walls, the “most important lessons learned” do tend to focus on the topics of drainage, construction, backfill, and modular block issues. Considering the importance given these topics by survey respondents, those issues could be important focal points in the development of future MSE wall assessment and/or management activities.

CHAPTER SIX

CONCLUSIONS

Combining a literature review with a survey and interviews, this synthesis project has attempted to determine:

- The current state of practice in assessing the performance of mechanically stabilized earth (MSE) walls, particularly in the long term;
- The direction of the state of practice;
- What the current and effective practices are; and
- What areas need improvement and/or research.

Key findings and conclusions regarding each of these items have been summarized and are presented below.

CURRENT STATE OF PRACTICE

MSE walls are important infrastructure assets. However, unlike bridges and pavements, they are often overlooked. The current state of practice with respect to the management of MSE walls as assets can be characterized thusly:

- There is no widely used, consistently applied system for managing MSE wall assets.
- Fewer than one-quarter of state-level transportation agencies have developed any type of MSE wall inventory data beyond that which may be captured as part of their bridge inventories.
- Still fewer agencies have the methods and/or means to support their inventories with data from ongoing inspections from which assessments of wall performance can be made.
- Some previously established wall inventory and inspection activities have ceased because of lack of resources and funding.

Regarding the inventory and gathering of MSE wall-related data once the walls are constructed and accepted, current practice can be generally described as follows:

- Responsibility for MSE walls after their construction usually rests with maintenance personnel operating in a decentralized structure, while most inventories are managed by a geotechnical engineer or similar person at an agency-wide level. However, in 20% of agencies, no one has end responsibility for MSE walls.
- Various types of data are collected and maintained in order to assess wall performance. Most frequently, the data consist of ratings that describe the observed condition of wall features.
- The manner in which wall features are observed and assessed varies between agencies, as do the rating criteria themselves.
- Rating criteria are usually more subjective than objective.
- When scheduled, the frequency of data collection varies from two to 15 years, although wall performance monitoring activities are most often (i.e., two-thirds of the time) simply reactive to reported incidents of adverse performance.

Once asset data have been collected, they must be assessed to predict future performance and determine maintenance and management activities. With respect to MSE walls, current practice in the area of assessment can be basically described this way:

- Agencies believe that drainage, global stability, and corrosion/degradation of internal reinforcement are the most important issues affecting the long-term performance of MSE walls.
- Wall performance is sometimes only one factor used in making asset-management decisions.
- No state transportation agency has a specific methodology for assessing long-term performance of existing MSE walls.
- Similarly, there appears to be no specific methodology for accurately predicting the remaining service life of an MSE wall.

DIRECTION OF STATE OF PRACTICE

As walls have aged and adverse performance (whether age-related or not) has occurred, more agencies are becoming aware of a need for long-term performance monitoring of MSE walls. An opinion voiced by some survey respondents is that there is insufficient attention given to long-term performance of MSE walls despite the potential for poor performance of this important asset. One reason is that, while other assets such as pavements and bridge structures are subject to formal inspection and reporting requirements, there are no such requirements for retaining walls, and in particular MSE walls. Without such requirements, respondents noted difficulty in obtaining funding for wall inspection and management. Consequently, it appears that the direction of practice is largely limited to the status quo, with relatively few agencies performing inspections or conducting assessments. However, it is anticipated that as experience with MSE walls accumulates, those that are able to secure funding and resources will continue to develop, refine, and better calibrate procedures regarding design, construction, condition assessment, and asset management decision making.

EFFECTIVE PRACTICES

Although wall inventory and monitoring practices vary between agencies, effective practices can be extracted from systems currently in use. The most well-implemented and developed wall inventory and assessment system in the United States appears to be the Wall Inventory Program developed by the FHWA for the National Park Service. The system uses "conditions narratives" (the preparation of which is illustrated by only general guidance, thus making them fairly subjective) to describe the conditions of certain wall elements, and then these narratives are converted to a numeric rating. Although the multiple steps in the rating process increase the effort required to use the system, an inherent strength is that it can be applied to many wall types (not just MSE walls).

Other wall inventory and assessment systems such as those used by Pennsylvania and Nebraska are relatively simple to use and appear to be less interpretive. Such characteristics typically lead to greater consistency in data interpretation and broader use. Without consistency in collected datasets, broadly applicable conclusions are more difficult to reach, and methodologies developed from inconsistent data are inherently less robust. The numeric ratings associated with these two particular systems are also compatible with the 0 (worst) to 9 (best) scale already used by many in the assessment of bridges, thus facilitating the development of readily accessible MSE wall assessment tools and methods within the domain of asset management already occupied by other asset types.

Other desirable practices include that reflected in the Nebraska system, in which rating criteria are specific to each element or wall condition rather than being generic. This specificity avoids vagueness and contributes to greater consistency. For example, a rating of 6 is assigned "when less than 25% of the wall area shows deterioration," and a rating of 5 is assigned "when wall panels have bowed outward to where connectors between panels are visible and deforming." This would be in contrast to a system in which a rating of 3 is assigned if "the wall exhibits 'extensive' distress."

The wall inventory and assessment system employed in Pennsylvania reflects another apparently effective practice, in that it actively and regularly inspects all of its retaining walls (inclusive of MSE types) and manages its inventory within the same framework as it does its bridges. In this manner, overlaps and gaps in inventory are minimized, and data and assessments are kept current.

Although individual experiences and beliefs regarding practices that improve wall performance vary, most agencies agree that the use of a pre-approved wall design and/or wall supplier helps ensure better wall performance. Similarly, based on the "most important lessons learned," many agencies believe that providing adequate drainage, both internal and external, is an essential practice in realizing good MSE wall performance.

In summary, current effective practices for inventorying and assessing the performance of MSE walls include:

- Use of inventory and assessment systems with features that are as simple to use and as objective as reasonably possible
- Use of rating criteria that are specific to particular wall elements and/or conditions
- Use of numeric rating scales that correspond to other scales already in use for other asset classes such as bridges
- Incorporation of MSE wall inventory and assessment systems together with systems for other asset classes.

Current effective practices for improving the performance of MSE walls include:

- Use of pre-approval process for wall design and/or wall supplier
- Provision of adequate internal and external drainage.

