Development of Mechanically Stabilized Earth (MSE) Wall Inspection Plan and Procedure For Failure Mode Analysis and Risk Assessment

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Utah State University

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DEVELOPMENT OF MECHANICALLY STABILIZED EARTH (MSE)
WALL INSPECTION PLAN AND PROCEDURE FOR FAILURE
MODE ANALYSIS AND RISK ASSESSMENT

by

Ryan Bruce Maw

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Civil and Environmental Engineering

Approved:

Dr. James A. Bay
Professor

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UTAH STATE UNIVERSITY
Logan, Utah
2009
ABSTRACT

Development of Mechanically Stabilized Earth (MSE) Wall Inspection Procedure for Failure Mode Analysis and Risk Assessment

by

Ryan Bruce Maw, Master of Science

Utah State University, 2009

Major Professor: Dr. James A. Bay
Department: Civil and Environmental Engineering

A large component of the State of Utah’s transportation network involves the use of MSE walls, which have proven useful in infrastructure for their reduced costs and footprint compared to other alternatives. As effective as MSE walls have been in responding to demands in transportation, they also have inherent challenges. For the majority of MSE walls the structure is limited in observation as structural components are buried as part of the soils mass. This inability to observe at can lead to the development of complex failure mechanisms, which can be difficult to assess and anticipate. As society becomes increasingly reliant on the transportation networks for goods, services, and security, properly understanding the potential failure mechanisms of MSE walls also increases in importance.

This thesis discusses the development of an inspection procedure, data collection, geotechnical asset management database, and an evaluation of gathered information to be used in a reliability analysis of MSE walls for the State of Utah. The findings suggest
areas of improvement in the design, specifications, maintenance, and further investigation of MSE walls.

(268 pages)
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I feel it important to express gratitude to my friends, my brothers: Dallin and Jaden; my grandparents, LeGrande and Marilyn; my parents, Bruce and Janet; and particularly I would like to thank my dear wife, Carly Lynn, for all of their examples, influence, patience, and loving support; to them I dedicate this thesis.

Ryan Bruce Maw
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CHAPTER 1

INTRODUCTION

1.1 MOTIVATION

The reinforcement of constructible mediums using a variety of materials has occurred throughout human history. Straw, grasses, sticks, and branches have been used to reinforce adobe bricks since the beginning of human existence. In the 17th and 18th centuries French settlers, along the Bay of Fundy in Canada, used sticks to reinforce mud dikes. The Chinese have utilized branches to reinforce levees for over a thousand years, and similar methods were used in the U.S. along the Mississippi River in the 1880’s (Elias et al. 2001).

More modern methods of soil reinforcement used in retaining walls were pioneered by Henri Vidal, a French architect and engineer who practiced in the early 1960’s. Vidal’s efforts created Reinforced Earth®, a system that utilized steel strip reinforcement. The first wall to use this technology in the U.S. was built in 1972 in California. It has been estimated that there are more than 23,000 Reinforced Earth Structures representing over 70 million m² (750 million ft²) of wall facing in 37 countries. In addition to Steel Strip reinforcement, the use of Geotextiles has grown in the U.S. since their introduction in 1974 (Elias et al. 2001).

Currently it has been estimated that more than 700,000 m² (7, 500, 000 ft²) of MSE retaining walls with precast facing are constructed on average per year in the U.S. These numbers gain significance as this represents more than half of the total number of retaining walls used in transportation applications (Elias et al. 2001). Our society relies on its transportation networks for goods, services, and security. As MSE Walls
(Mechanically Stabilized Earth) become an increasingly integral part of our transportation network, understanding frailties in application, design, specifications, and construction is critical in mitigating potential problems for both existing and future walls.

The State of Utah has a large inventory of Material Stabilized Earth Walls (MSE) that composes a significant component of its transportation infrastructure. Since their integration MSE walls have proven useful in enabling the construction of large transportation systems, while reducing the demand on available space for construction. However, one of the greatest challenges in maintaining MSE walls compared to other alternatives is that much of the structural support for an embankment is part of the buried structure. The inability to observe the degradation or failure of the structural components of the MSE WALL can lead to complex failure mechanisms barely observable from the exterior. Successful identification of the developmental phases of these mechanisms enables us to detain or halt future failures, which could range from the loss of the wall all the way to the loss of life.

1.2 Thesis Outline

The direct purpose of work performed as part of this thesis is to augment the understanding and identification of mechanisms that could lead to varying degrees of failure, provide UDOT with an increased understanding of the current status of their walls, construct a database to house acquired information, and conduct an expert panel meeting to review observations for future work to be performed as part of a failure modes analysis. The major tasks proposed to be accomplished as part of research for this thesis can be identified as:
1.2.1 Develop a Catalogue of UDOT MSE Walls

As much of the information regarding the structure of a MSE wall is buried within the structure. It was imperative to collect all available information, from wall characteristics to available institutional knowledge, in order to develop the most complete record of UDOT’s walls possible.

1.2.2 Compile a History of MSE Wall Failures

In order to better understand the critical mechanisms of failure regarding MSE wall failures it is important that a history of MSE wall failures be compiled.

1.2.3 Limited Field Investigation to Evaluate the Status and Distresses of Walls throughout the State of Utah

Along with the compilation of MSE failures mechanisms observed reviewing previous MSE wall failures numerous meetings were coordinated with local experts both from within and outside of UDOT to postulate possible failure mechanisms. The information collected from these sources was developed into an inspection form shown in Appendix A and procedure used in the wall inspections. The proposed methods were evaluated through site visits and further refined in the training of the groups who performed the inspections.

1.2.4 Assembly of Data for Evaluation and Future Consideration

Although not initially required, a Geotechnical Asset Management Program was developed with the help of the Utah Local Technical Assistance Program (LTAP) and a
Mapwindow interface program called Transportation Asset Management Software (TAMS). This database allows for the long term storage of information collected as a result of the inspections, as well as the potential to continue to add invaluable data (wall drawings, locations, construction issues, etc.) as additional walls are added to the state’s infrastructure.

### 1.2.5 Assemble an Expert Panel and Provide Them with the Developed Catalogue and Historical Data for Discussion and Evaluation

A panel of experts from around the country was invited to a two day panel discussion of potential mechanisms of MSE failure and evaluation of significance of field observations and data collected specifically for the State of Utah.

### 1.3 Contributions

This research is significant in its relative temporal placement as of many of the first MSE walls are approaching their specific design lives and its application to the safety of an integral part of our nation’s infrastructure. Specifically these contributions include:

- The development of an inspection form and procedures that can be used in future applications both for the State of Utah and throughout the nation.

- The creation of a Geotechnical Asset Management program specifically for retaining walls. Although the program was adapted for MSE walls, allowances were made for additional retaining systems and holds possibilities for the management of other assets.
• The collection of data, which provides a ‘snap shot’ of the current status of MSE walls throughout the state. This information will be invaluable in future consideration and evaluation for walls that fall short, meet, and exceed their design life. This information will also be useful in identifying failure mechanisms and restricting losses for issues identified with wall systems or sections.

It is the hope that through meeting these objectives this thesis will represent a significant contribution to the State of Utah, the profession of geotechnical engineering, and lay the groundwork for future research in related fields.
CHAPTER 2
REVIEW OF LITERATURE

2.1 INTRODUCTION

The design considerations in MSE walls can be developed into two categories, internal stability and external stability. The current practice in design consists of determining the geometric and reinforcement requirements to prevent internal and external failure using the limit equilibrium methods of analysis (Elias et al. 2001). Internal and external stability can be further categorized:

I. External Stability
   a. Bearing Capacity
   b. Deep Stability (Rotational)
   c. Overturning (Eccentricity)
   d. Sliding

II. Internal Stability
   a. Tension in Reinforcement
   b. Pull Out

It is generally agreed that a complete design approach should consist of a working stress analyses, limit equilibrium analyses, and deformation evaluations (Elias et al. 2001).
A working stress analysis should consist of the following:

- Selection of reinforcement location and a check that stresses in the stabilized soil mass are compatible with properties of the soil and inclusions
- Evaluation of local stability at the level for each level of reinforcement

A limit equilibrium analysis should include:

- External stability analysis involves the overall stability of the stabilized soil mass considered as a whole and is evaluated using slip surfaces outside the soil mass.
- Internal stability analysis consists of evaluating potential slip surfaces within the reinforced soil mass.
- Consideration of failure plan that involves both an external and internal failure (i.e., pass through the internal and external boundaries)

Deformation analysis is an evaluation of the anticipated performance of the structure with respect to horizontal and vertical displacement. Horizontal deformation analyses are the most difficult and least certain of the performed analyses. Vertical deformations are obtained from conventional settlement, with particular emphasis on differential settlement, longitudinally along the wall face, and transversely from the face to the end of the reinforced soil volume. The results of the deformation analysis can impact the choice of wall type, facing, facing connections, and/or backfill sequences (Elias et al. 2001).
The External Stability of MSE WALL structures treat the reinforced section as a composite homogenous soil mass and its stability with conventional failure considerations for gravity type wall systems. However, differences exist in present practice for the specification of the required reinforcement in internal stability (Elias et al. 2001). These methods include the Coherent Gravity Method, Simplified Method, and new proposed methodologies. One of these new proposed methods that will be discussed in this chapter is the $K_0$-Stiffness Method (Allen and Bathurst 2003).

These design considerations have developed over time based upon case studies of wall failures. These methods serve to evaluate the Internal and External stability of the walls for the cases of Bearing Capacity, Deep Stability, Overturning, Sliding, Tension in Reinforcement, and pullout, however, when these MSE Walls are placed into location for their specified uses other aspects of their design, specification, and construction become critical to the integrity of the earth structure. Often times these other classes of failures are dependent on site specifics, owners desired use, desired reliability of the structure, and considerations that would not be considered under normal conditions (often referred to as “odd ball failures”).

### 2.2 Overview of Design Methods

#### 2.2.1 Coherent Gravity Method

The Coherent Gravity Method was developed to better estimate the stresses in inextensible strip reinforcement for precast panel-faced MSE walls. This method assumes that the reinforced soil behaves as a rigid body, and using the principals developed by Meyerhof for eccentrically loaded footings, relates this to a lateral load acting at the back.
of the reinforced area creating an overturning moment. This overturning moment creates an increase in vertical stress at the toe of the wall, which is resisted soil beneath the eccentrically loaded footing.

The force and resultant stresses transferred by the soil mass to the reinforcement is a function of the lateral earth pressure coefficient ($K_0$ or $K_a$), which is determined by the soil friction angle, applied to the vertical stress on the reinforced section. The stress on each reinforcement section is assumed to be equivalent to the lateral soil stress over the tributary area for each strip of reinforcement. The value of the lateral earth coefficient is dependent on the height of the reinforced mass. This method is largely based on the assumption that the concrete MSE face panel becomes an anchor point as the steel strip reinforcement behaves similar to a tieback in the compacted soil mass (Allen et al. 2001).

The Coherent Gravity Method can be summarized by the following equations and Figs. 2.1 and 2.2:

\[
T_{\text{max}} = S_R f_v (\sigma_v K_p) \quad \text{(Eqn. 2.1)}
\]

\[
\sigma_v = \frac{V_1 + V_2 + F_v \sin \beta}{L - 2e} \quad \text{(Eqn. 2.2)}
\]

\[
e = \frac{F_v (\cos \beta) h / 3 - F_v (\sin \beta) L / 2 - V_2 (L / 6)}{V_1 + V_2 + F_v \sin \beta} \quad \text{(Eqn. 2.3)}
\]

\[
K_0 = 1 - \sin \phi \quad \text{(Eqn. 2.4)}
\]

\[
K_a = \tan^2 (45 - \phi / 2) \quad \text{(Eqn. 2.5)}
\]

\[
\sigma_v = \frac{V_1 + V_2 + F_v \sin \beta}{L - 2e} \quad \text{(Eqn. 2.6)}
\]
where: 

\( T_{\text{max}} \) is the maximum reinforcement load for each reinforcement level,

\( S_v \) is the vertical spacing of the reinforcement,

\( R_c \) is the reinforcement coverage ratio,

\( \sigma_v \) is the vertical stress at each reinforcement level,

\( K_f \) varies from \( K_o \) to \( K_a \) based on the reinforcement zone soil properties,

\( \Phi \) is the reinforced backfill peak soil friction angle,

\( e \) is the force eccentricity,

and all other variables are shown in Figs. 2.1 and 2.2 (Allen et al. 2001).

Fig. 2.1 Forces and stresses for calculating Meyerhof vertical stress distribution in the Coherent Gravity Method (from AASHTO 1999).
2.2.2 The Simplified Method

The Simplified Method was a development to combine the best and simplest features of the various methods allowed by AASHTO Standards into one method. One example of this was to account for the differences among the various types of reinforcement and their typical global stiffness’s, yet simplify the calculation by avoiding the need to iterate each time the reinforcement density was adjusted to match the reinforcement stresses to the reinforcement capacity available for the wall. Additionally, the Coherent Gravity method did not provide a way to account for the differences in reinforcement type, since $K_a$ and $K_o$ were used directly in that method to calculate reinforcement stresses regardless of the reinforcement type. Another significant difference among the methods was the calculation of the vertical soil stress, whether the wall should be treated internally as a rigid body, which would allow an overturning moment to be transferred throughout the reinforced soil mass, elevating the vertical stress in the wall. If considered this calculation adds a significant complication to the internal stress computation and its significance has been questioned by the FHWA. It was later decided that the overturning moment should not be considered, but be retained only for external bearing stress computations as a conservative measure. The equation to calculate the maximum tension in the reinforcement can be found in Eqn. 2.7, except that $K_d/K_a$ is determined directly from Fig. 2.3 (Allen et al. 2001).
Fig. 2.2 Determination of lateral pressure coefficients failure plane location for internal stability design using the Coherent Gravity Method (from AASHTO 1996).
\[ T_{\text{max}} = S_r R K_r (\gamma Z + S + q) \]  
(Eqn. 2.7)

**Fig. 2.3** Determination of \( K_r/K_a \) for the Simplified Method (from AASHTO 1999).

### 2.2.3 The \( K_0 \)-Stiffness Method

The \( K_0 \)-Stiffness Method was developed to apply new design methods based on working stress principals, in an effort to provide more accurate estimates of reinforcement stresses and strains. The development of this method was of particular significance to extensible geosynthetic reinforcement, that were considered to be overly conservative using other methods. This conservancy is due to hidden factors of safety incorporated into design by empirical or theoretical relationships and the inherent uncertainty of material properties. The \( K_0 \)-Stiffness Method represents significant contributions by Tony M. Allen and Dr. Richard J. Bathurst in combination with the
FHWA, Washington State Department of Transportation and the Royal Military college of Canada (Allen and Bathurst 2003).

The Structure Stiffness Method shares some similarities with other methods in the assumption that the reinforcement and panel interaction is similar to that observed in tiebacks. However it differentiates in calculating the lateral earth pressure coefficient, applied to the vertical stresses. It assumes that the lateral earth pressure coefficient is a function of the depth below the top of the wall, the type of reinforcement, and the overall global stiffness of the wall. The failure surface assumed is similar to that developed in the Coherent Gravity Method with inextensible soil reinforcement. Additionally, the $K_0$-Stiffness Method considers directly or indirectly, the overall stiffness of all wall components relative to soil stiffness in estimating the distribution and magnitude of $T_{\text{max}}$ and was developed and confirmed through the empirical interpretation of full-scale wall testing and case histories (Allen and Bathurst 2003).

The $K_0$-Stiffness Method considers the following variables:

- Wall geometry, $H$ (the total height of the wall), $S$ (the average surcharge height above the wall), $S_v$ (tributary area, equivalent to the average vertical spacing of the reinforcement near each layer location when analyses are carried out per unit length of wall), and $\Phi_{fb}$ (a factor to account for the effect of wall face batter)
- Reinforcement properties, $S_{\text{local}}$ (the local reinforcement stiffness, equal to $J/S_v$ where $J$ is the reinforcement stiffness), and $S_{\text{global}}$ (the
global wall stiffness, equal to \( J_{ave}/(H/n) \) where \( J_{avg} \) is the average stiffness for all reinforcement layers and \( n \) is the number of layers)

- Facing stiffness, \( \Phi_{fs} \) (facing stiffness factor)
- Soil properties, \( \gamma \) (the backfill soil unit weight), and \( K_0 \) (the at-rest earth pressure coefficient based on the peak plane strain soil friction angle).

\( K_0 \)-Stiffness Method was developed beginning with the conventional equation for earth pressure behind a rigid mass, shown in Eqn. 2.8. This equation is a starting point as it does not include assumption about the distribution applied pressures (Allen and Bathurst 2003).

\[
\sigma_v = \frac{1}{2} K \gamma (H + S)
\]  
\text{(Eqn. 2.8)}

For the case of inextensible reinforced systems, such as steel, the lateral pressure coefficient “K” was set equal to \( K_0 \). The factor \( (D_{max}) \) was introduced to characterize the differing distributions observed for steel and geosynthetic reinforcements. A trapezoidal distribution representing well the distribution stresses for geosynthetics and that of a triangle for steel reinforcements. Applying the factor \( D_{max} \) to Eqn. 2.8 results in a distributed earth pressure of the proper shape relative corresponding to the reinforcement type.

Relating the vertical spacing of the reinforcement, \( S_v \), which representatively quantifies the tributary area of stresses on the reinforcement for a unit of wall width generates Eqn. 2.9:
\[ T_{\text{max}} = \frac{1}{2} K \gamma (H + S) S_v D_{\text{max}} \phi \]  

(Eqn. 2.9)

The development of Eqn. 2.9 incorporates several factors; however, no correction has been made to fit the equation to empirical interpretation of field observations. This correlation is applied through the application of \( \Phi \). Where \( \Phi \) incorporates global and wall facing stiffness, batter of the wall facing, and the distribution of local stiffness through the tributary area of the soil mass. Applying simple regression techniques to fit the equation to the empirical data, the final form of the equation for \( T_{\text{max}} \), in each reinforcement layer can be determined as follows:

\[
T_{\text{max}} = 0.5 S_v K_0 \gamma (H + S) D_{\text{max}} \left( \frac{S_{\text{Local}}}{S_{\text{Global}}} \right)^d \left( \frac{K_{abh}}{K_{avh}} \right)^d \Phi_{fs} 0.27 \left( \frac{S_{\text{global}}}{p_a} \right)^{0.24} \]  

(Eqn. 2.10)

where:
- \( a \) is a coefficient (currently set equal to 1 for geosynthetic walls and 0 for steel reinforced walls),
- \( K_{abh} \) is the horizontal component of active pressure coefficient accounting for wall face batter,
- \( K_{avh} \) is the horizontal component of active earth pressure coefficient, assuming the wall is vertical,
- \( d \) is a constant coefficient (currently set equal to 0.5),
- \( p_a \) is the atmospheric air pressure (a constant equal to 101 kPa)
- \( \Phi_{fs} \) the facing stiffness factor is set equal to 0.5 to 1.0, depending on the stiffness of the facing, the wall height, and the reinforcement type (geosynthetic or steel).
\((S_{\text{local}}/S_{\text{global}})^a\) is a factor that accounts for the effects of local stiffness,

\((K_{ab}/K_{av})^d\) is the batter factor \(\Phi_{fb}\), and all other variables have been described previously (Allen and Bathurst 2003).

Equation 2.9 can be applied for both geosynthetic and steel reinforced MSE walls to estimate both reinforcement loads and strains. Strain can be estimated by simply dividing \(T_{\text{max}}\) by the reinforcement modulus. While the \(K_0\)-stiffness represents significant developments in understanding the stresses involved in MSE wall reinforcements, this method will continue to benefit from research due to its empirical components (Allen and Bathurst 2003).

2.3 SELECT HISTORIES OF MSE WALL FAILURES

2.3.1 Introduction

The information included in this section was adapted from a document produced for the panels of experts in conjunction with the Potential Failure Modes conference. This document includes contributions from myself, Holly J. Griffin, Dr. Travis M. Gerber, and Dr. Jim A. Bay. This information is included due to its significant nature in relation to other aspects of the project continued hereafter.

2.3.2 Soda Springs, Idaho

The Idaho Transportation Department (ITD) designed and constructed an MSE Bridge abutment over the Union Pacific Railroad (UPRR) tracks of Soda Springs in 1978. This wall, shown in Fig. 2.4, was considered to be the first true MSE abutment in the
United States, and was featured as part of an FHWA Demonstration project. The bridge abutment used spread footings designed to bear directly on the MSE Walls. During the summer of 2002, roughly six pre-cast concrete panels popped out in a localized area of an abutment. It was concluded that the galvanized steel soil reinforcing strip had corroded at a panel connection to a point at which the lateral earth pressures exceeded the connection’s remaining capacity (Armour et al. 2004).

The backfill for the MSE wall was a chemically aggressive slag waste purchased from a local phosphate mining company. At the time of construction, the only requirement for the MSE backfill material was a cohesionless material with a specified gradation (Armour et al. 2004).

This failure occurred on July 9, 2002, when a section of the southwest approach popped out along the first row of panels. This failure created unstable conditions that allowed the second row of panels to also fail as shown in Fig. 2.5 (Armour et al. 2004).

Fig. 2.4 Aerial view of state highway 34 and railroad intersection (from Armour et al. 2004).
Upon investigation, ITD engineers determined that the failure was caused by the corrosion of the metallic soil reinforcing strips attached to the lower concrete facing panels, as shown in Figs. 2.6 and 2.7. The hot-dipped zinc galvanizing had been consumed along the straps and in some cases facilitated corrosion of the reinforcement through the steel (Armour et al. 2004).

The electrochemical properties of the backfill material were measured as part of the forensic investigation. The results of these tests as well as the 2002 AASHTO LRFD Bridge Construction Specifications and current ITD MSE wall backfill are shown in Table 2.1 (Armour et al. 2004).

![MSE wall after initial failure on July 12, 2002](from Armour et al. 2004)

**Fig. 2.5** MSE wall after initial failure on July 12, 2002 (from Armour et al. 2004).
Fig. 2.6 Corroded metallic soil reinforcements on panel (from Armour et al. 2004).

Fig. 2.7 Corroded straps in backfill (from Armour et al. 2004).

According to *Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes* (Publication No. FHWA-SA-96-072) resistivities in this range are rated as corrosive to moderately corrosive. Chlorides and sulfates in this range are equivalent to a resistivity of less than 700 ohm-cm, which is
classified as a very corrosive environment for metallic reinforcing strips. Soils with high alkalinity and/or high pH are associated with significant corrosion rates. The poor quality backfill led to corrosion and premature failure of the soil reinforcement system. Therefore, the original design life of 75 years was reduced to only 25 years (Armour et al. 2004).

2.3.3 Susquehanna County, Pennsylvania

Between June 24 and June 28, 1989 an MSE Wall (Retained Earth™) located in the Lennox Township of Susquehanna County Pennsylvania experienced a failure. The simple span bridge across the east and west abutments was supported on a spread footing foundation that rested directly on the MSE Wall, built in 1985-1986.

Table 2.1 MSE Wall Backfill Electrochemical Properties: Observed vs. Specified (after Armour et al. 2004).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test Sample</th>
<th>2002 AASHTO LRFD Bridge Construction Specifications</th>
<th>Current ITD Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistivity (ohm-cm)</td>
<td>820</td>
<td>&gt; 3000</td>
<td>&gt; 3000</td>
</tr>
<tr>
<td>Soluble Chlorides (ppm)</td>
<td>690</td>
<td>&lt; 100</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>Sulfates (ppm)</td>
<td>1770</td>
<td>&lt; 200</td>
<td>&lt; 200</td>
</tr>
<tr>
<td>PH</td>
<td>9.9</td>
<td>5 to 10</td>
<td>4.5 to 9.5</td>
</tr>
</tbody>
</table>
This failure, shown in Figs. 2.8 and 2.9, opened up a cavity of approximately 100 square ft in the lower right quadrant of the east abutment. This opening contributed to the loss of 70 cubic yards of backfill and stone aggregate from the wall. Additionally a number of pre-cast concrete panels toppled away from the wall (Elias et al. 1991).

![Fig. 2.8 View of failed section (Elias et al. 1991, Appendix A).](image)

![Fig. 2.9 Internal view of failed Section (Elias et al. 1991, Appendix A).](image)
The Pennsylvania Department of Transportation (PENNDOT) initiated investigations to determine the cause for the walls failure. This investigation encompassed the design, construction, inspection during all phases, and the forensic study of materials involved in the failure. This investigation eliminated the possibility of foundation failure as the wall was constructed on bedrock. The button head failure at the panel with the absence of corrosion suggest that overstress on the reduced section in the critical bottom third of the wall was the primary cause of failure. The report suggests that there were five possible mechanisms which accrue stress at the connection:

I. Initial tension-developed from earth pressures and surcharge loads,

II. Hydrostatic Pressures-developed from unanticipated pore pressure buildup behind facing

III. Freeze Pressures-developed from ground water or surface water trapped in the reinforced fill freezing and expanding against the concrete panels, which are restrained from horizontal movement by friction or passive resistance developed along the full length of the bar mats in the fill.

IV. Increase in tension due to differential thermal expansion coefficients of the steel mesh and granular backfill in the fill zone adjacent to the panels.

V. Increase in tension due to differential settlement, between panels founded on an incompressible foundation and settling fill behind the face (Elias et al. 1991).
Through the course of the analysis it was determined that the structural failure at Abutment No. 2 can be primarily attributed to:

- Excess freeze and normal earth pressures overstressing a statistically significant number of button head connections contain initial cracks. These initial cracks are attributed to the cold forming process of fabrication and/or possibly by hydrogen absorbed during subsequent galvanizing.

- It should be noted that under the **worst** postulated conditions the maximum inferred tension in the longitudinal rods is on the order of 77 ksi, which is less than the measure average breaking strength of 87 ksi. The reduced cross-sectional area in a statistically significant number of button heads/rod assemblies of up to 50% of the original cross-sectional area caused an initial local failure and precipitated a progressive failure as stress redistribution occurred at each panel.

- It is further believed that an initial failure of button heads occurred during the first winter. The later catastrophic evidence of failure noted in June 1989 is largely unexplained. It appears that creek levels were below the top of riprap therefore, cannot be directly linked to some initial dislodging of panels. The continuing seepage noted in the failed area may have contributed to an initial dislodge of the unsupported panels.
thereby causing the progressive failure noted (Elias et al. 1991).

2.3.4 Rockville, Maryland

Another failure of an MSE wall occurred in Rockville, Maryland in 2003. Constructed in 1996, the segmental block wall was 750 ft in length and 15 ft tall, located alongside a residential development. Geosynthetic reinforcement was used in the construction of the wall, with reinforcement sections 10 ft in length. Granular fill soils were used as the backfill. The wall was constructed using 8 in. standard keystone blocks, with a 4 in. cap block at the top of the wall (Hossain and Omelchenko 2005).

The portion of the wall analyzed in the failure analysis was at an elevation of approximately 354 ft (at the top of the wall). The ground surface at the top of the wall was grass covered. The slope at the top of the wall was generally level or negative for a distance of about 1 to 2 ft, at which point the slope rose gradually. The slope at the toe of the wall was generally level or slightly descending. Townhouses were located approximately 36 ft from the face of the wall. Prior to placement of a conduit, water from the downspouts of town home units drained into the reinforced soil zone of the MSE wall (Hossain and Omelchenko 2005).

Inspectors observed large gaps and separation in the wall facing blocks in 2002, which became more severe in the following months. At failure, leaning and bulging of the wall face was observed, most severely exhibited where the wall was highest. A bulging of the face occurred at a location of about 2.5 to 5.5 ft above the base of the wall, with gaps of up to 1 in. between blocks. The top of the MSE wall had moved 12 to 18 in. upon failure. Scarp-like failures were noted at several locations along the slope at the top
of the wall, located at a distance of about 16 to 17 ft behind the wall (Hossain and Omelchenko 2005).

Upon completion of a slope stability analysis, it was determined that the factor of safety was approximately 1.0. However, when the wall design is subjected to a partially saturated condition, the factor of safety is below 1.0, indicating imminent failure. Site visits revealed that portions of the wall face were wet, even after extended periods of relatively dry weather. This observation is indicative of water flow through the backfill, the origin of which could be several sources (Hossain and Omelchenko 2005).

Excavation of two test pits revealed that the geogrid reinforcement were not horizontal. The top layer of geogrid at the site of the analysis sloped downward before connecting to the block facing. As a result of this bend, a 2 to 3 in. void space was observed beneath the geogrid where it sloped downward. The second geogrid layer exhibited similar characteristics, with a bend of approximately 45 degrees where it connects to the block facing (Hossain and Omelchenko 2005).

Compaction tests confirmed that the bend was due to settlement of the upper layer of fill. The compaction of the upper layer of fill was only 81.0% of maximum dry density for the Standard Proctor test, which was noncompliant with the 95% compaction requirement for the project. The lower backfill soils were compacted sufficiently upon construction of the wall, however the soil became softer and moisture content increased over time. Compaction was at 81.0% and 81.3% for soils below the top two geogrid layers (Hossain and Omelchenko 2005).

It was ultimately concluded that the wall failure was due to three primary factors:
improper installation of the geogrid, inadequate internal drainage of the backfill soil, and inadequate compaction of the reinforced soils (Hossain and Omelchenko 2005).