AREAS NEEDING IMPROVEMENT AND/OR RESEARCH

Today there are many millions of square meters of MSE walls with typical design lives of 75 to 100 years. The oldest of these walls are about 40 years old. Instances of MSE wall failures and poor performance are expected to increase as walls age. To better assess the performance of MSE walls, the following practices would be beneficial:

- Greater recognition of MSE walls and retaining walls in general as important infrastructure assets
- Increased availability of funding and other resources for inventory and assessment activities
- Active involvement of a larger number of agencies in MSE wall inventory and assessment activities
- Greater consistency across agencies relative to the way that inventory and assessment activities are performed
- Greater use of bridge and other existing asset inventory data for MSE wall inventories.

To move beyond current inventory and the data baselines now being established, repeated observations and performance predictions will be needed, as will specific decision-making methodologies. To this end, research relative to the following topics would be helpful:

- Improved ability to evaluate the integrity of existing MSE reinforcement systems using methods that are economically and logistically effective
- Standards for performance data baselines and data collection activities
- Predictive models for remaining MSE wall service life
- Methods of risk assessment specifically for MSE walls and, more generally, for various types of retaining walls.

A potential research problem statement for predictive models for remaining MSE wall service life is presented in Appendix D. The statement is adaptable to the other identified research needs.

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APPENDIX A

Survey Questionnaire

NCHRP Synthesis Survey: Long-term Performance of Mechanically Stabilized Earth (MSE) Walls

Introduction Page

Dear Recipient:

The Transportation Research Board (TRB) is preparing a synthesis on Long-term Performance of Mechanically Stabilized Earth (MSE) Walls. This is being done for the National Cooperative Highway Research Project (NCHRP), under the sponsorship of the American Association of State Highway and Transportation Officials, in cooperation with the U.S. Federal Highway Administration.

Mechanically Stabilized Earth (MSE) walls were introduced in North America about 40 years ago. As the technology has improved and gained wider recognition, the number of MSE walls designed and constructed has increased dramatically. The long-term performance of these structures depends on various factors, and unfortunately there have been instances of adverse performance. Multiple states have established MSE wall monitoring programs, while several others are looking for guidance, tools, and funding to establish their own monitoring program. This project will study how state transportation agencies monitor, assess, and predict the long-term performance of MSE walls. It is anticipated that synthesis of this information will lead to better design, construction, monitoring, and maintenance of these important structures.

This survey is being sent to all state and provincial transportation agencies in the US and Canada. Your cooperation in completing the questionnaire will ensure the success of this effort. If you are not the appropriate person at your agency to complete this survey, please forward it to the correct person.

Please compete and submit this survey by Friday, MARCH 11, 2011. This survey is dynamic in nature, and the total number of questions asked and time to complete will depend upon your level of experience with MSE walls and your responses. Some agencies will be able to provide more feedback than others. The number of questions will be a minimum of 12 (taking approximately 20 minutes) and a maximum of 20. Whatever your experience is relative to the long-term performance of MSE walls, reporting that experience is valuable in determining current practices and realizing the objectives of this synthesis project. If you have any questions, please contact our principal investigator, Travis M. Gerber (email: tgerber@byu.edu; phone: 801.422.1349). Any supporting materials can be sent directly to Dr. Gerber by e-mail or at the postal address shown at the end of the survey.

Confidentiality: All answers provided by survey respondents will be treated as confidential and aggregated with other responses in the reporting. Survey respondents will receive a link to the synthesis report when it is published.

SURVEY/QUESTIONNAIRE INSTRUCTIONS

NCHRP Synthesis Survey: Long-term Performance of Mechanically Stabilized Earth (MSE) Walls

To view and print the entire questionnaire, Click on this link, and print using "control p".
To save your partial answers, or to forward a partially completed questionnaire to another party, click on the "Save and Continue Later" link in the upper right hand corner of your screen. A link to the partial survey will be e-mailed to you or a colleague.
To view and print your answers before submitting the survey, click forward to the page following question K1. Print using "control p".
To submit the survey, click on "Submit" on the last page.

The following definitions are used in this questionnaire:

- MSE wall: Retaining walls which rely on internal reinforcement for stability. The reinforcement can be either metallic strips or meshes, or geosynthetic fabrics or grids. Soil nail or anchor walls are not considered to be MSE walls for the purposes of this Synthesis.

- Panel MSE wall: Either one- or two-stage MSE walls that having concrete facing panels; internal soil reinforcement is usually metallic

- One stage MSE wall: A MSE wall which uses a concrete panel attached to the internal reinforcement to retain the backfill

- Two-stage MSE wall: A MSE wall which uses a metallic mesh and geosynthetic liner face attached to the internal reinforcement to retain the backfill. A concrete panel is subsequently attached to the vertical mesh. This wall type is typically used where settlements are expected to be relatively large.

- Block MSE wall: A MSE wall which uses a modular block facing attached to the internal soil reinforcement; also referred to as a segmental block wall and the reinforcement is often geosynthetic.

Please enter the date (MM/DD/YYYY). (Required)

Please enter your contact information.

First Name (Required)

Last Name (Required)

Title (Required)

Agency/Organization (Required)

Street Address (Required)

Suite

NCHRP Synthesis Survey: Long-term Performance of Mechanically Stabilized Earth (MSE) Walls

City (Required)

State (Required)

Zip Code (Required)

Country (Required)

Email Address (Required)

Phone Number (Required)

Do You Have an MSE Wall Inventory?

1. A1. Who in your agency typically has responsible charge for MSE walls once the walls are constructed and accepted? (select most representative response) (Required)

- A. Structural engineer(s) or similar at an agency-wide level
- B. Structural engineer(s) or similar at a regional or district level
- C. Geotechnical engineer or similar at an agency-wide level
- D. Geotechnical engineer(s) or similar at a regional or district level
- E. Maintenance engineer or similar at an agency-wide level
- F. Maintenance engineer(s) or similar at a regional or district level
- G. No one has this charge
- H. Other (specify [don't forget to select button at left when entering response in following text box])

2. A2. Does you agency maintain an inventory of your MSE walls? (select most representative response) (Required)

- A. No
- B. Yes
- C. Yes, but inventory is limited to (specify limitation such as specific geographic areas, wall types, etc [don't forget to select button at left when entering response in following text box]):

Aspects of Your MSE Wall Inventory

3. B1. What types of permanent MSE walls does your agency include in your inventory? (select as many as applicable) (Required)