2.3.5 Clearfield, Utah

Locally, MSE wall abutments for a single span bridge over multiple railroad tracks experienced numerous modes of failure. The bridge, located in Clearfield, Utah, was supported by concrete caissons, which extended down through MSE wall abutments. The bridge was open to traffic on November 7, 2001. Soon after, the first observations of distress were made on Thanksgiving weekend of 2001, in the form of a vertical separation of MSE Wall panels.

Visible modes of distress (highlighted in Figs. 2.10 and 2.11) included vertical separation between wall panels; undermining and displacement of MSE wall leveling pads; rotation of wall panels with accompanying spalling of several panel corners; outward rotation of the top MSE walls panels and overlying coping; cracking of the MSE wall coping; outward rotation/translation of barrier sections; cracking and displacement of the roadway pavement section near the southwest corner of the bridge; horizontal and vertical displacement of the sidewalk along the north side of the west approach embankment; and development of voids beneath the sidewalk, and beneath the roadway slabs. Slope movement at the southwest corner of the west MSE abutment wall was on the order of 1.5 feet.
Fig. 2.10 Rotation of upper MSE panels.

Fig. 2.11 Slope movement and subsequent erosion of foundation soil beneath MSE wall leveling pads (from IGES 2003).
A forensic investigation of the MSE wall failure was undertaken by IGES (2003). A number of concerns throughout the construction phases were considered as potential contributors to the problems seen within this MSE wall. These concerns were evaluated but later dismissed as causes for failure. IGES concluded that the major factors contributing to the wall failure were related to the following issues:

I. AASHTO’s Standard Specifications for Highway Bridges prescribe that such a (MSE wall) bench have a 4-ft minimum horizontal width. Based on site observations, it appears that a bench was constructed in some locations, but not to a full 4 ft width in all locations.

II. Changes in embankment material originally specified to AASHTO classification A-1. Material recovered during the investigation ranged from A-1 to A-6, with A-4 and A-6 being the most prominent.

III. Insufficient compaction with very loose materials existing within 12 to 20 in. of the wall panels.

IV. Subsequent erosion from runoff either through cracks in the pavement or around the end of the barrier at the top of the wall further contributed to the observed distress.

The primary failure mechanism was identified by IGES as “progressive creep or local shear failure occurring within the steep portions of the two approach embankments.” This was verified by slope stability analyses and IGES (2003) concluded:
We believe that the distress observed in the MSE walls near the bridge abutments is principally a result of slope instability in the underlying embankment. We believe this instability has been caused by the slope being too steep for the materials used in its construction. The load imposed on the slope by an inadequately founded MSE wall section (i.e., lacking sufficient embedment and a full 4-ft wide toe bench) further decreases the slope’s stability.

2.3.6 Salt Lake City and Orem, Utah

In September 2005, a localized buckling of MSE wall panels was observed on the northwest corner of the west abutment of the 600 North interchange of I-15 in Salt Lake City, Utah (see Fig. 2.12). The wall is a “2-stage” wall which is frequently used in the area when ground settlements due to soft clayey soils in the foundation are expected to be relatively large. The wall section developed by VSL consists of vertical welded wire mesh panels (with geosynthetic fabric facing) connected to narrower horizontal welded wire meshes embedded in the backfill. After the wall has settled, concrete facing panels are attached to the wire mesh by turnbuckles.

It was observed that wall panels above the buckled zone (and even the coping and traffic barrier at the top of the wall) had moved downward when the panels buckled. Inspection of the back of the panels revealed that corrosion had deteriorated one of the connections between the panel and turnbuckle. It was theorized that the corrosion of the connection allowed the panel to lose rotational restraint and buckle.
The panels were ultimately removed and the gap repaired with a cast-in-place concrete section whose finished surface protrudes several inches outward from the rest of the wall face.

Recent pictures (see Fig. 2.13) taken at the top of the wall suggest that movement may still be occurring within the reinforced backfill zone since the barrier has continued to spall well after the panels were repaired. The existence of this failure mechanism is supported in part by the construction history of the wall. The wall was constructed in 1997-98 during the early stages of the I-15 corridor reconstruction project. Initially, a very poorly graded, granular backfill material was used for the MSE walls. As walls began to be built to full height, bulging/buckling of the welded wire mesh at the base of the walls was observed for several walls as shown in Fig. 2.14. The consensus of the wall manufacturer and members of the project design team at the time was that the

Fig. 2.12 Buckling of 2-stage MSE wall panels at 600 North interchange of I-15 in Salt Lake City, Utah.
bulging/buckling was caused by internal settlement of the wall backfill immediately next to the face of the wall which was inherently loose due to the flexible nature of the wall face and specifications which did not require a high degree of compaction with one meter of the wall face. Remedial measures consisted of additional compactive effort closer to the wall face and a change in the gradation of the backfill material. For walls already constructed, vibratory probes were inserted vertically near the wall faces in an effort to densify the backfill materials. Documentation is incomplete to verify whether this procedure was employed near the location of the buckled panels.

Another instance of adverse MSE wall performance in Utah was observed at the University Parkway interchange of I-15 in Orem/Provo during the fall of 2003. During construction of an adjacent project, a UDOT inspector noticed that a large void had developed behind the back of the MSE wall at the northeast corner of the east bridge abutment.

Fig. 2.13 Continuing damage to parapet and traffic barrier above location of buckled MSE wall panels.
Unfortunately, no pictures and little documentation regarding this occurrence exist, but a current view of the site is shown in Fig. 2.15. The void was located at the high point along the top of the MSE wall, before the wall slopes down the spill slope. The wall had been constructed 2 years previously. The void was approximately 1-1/2 panels deep and exposed the flat reinforcing straps and their connection to the panels. Repair personnel attributed creation of the void to poor drainage and subsequent erosion; however, from the location of the spot behind traffic barriers and at a local high point, these factors alone do not seem to adequately describe what was observed. No eroded material appeared at the base of the wall either, suggesting that the void may have been the result of internal erosion or settlement behind the wall panel. The void was filled by a maintenance crew with approximately a half yard of pea gravel and then it was paved over. A recent visit to the site shows that a small hole has developed in the area of the
asphalt patch, suggesting that the original distress mechanism may still be active.

2.3.7 Northeastern Tennessee

An MSE wall using geogrid reinforcement was constructed in Tennessee in 1999, measuring 450 ft in length and 28 ft in maximum height. The wall experienced a movement which was exhibited in deformations in spread footings above and adjacent to the retaining wall, as well as in nearby electrical duct manholes about nine months after it was constructed (Scarborough 2005).

There were 45 compaction tests performed on materials within the reinforced fill. Within the reinforced fill, the test results ranged from 96.6 to 101.2% of the standard Proctor maximum dry density (MDD) and 2.0% dry of optimum to 2.6% wet of optimum for moisture content. The average level of compaction was 99% at 0.7% wet of optimum. The average moist unit weight for the reinforced fill was 18.24 kN/m$^3$ (116.1 pcf) (Scarborough 2005).

Compaction tests were also performed in the retained fill around the vicinity of the wall. This material also had adequate compaction. Index testing and triaxial compression tests with pore pressure measurements were also performed and the summary of the results are shown in Table 2.2 (Scarborough 2005).

Initial design calculations were performed using a friction angle of 25° with a non-cohesive backfill. Upon completion of pre-construction triaxial shear tests, the design was revised based on a friction angle of 22°, again with a non-cohesive backfill. No soil type was specified for the reinforced soil or the retained fill (Scarborough 2005). Further forensic analysis determined that no global stability analysis was performed prior
to the construction of this wall, as it was not included in the contract. Upon completion of a post-failure global stability analysis, it was determined that the minimum factor of safety was approximately 1.1, using the pre-construction strength parameters. Global stability analyses prior to construction of the wall would have revealed the necessity of more numerous and elongated geogrid reinforcement. Inadequate reinforcement was determined to be the ultimate cause of the observed movement in this wall, although the use of clayey backfill was probably a contributing factor (Scarborough 2005).

### 2.3.8 Southwestern Virginia

Another MSE wall failure occurred in southwestern Virginia in 2000, pictured in Fig. 16. This wall, which stood 30 feet high and 500 feet long, was constructed of segmental masonry blocks using geogrid reinforcement with a clayey backfill. The wall experienced failure approximately one year after its completion. Upon failure, the reinforced soil remained fairly intact, while the geogrid reinforcement had pulled from between the masonry blocks (Scarborough 2005).

This wall, like the Tennessee wall, was built in the Valley and Ridge physiographic province, in which residual soils consisting of silty clays and clayey silts are common. A full-service car wash was located directly above the wall. An inspection immediately following the failure revealed cracking in the ground surface behind and parallel to the wall, approximately 15 to 36 feet from the wall facing (Scarborough, 2005).

Samples of the reinforced soil were taken after the failure, revealing compaction that was described as erratic. Moisture contents ranged from 20 to 40%, which were 15-
20% higher than the specified moisture contents. Densities were between 80 and 100% of the standard Proctor maximum dry density (Scarborough 2005).

A post-failure stability analysis was performed on the wall as part of the forensic analysis. This included consolidated-undrained as well as unconsolidated-undrained triaxial tests to measure the total and effective shear strength of the soil. The triaxial soil specimens were remolded to 98% of the soil’s standard Proctor maximum dry density at about 3 percentage points wet of optimum moisture content. Confining pressures of 69, 138, and 207 kPa (10, 20 and 30 psi) were used (Scarborough 2005), with the results summarized in Table 2.3.

This analysis of the as-designed geometry (24 ft high) and preliminary design strength parameters revealed a calculated safety factor of 1.48 for the global stability of the wall. Using the as-built geometry (30 ft high), and laboratory-measured long-term shear strength parameters (using effective strength parameters), a factor of safety of 1.24 was calculated (Scarborough 2005).

**Fig. 2.15** Recent view of MSE wall at University Parkway interchange where void
behind wall was observed previously.

Fig. 2. Failure of Virginia MSE wall (from Scarborough 2005).

Table 2.2 Soil Shear Strength Test Results (from Scarborough 2005)

<table>
<thead>
<tr>
<th>When tested</th>
<th>Soil description</th>
<th>Effective stress</th>
<th>Average Moist unit Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Friction angle, $\phi$</td>
<td>Cohesion $c'$</td>
</tr>
<tr>
<td>Pre-construction</td>
<td>Remolded specimens Brown, yellow clay LL=62 PI=30</td>
<td>23 degrees</td>
<td>21.1 kPa (440 psf)</td>
</tr>
<tr>
<td>Pre-construction</td>
<td>Remolded specimens Red, brown, sandy clay LL=62 PI=31</td>
<td>21 degrees</td>
<td>30.2 kPa (630 psf)</td>
</tr>
<tr>
<td>Post-failure</td>
<td>Relatively undisturbed specimens Brown, red sandy silt LL=62 PI=19</td>
<td>22 degrees</td>
<td>28.7 kPa (600 psf)</td>
</tr>
<tr>
<td>Post-failure</td>
<td>Relatively undisturbed specimens Yellow, red silt LL=50 PI=19</td>
<td>31 degrees</td>
<td>18.2 kPa (380 psf)</td>
</tr>
<tr>
<td>Post-failure</td>
<td>Relatively undisturbed specimens Brown red clay LL=56 PI=34</td>
<td>16 degrees</td>
<td>34.5 kPa (720 psf)</td>
</tr>
<tr>
<td>Post-failure</td>
<td>Relatively undisturbed specimens Brown red clay LL=60 PI=38</td>
<td>14 degrees</td>
<td>23.0 kPa (480 psf)</td>
</tr>
</tbody>
</table>

*LL = Liquid limit & PI = Plasticity index*

Wall facing stability analyses were performed using clayey backfill with as-designed geometry and preliminary parameters. This analysis resulted in a factor of safety of 1.2. Another stability analysis was performed simulating a 10 ft height of water behind a 10 ft high wall using clayey backfill. This analysis resulted in a factor of safety
of less than 1.0 (Scarborough 2005).

Based on the observations of the failure at the site, and the analyses performed it was concluded that the most likely cause of the failure was poor drainage leading to a buildup of hydrostatic pressure behind the wall facing. Contributing factors likely included erratic compaction of the fill soils, the increased height of the wall, and the use of clayey backfill within the reinforced zone (Scarborough 2005). This wall failure suggests that additional design considerations are imperative with the use of clayey soils or poorly draining soils as backfill in an MSE wall (Scarborough 2005).

2.4 OTHER MSE WALL QUALITY ASSESSMENT PROJECTS

2.4.1 Ohio Department of Transportation-MSE Assessment

The Ohio Department of Transportation (ODOT) initiated an inspection and inventory program for all of their MSE Retaining Walls. The Department had faced a variety of problems with MSE walls, both during and after construction. On December 7, 2005 a three-lane collector-distributor road along I-270 was shut down when a large void underneath the approach slab at a bridge with MSE walls at the abutment. The void extended 30 ft from the bottom of the MSE wall to the underside of the approach slab. It was determined that the reason for the void was a drainage problem. Further investigation revealed similar drainage problems at six other bridges (T. Keller, unpublished internal report, December 2005).

A short-term inspection program was launched to gather information on the status of ODOT MSE walls. The responsibilities for inspections were divided within each
respective district and supervised under the direction of Peter Narsavage. An inspection procedure and database were established and a photographic as well as a statistical summary was prepared (T. Keller, unpublished internal report, December 2005). The results of this inspection are shown in Table 2.4 and Fig. 2.17.

Table 2.3 Results of Triaxial Shear Strength Tests (from Scarborough 2005)

<table>
<thead>
<tr>
<th>Sample (remolded)</th>
<th>Effective stress</th>
<th>Total stress</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Friction angle $\phi'$</td>
<td>Cohesion $c'$</td>
</tr>
<tr>
<td>Reinforced fill</td>
<td>31 degrees</td>
<td>0 kPa</td>
</tr>
<tr>
<td>Retained fill</td>
<td>30 degrees</td>
<td>0 kPa</td>
</tr>
<tr>
<td>Foundation soil</td>
<td>30 degrees</td>
<td>2.4 kPa (50 psf)</td>
</tr>
</tbody>
</table>

Table 2.4 MSE Wall Inspection Statistics (Peter Narsavage, unpublished internal report, August 2007).

<table>
<thead>
<tr>
<th>Number of MSE Walls</th>
<th>Percent of Total Inspected</th>
<th>No Observed Issues</th>
<th>Minor Issues</th>
<th>Significant Issues</th>
<th>Major Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>4.1%</td>
<td>2</td>
<td>12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>3.5%</td>
<td>7</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>32</td>
<td>9.4%</td>
<td>0</td>
<td>29</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>65</td>
<td>19.2%</td>
<td>11</td>
<td>49</td>
<td>4</td>
<td>1</td>
</tr>
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Ohio Department of Transportation MSE Wall Inspections

2.4.2 Ohio Department of Transportation
Construction Observations

The Ohio Department of Transportation created a document reviewing issues encountered during the construction process of their MSE walls during the 2005 season. The document was a compilation of feedback from project representatives, contractors, and wall manufacturers. Problems were divided into four categories:

I. Construction related
II. Design related
III. Specification related
IV. Manufacturer

Various issues were associated with Reinforced Earth walls. Among the issues was the fact that tabs on the wall were occasionally not long enough to insert the straps. It is common practice in the field to cut the straps, however this should not be permitted.
On occasion there is concrete in the tabs, and by cleaning out this concrete, the chances that the straps require cutting is reduced. Another issue with Reinforced Earth walls was the construction of panels around a curve, and the subsequent hanging of panels over the leveling pad. This should not be permitted, and the leveling pad should be made wider to accommodate the panels. Additional suggestions for Reinforced Earth walls included using restricting the use of bearing pads on the leveling pad, not leaving wooden wedges in place upon completion of the wall, as shown in Fig. 18, and not constructing walls with acute angles. Finally, it was observed that adequate traffic barrier design was lacking (R. Morris, unpublished internal report, October 2005).

Specification-related suggestions included adding detail regarding the placement of adhesive on fabric and then fabric on the wall, as well as adding additional specifications in the Construction Details. Some individuals commented that drainage was not accounted for in the specifications, or became problematic in the design of their Reinforced Earth MSE walls.

Finally, it was observed that textured Reinforced Earth walls were not formed correctly, and bows in the panels failed to correct the joint gap. It was suggested that flush walls be used, as they can be more effectively battered (R. Morris, unpublished internal report, October 2005).
Foster walls experienced issues as well. It was observed that wire mesh had dimensions which resulted in confusion as to its proper placement on the wall. A similar texturing issue was observed in Foster walls, and it was suggested that the inside of the wall be made smoother, or that no texturing be created on the outside of the wall to maintain proper batter. Also, the wall and coping interface have a void between them on textured walls. Lifting eyelets were said to be too small for some walls, and painted on Epoxy sealer was said to be aesthetically displeasing (R. Morris, unpublished internal report, October 2005). Although traffic barriers were designed for the Foster walls covered in this document, traffic barrier expansion joint details were lacking, as shown in Fig. 19.

It was also observed that “Re-steel” tie bar through the loops that hold the re-steel in place needs to be longer for construction. Another complaint for Foster walls was that the manufacturer should provide wedges to the contractor. Backfill for Foster walls
was said to go in easily, and fabric wrapped pipe was said to work well. A general comment regarding Foster walls was that the larger panels make it more difficult to achieve joint tolerances (R. Morris, unpublished internal report, October 2005).

In a comparison between Reinforced Earth and Foster walls, it was said that the square panels were favored by the individuals, and that Reinforced Earth walls are not as forgiving in and out of the wall face. The bolts are more labor intensive (associated with Foster walls), and 15 out of 70 cut straps at the eyes due to tabs being too short on Reinforced Earth walls. Finally, the contractors believe that Foster walls are easier to construct (R. Morris, unpublished internal report, October 2005).

Additional comments on the Foster walls included the need for clarification of specified slopes to the wall, the inclusion of 3-line diagrams in the plans, the need to connect taller panels better (or eliminate the half height walls), and the need for enhanced drainage design.

**Fig. 2.19** Coping panel and traffic barrier joints misaligned (R. Morris, unpublished internal report, October 2005).
It was observed that the fin design broke too easily, and is too fragile. Also, there are continual problems with the bridge/MSE wall interface, and footing and backfill drainage are not addressed in plans. Like Reinforced Earth walls, it was suggested that acute angles no longer be designed for Foster walls (R. Morris, unpublished internal report, October 2005).

Individuals noted that Foster projects need more detailed plans, specifications and special provisions, and also that there are manufacturing problems associated with panels, including dimensions and tolerances. Shop drawings were said to be unclear, and too many changes were noted for the reinforcing steel. In addition, contractors working with Foster walls would like to minimize the steps involved with the leveling pads, and would like more guidance on the rejection of panels (R. Morris, unpublished internal report, October 2005).

Several comments were included specifically addressing issues with Reinforced Earth’s textured walls. It was suggested that fewer steps be required to construct the wall, that pre-cast leveling should be eliminated, that a wider leveling pad should be used, and that fabric should be replaced with wall drain plastic on one side and fabric on the other. Also, it was suggested that the tab width between the joints needs to be increased to create a better interlocking system. It was suggested that an MSE inspection form be provided as well. With respect to Reinforced Earth’s non-interlocking paneled walls, one of the walls was battered too much, and wide joints were observed (both vertical and horizontal). The presence of sand on lower joints was another cause of concern with Reinforced Earth walls, suggesting potential joint leakage, as shown in Fig.

Fig. 2.20 Presence of sand on lower joints (R. Morris, unpublished internal report, October 2005).
CHAPTER 3
WALL INSPECTION

3.1 INTRODUCTION

To further develop the potential MSE WALL issues specific to the State of Utah and characterize the current condition of the state’s walls a site by site inspection was required. Referencing previous work and inspection performed by ODOT, as discussed in Chapter 2, several meetings were coordinated with UDOT and a partnering Brigham Young University (BYU) to discuss potential failure mechanisms. The meetings regarding potential failure mechanisms developed areas in which to focus during the inspection process. These areas of focus where incorporated in an inspection form that would facilitate the collection of data during inspection. The ability to satisfy required data acquisition was evaluated as part of field trials and training of the developed form in conjunction with UDOT and BYU. The developments from these meetings and trainings can be seen in the Inspection Form (shown in Appendix A) and discussed within this chapter.

3.2 INSPECTION CONSIDERATIONS

UDOT has maintained a centralized record of retaining walls constructed along state routes. These numbers, specific to retaining structures, are denoted with an “R” followed by the associated number and other independent identifiers increasing chronologically from the date of proposed design. The “R” number was a unique identifier ranging from a section of walls for a given project to a singular wall. For a given R-number there could be several walls identified by number (i.e., R-351-30) or
letter (R-376-A). The purpose of this record, in its tabular form, was to record the wall number, type and location of drawings, brief description, and remarks specific to wall location. This list and tracking method functioned well during its conception, however, as infrastructure needs have grown, as well as the increase and augmentation in design, construction, and demands on space for record keeping. This coupled with the decentralized nature of records as operation, construction management, and maintenance has been located to each of 5 UDOT regions throughout the state have also lead to a separation of records. Although, not entirely different in needs or risks from bridges, federal funding does not support the documentation and inspection of MSE walls.

Over time the aforementioned factors have contributed to a disparity in records between central records and installation of retaining walls throughout differing regions of the state. This is additionally complicated by the competition for space among records in archives. Unfortunately, some records specific to the construction of these MSE walls have been casualties of the war of competing resources and disposed of by those unfamiliar and unaware of their potential future relevance to making engineering decisions. These issues are not unique to the State of Utah, but create challenges throughout the country.

The limitations created as a result of these factors required additional investigation beyond the available “R” list. Through the assistance of various UDOT regions, archives, and the help of Blaine Leonard of UDOT available drawings, institutional knowledge, and other available information was compiled. The predominate source of documentation was Situation and Layout drawings, which provided
approximate locations and other superficial information. However, shop drawings, project specifications, and as-built drawings were rarely readily available.

The lack of known information created issues in correctly identifying walls and developing statistical relationships. For the walls lacking situation and layout and other drawings, information was collected from the “R-list” and any other resources available. However, although a rough location might have developed, information specific to the labeling of individual walls within an R-number often was not. The numbering of a given wall along a bridge abutment could potentially have a separate secondary wall number for each side (i.e., R-359-1, R-359-2, R-359-3, etc.) or for a different project and design a different numbering scheme. Often without the assistance of specific drawings it was not attempted to segregate a given “R-number” into secondary sections, but considered as a whole. Additionally, other issues arose with how to define a wall depending on size, date of construction, location, etc., within a specified “R-number” in the case of inspection. These factors created difficulty for the purpose of inspection in not only locating walls, but also for separating walls during inspection and furthermore in statistical analysis.

A traditional statistical approach to these issues would be to treat a collection of multiple walls within a give “R-number” to a singular wall in considering the adjusted weights as a sample to subsample relationship. Therefore, allowing the comparison of data between the two sets to be compared if a comparative normalized relationship appeared to be congruent between the two sets. This approach requires dependent variables to help normalize the data and allow for cross tabulation to identify trends or independent relationships. When this approach was applied to data collected the normalized relationship did not appear to be congruent between independent walls and
walls treated as a group. Further statistical corrections exist, but for the limited sample size and excessive number of independent factors inherent in the walls, it becomes increasingly more difficult to separate statistical correction from actual relationships. The independent factors inherent in the data including location, time of construction, system, designer, contractor, geologic factors, subsurface investigation, unknown maintenance or updates to walls, etc, induce a wide range of independent factors that, due to the lack available information, require an approximated approach.

The approach used in this presentation involves the application of a multiple determined from the ratio of the number of walls included in groups during inspection by the potential number of walls within the sample group. This multiple was then applied to the walls depending on type and original grouping.

3.3 Inspection Form

The inspection form can be separated into the following sections: Inspector and general wall information, Summary of key observations, Plan/Drainage View, Cross-Sections, and Specific Wall Characteristics.

3.3.1 Inspector and General Wall Information

The inspector and general wall information contains instructions for the form, date, subsection of the State, road location, and inspector name. Additionally, general information concerning the wall such as manufacturer, GPS location, wall height, length, etc, as can be seen in Fig. 3.1.
3.3.2 Summary of Key Observations

The summary of key observations allows the inspectors to summarize their observations at the time of inspection as well as problems or concerns. This space can be seen near the bottom of Fig. 3.1 and as part of the inspection form in the Appendix A.

3.3.3 Plan/Drainage View

During the course of inspection wall position relative to identifying objects, such as intersections, water sources, cardinal direction, etc., how water travels in and around the wall, the location of observations or problems noted as part of the inspection, and other significant features should be sketched in the Plan/Drainage View.
3.3.4 Cross Sections

Important issues that potentially could be difficult to annotate as part of a plan view can be drawn in the cross sections area of the inspection. Common items included in this section would be slope in front and on top of wall, wall batter, location of coping and parapet, and approximate embedment.

3.3.5 Specific Wall Characteristics

The specific wall characteristics contain questions relating to failure mechanisms and help to characterize the condition of the walls relative to potential issues. The investigative questions are categorized into nine sections:

I. MSE Wall Drainage
II. MSE Wall Joints
III. MSE Wall Facing
IV. MSE Top of Wall
V. Foundation Conditions and external stability
VI. Corrosion
VII. Impact and Collision
VIII. Miscellaneous

The questions within each section were initially answered as Yes, No, Unknown (UKN), or Not Applicable (N/A). Often a question had to be marked unknown due to a lack of information such as sufficient or correct plans, not visible or measureable like depth embedment, etc. The N/A section was marked in cases such as metallic corrosion on a Modular Block wall. Another challenge observed during the inspection of trial and
training walls, was quantifying issues that were inherently difficult in counting or assigning a value. A percentage system was created to estimate the amount each question was exhibited as part of the inspection. This approach consisted of 0, for not exhibiting the characteristic, or 1%, 5%, 10%, 15%, 25%, 50%, 75%, 90%, 95%, or 100%.

3.4 INSPECTION PROCEDURE

The questions from the inspection are included in this section along with pictures taken to provide photographic examples. In cases where measurements should be taken an explanation of how measurements were taken is included.

3.4.1 Drainage

Question #1 from the MSE inspection form: “Is there an active water source near the toe of the wall (is the wall near a body of water with scour potential)?” Fig. 3.2 shows an example of an active water source (Box Elder Creek) and its interaction with the MSE wall and culvert passing through the earth structure. Fig. 3.3 shows the preferential use of Modular block walls used in areas with an active water source at their base.

Question #2 from the MSE inspection form: “If applicable, are the catch basins at the base of the wall blocked?” Fig. 3.4 shows how a drainage pipe located inside a debris filled catch basin can begin fill leading to pipe blockage.
Fig. 3.2  The Box Elder Creek Flows along the base of the MSE wall and through a culvert. High water level stains and a vertical drain protruding through the backfill (R-281, RECO Cruciform) are also shown.

Fig. 3.3  A bar chart of responses to Question #1: “Is there an active water source near the toe of the wall (is the wall near a body of water with scour potential)?”
Question #3 from the MSE inspection form: “*Are there culverts protruding through the wall?*” Fig. 3.6 shows a culvert passing beneath a MSE wall with a protective grate put in place to reduce debris flow into culvert.

![Image of culvert passing beneath MSE wall]

**Fig. 3.4** A catch basin that is partial blocked (600 North and I-15, VSL).

![Bar chart of responses]

**Fig. 3.5** A bar chart of responses to Question #2: “*If applicable, are the catch basins at the base of the wall blocked?*”
Figure 3.7 shows that a number of walls have a culvert, which passes through or beneath the MSE wall, with a significant proportion being Modular Block walls.

**Fig. 3.6** Culvert passing through MSE wall (R-350-31, VSL).

**Fig. 3.7** A bar chart of responses to Question #3: “Are there culverts protruding through the wall?”
Question #4 from the MSE inspection form: “Are there vertical drains that travel through the backfill?” Fig. 3.8 shows an exit pipe from a vertical drain that passes through the MSE wall. These exits were used to identify walls that contained pipes, draining the roadway above, which passed through the MSE structure. Fig. 3.9 is a typical situation and layout drawing for roadway drainage and pipes intersecting the MSE backfill, included in the I-15 reconstruction. Figure 3.10 shows that a significant number of drain pipes travels through the backfill particularly for two-stage walls.

Question #5 from the MSE inspection form: “Is there erosion at the base of the wall or leveling pad?” Fig. 3.11 shows the effect of improper drainage, which has lead to erosion along the face of the wall near the wall’s panel face. Fig. 3.12 shows a wall that has been compromised through erosion along its base from excess water flow passing through the culvert shown.

Fig. 3.8 A vertical drain exit covered by a metal grate in a MSE wall backfill, typical for the I-15 corridor (R-344-7, VSL).
Fig. 3.9  Plan view of drain detail through a typical I-15 reconstruction detail (R-349-5, VSL).

Fig. 3.10  A bar chart of responses to Question #4: "Are there vertical drains that travel through the backfill?"
Question #6 from the MSE inspection form: “Is there erosion along the wing walls?” Fig. 3.14 shows erosion that has taken place along the wing walls of an MSE wall as water has accelerated down the steep fill behind the wall. This erosion has exposed the geosynthetic straps and removed significant fill along the panel edges.