- ☐ A. One-stage panel walls
- ☐ B. Two-stage panel walls
- ☐ C. Block walls

4. B2. What criteria OR partial criteria does your agency use to determine what MSE walls to include in your inventory? (select as many as applicable)

- ☐ A. Wall owned by my agency
- ☐ B. Walls owned by others but adjacent to facilities for which my agency is responsible
- ☐ C. Wall owned by others but may negatively impact adjacent facilities for which my agency is responsible
- ☐ D. Wall is associated with a bridge structure
- ☐ E. Wall is associated with a culvert
- ☐ F. Walls is not associated with a bridge or culvert
- ☐ G. Minimum wall height (specify height, in meters [don't forget to select checkbox at left when entering response in following text box]) ☐
- ☐ H. Minimum height of retained earth (specify height, in meters [don't forget to select checkbox at left when entering response in following text box]) ☐
- ☐ I. Minimum wall length (specify length, in meters [don't forget to select checkbox at left when entering response in following text box])
- ☐ J. Minimum wall area (specify area, in square meters [don't forget to select checkbox at left when entering response in following text box])
- ☐ K. Other (specify [don't forget to select checkbox at left when entering response in following text box])

5. B3. Approximately how many MSE walls does your agency have? (indicate number)

[ ]

6. B4. Approximately what percentage of the MSE walls that your agency has, which also satisfy your previously identified inclusion criteria, are currently in your inventory database? (indicate percentage, expressed as a decimal)

[ ]

Type of Information in Your MSE Wall Inventory

7. C1. What types of data does your agency generally collect or maintain in your inventory for each MSE wall? (select as many as applicable)

- ☐ Aa. Location by Street Address
- ☐ Ab. Location by Lat / Long
- ☐ Ac. Location by Route, Milepost
- ☐ Ad. Location by State Plane Coordinates
- ☐ B. Wall Type
- ☐ C. Wall Function
- ☐ Da. Wall Geometrics - Max Wall Height
- ☐ Db. Wall Geometrics - Average Wall Height
- ☐ Dc. Wall Geometrics - Wall Length
- ☐ Dd. Wall Geometrics - Slope in Front of Wall
- ☐ De. Wall Geometrics - Slope Behind Wall
- ☐ Df. Wall Geometrics - Road/traffic offset
- ☐ E. Date Constructed
- ☐ F. Manufacturer
- ☐ G. Contractor / Installer
- ☐ H. Reinforcement Type
- ☐ Ia. Drainage Conditions - Proximity of external water sources (e.g., river, sprinklers, etc)
- ☐ Ib. Drainage Conditions - Location and condition of drainage discharge points
- ☐ J. Nature of adjacent facilities owned by agency
- ☐ K. Nature of adjacent facilities or utilities owned by others (e.g., railroad)
- ☐ L. Characterization of adjacent roadway traffic
- ☐ M. Design Data
- ☐ Na. Construction Data - Plans
- ☐ Nb. Construction Data - Specifications
- ☐ Nc. Construction Data - Shop drawings / submittals
- ☐ Nd. Construction Data - Inspection documentation
- ☐ Ne. Construction Data - As-builts
- ☐ O. Post-construction modifications
- ☐ P. Photographs
- ☐ Qa. Condition of Structure - External inspection data (components to be specified in a subsequent survey question)
- ☐ Qb. Condition of Structure - Internal inspection data (e.g., corrosion / degradation assessment)
- ☐ R. Maintenance activities
- ☐ S. Other (specify [don't forget to select button at left when entering response in following text box])

Asset Management System (AMS) User and Tools

8. D1. Who in your agency principally manages/maintains your inventory of MSE walls? (select most representative response) (Required)

- A. Structural engineer(s) or similar at an agency-wide level
- B. Structural engineer(s) or similar at a regional or district level
- C. Geotechnical engineer or similar at an agency-wide level
- D. Geotechnical engineer(s) or similar at a regional or district level
- E. Maintenance engineer or similar at an agency-wide level
- F. Maintenance engineer(s) or similar at a regional or district level
- G. Other (specify [don't forget to select button at left when entering response in following text box])

9. D2. What primary tool does this person use as an asset management system (AMS) for your MSE wall inventory? (select most representative response) (Required)

- A. File boxes/cabinets
- B. Spreadsheet
- C. MS Access database without GIS support
- D. Oracle database without GIS support
- E. PONTIS
- F. Other non-GIS supported database (specify [don't forget to select button at left when entering response in following text box])
- G. GIS-based software (specify [don't forget to select button at left when entering response in following text box])

Aspects of MSE Wall Monitoring

10. E1. Which of the following statements best describes your agency's MSE wall performance monitoring activities? (select most representative response) (Required)

- A. Reactive to reported incidents of adverse performance
- B. Irregular inspection/assessment of some MSE walls
- C. Regular inspection/assessment of some MSE walls
- D. Irregular inspection/assessment of most or all walls in inventory
- E. Regular inspection/assessment of most or all walls in inventory

Aspects of MSE Wall Monitoring - Features and Conditions

11. E2. What MSE wall features and/or conditions does your agency assess as part of your monitoring? (select as many as applicable)

- ☐ A. Wall plumbness
- ☐ B. Bulging or distortion of wall facing
- ☐ C. Alignment and spacing of joints between facing elements
- ☐ D. Cracking of facing elements
- ☐ E. Damage to corners of facing elements
- ☐ F. Damage from vehicular impact
- ☐ G. Settlement along line of wall
- ☐ H. Settlement behind wall
- ☐ I. Distress in ground or pavement in front of wall
- ☐ J. Distress in ground or pavement behind wall
- ☐ K. Displacement of coping or parapet
- ☐ L. Rust stains or other external evidence of corrosion
- ☐ M. Functionality of drainage/catch basin
- ☐ N. Functionality of internal drainage features (e.g., weepholes and piping)
- ☐ O. External erosion
- ☐ P. Internal erosion of backfill
- ☐ Q. Changes to wall geometry (e.g., excavation at toe, addition of surcharge load)
- ☐ R. Vegetation growth
- ☐ S. Internal corrosion / degradation of reinforcement
- ☐ T. Other (specify [don't forget to select checkbox at left when entering response in following text box])

12. E3. For internal reinforcement, what methods of corrosion / degradation assessment does your agency generally use? (select as many as applicable [don't forget to select checkbox at left when entering response in following text box])

- ☐ A. Do not currently assess
- ☐ B. Linear polarization resistance (LPR) for metallic (specify assessment interval)
- ☐ C. Extractible coupons for metallic (specify assessment interval)
- ☐ D. Exhumation for geosynthetic (specify assessment interval)
- ☐ E. Other (specify)

Reinforcement Monitoring Site Description/Criteria

13. E4. Explain the nature and criteria your agency uses for establishing corrosion/degradation monitoring sites.

Approaches Developed to Improve MSE Wall Performance

14. F1. Besides monitoring, what particular approach(es) has your agency developed/implemented to improve the long-term performance of MSE walls? (select as many as applicable [don't forget to select checkbox at left when entering response in following text box])

- ☐ A. Regularly scheduled cleanout/maintenance of catch basins (please elaborate)
- ☐ B. Different requirements for backfill immediately behind wall face as compared to remainder of reinforced backfill (please elaborate)
- ☐ C. Developed special drainage details at ends of MSE walls (please elaborate)
- ☐ D. Developed special drainage details behind MSE walls (please elaborate)
- ☐ E. Specified vertical and horizontal distances for discharge points and water sources (please elaborate)
- ☐ F. Increased wall embedment (please elaborate)
- ☐ G. Other design specifications (please elaborate)
- ☐ H. Contractor/installer qualifications (please elaborate)
- ☐ I. Construction inspection (please elaborate)
- ☐ J. Post-construction inspection (please elaborate)
- ☐ K. Other (specify)

Specific Assessment Methodology for MSE Wall Performance

15. G1. Does your agency have a specific methodology for assessing long-term performance of existing MSE walls? Please explain the methodology in the text box below (consider using cut/paste); alternatively, use the next query to attach an external file and leave the following text box blank.

17. G2. Does your agency have a specific methodology for assessing risk from adverse, long-term performance of MSE walls? If so, identify which of the following features are part of your methodology (select as many as applicable). Please use the next query to attach any pertinent file.

- ☐ A. Do not have specific methodology
- ☐ B. Quantitative assessment of failure potential
- ☐ C. Qualitative assessment of failure potential
- ☐ D. Quantitative assessment of life-safety impacts
- ☐ E. Qualitative assessment of life-safety impacts
- ☐ F. Quantitative assessment of economic loss of service costs
- ☐ G. Qualitative assessment of economic loss of service costs
- ☐ H. Quantitative assessment of economic repair/remediation costs
- ☐ I. Qualitative assessment of economic repair/remediation costs
- ☐ J. Explicit use of wall geometrics
- ☐ K. Explicit use of inspection or wall condition data
- ☐ L. Explicit use of wall age
- ☐ M. Explicit use of MSE wall type
- ☐ N. Largely based on subjective judgment with limited input from asset management system (AMS)

Causal Features and Conditions Affecting MSE Wall Performance

19. H1. How important do you think that each of the following wall features/conditions are in assessing the long-term performance of MSE walls?

		Not important (1)	Mildly important (2)	Moderately important (3)	Very important (4)	Most important (5)
A.	Wall type	○	○	○	○	○
B.	Maximum wall height	○	○	○	○	○
C.	Average wall height	○	○	○	○	○
D.	Wall length	○	○	○	○	○
E.	Slope in front of wall	○	○	○	○	○
F.	Slope behind wall	○	○	○	○	○
G.	Presence of bench at toe of wall founded on slope	○	○	○	○	○
H.	Embedment of wall	○	○	○	○	○
I.	Road/traffic offset	○	○	○	○	○
J.	Date constructed	○	○	○	○	○
K.	Manufacturer	○	○	○	○	○
L.	Reinforcement type	○	○	○	○	○
M.	Post-construction modifications	○	○	○	○	○
N.	Drainage conditions	○	○	○	○	○
O.	Proximity of external water sources (e.g., river, sprinklers, etc)	○	○	○	○	○
P.	Location and condition of drainage discharge points	○	○	○	○	○
Q.	Wall plumbness	○	○	○	○	○
R.	Bulging or distortion of wall facing	○	○	○	○	○
S.	Alignment and spacing of joints between facing elements	○	○	○	○	○
T.	Cracking of facing elements	○	○	○	○	○
U.	Damage to corners of facing elements	○	○	○	○	○
V.	Damage from vehicular impact	○	○	○	○	○
W.	Settlement along line of wall	○	○	○	○	○
X.	Settlement behind wall	○	○	○	○	○
Y.	Distress in ground or pavement in front of wall	○	○	○	○	○
Z.	Distress in ground or pavement behind wall	○	○	○	○	○
AA.	Displacement of coping or parapet	○	○	○	○	○
AB.	Rust stains or other external evidence of corrosion	○	○	○	○	○
AC.	Functionality of drainage/catch basins	○	○	○	○	○
AD.	Functionality of internal drainage features (e.g., weepholes and piping)	○	○	○	○	○
AE.	External erosion	○	○	○	○	○
AF.	Internal erosion of backfill	○	○	○	○	○
AG.	Changes to wall geometry (e.g., excavation at toe, addition of surcharge load)	○	○	○	○	○
AH.	Vegetation growth	○	○	○	○	○
AI.	Internal corrosion / degradation of reinforcement	○	○	○	○	○

NCHRP Synthesis Survey: Long-term Performance of Mechanically Stabilized Earth (MSE) Walls

Distress Mechanisms for MSE Walls

20. I1. How significant do you think each of the following potential failure/distress modes are relative to the long-term performance of MSE walls?

	Not significant (1)	Mildly significant (2)	Moderately significant (3)	Very significant (4)	Most significant (5)
A. Facing failure	○	○	○	○	○
B. Reinforcement rupture	○	○	○	○	○
C. Reinforcement pullout	○	○	○	○	○
D. Sliding	○	○	○	○	○
E. Overturning	○	○	○	○	○
F. Loss of foundation support due to erosion	○	○	○	○	○
G. Loss of foundation support to bearing capacity failure	○	○	○	○	○
H. Global stability	○	○	○	○	○
I. Excessive settlement	○	○	○	○	○

Lesson Learned

21. J1. In your opinion, what is the most significant "lesson learned" by your agency with respect to the long-term performance of MSE walls? If desired, use the next query to attach an external file and leave the following text box blank.