Question #7 from the MSE inspection form: “Are there any signs of water flow along the base of the wall?” Fig. 3.16 shows residual fill that exited behind panels onto the adjacent sidewalk, which serves as evidence of water drainage and flow along the base of the wall. Fig. 3.17 shows water stains along the face of the MSE wall panels; this staining indicates potential drainage of water from behind panels.

**Fig. 3.11** Improper drainage and lack of a proper sloped bench has led to erosion along the MSE wall bridge abutment (R-346, VSL).
Fig. 3.12 Erosion of leveling pad below block wall due to surface runoff and stream flow (R-407-D, Genesis).

Fig. 3.13 A bar chart of responses to Question #5: “Is there erosion at the base of the wall or leveling pad?”
Fig. 3.14 Erosion along the back of back and wing wall section of MSE wall (R-376, Genesis).

Fig. 3.15 A bar chart of responses to Question #6: “Is there erosion along the wing walls?”
Fig. 3.16 Residual fill that exited behind panels onto the adjacent sidewalk, which serves as evidence of water drainage and flow along the base of the wall (R-349-5, VSL).

Fig. 3.17 Residual stains along the face of MSE panels indicating water traveling along panel face (R-346-8, VSL).
Question #8 from the MSE inspection form: “Is there less than 14 feet between irrigation sprinklers and wall?” Fig. 3.19 shows irrigation sprinklers (black with white nozzle) placed directly behind the earthen side of the retaining blocks.

**Fig. 3.18** A bar chart of responses to Question #7: “Are there any signs of water flow along the base of the wall?”

**Fig. 3.19** Irrigation sprinkler placed directly behind the earthen side of the retaining blocks (R-427, Genesis).
Question #9 from the MSE inspection form: “Does the backfill or joint fabric appear to be saturated?” Irrigation pipes located around landscaping in the back fill of a modular block wall have begun leaking through the backfill shown in Fig. 3.21. The effects of this leakage can be observed by the saturation of the backfill and blocks.

Fig. 3.20 A bar chart of responses to Question #8: “Is there less than 14 feet between irrigation sprinklers and wall?”

Fig. 3.21 Irrigation leakage through the block wall shown in Fig. (R-423, Genesis).
**Fig. 3.22** A bar chart of responses to Question #9: “Does the backfill or joint fabric appear to be saturated?”

Question #10 from the MSE inspection form: “Is there vegetation growing in panel joints?” Figs. 3.23 and 3.24 provide examples of how vegetation grows out of panel joints.

**Fig. 3.23** Vegetation growing in vertical panel joints (R-359, VSL).
Question #11 from the MSE inspection form: “Are the deck drains and outlets at the top of the wall blocked?” Fig. 3.26 shows how road debris can collect and eventually block deck drains, which can also lead to the blockage of outlets.

Fig. 3.24 Vegetation growing in between horizontal panel joints (R-369, Foster).

Fig. 3.25 A bar chart of responses to Question #10: “Is there vegetation growing in panel joints?”
Question #12 from the MSE inspection form: “Can water enter the wall between the coping and approach slab (i.e., drain appropriately)?” Fig. 3.28 shows an example of how water collecting along the roadway can be directed along the approach slab and in coping, potentially leaking into the reinforced soil mass.

Question #13 from the MSE inspection form: “Is there evidence at discharge point of fill washing through drain pipes?” Fig. 3.30 shows an example of blockage that can collect in drain pipes and resulting vegetation growing from fill collected in the drain.

3.4.2 Joints

Question #14 from the MSE inspection form: “Is backfill coming out of joints or are there piles of backfill at the base of the wall?” Figs. 3.32 and 3.33 show examples of backfill collecting at the base of a MSE wall from behind the panels. A measurement of the size of the pile can be taken by measuring the height of the pile or volume observed. It is of particular importance that the observation is documented with a photo.

Fig. 3.26 An example of how road debris can collect and eventually block deck drains, which can also lead to the blockage of outlets (R-281, RECO Cruciform).
**Fig. 3.27** A bar chart of responses to Question #11: “Are the deck drains and outlets at the top of the wall blocked?”

**Fig. 3.28** Separation of parapet and coping at roadway surface creating a gap at the coping allowing drainage into the backfill (Clearfield, RECO)
Fig. 3.29 A bar chart of responses to Question #12: “Can water enter the wall between the coping and approach slab (i.e., drain appropriately)?”

Fig. 3.30 A road drain that travels vertically through a MSE (Block) backfill is clogged at its exit by vegetation and road debris (R-376-F, Genesis).

Question #15 from the MSE inspection form: “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.” Fig. 3.35 shows an example of excessive joint spacing.
exposing the joint fabric and backfill. The measurement being taken is exemplified by the measuring tape.

Question #16 from the MSE inspection form: “Is exposed backfill visible in the horizontal joints?” Fig. 3.37 shows an example of backfill that has collected along horizontal panel joints.

**Fig. 3.37** Backfill leakage from behind an MSE wall panel, (R-325-F, VSL).

**Fig. 3.31** A bar chart of responses to Question #13: “Is there evidence at discharge point of fill washing through drain pipes?”
**Fig. 3.33** Backfill leaking from MSE panels vertical joint (R-384, Foster).

**Fig. 3.34** A bar chart of responses to Question #14: “Is backfill coming out of joints or are there piles of backfill at the base of the wall?”
**Fig. 3.35** (R-146, VSL Hex Panel with fabric exposed between joint spacing)

**Fig. 3.36** A bar chart of responses to Question #15: “Are the joints wide enough to see fabric or backfill behind panels when looking into joints?”
Fig. 3.37 Fill along horizontal joint (600 North & I-15, VSL).

Fig. 3.38 A bar chart of responses to Question #16: “Is exposed backfill visible in the horizontal joints?”
Fig. 3.39 Exposed fabric with small tear shown between vertical joints (R-409, Foster).

Question #18 from the MSE inspection form: “Is there evidence of backfill or water leaking through tears in fabric behind panels (Do not induce additional damage to fabric)?” Fig. 3.41 shows a photograph of water leaking from behind a MSE wall panel during a rain storm. This photo was collected by UDOT, while documenting the drainage issues of this wall.

Question #19 from the MSE inspection form: “Do the joints have a non-uniform horizontal spacing/size? (Are some horizontal joints larger/smaller than others?) A measurement should be taken at point of maximum distance between panels.” Fig. 3.43 shows an example of a non-uniform horizontal spacing and offset.

Question #21 from the MSE inspection form: “Do the joints have a non-uniform vertical spacing/size (i.e. are some horizontal joints larger/smaller than others)? If so, please record the measurement.” This measurement should be the maximum distance between the two panel edges. Figs. 3.45 and 3.46 show examples, for two different wall systems, of a non-uniform vertical spacing/size between panels.
Fig. 3.40  A bar chart of responses to Question #17: “Are there visible tears in the fabric?”

Fig. 3.41  Leaking water from behind MSE panel (R-349-5, VSL).
Fig. 3.42 A bar chart of responses to Question #19: "Is there evidence of backfill or water leaking through tears in fabric behind panels".

Fig. 3.43 The movement of MSE panels can be seen along the horizontal joints of the MSE wall (600 North and I-15, VSL).

Question #22 from the MSE inspection form: “Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum.” This measurement should be the maximum distance between panel edges.” Fig. 3.48 shows an example of panel offset between vertical joints.
Fig. 3.44 A bar chart of responses to Question #20: “Do the joints have a non-uniform horizontal spacing/size? (Are some horizontal joints larger/smaller than others?)”.

Fig. 3.45 Irregular joint spacing can be seen in the first row of panels from the MSE wall coping at a bridge abutment (R-146, VSL Hex Panels).
Fig. 3.46 Joint Spacing irregularities can be seen in the first panel below the coping (R-342-7, VSL).

Fig. 3.47 A bar chart of responses to Question #21: "Do the joints have a non-uniform vertical spacing/size? (i.e., are some horizontal joints larger/smaller than others?)"
Fig. 3.48 shows the horizontal displacement of panels along vertical joints (600 North & I-15, VSL).

Fig. 3.49 A bar chart of responses to Question #22: “Are the panels offset at the joints either in or out of the wall?”

Question #23 from the MSE inspection form: “Does the fabric appear brittle, or appear as if it has undergone excessive UV exposure?”
Fig. 3.50 A bar chart of responses to Question #23: “Does the fabric appear brittle, or appear as if it has undergone excessive UV exposure?”

3.4.3 Wall Facing

Question #24 from the MSE inspection form: “Were the panels built using "Tilt-Up” construction? Is there excessive cracking in the panels?” Fig. 3.51 shows a typical tilt-up panel used in the I-15 reconstruction. Characteristics of tilt up panels include no horizontal joints and often excessive cracking in panels from construction and post-construction effects.

Question #25 from the MSE inspection form: “Is there excessive cracking in panels?” Fig. 3.53 shows an example of excessive cracking along panel joints.

Question #26 from the MSE inspection form: “Are there cracks that continue vertically through adjacent panels? Crack size should be measure at the maximum crack spacing. Depending on the size of the crack it might be significant to measure the total length of the crack.”
Question #27 from the MSE inspection form: “Are there cracks that continue horizontally through adjacent panels? The measurement recorded should be the maximum crack width and then its length.” Fig. 3.56 shows an example of cracks that continue horizontal through panels and continue up through the coping.

Question #28 from the MSE inspection form: “Are the panel corners making contact with each other?” Fig. 3.58 shows an example of panel corners making contact creating stress concentration and leading to cracking of panel corners.

**Fig. 3.51** Panel with no horizontal joints indicating Tilt Up construction (R-385, VSL).
Fig. 3.52  A bar chart of responses to Question #24: “Were the panels built using "Tilt-Up" construction? Is there excessive cracking in the panels?”

Fig. 3.53  Cracks along vertical panel joints (R-342-11, VSL).
Fig. 3.54 A bar chart of responses to Question #25: “Is there excessive cracking in panels?”

Fig. 3.55 A bar chart of responses to Question #26: “Are there cracks that continue vertically through adjacent panels?”
Fig. 3.56 Cracks that continue horizontal through wall panel (R-365, RECO).

Question #29 from the MSE inspection form: “Are the panel’s corners "popped-off" or chipped from contact with adjacent panel(s)?” A “popped corner” is a result of panels making contact with each other, which creates stress concentrations resulting in the cracking of the panels and eventual loss of the cracked concrete section. Fig 3.60 shows an example of multiple panel corners that have made contact with one another, which has lead to cracking and Fig. 3.61 shows an example of a popped corner.

Question #30 from the MSE inspection form: “Does crack spacing suggest differential settlement?” Fig. 3.63 shows an example of panel movement after construction, these gaps indicate differential settlement.

Question #31 from the MSE inspection form: “Does the overlying coping exhibit vertical offset?” Fig. 3.65 shows an example of coping offset from panels and Fig. 3.66 show deformation of the coping in the form of indentation and cracks.
Fig. 3.57  A bar chart of responses to Question #27: “Are there cracks that continue horizontally through adjacent panels?”

Fig. 3.58  Panels making contact along with popped corners (R-344-18, VSL).
Fig. 3.59  A bar chart of responses to Question #28: “Are the panel corners making contact with each other?”

Fig. 3.60  Multiple popped corners along a panel (R-344-7, VSL).
**Fig. 3.61** A popped corner on a concrete panel (R-359-2, Foster).

**Fig. 3.62** A bar chart of responses to Question #29: "Are the panel's corners "popped-off" or chipped from contact with adjacent panel(s)?"
Fig. 3.63 Gapping at joints between panels suggesting wall panel and/or backfill movement (R-387-D, SSL or Foster).

Fig. 3.64 A bar chart of responses to Question #30: “Does crack spacing suggest differential settlement?”
Question #32 from the MSE inspection form: “Are the coping and parapets loose or detaching?” Fig. 3.68 shows an example of a parapet that has cracked and detached resulting in a section of concrete falling to the roadway and exposure of rebar.

**Fig. 3.65** Coping offset from panel (R-409, Foster).

**Fig. 3.66** Cracking and movement of coping (600 North & I-15, VSL).
Fig. 3.67 A bar chart of responses to Question #31: “Does the overlying coping exhibit vertical offset?”

Question #33 from the MSE inspection form: “Are the panels in danger of falling off?” Fig. 3.70 shows an example of a section of two-stage MSE panels that have buckled resulting in a situation in which the panels were in danger of falling off or becoming unzipped.

Question #34 from the MSE inspection form: “Do the panels exhibit bulging? If so, record maximum deformation from accessible coping to leveling pad”. This measurement should be taken using a level and measuring the maximum offset from flush with the coping to point of intersection with what would be vertically level according to the level. Fig. 3.72 shows an example of a wall that exhibits sever bulging producing a significant gap between joints. Fig. 3.73 shows a section of wall that exhibits bulging, although difficult to demonstrate photographically, with the lined nature of the panel it can be observed near the center of the wall.
Fig. 3.68 Detachment of concrete parapet section (600 North & I-15, VSL).

Fig. 3.69 A bar chart of responses to Question #32: “Are the coping and parapets loose or detaching?”
Fig. 3.70 Buckling of 2-stage MSE wall panels (R-337-C, VSL).

Fig. 3.71 A bar chart of responses to Question #33: “Are the panels in danger of falling off?”
Fig. 3.72  Bowing in panels has lead to a 2 inch gap (R-442, RECO Curved Face Panels).

Question #35 from the MSE inspection form: “Is there 'tipping' at the top or bottom of the wall? (Record maximum degree of tipping from azimuth using vertical level and affected area).” The measurement of the tipping can be taken using a level to measure the maximum offset from vertical level. Fig. 3.75 shows an example of a section MSE wall that exhibits tipping. This is evident in this figure by the coping that has shifted and detached from the wall section. Fig. 3.76 shows a section of wall that exhibits tipping and bulging from construction, this is evident by the differential width of the coping (seen from beneath the wall) along the length of the wall.

Question #36 from the MSE inspection form: “Is there excessive degradation of wall panels?” Fig. 3.78 shows an example of degradation of panels as the wall has aged and the rebar has expanded further cracking the joints.
3.4.4 Top of Wall

Question #37 from the MSE inspection form: “Is there evidence of settlement at the top of the wall (pavement cracking, etc)?” Figs. 3.80 and 3.81 show examples of settlement at the top of the wall, for these cases movement of parapets indicated the settlement. This movement can result in gapping or cracking of parapets due to stresses of expansions gap closure.

Question #38 from the MSE inspection form: “Are there any non-hairline cracks in the concrete coping? If yes, record the approximate maximum crack width.” The cracking in coping should be measured as the maximum crack width. Additionally, it may be appropriate to measure the length of the crack. Figs. 3.83 and 3.84 show examples of non-hairline cracks in the concrete coping.