Additional Person to Contact

23. K1. Is there someone else within your agency that we should contact for additional information relative to this synthesis topic? (Required)

- ○ No
- ○ Yes

NCHRP Synthesis Survey: Long-term Performance of Mechanically Stabilized Earth (MSE) Walls

Additional Person to Contact - Details

Complete this section only if: "K1. Is there someone else within your agency that we should contact for additional information relative to this synthesis topic?" matches: 'Y'

24. K1a. Please provide contact information for another individual in your agency who might be able to provide additional information relative to the completion of this survey.

First Name

Last Name

Title

Company Name

Street Address

Apt/Suite/Office

City

State

Postal Code

Country

Email Address

Phone Number

APPENDIX B

List of Survey Respondents

SURVEY RESPONDENTS (BY INDIVIDUAL)

Ahmad, Ken; Foundation Engineer; Ontario, Ministry of Transportation (Ontario, Canada)
Annable, Jonathan; Assistant Division Head—Materials; Arkansas State Highway and Transportation Department (Arkansas)
Arndorfer, Robert; Foundation and Pavement Engineering Supervisor; Wisconsin DOT (Wisconsin)
Bart, Bradley; Kentucky Transportation Cabinet (Kentucky)
Benda, Christopher; Soils and Foundations Engineer; Vermont Agency of Transportation (Vermont)
Brennan, James; Assistant Geotechnical Engineer; Kansas DOT (Kansas)
Buu, Tri; Geotechnical Engineer; Idaho Transportation Department (Idaho)
Chlak, Byron; Bridge Preservation Specialist; Alberta Transportation (Alberta, Canada)
Connors, Peter; Geotechnical Engineer; Massachusetts DOT (Massachusetts)
Davis, Kaye; Geotechnical Engineer; Alabama DOT (Alabama)
Dickson, Todd; Civil Engineer 2; New York State DOT Geotechnical Engineering Bureau (New York)
Dusseault, Chuck; Geotechnical Section Chief; New Hampshire DOT (New Hampshire)
Endres, Richard; Supervising Engineer of Geotechnical Services; Michigan DOT (Michigan)
Falk, Mark; Assistant Chief Engineering Geologist; Wyoming DOT (Wyoming)
Fisher, James; Lab Coordinator; West Virginia DOT (West Virginia)
Fontaine, Leo; Transportation Principal Engineer; Connecticut DOT (Connecticut)
Griese, Kevin; Geotechnical Engineer; South Dakota DOT (South Dakota)
Griswell, Kathryn; Earth Retaining Systems Specialist; Caltrans (California)
Guido, Jonathan; Senior Geotechnical Engineer; Oregon DOT (Oregon)
Higbee, Jim; Geotechnical Engineer; Utah DOT (Utah)
Hoyt, James; Assistant Director Materials Research and Environment; New Brunswick DOT (New Brunswick, Canada)
Hunter, Brian; Chemical Testing Engineer; North Carolina DOT Materials and Tests (North Carolina)
Jackson, Jeff; Geotechnical Engineer; Montana DOT (Montana)
Ketterling, Jon; NDDOT Geotechnical Engineer; North Dakota DOT (North Dakota)
Kramer, Bill; Foundations Engineer; Illinois DOT (Illinois)
Krusinski, Laura; Senior Geotechnical Engineer; Maine DOT (Maine)
Lawler, Ashton; State Program Manager for Geotechnical Design of Structures; Virginia DOT (Virginia)
Lindemann, Mark; Soil Mechanics Engineer; Nebraska Department of Roads (Nebraska)
MacAskill, Wayne; Contract Administrator; Nova Scotia Transportation and Infrastructure Renewal (Nova Scotia, Canada)
Marcus, Galvan; State Geotechnical Engineer; Texas DOT (Texas)
McLain, Kevin; Geotechnical Engineer; Missouri DOT (Missouri)
Meyers, Robert; NMDOT State Geotechnical Engineer; New Mexico DOT (New Mexico)
Nelson, Blake; Geotechnologies Engineer; Minnesota DOT (Minnesota)
Oliver, Len; Civil Engineering Manager 2; Tennessee DOT (Tennessee)
Romero, Ricardo; Acting Chief, Soils Engineering Office; Puerto Rico Highway Authority (Puerto Rico)
Salazar, John; Chief Geotechnical Engineer; Nevada DOT—Materials Division~Geotechnical Engineering Branch (Nevada)
Scruggs, Thomas; State Geotechnical Engineer; Georgia DOT (Georgia)
Sizemore, Jeff; Geotechnical Design Support Engineer; South Carolina DOT (South Carolina)
Smadi, Malek; Supervisor, Geotechnical Operations; Indiana DOT (Indiana)
Stanley, Robert; Soils Design Engineer; Iowa DOT (Iowa)
Tsai, Ching; Senior Geotechnical Specialist; Louisiana Department of Transportation and Development (Louisiana)
Wang, Trever; Supervising Professional Engineer; Colorado DOT (Colorado)
Wetz, Norman; Geotechnical Design Engineer; Arizona DOT (Arizona)
Yea, Howard; Director, Bridge Standards; Saskatchewan Ministry of Highways and Infrastructure (Saskatchewan, Canada)

SURVEY RESPONDENTS (BY AGENCY LOCATION)

Alabama
Arizona
Arkansas
California
Colorado
Connecticut
Georgia
Idaho
Illinois
Indiana
Iowa
Kansas
Kentucky
Louisiana
Maine
Massachusetts
Michigan
Minnesota

Missouri
Montana
Nebraska
Nevada
New Hampshire
New Mexico
New York
North Carolina
North Dakota
Oregon
Puerto Rico
South Carolina
South Dakota
Tennessee
Texas
Utah
Vermont
Virginia
West Virginia
Wisconsin
Wyoming
Alberta, Canada
New Brunswick, Canada
Nova Scotia, Canada
Ontario, Canada
Saskatchewan, Canada

APPENDIX C

"Most Signficant Lesson(s) Learned" as Reported by Agencies

- "Use the right technology for the right application. For example, consider need and possibility to achieve various settlement/rigidity constraints and match service level to appropriate cost for application."
- "Providing a sound and firm foundation for support of the wall; and providing proper drainage within the wall system and adjacent to the wall geometry."
- "Performance depends on quality of construction and quality of retained backfill materials."
- "Make sure the contractor is using the specified reinforced fill material and is constructing according to plans."
- "By having a formal wall approval process we have limited the use of modular block wall systems and the deterioration of these facing elements due to deicing chemicals."
- "The systems can last forever but must be designed and built correctly."
- "Electrochemical property requirements for backfill material were not specified for one wall built in the late 70s. As a result, the wall failed due to corrosion of the steel reinforcements when it was about 25 years old."
- "You need to have an inventory and know where all the walls are that you own."
- "For the most part, NYSDOT has had very few problems with MSE Structures. We do know that great care must be taken in constructing these structures. If you start wrong in the beginning you'll always be seeing problems in the walls."
- "The inadequate durability of modular block MSE wall facings in locations affected by winter roadway salt application."
- "Prevent surface runoff or other external water sources from inundating reinforced zone."
- "I think we are so conservative in our designs that we have not had any problems with our long term stability of our MSE walls."
- "This is an issue which has not been addressed by the agency."
- "Lesson(s) learned—'The outside may get ugly—it's the inside that matters.' We had an MSE ride a landslide downslope 32 ft back in the 1970's. It deformed significantly, but is still in service today. We have had several lose foundation support. But as long as they were able to move and readjust the stresses through deformation, with no loss of backfill, they have all been able to stay in service, some for decades. However, excessive consolidation settlement and internal drainage failures have lead to issues with cavities and retainment loss. These MSE failed within months and had to be replaced. Amazing[ly] flexible, but only up to a limit. It's what's inside that counts."
- "Quality of construction. Drainage, drainage, drainage (including erosion). Corrosion of metallic reinforcement."
- "Ensure corrosion monitor readings are performed at a regular inspection rate. If a failure occurs then notify appropriate subsection."
- "We don't have a lot of MSE walls relative to other states, so this question is difficult to answer. We have not had problems that I am aware of with our MSE walls."
- "Put tight requirements on the modular blocks. Make sure the wall is well drained internally and externally."
- "So far have performed very well."
- "Proper drainage within the wall and proper external drainage behind and in front of the wall."
- "Use of fine-grained select fill has resulted in the migration of material out from behind walls. We have thousands of square foot of wall that was backfilled with this type of material. Many walls have shown distress as a result. We have coarsened up the gradation of select fill to lessen the potential of fill migration."
- "We have had some failures and problems that have shown the need for an assessment, inventory, and inspection program."
- "Drainage, drainage, drainage."
- "W-a-t-e-r: from any and all directions and sources."
- "Following proper construction procedures and following material specifications."
- "Performing and adequate geotechnical subsurface investigation."
- "Settlement."
- "Investigate and address identified problems quickly."
- "The recognition that most MSE wall problems are almost always related to a combination of deficiencies, hardly ever just one single issue. The 'devil is always in the details,' so to speak. It is important to keep in mind that most walls are categorized as a Series Engineering System, as opposed to a Parallel Engineering System with respect to external and global stability considerations. Using 'averaged' shear strengths along a Linear/Series Wall System can actually cause a real stability failure within a known weak design reach . . . as the weakest link will most assuredly show up as a stability issue on any shallow wall foundation. There is typically no benefit from a redundant parallel system as in most other structure types. Also, we have learned the hard way that MSE Wall reinforcing details around obstructions must be identified early-on in the design phase, as it is always a hassle to deal with during construction. And last, but certainly not the least, wall drainage is a huge component in any MSE Wall project, both during construction and throughout the lifetime of the structure. In summary . . . external/global stability, internal reinforcing details and drainage should be high on any engineer's checklist of important considerations necessary for the successful performance of any MSE Wall Project."
- "Freeze and thaw of block wall, surface run-off seep into the wall."
- "Improve Specifications, Approved Products List, Inspector and contractor training."

- "[Our agency] has been using MSE walls for over 30 years with great success. Our only problems have been poor construction practices which are found and corrected before walls are accepted from the Contractor. We attribute our success to good geotechnical design, quality backfill required and only using pre-approved walls systems that meet AASHTO requirements."
- "To make sure the ends of the wall where the access trails to build the wall are properly compacted."
- "We have to get beyond our reactive mentality and be proactive in monitoring these walls."
- "None of our installations have reached an age where failure would be anticipated. To date, no significant performance issues have been identified."
- "[. . . N]eed to model to predict the life of the reinforcement."
- "Performance of nearby drainage culverts can have significant impacts on wall performance. In our case, a collapsed culvert resulted in local groundwater table above the height of the wall. Other lessons: the bench at the base of the MSE wall is important to maintain."

APPENDIX D

Research Problem Statement

PROBLEM TITLE

Prediction of Remaining Service Life for Mechanically Stabilized Earth (MSE) Walls

RESEARCH PROBLEM STATEMENT

There are an estimated 16.3 million square meters of various types of walls along the nation's highways (DiMaggio 2008), with an average of 850,000 square meters of mechanically stabilized earth (MSE) wall with precast facing now being built each year in the United States at a cost of $160 to $650 per square meter (Elias et al. 2004; Berg et al. 2009). However, unlike bridges and pavements, MSE walls and retaining walls in general are often overlooked as assets. While the U.S. federal government has fostered the development of the National Bridge Inventory System (NBIS) that involves inspection of the nation's bridges every two years, there is no existing, dedicated management system addressing the whole of the nation's retaining walls, MSE or otherwise. The long-term performance of MSE walls depends on various factors, and unfortunately there have been instances of adverse performance. Like every important class of assets, MSE walls need periodic inspection, assessment, and management. To date, some states have established MSE wall monitoring programs, while several others are looking for guidance, tools, and funding to establish their own monitoring program (Gerber 2012).

During the development of NCHRP Project 20-05, Synthesis Topic 42-05, Assessing the Long-Term Performance of Mechanically Stabilized Earth (MSE) Walls, it was determined that less than a quarter of state-level transportation agencies in the United States have developed some type of MSE wall inventory beyond that which may be captured as part of their bridge inventories (Gerber 2012). Fewer still have the methods and means to populate their inventories with data from ongoing inspections from which assessments of wall performance could be made. The synthesis project determined that in order to "move beyond current inventorying activities and the data baselines now being established, repeated observations and performance predictions will be needed, as will rational decision-making methodologies" (Gerber 2012). To make this leap in asset management practice, research relative to the following topics is needed:

- "Improved ability to evaluate the integrity of existing MSE reinforcement systems using methods that are economically and logistically effective.
- Standards for performance data baselines and data collection activities.
- Predictive models for remaining MSE wall service life.
- Methods of risk assessment specifically for MSE walls and more generally for various types of retaining walls."