Fig. 3.73 Bowing in wall can be seen in middle section offset of panels (R-384-B, Foster).
Fig. 3.74 A bar chart of responses to Question #34: “Do the panels exhibit bulging? If so, record maximum deformation from accessible coping to leveling pad.”

Fig. 3.75 Tipping near the top of the wall can be seen by the detaching of the vertical coping (R-476, VSL).
**Fig. 3.76** Tipping and bulging observed in wall (R-409, Foster).

**Fig. 3.77** A bar chart of responses to Question #35: “Is there ‘tipping’ at the top or bottom of the wall?”
**Fig. 3.78** Degradation of panels (R-442, RECO Curved Face Panels).

**Fig. 3.79** A bar chart of responses to Question #36: “Is there excessive degradation of wall panels?”
Fig. 3.80  Separation of parapet and coping (Clearfield, RECO).

Fig. 3.81  Gap in parapet (R-409, Foster).
Fig. 3.82 A bar chart of responses to Question #37: “Is there evidence of settlement at the top of the wall (pavement cracking, etc)?”

Fig. 3.83 Non-hairline Cracks in the concrete coping (R-346-8, VSL).
Fig. 3.84 Non-hairline Cracks in the concrete coping (R-384, Foster).

Question #39 from the MSE inspection form: “Have the construction joints in the concrete coping opened up? If yes, record the maximum joint width.” This measurement includes the maximum gap between joints. Fig. 3.86 shows an example of issues associated with construction joints. For this case the construction joints appear to be distressed, which has lead to cracking of the concrete.

Question #40 from the MSE inspection form: “Is there a large gap between the approach slab and pavement? Often this produces a bumping sensation as the overpass is crossed. Record the approximate maximum gap size.” This measurement represents the maximum width across the gap. Fig. 3.88 shows an example of a gap that has developed between the approach slab and approach pavement. Of particular interest is the differential distance of the gaps at opposite sides of the roadway. Fig. 3.89 shows the measurement of the maximum gap (attempted to be sealed by asphalt) between approach sections.
Question #41 from the MSE inspection form: “At the abutments, has the joint between the wall coping and abutment opened up significantly? If so record maximum distance.” The measurement should include a measured horizontal, vertical, and diagonal component. Fig. 3.91 shows an overhead perspective a joint between the wall and coping that has opened up significantly. Fig. 3.92 Show the lateral displacement of a parapet that caused the opening up of the joint shown in Fig. 3.91.

Fig. 3.85 A bar chart of responses to Question #38: “Are there any non-hairline cracks in the concrete coping?”

Fig. 3.86 Cracking of concrete at the construction gap (R-409-E, Foster).
Fig. 3.87  A bar chart of responses to Question #39: “Have the construction joints in the concrete coping opened up?”

Fig. 3.88  Opening of gap between approach slab and approach pavement (600 North & I-15, VSL).
Fig. 3.89  Opening of gap between approach slab and approach pavement (R-376 B, Genesis).

Fig. 3.90  A bar chart of responses to Question #40: “Is there a large gap between the approach slab and pavement?”
Fig. 3.91 Opening of gap between parapet and coping (Clearfield, RECO).

Fig. 3.92 Opening of gap between parapet and coping (Clearfield, RECO).
Question #42 from the MSE inspection form: “Is the coping/wall pulling away from pavement and roadway section? Please record maximum displacement for wall. The measurement should include the maximum measured gap.” This instance is applicable for cases were the coping and pavements are separate pieces. For the vast majority of the walls visited the coping and roadway were connected by a monolithic poured coping, parapet, and moment slab, which reduced the applicability of this question.

3.4.5 Foundation Conditions and External Stability

Question #43 from the MSE inspection form: “What is the location or depth of Leveling pad?” For this case the procedure included pounding a metal Geo-Probe into the soil located 2 inches from wall to a maximum depth of 24 inches (24 inches is the minimum specified depth for a MSE Wall). Measure the depth of the probe, when it contacts leveling pad. Note that this may require multiple attempts to assure that the leveling pad that is being measured. However, if the depth of the leveling pad exceeds 24 inches, it will become difficult to locate and can be considered sufficient based on an H 1.5: V 1 slope. Fig. 3.95 shows walls that have a leveling pad deeper than 24 inches for the complete length of the wall as 100%, Unknown for walls that a leveling pad that could not be located, possibly being embedded deeper than 24 inches, and no for walls with exposed leveling pad or leveling pad inadequately embedded.
Fig. 3.93 A bar chart of responses to Question #41: “At the abutments, has the joint between the wall coping and abutment opened up significantly?”

Fig. 3.94 A bar chart of responses to Question #42: “Is the coping/wall pulling away from pavement and roadway section?”

Question #44 from the MSE inspection form: “Is the leveling pad exposed?” Fig. 3.96 shows an example of an exposed section of a leveling pad.
Fig. 3.95  A bar chart of responses to Question #43: “What is the location or depth of leveling pad?”

Fig. 3.96  Exposed leveling pad shown beneath MSE panel (R-344-9, VSL).

Question #45 from the MSE inspection form: “Is there cracking in the leveling pad? If so, record the maximum crack size with a ruler or gage.” This measurement can be
recorded based on the maximum crack width. Fig. 3.98 shows an example of an exposed section of a leveling pad with crack being measured by a crack gauge.

**Fig. 3.97** A bar chart of responses to Question #44: “Is the leveling pad exposed?”

**Fig. 3.98** Cracking in leveling pad and its associated measurement (R-376-B, Genesis).
Question #46 from the MSE inspection form: “Is there a four foot bench (level slope) along the base of the wall before the slope changes? If not record width of bench?” The bench is measured from the wall face to the point where the slope breaks. This measurement can be obtained by using a vertical level and a tape measure or by approximating the point where the soil breaks and measuring that distance. Fig. 3.100 shows an inadequate bench, which doesn’t meet the specified four feet before the slope change. Fig. 3.101 shows an example of this measurement approximation technique exemplified by Dr. Travis Gerber and Holly Griffin.

![Bar chart](image)

**Fig. 3.99** A bar chart of responses to Question #45: “Is there cracking in the leveling pad?”
Fig. 3.100  Inadequate bench at base of MSE wall situated on a steep slope (R-444, VSL).

Fig. 3.101  Bench Measurement (R-349-5, VSL).

Question #47 from the MSE inspection form: “Is there a slope steeper than Horizontal: 1.5 to Vertical: 1 behind the wall?”
Fig. 3.102  A bar chart of responses to Question #46: “Is there a four foot bench (level slope) along the base of the wall before the slope changes?”

Fig. 3.103  A bar chart of responses to Question #47: “Is there a slope steeper than Horizontal: 1.5 to Vertical: 1 behind the wall?”

Question #48 from the MSE inspection form: “Please record slope. Is there a slope greater than Horizontal: 1.5 to Vertical: 1 below/in front of the wall? Please record slope.” This measurement can be obtained by using a horizontal level set to level
along the slope and from the set level the distance to the embankment. Additionally, a vertical level or Brunton compass can be used to approximate the slope angle. Fig. 3.104 shows an example of a steep slope and the effects on a wall with a poor quality fill.

### 3.4.6 Corrosion

Question #49 from the MSE inspection form: “Is there excessive corrosion on guardrails or other exposed metal that might indicate corrosive conditions?” Fig. 3.106 shows an example of excessive corrosion on a guardrail, which could potentially indicate a high salt use. Fig. 3.107 shows salt, which has precipitated on the ground beneath horizontal joints in the panels.

![Image of a guardrail with corrosion](image)

**Fig. 3.104** Steep sloping of poor quality fill at base of MSE wall (200 South / Center Street, Clearfield, Foster).
Fig. 3.105  A bar chart of responses to Question #48: “Please record slope. Is there a slope greater than Horizontal: 1.5 to Vertical: 1 below/in front of the wall?”

Fig. 3.106 Oxidized Guard Rail shown along the road shoulder (Logan Canyon MP 472, Genesis).

Question #50 from the MSE inspection form: “Are there significant rust stains on face of the wall? Or along panel joints?” Fig. 3.109 shows an example of rust stain that has resulted from exposed rebar.
Fig. 3.107  Salt deposited at the base of a MSE wall panel (R-343-8, VSL).

Fig. 3.108  A bar chart of responses to Question #49: “Is there excessive corrosion on guardrails or other exposed metal that might indicate corrosive conditions?”

Question #51 from the MSE inspection form: “Are any internal straps exposed? If exposed, does there appear to be corrosion on straps?” Fig. 3.111 shows an example of internal reinforcement that has been exposed as result of improper drainage and erosion.
Fig. 3.109 A Rust stain is visible on the face of a panel where steel reinforcement has been exposed (R-146, VSL Hex Panels).

Fig. 3.110 A bar chart of responses to Question #50: “Are there significant rust stains on face of the wall or along joints?”

Question #51 from the MSE inspection form: “If exposed, does there appear to be corrosion on straps?” Fig. 3.112 shows that of the straps exposed (Question #50) no apparent straps displaced corrosion.
Fig. 3.111 Exposure of internal straps (R-376B, Genesis).

Fig. 3.112 A bar chart of responses to Question #51: “Are any internal straps exposed? If exposed, does there appear to be corrosion on straps?”

Question #52 from the MSE inspection form: “Was a resistivity sample taken of soil? If so, please indicate depth taken in inches?” If accessible, a resistivity sample can be taken and it is significant to note the depth that the sample was taken in order to estimate the penetration of the salt.
Question #53 from the MSE inspection form: “Is there indication of rebar corrosion (i.e., swelling bars, rust, exposed metal inside epoxy coating)?” Fig. 3.115 shows an example of rebar that has been exposed and has begun to oxidize. The effects of this oxidation include expansion, which can lead to the fracture of the panel as can be seen in Fig. 3.116.

3.4.7 Test Wires/Coupons

Question #54 from the MSE inspection form: “Is there evidence of Test Wires or Coupons included in the wall? If so, please indicate the possible number of Test wires available?” In order to monitor corrosion within metallic reinforced MSE walls, metal rods or straps of similar material as that of the reinforcement, often called Test wires or coupons, are placed into the wall, but allow access from outside the panels. Fig. 3.118 shows an example of panel, which allows exterior access to these test wires. The access points are protected from the outside environment by rubber stoppers. The rubber stopper can be removed allowing the extraction of the test wires, using the threaded portion of the rod shown in Fig. 3.119. Fig. 3.120 shows a list of coupons collected as part of the site visits.

3.4.8 Impact and Collision

Question #55 from the MSE inspection form: “Are guardrails/wall protections in place at the base of the wall (to protect it from potential traffic hazards)?”

Question #56 from the MSE inspection form: “Does it appear that the wall has been involved in an accident (replaced panel, recent dings in the wall)?”
Question #57 from the MSE inspection form: “*Does it appear the walls functionality and integrity has been compromised by a collision or accident?*”

**Fig. 3.113** A bar chart of responses to Question #51: “*If exposed, does there appear to be corrosion on straps?*”

**Fig. 3.114** A bar chart of responses to Question #52: “*Was a resistivity sample taken of soil? If so, please indicate depth taken in inches?*”
Fig. 3.115 Corroded rebar protruding from a MSE panel (R-281, RECO Cruciform).

Fig. 3.116 Exposed rebar from panel (R-442, RECO Curved Face Panels).
3.4.9 Miscellaneous

Question #58 from the MSE inspection form: “Are there acute wall angles (<90 degrees)?” Fig. 3.124 shows an acute wall corner, including metallic reinforcement.
straps and pipe piles, during construction. The placement of the straps to accommodate an acute angle as well as pipe piles included in the embankment produce a challenging situation for analysis and construction.

Question #59 from the MSE inspection form: “Are there available drawings for the wall? Please indicate type (Situation and Layout, Design, As Built, etc.)”

Question #60 from the MSE inspection form: “Is the layout in general accordance with drawings?”

Question #61 from the MSE inspection form: “Are the panels CIP (Cast in Place)?”

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**Fig. 3.119** Threaded rod behind stopper, which is connected to coupon (R-344-18, VSL).
Utah Department of Transportation
MSE Inspection Wall Project
List of observed Coupons

Note: It should be observed that for each coupon listed that there are 6 potential coupons within each panel. Please see sample photo for coupons in R-344-2.

<table>
<thead>
<tr>
<th>Wall #</th>
<th>Number of Walls</th>
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<td>R-342-11</td>
<td>1</td>
</tr>
<tr>
<td>R-342-13</td>
<td>2</td>
</tr>
<tr>
<td>R-343-7</td>
<td>3</td>
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<td>4</td>
</tr>
<tr>
<td>R-343-37</td>
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<td>R-343-42</td>
<td>6</td>
</tr>
<tr>
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<td>7</td>
</tr>
<tr>
<td>R-344-2</td>
<td>8</td>
</tr>
<tr>
<td>R-344-2 (2nd Set)</td>
<td>9</td>
</tr>
<tr>
<td>R-344-7</td>
<td>10</td>
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<tr>
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<td>11</td>
</tr>
<tr>
<td>R-344-18</td>
<td>12</td>
</tr>
<tr>
<td>R-345-3</td>
<td>13</td>
</tr>
<tr>
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<td>R-345-9</td>
<td>15</td>
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<tr>
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</tr>
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<td>17</td>
</tr>
<tr>
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</tr>
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<td>R-346-8</td>
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<tr>
<td>R-346-8 (2nd Set)</td>
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<tr>
<td>R-351-30</td>
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<tr>
<td>R-385-West Abutment</td>
<td>22</td>
</tr>
<tr>
<td>Potential Total</td>
<td>132</td>
</tr>
</tbody>
</table>

**Fig. 3.120** A list of observed coupons as part of the inspection.

**Fig. 3.121** A bar chart of responses to Question #55: Are guardrails/wall protections in place at the base of the wall (to protect it from potential traffic hazards)?
Fig. 3.122 A bar chart of responses to Question #56: “Does it appear that the wall has been involved in an accident (replaced panel, recent dings in the wall)?”

Fig. 3.123 A bar chart of responses to Question #57: “Does it appear the walls functionality and integrity has been compromised by a collision or accident?”
Fig. 3.124  Complex strap orientation during construction for acute corner (Legacy Parkway).

Fig. 3.125  A bar chart of responses to Question #58: “Are there acute wall angles (<90 degrees)?”
Fig. 3.126 A bar chart of responses to Question #59: “Are there available drawings for the wall?”

Fig. 3.127 A bar chart of responses to Question #59: “Are there available drawings for the wall? Please indicate type (Situation and Layout, Design, As Built, etc.).”
Question #62 from the MSE inspection form: “Was Geofoam used in the construction of the wall?” Fig. 3.130 shows the placement of Geofoam as part of an MSE embankment under construction. The use of Geofoam as a lightweight fill for MSE restructures has been used to reduce the settlement through sections where settlement control is critical. Fig. 3.131 shows a Geofoam wall transition between earth fill and Geofoam. This intersection is marked by “Tilt-up” or “Cast in place” Panels for Geofoam with only vertical joints and traditional rectangular panels for earth fill.

Question #63 from the MSE inspection form: “Are there any structures on or near wall that were not included in initial drawings?” Fig. 3.133 shows an example of structures and or Utilities that could potentially be added behind a retaining structure that was not considered/included in the original drawings of the retaining wall.

Question #64 from the MSE inspection form: “Are there any irrigation, utilities, or intrusions that are not part of the initial drawings?” Consult Fig. 3.133 above for an applicable example.

Question #65 from the MSE inspection form: “Have there been any excavations or evidence of excavations near the wall?” Fig. 3.136 shows an example of an excavation that has been made for an adjacent parking area, which was not included in original MSE wall drawings.

Question #66 from the MSE inspection form: “Have local property owners changed the dynamics of the wall (additional structures, irrigation, vegetation, etc.)?” Fig. 3.138 shows an example of changes that have been made by local property owners, with the addition of a landscaped retaining wall over the top of an existing MSE block wall along a state road.
**Fig. 3.128** A bar chart of responses to Question #60: “Is the layout in general accordance with drawings?”

**Fig. 3.129** A bar chart of responses to Question #61: “Are the panels CIP (Cast in Place)?”
Fig. 3.130  Transition from MSE to Geofoam wall (Legacy Parkway).

Fig. 3.131  Transition from MSE to Geofoam wall (R-346-A, VSL).
Fig. 3.132 A bar chart of responses to Question #62: “Was Geofoam used in the construction of the wall?”

Fig. 3.133 Major power lines located on top of slope supported by MSE wall (R-442, RECO Curved Face Panels).
Fig. 3.134 A bar chart of responses to Question #63: “Are there any structures on or near the wall that were not included in initial drawings?”

Fig. 3.135 A bar chart of responses to Question #64: “Are there any irrigation, utilities, or intrusions that are not part of the initial drawings?”
Fig. 3.136 Excavation of soil near MSE wall for adjacent parking lot and small retaining wall (R-383-H, SSL).

Fig. 3.137 A bar chart of responses to Question #65: “Have there been any excavations or evidence of excavations near the wall?”
Fig. 3.138  Addition of landscaped block wall over the top of an existing MSE block wall (R-383-J, SSL).

Fig. 3.139  A bar chart of responses to Question #66: “Have local property owners changed the dynamics of the wall (additional structures, irrigation, vegetation, etc.)?”

Question #67 from the MSE inspection form: “Are there piles or other bridge support systems located in the wall (bridge abutment)?” Fig. 3.140 shows an example of piles placed within the MSE wall during construction. The placement of these piles within the reinforced mass potentially creates issues with reinforcement as can be seen in Fig. 3. 141.
Fig. 3.140 Piles and bridge deck supports located within the MSE abutment (Legacy Parkway, RECO).

Fig. 3.141 Skew of reinforcement around bridge pile supports (R-383-H, SSL).
Fig. 3.142 A bar chart of responses to Question #66: “Are there piles or other bridge support systems located in the wall (bridge abutment)?”

3.5 SUMMARY

Considering the data summary presented in the charts above an overall picture of the response of UDOT’s MSE walls observed to general failure modes can be developed. Beginning with drainage, Question #5 shows that erosion at the base of walls creates a viable concern in global stability. This issue can further be complicated by inadequate depth of wall embedment observed in the response of Questions 34 and 37, apparent by deformation and bulging of panel facing.

Additionally Question #14 shows that the proximity of irrigation networks near wall faces creates further concern with an increase in the risk of wall leaking, erosion, unanticipated backfill saturation, and the potential build up in hydrostatic pressures from pipe breakage. The issues of erosion and drainage correspond to an additional concern that affects the performance of walls, evident in Question #64. Landowners, including private as well as municipalities, with property rights approaching the state’s right of way
can alter intended wall design by changing wall dynamics not accounted for originally. These changes can affect the intended factors of safety ranging from the introduction of irrigation, drainage, excavations, or the addition of structures near the wall. These changes can be made without consultation with appropriate entities, or in the case of proper consultation no wall drawings or records from initial construction being available. These encroachments can potentially go unnoticed over time and without regular inspection these encroachments become more dramatic and potentially contribute to failure.

The relative high occurrence in panel joint movement (Question numbers 20, 21, and 22) considered with the correspondence of issues regarding wall facing (Question numbers 28, 29, 30, and 38). Indicate the occurrence of post construction movement and settlement, which should encourage the evaluation of standards and specifications in evaluating settlement particularly the reduced percentage of total settlement for two stage walls. The actual occurrence of wall settlement indicators could potentially be higher due to obstacles in access coupled with a lack of fixed points documented at the time of construction to track movements. Additionally, it should be noted that the number of incidences in which backfill migrated from behind wall panels and became visible in other areas (Question numbers 14 and 16), creates concerns regarding the potential for failure from lack of confinement.

In considering these results, one potential failure mode that could not be evaluated without more invasive inspection was corrosion. The majority of the state’s walls were introduced as part of the I-15 reconstruction through the Salt Lake Valley, in preparation for the 2001 Winter Olympics. This road reconstruction occurred roughly 10 years prior
to this inspection, early in the intended design life. Extraction of the test wires could
serve to decrease the ambiguity regarding the progression of corrosion by tracking the
affects of corrosion to date. At the time of construction no metrics were taken on the
wires to create a starting point from, which to track the rate of corrosion. For this reason
it is advisable that select test wires be exhumed and examined at this junction to create a
baseline for tracking purposes as well as to evaluate concerns about corrosion issues.

When considering failure it is important to process this data with the
understanding that, while these figures provide us with a broad picture of the status of
MSE walls in the state of Utah they are not by themselves complete. Therefore, in
assessing and anticipating failure a quantitative analysis is inadequate without qualitative
insight. Considering that general trends for the walls in the state may provide insights,
they most likely will not lead to massive failure at one time. However, the failure of one
wall, showing excessive amounts of one characteristic could carry potently catastrophic
results realized in loses of public safety and public opinion of the state’s infrastructure.
This was the case for wall R-407-D, shown in Fig 3.143, in which through inspection,
reporting, and maintenance mitigated potential failure due to erosion at the base of wall
near a culvert.

This rationale is applied in reviewing the walls inspected with a panel of national
experts to provide their insights and experience in evaluating and isolating the critical
paths leading to failure. Chapter 5 presents further insights into the trends noted from
inspection and the discussion on panel observations presented in Chapter 6.
Fig. 3.143  Erosion of leveling pad below block wall due to surface runoff and stream flow (R-407-D, Genesis).
CHAPTER 4  
DATABASE DEVELOPMENT

4.1 INTRODUCTION

A primary obstacle in the inspection of the walls was locating, correctly identifying, and obtaining drawings of walls. Additionally, once obtained the organization of a database to maintain the data collected from the site by site visits originally recorded on paper, by photography, and documentation/drawings found in the process of locating the sites. A non-profit department lead by Doyt Bolling of Utah State University known as Utah Local Technical Assistance Program (LTAP) has developed a software Transportation Asset Management System (TAMS) to be used in transportation maintenance applications. This software uses a GIS program, MapWindow GIS (MapWindow 2008), to tie information to a GPS point. TAMS provides the interface between MapWindow GIS and Microsoft’s Access. In conjunction with the TAMS program a tool package was developed for MSE Walls with the support of Jeff Spaulding of LTAP, which creates an electronic database of information recorded from field observations, files collected, and provides a defined GPS coordinate for each wall. The objective in development of the software and tools was to provide a system that could be maintained through the life of a wall. The drawings and information for existing walls that was difficult or impossible to locate can now be stored in the developed database.

4.2 GIS PROGRAM

A map of the state of Utah can be seen in Fig. 4.1, this view represents the initial interface for the Map Windows program. Each wall is uniquely represented by a GPS
point and its type is indicated within the circles by One Stage (1), Two Stage (2), and Modular Block (B). Allowances have been made so that additional wall types ranging from Cantilever (C) to Crib Walls (BC) can be added to the database as part of current construction. In the left column one can select the visible layers and the red box shows the section of state being viewed on the GIS map.

Figure 4.2 shows the available MSE Walls tools. These tools allow for the creation of a new project, to upload an existing project, add a new MSE WALL to the database, select a node from the map, search the database for specific MSE wall by its State Number (i.e., R-281), select a wall by its attributes such as state route number, merge an existing database with another (i.e., BYU’s with USU’s version), and also to replace and reappoint Route and Mileposts when new shape files are implemented.

The addition of a wall requires the selection of ‘Add New MSE Wall Location’ after selection the form shown in Fig. 4.3 is introduced. General wall information is input into the left column of the form, whereas related files such as drawings, specifications, calculations, important photos, Communication memos, and other miscellaneous files are input into the right column. Fig. 4.4 shows the same form, however, with construction tab selected. Important details, observations, changes to specifications or plans that occur during construction can be appended in this section. By activating the available tabs files can be added from within the computer using Window’s explorer.

In Fig. 4.6 a completed form for MSE WALL R-281 can be seen. As this was an existing wall there was limited information and drawings available, however, from hard copies scanned into electronic format several situation and layout drawings shown. File
names can be input by the user at the time of file addition or for larger file collections such as the I-15 reconstruction a central file location can be attached to multiple walls reducing the amount of repetitive files being stored. To access these files the user must simply click on the name and the file will be opened using an appropriate program available from the user’s program files. Additional option buttons exist to remove (delete) files or to export them to other locations.

Once a wall is saved to the database the option to introduce a dated inspection becomes available to the user. Fig. 4.7 shows a form with the available fields completed for the inspection date July 25, highlighted in the calendar shown. For the user’s convenience the current date can also be seen below the calendar. The available fields at the top of the form allow for the user to input their name, summaries from the inspection, input files associated with the inspection. For the case of R-281 the related files include a scanned copy of the hard-copy of the inspection form shown in Fig. 4.9. General Photos taken at the time of this inspection can be seen by selecting the General Photos of Wall at time of Inspection as seen in Fig. 4.10. The Save and Exit tab allows the user to save the data input to that point and exit back to the general wall form. The tabs shown allow the user to toggle between different sections of the inspection form. Each question can be answered by selecting the toggle box and selecting a gradated percentage according to the amount each wall exhibits. As part of the inspection each question answered affirmatively should have an associated photograph. Available photographs for each issue can be viewed by selecting the tab or added by activating the Add a Photo tab shown in Fig. 4.8. Additional alternatives to delete a photo or export the file are also and can be activated by selecting the associated tabs. The number of photos available for each issue
observed is indicated on the associated tab. For the case of R-281 the associated answers for drainage can be observed in Fig. 4.7.

Figures 4.11, 4.12, 4.13, 4.14, 4.15, 4.16, and 4.17 show each section of the MSE Wall inspection viewed after the selection of its respective tab for wall R-281. As can be seen the top section of the form stays constant regardless of the tab selected to enable the user to update important overall observations and files that might be needed to access in the completion of the inspection form.

Once the MSE WALL information has been incorporated into the database the information can be made readily available by using the Report tool shown in Fig. 4.18. Two options are available to the user. The generate wall report option creates a general wall report, shown in Fig. 4.19. In order for the user to create a report based on an inspection an inspection must be selected and then the user selects the Generate report from selected inspection within the menu bar. This generates a report containing information gathered from the selected inspection along with associated photos. The beginning and end of the selected inspection report is shown in Figs. 4.20 and 4.21.

![Fig. 4.1 Interface view for MAPWindows program.](image)
Fig. 4.2 MSE tools package toolbar.

Fig. 4.3 MSE wall information general wall information form.
Fig. 4.4 MSE Wall general information form with construction tab shown.

Fig. 4.5 GPS Input Location Tools.
Fig. 4.6 Completed MSE wall interface.

Fig. 4.7 Completed section of drainage inspection for MSE wall R-281.
Fig. 4.8 Photo of drainage issue for MSE wall R-281.

Fig. 4.9 MSE inspection form view of files associated with dated inspection.
Fig. 4.10 View of general photos for wall.

Fig. 4.11 MSE Wall joints section of the inspection performed on R-281.
Fig. 4.12 Wall facing section of the inspection performed on R-281.

Fig. 4.13 MSE Top of Wall section of the inspection performed on R-281.
Fig. 4.14 Foundation condition and external stability section of the inspection performed on R-281.

Fig. 4.15 Metal corrosion section of the inspection performed on R-281.
Fig. 4.16 Impact and collision section of the inspection performed on R-281.

Fig. 4.17 Miscellaneous section of the inspection performed on R-281.
Fig. 4.18 Access to the report generation tool.

Fig. 4.19 General MSE wall information report.
4.3 **SUMMARY**

The necessity of retention of communications, specifications, drawings, and files for future consideration become critical with the potential occurrence of wall failure. In large projects such as the I-15 reconstruction an inadequate design or construction issue
that leads to a failure potentially could be replicated many times. With proper documentation of observed issues, wall design and construction it is possible to stop, delay, or rectify potential failures before they reach a critical status. For state departments with human capital and budgets stretched thin a primary concern is finding the means to maintain any new programs or databases. This software was developed to be usable by individuals with a wide range of computer skills, which would enable a variety of users to aid in the maintenance of a database.
CHAPTER 5

SYNTHESIS OF INSPECTION OBSERVATIONS

5.1 INTRODUCTION

The results of the site by site inspections are summarized in this chapter. The synthesis was a result of two teams who made site by site visits to the MSE walls throughout the state. In order to provide a complete perspective of data collected the information and conclusions of these groups have been summarized jointly. This compilation represents the collection of information, observations, and summaries of Utah State University by Ryan B. Maw, Dr. James A. Bay, Holly J. Griffin, and Dr. Loren R. Anderson with the addition work performed by Brigham Young University by Dr. Travis M. Gerber, Colin R. Cummins, and Adam M. Swenson. This data was presented to the expert panel as brief summary of MSE Walls throughout the State of Utah.

During the summer of 2007, nearly all of the Mechanically Stabilized Earth (MSE) walls in the Utah Department of Transportation (UDOT) inventory were visited and inspected by research teams from Utah State University (USU) and Brigham Young University (BYU). In addition to these inspections, available situation and layout, shop drawings, and specifications for UDOT MSE walls were collected. Those documents and data from the inspections have been assembled into an inventory database. This document highlights examples of problems and potential problems observed with MSE walls in the UDOT inventory. This document is intended to be a resource for the expert failure-modes analysis panel that will evaluate possible failure modes and probabilities of failure of UDOT MSE walls.
Potential issues relating to UDOT MSE walls have been divided into seven broad categories, with each category being presented in a subsequent section of this document as follows:

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Particular issues in each category are illustrated by photographs. The first six issues categories are pertinent to MSE walls constructed with either (1) a traditional panel generally anchored by inextensible reinforcement, or (2) a wire-mesh panel (with Geosynthetic fabric facing) anchored by inextensible reinforcement to which a facing panel is later attached. The former wall-type is locally referred to as a single- or one-stage wall, whereas, the latter is referred to as a two-stage wall (which is often constructed when ground settlements are expected to be relatively large). A third type of internally stabilized wall prevalent in the UDOT wall inventory is a segmented block wall typically anchored with extensible reinforcement. Given the inherent differences between the panel and block-wall systems, issues related to block-wall systems are presented separately from wall panels within the last issue category.

This document does not attempt to quantify the prevalence of each potential problem within the wall inventory, but simply identifies problematic and potentially problematic conditions observed during the wall inspection process.
5.2 Water Issues

The issues addressed in this section are surface drainage at top of the wall, blocked drains, drainage at bottom of the wall, permanent water flows, and runoff.

5.2.1 Surface Drainage at Top of the Wall

Surface drainage at the top of the wall encompasses the movement of water from the MSE Wall slopes and roadway to catch basins. Much of this water diversion requires the use of vertical drains, which were difficult to fully inspect as they were encased within the MSE abutment.

Figure 5.1 shows drainage directed to the top of an MSE wall from an adjacent roadway. In this instance water can either erode soils along the coping, or flow over the wall and erode the toe of the wall. Surface drainage (either controlled or uncontrolled) can be particularly problematic near the ends of MSE walls as shown in Figs. 5.2 and 5.3 where Geogrid has been exposed due to erosion.

![Fig. 5.1 Drainage from roadway is directed to top of MSE wall. (R-407-D, Genesis).](image)
Fig. 5.2 Improper drainage has lead to erosion of the block walls at this bridge abutment (R-376-B, Genesis).

Fig. 5.3 Eroded backfill and exposed Geogrid (R-376-B, Genesis).

Figure 5.4 shows another issue associated with surface drainage at the top of an MSE wall. In Fig. 5.4, a gap has opened up along the roadway between pavement sections supported by an MSE abutment and the integral bridge abutment. It appears that an attempt was made at one time to close this gap with asphaltic sealant; however, as the now-open hole to the left of the calipers in picture indicates, it is still possible for water to enter the underlying MSE backfill.
5.2.2 Blocked Drains at Top of Wall

Blocked drains at the top of walls can lead to two potential problems. First, water might be diverted from the drain into the MSE wall backfill. Second, pressure in the blocked drain pipes can lead to leakage from the drain pipes and again divert water into the MSE wall fill.

Figure 5.5 shows a partially blocked drain below the drain grate where roadway debris has filled the catch basin allowing incoming material to travel through the vertical drain.

Figure 5.6 shows a roadway drain, whose grate has been covered by road debris. Water that cannot make it through the debris covering the drain grate is directed along the back of the wall.

Fig. 5.4 Crack in pavement between the different pavement sections near an MSE abutment near a bridge providing a conduit for water in the underlying MSE wall backfill (R-376-A, Genesis).
5.2.3 Surface Drainage at Bottom of Wall

Surface drainage issues at the bottom of the wall can be separated into two sub-categories: permanent flow and temporary runoff. In the case of permanent flow, mitigation of potential scour is of particular concern and typical measures consist of deeper wall embedment, protection provided by gabion baskets, and use of concrete headwalls near water passages. In the case of runoff, positive drainage by grading and pipe drains is commonly used.
5.2.3.1 Permanent Water Flow

The potential for scour and drainage issues is shown in Fig. 5.7, where Box Elder Creek can be seen flowing along the base of wall R-281. The water flows through a culvert with a concrete headwall. However, as can be seen by the high water mark stains along the culvert and MSE panels, water has made contact with upstream panels beyond the end of the headwall. In the background, there is a vertical drain from the roadway surface which discharges near the unprotected base of the MSE wall.

Figure 5.8 shows the undermining of the leveling pad beneath an MSE block wall near a culvert. This erosion is likely attributable to both runoff coming down the wall face from the roadway above and flow from the stream channel which was not confined by the concrete wingwall nor the gabion-type basket shown in the foreground.

Fig. 5.7 Water flowing along the base of a MSE wall and through a culvert (R-281, RECO Cruciform).
5.2.3.2 Runoff

Water collected on a roadway surface is often passed into catch basins which in turn pass water through pipes located either within or beyond the zone of MSE wall backfill. Sometimes the discharge points for these pipes are blocked by debris and vegetation as shown in Fig. 9. If the pipe is blocked, there is potential for the water to enter the MSE wall backfill. Also, the discharge flow can be a source of erosion if it is not directed away from the wall and nearby foundation soils.

The leveling pad and base of the abutments can be left exposed or eroded by improperly or uncontrolled controlled runoff. An occurrence of this can be observed in Fig. 5.10 where water has drained from the road surface and down the embankment, eroding a path along the coping and then under the bridge deck. Fig. 5.11 shows the space eroded under the bridge deck from within the cavity.

Fig. 5.8 Erosion of leveling pad below block wall due to surface runoff and stream flow (R-407-D, Genesis).
Fig. 5.9 A road drain that travels vertically through a MSE (Block) backfill is obstructed at its discharge point by vegetation and road debris (R-376-F, Genesis).

Fig. 5.10 Erosion along the sides of a MSE wall bridge abutment have led to erosion beneath the bridge deck further shown in Fig. 5.11 (R-343-42, VSL).
Fig. 5.11 The outside view of the erosion along a MSE wall at a bridge abutment (Fig. 5.10) is further explored beneath the bridge deck (R-343-42, VSL).

5.2.4 Internal Drainage

Issues associated with internal drainage can be separated into two sub-categories: pipes in walls and internal drainage within the wall structure.

5.2.4.1 Pipes in Walls

Water from the roadway surface is collected into catch basins at the top of the wall and then later drained into a vertical drains located at the base of the wall. Often these vertical drains are covered by steel grates which can collect debris, as shown in Fig. 5.12. Another drainage pipe shown exiting through a MSE wall panel above grade onto a concrete walkway is shown in Fig. 5.13. In this figure, soil seen on the walkway might be backfill material carried from the drain pipe.

Figure 5.14 shows a horizontal culvert along the I-15 corridor which protrudes through a MSE wall. Water collecting on the adjacent residential street passes through the culvert to the west side of I-15. A grating has been placed to reduce the flow of debris.
Although this grating reduces the passage of large items into the culvert, smaller debris still collects in the culvert.

**Fig. 5.12** A vertical drain exit covered by a metal grate in a MSE wall backfill, typical for the I-15 corridor (R-344-7, VSL).

**Fig. 5.13** A vertical drain extending through MSE wall panel (R-385, VSL).
Fig. 5.14 A grated culvert extends through a MSE backfill. Note the debris collected at the base of the wall (R-351-30, VSL).

5.2.4.2 Internal Drainage within Wall Structure

Evidence of drainage issues within a MSE wall can be observed by fill that has been leaking through panel joints and deposited on the ground below the wall as shown in Fig. 5.15.

Another example of fill migrating from within an MSE wall can be seen by the soil at the base of the panels in Fig. 5.16. This figure also displays foam joint filler placed during construction that has degraded just above the leaking backfill. Fig. 5.17 illustrates additional leakage of backfill from behind an MSE wall panel through a relatively wide joint. The soil deposits shown in these photos may or may not be associated with internal drainage. However, Fig. 5.18 shows a culvert located at the base of an MSE wall with a moist crack at the top of the culvert. The persistence of this saturated condition can be seen by the water stains in the crack. Figure 5.19 is a dramatic photo, taken by UDOT employees, showing water flowing from behind a two-stage MSE
wall panel during a rain storm. This wall has a vertical drain in the embankment. Fig. 5.20 shows soil that was carried out of the wall by leaking water.

**Fig. 5.15** Backfill leakage from an MSE wall panel, (R-325-F, VSL).

**Fig. 5.16** MSE backfill leakage through panel gaps (R-351, VSL).
Fig. 5.17 A MSE wall joint allows for fill to leak from behind the panels (R-444, RECO).

Fig. 5.18 A moist crack located above a culvert that allows the Box Elder Creek to pass beneath an MSE wall indicates saturated conditions in the MSE wall backfill (R-281, RECO).
5.2.4.3 Irrigation Systems

Irrigation systems behind or above an MSE wall poses two potential hazards. First, over watering can saturate the MSE wall fill, and second, broken or leaking irrigation pipes can cause high pore pressures to develop in the fill. Fig. 5.21 shows a landscaped area with vines growing on the wall and a rotating sprinkler located at the base of the wall.

Irrigation systems are located along certain portions of the I-15 corridor in the Salt Lake Valley. These systems irrigate plants which are intended to increase the aesthetic appearance of the highway corridor. These systems are often located in difficult to access areas between concrete traffic barriers and sound walls at the top of the MSE walls. Fig. 5.22 shows a small bush growing behind a sound wall at the top of an MSE wall. Irrigation piping and aesthetic plantings are usually located on the opposite side (traffic side) of the sound wall.
Figure 5.23 shows a drip irrigation system used on a terraced MSE block wall supporting a state road while Fig. 5.24 shows water leakage through the block wall from irrigation.

Fig. 5.20 Soil carried out of an MSE wall by water that leaked from behind the panel shown previously in Fig. 19 (R-349, VSL).

Fig. 5.21 Irrigation next to an MSE wall with vegetation growing out of the wall (R-369, RECO).
Fig. 5.22 A small bush growing behind the parapet of an MSE wall (R-344-44, VSL).

Fig. 5.23 Drip line irrigation system used on a block wall (R-423, Genesis).
**Fig. 5.24** Irrigation leakage through the block wall shown in Fig. (R-423, Genesis).

An irrigation sprinkler placed directly next to an MSE block wall can be seen in Fig.5.25. This irrigation layout is typical for modular block walls constructed within some area of Salt Lake Valley.

**5.2.5 Vegetation**

Vegetation in panel joints and at the base of MSE walls can be evidence of drainage issues which allow for water to be available for plants. Figs. 5.26 and 5.27 show the growth of vegetation at the base of a MSE panel wall. These trees will continue to grow and potentially disrupt key components (i.e. leveling pad) of the retaining wall structure.

Water that has been available during the early spring season where runoff was available for plants to develop and grow may go unobserved; however, in Fig. 5.28 dead vegetation is evidence of an existing drainage issue.
Fig. 5.25 Irrigation sprinkler placed immediately behind the wall face for a MSE block wall (R-427, Genesis).

Fig. 5.26 A tree grows beneath the base of a MSE wall (R-476, VSL).
MSE wall panel issues can be separated into subcategories consisting of irregular panel spacing and movement, popped corners, cracked panels, bowing in wall, and tears in fabric. All of these issues can result from incorrect wall installation during
construction, movement of the wall during or after construction due to settlement of the wall backfill and/or foundation soils, or any combination of these.

5.3.1 Irregular Panel Spacing

Irregular panel spacing can be associated with two different distress mechanics, yet each poses similar problems. Irregular panel spacing can occur during construction and/or afterwards. Evidence of irregular joint spacing due to construction can sometimes be identified by the in-filling of joints with foam. In such cases, subsequent post-construction movement can be detected by any gapping between the panel and filler material. Otherwise, distinguishing between irregularities due to construction and irregularities due to post-construction movement is difficult. Often, one must rely upon the assumption of competent foundation and backfill soils to attribute construction methods and techniques as the source of irregular panel spacing. In many parts of Utah, soft compressible foundation soils exist, so significant post-construction movement is possible.

5.3.1.1 Construction Related Joint Spacing Irregularities

Irregular joint spacing due to construction irregularities is shown in Fig. 5.29. Foam placed in the panel joints indicates that the joint irregularities are related to construction rather than post-construction settlement. With time and exposure, the foam material used to fill in the joints after construction can degrade, allowing soil material and water to both enter and exit the wall. Evidence of the severity of this degradation and gapping in panels due to construction can be observed in Fig. 5.30.
5.3.1.2 Post-Construction Related Joint Spacing Irregularities

In Fig. 5.31, irregular spacing in joints can be seen in the first row of panels from the coping. Fig. 5.32 shows another example of irregular joint spacing in the vertical joints below the coping. Additional evidence of movement and subsequent contact between panels can be seen in the popped corner of the top row of panels.

During construction, orange foam (later painted gray) was used to fill in gaps between panels and after construction the gapping between the panels has increased, leaving gaps between the foam and panel as can be seen in Fig. 5.33. Movement of panels near the top of the wall can be seen in the different gap sizes in the joints from the top to bottom panels in Fig. 5.34. A more consistent shifting of panels is seen in Fig. 5.35.

![Image](image_url)  

**Fig. 5.29** Construction related non-uniform joint spacing and alignment (R-325-F, VSL).
Fig. 5.30 Irregular joint spacing was filled during construction by foam which has since degraded over time (R-325-B, VSL).

Fig. 5.31 Irregular joint spacing in the first row of panels below the coping at a bridge abutment (R-146, VSL Hex Panels).
**Fig. 5.32** Joint spacing irregularities in the first panel below the coping (R-342-7, VSL).

**Fig. 5.33** Foam used to fill in joint spacing during construction with gapping from post-construction movements (R-342-7, VSL).
**Fig. 5.34** Irregular spacing in panels can be seen with the larger gaps appearing directly below the coping (R-409, Foster).

### 5.3.2 Significant Panel Movement

The picture (taken by a UDOT employee several years ago) presented as Fig. 5.36 shows the buckling of panels in a two-stage MSE wall located at the 600 North, I-15 interchange in Salt Lake City. The panels (and even coping) above these panels appear to have moved downward as well (see subsequent section on coping and parapet issues). While the complete failure mechanism is not known, corrosion and subsequent failure of the connection between the panel and turnbuckle was observed. This section of panels has since been repaired with a cast-in-place concrete section whose finished surface protrudes several inches outward from the rest of the wall face.

Figure 5.37 illustrates another case of horizontal panel movement, where the movement is uniform along a vertical joint.
Fig. 5.35 Gapping at joints between panels suggesting wall panel and/or backfill movement (R-387-D, SSL or Foster).

5.3.3 Popped Corners

Panel movement may also be inferred from the breaking of panel corners where panels are over stressed due to contact with adjacent panels. These fractures are referred to as a popped corner. Popped corners can also result from poor handling of panels during placement; however, in such instances, the panels are either repaired by the contractor or rejected by the inspector. Fig. 5.38 shows a typical example of a