LITERATURE SEARCH SUMMARY

As part of NCHRP Project 20-07, Task 259, Brutus and Tauber (2009), concluded that there was/is no data or methods available in technical literature for the estimation of design/service life of existing retaining walls. Based on a survey of transportation agencies, a similar conclusion was reached by Gerber (2012)—no transportation agency currently has a well-established methodology for predicting future MSE wall performance or remaining design life. Certainly some agencies are monitoring corrosion in some walls (see Fishman and Withiam 2011), but a systematic procedure for determining remaining wall life with consideration of all other parameters believed to be important to performance (such as drainage) was not identified. Additionally, methods for risk assessment for MSE walls were found to largely be absent, although nascent efforts can be found in work reported by Bernhardt et al. (2003), Bay et al. (2009), and DeMarco et al. (2010). Consequently both methods for design life prediction and risk assessment are needed. Also needed are well-developed tools for gathering wall performance data that will be needed as input and/or calibration parameters for such methods. Again, some efforts in the area are underway (see Fishman and Withiam 2011 regarding corrosion monitoring, Lostumbo and Artieres 2011 regarding in-situ stress monitoring of reinforcement), but greater progress is needed. Recent technological advances in structural health monitoring present promising avenues of research and progress in asset management.

References

Bay, J.A., L.R. Anderson, T.M. Gerber, and R.B. Maw, *An Inspection, Assessment, and Database of UDOT MSE Walls*, Report Number UT- 09.21, Utah Department of Transportation, Salt Lake City, 2009.

Berg, R.R., B.R. Christopher, and N.C. Samtani, *Design of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes*, Volume 1, Report FHWA-NHI-10-024, Federal Highway Administration, Washington, D.C., 2009, 306 pp.

Bernhardt, K.L.S., J.E. Loehr, and D. Huaco, "Asset Management Framework for Geotechnical Infrastructure," *Journal of Infrastructure Systems*, Vol. 9, No. 3, 2003, pp. 107–116.

Brutus, O. and G. Tauber, *Guide to Asset Management of Earth Retaining Structures*, prepared as part of NCHRP Project 20-07, Task 259, Transportation Research Board of the National Academies, Washington, D.C., Oct. 2009, 120 pp.

DeMarco, M.J., R.J. Barrows, and S. Lewis, "NPS Retaining Wall Inventory and Assessment Program (WIP): 3,500 Walls Later," *Proceeding of Earth Retention Conference 3*, Bellevue, Wash., Aug. 1–4, 2010a, pp. 870–877.

DiMaggio, J.A., "Geotechnical Engineering Assets and Liabilities on Surface Transportation Facilities," presented at National Workshop on Highway Asset Management and Data Collection, Durham, N.C., Sep. 25, 2008.

Elias, V., J. Welsh, J. Warren, R. Lukas, J.G. Collin, and R.R. Berg, Ground Improvement Methods, Participant Notebook, NHI Course 132034, FHWA NHI-04-001, National Highway Institute, Federal Highway Administration, Washington, D.C., 2004, 1,022 pp.

Fishman, K.L. and J.L.Withiam, *NCHRP Report 675: LRFD Metal Loss and Service-Life Strength Reduction Factors for Metal-Reinforced Systems*, Transportation Research Board of the National Academies, Washington, D.C., 2011, 116 pp.

Gerber, T.M., Assessing the Long-term Performance of Mechanically Stabilized Earth (MSE) Walls, NCHRP Project 20-05, Synthesis Topic 42-05, Transportation Research Board of the National Academies, Washington, D.C., 2012.

Lostumbo, J.M. and O. Artieres, "Geosynthetic Enabled with Fiber Optic Sensors for MSE Bridge Abutment Supporting Shallow Bridge Foundations," *Proceedings of GeoFrontiers 2011*, Dallas, Tex., Mar. 13–16, 2011, pp. 3497–3504.

RESEARCH OBJECTIVE

The primary objective of this research effort is to establish a methodology for predicting the remaining service life of MSE walls. To meet this objective, the following tasks are proposed.

Task 1: Review literature for information regarding methods for predicting service life of engineered structures other than retaining walls (such as pavements and bridges). From this review, identify key parameters and/or approach concepts that can be applied to MSE walls. Also part of this task will be the collection of case history data for subsequent calibration and verification activities.

Task 2: Develop an initial methodology based on the results of Task 1. While corrosion rate is anticipated to play a major role in the method, other parameters such as drainage are also anticipated to be important. It is anticipated that the method will tie wall features and performance observations to particular distress mechanisms. Because of this, particular consideration will be given to the nature and robustness of the analytical model's input parameters. The parameters selected for the model will influence future standards for MSE wall performance data baselines and data collection activities.

Task 3: Apply the method in order to both calibrate and verify it against case histories and/or known performance data for particular groups of MSE walls. It is recognized that a rigorous assessment of the method's predictive ability by comparison with existing wall inventories will be limited by the availability of performance data as well as the ages of walls in our existing MSE wall inventories.

Task 4: Publish and disseminate results.

ESTIMATE OF PROBLEM FUNDING AND RESEARCH PERIOD

Recommended Funding:

$XXX,XXX.XX

Research Period:

XX Months

URGENCY, PAYOFF POTENTIAL, AND IMPLEMENTATION

MSE walls are being constructed at an ever-increasing rate. The oldest walls in the U.S. inventory are about 40 years old, and most walls have an intended design life of 75 to 100 years. However, the age-related performance of the technology has not been fully assessed, and more instances of adverse performance are expected with time. Some agencies are now gathering performance data, but predictive models for remaining MSE wall service life are needed so that appropriate management and maintenance and/or replacement decisions can be made. The initial availability of predictive tools would assist agencies in determining whether and/or how much to invest in MSE wall inventory and assessment systems. By facilitating broader participation and greater consistency in methods and practice, greater improvements in asset management and service-life predictive models will be realized. Without the initial investment represented by this development of a remaining service life model, needed progress will continue to go unrealized.

STATE OF OHIO DEPARTMENT OF TRANSPORTATION

MSE WALL INSPECTION CHECKLIST

District ☐ ☐ Date Inspected ☐ Name of Inspector

Is MSE wall at a bridge? (Y/N) ☐ ☐ County ☐ Route ☐ Section ☐ L/R ☐ RA/FA ☐ End Sec.

Instructions are on the 2nd page.

Yes No N/A		Measurement
	Joints	
○ Y ○ N ○ X	1. Is sand or gravel coming out of joints or are there piles of sand or gravel at the base of the wall? (Photos 2 & 3)	
○ Y ○ N ○ X	2. Is sand or gravel visible in the horizontal joints? (Photo 4)	
○ Y ○ N ○ X	3. Are the joints wide enough to see the sand, gravel or fabric behind the panels when looking perpendicular to the wall face using a flashlight? (Photo 5) If yes, record the approximate maximum joint width, in inches.	
○ Y ○ N ○ X	4. If fabric is visible in the joints, is it torn? IMPORTANT - DO NOT POKE OR CUT THE FABRIC.	
○ Y ○ N ○ X	5. Do the joints have a nonuniform size, or are some joints noticeably wider than others? (Photo 6)	
○ Y ○ N ○ X	6. Are the panels offset at the joints either in or out of the wall? (Photo 7) If yes, record the approximate maximum offset.	
○ Y ○ N ○ X	7. Is there vegetation growing in the joints? (Photo 8)	
	Wall Facing	
○ Y ○ N ○ X	8. Are there cracks in more than two facing panels? (Photos 9 & 10) If yes, record the approximate number of panels that are cracked.	
○ Y ○ N ○ X	9. Is the face of the wall bowed or bulged? (Photo 11)	
	Drainage	
○ Y ○ N ○ X	10. Are there any signs of water flow along the base of the wall?	
○ Y ○ N ○ X	11. Is there erosion of the embankment at the base of the wall? (Photo 12)	
○ Y ○ N ○ X	12. If there is erosion, is the leveling pad exposed at the base of the wall? (Photo 13)	
○ Y ○ N ○ X	13. Are the catch basins or the catch basin outlets near the wall blocked? (Photo 14)	
○ Y ○ N ○ X	14. Is the roadway drainage system above the wall malfunctioning?	
○ Y ○ N ○ X	15. Does water at the top of the wall collect behind the concrete coping?	
	Top of Wall	
○ Y ○ N ○ X	16. Is there settlement at the top of the wall?	
○ Y ○ N ○ X	17. Are there any open cracks in the concrete coping (not hairline cracks)? If yes, record the approximate maximum crack width.	
○ Y ○ N ○ X	18. Have the construction joints in the concrete coping opened up? (Photo 6) If yes, record the approximate maximum joint width.	
○ Y ○ N ○ X	19. Is there a gap larger than 1 inch between the approach slab and the approach pavement? (Photo 15) If yes, record the approx. max. gap size.	
○ Y ○ N ○ X	20. At abutments, has the joint between the wall coping and the abutment opened up more than two inches? (Photo 16)	

Revised 12/15/2005

STATE OF OHIO DEPARTMENT OF TRANSPORTATION

MSE WALL INSPECTION CHECKLIST

District ☐ Date Inspected ☐ Name of Inspector ☐

Is MSE wall at a bridge? (Y/N) ☐

County	Route	Section	L/R	RA/FA	End Sec.

Instructions are on the 2nd page.

Comments

<u>Instructions</u>

1. Enter the District, date inspected, and the name of the inspector.

2. Identify the MSE wall location.
   For MSE walls at bridges, use the section for the bridge in the C/R/S. For twin bridges with separate MSE walls, identify if the MSE wall is on the left or right. Identify if the MSE wall is at the rear or forward abutment.
   For MSE walls away from bridges, use the section at the beginning of the wall in the C/R/S. Identify if the wall is on the left or right of the roadway. Fill in the section for the end of the MSE wall.

3. Inspect the wall and answer the 20 questions. Refer to the example photos to identify the parts of an MSE wall and for guidance as to what to look for. A "Yes" answer to any of the questions may indicate a potential problem with the wall. When required, take an approximate measurement and record it in the box to the right of the question.

4. Take photos showing the entire height of the wall. For long walls, take multiple photos to show the entire length of the wall. For walls at bridges, take one photo of each section of wall.

5. For each "Yes" answer to a question, take a photo that shows the relevant item in sufficient detail to understand the reason for the "Yes" answer.

<u>Necessary equipment</u>
Digital camera, ruler, and flashlight.

SPECIFIC WALL CHARACTERISTICS

DRAINAGE

Required Tools: Nylon Mallet-Water Bottle-Camera-Tape Measure

Yes	No	N/A	UKN	Issue	Measurement / Explanation (if applicable)	Percentage of Wall Affected / Extent of Problem / Photo #
Y	N	N/A	UKN	Is there an active water source near the toe of the wall (is the wall near a body of water with scour potential?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	If applicable, are the catch basins at the base of the wall blocked?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Are there culverts protruding through the wall?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Are there vertical drains that travel through the backfill?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there erosion at the base of the wall or leveling pad?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there erosion along the wing walls?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Are there any signs of water flow along the base of the wall?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there less than 14 feet between irrigation sprinklers and wall?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Does the backfill or joint fabric appear to be saturated?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there vegetation growing in panel joints?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Are the deck drains and outlets at the top of the wall blocked?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Can water enter the wall between coping and slab (i.e.. Drain appropriately)?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there evidence at discharge point of fill washing through drain pipes?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%

MSE WALL JOINTS

Required Tools: Long Level-String-Camera-Tape Measure

Yes	No	N/A	UKN	Issue	Measurement / Explanation (if applicable)	Percentage of Wall Affected / Extent of Problem / Photo #
Y	N	N/A	UKN	Is backfill coming out of joints or are there piles of backfill at the base of the wall?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Are the joints wide enough to see fabric or backfill behind panels when looking into joints? If yes, record the approximate maximum joint width in inches.		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is exposed backfill visible in the horizontal joints?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Are there visible tears in the fabric?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Is there evidence of backfill or water leaking through tears in fabric behind panels? (Do not induce additional damage to fabric)		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Do the joints have a non-uniform horizontal spacing/size? (I,e. Are some horizontal joints larger/smaller than others?)		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Do the joints have a non-uniform vertical spacing/size? (I,e. Are some horizontal joints larger/smaller than others?)		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum offset.		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%
Y	N	N/A	UKN	Does the fabric appear brittle, or appear as if it has undergone excessive UV exposure?		0/No 1% 5% 10% 25% 50% 75% 90% 95% 100%

Abbreviations used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation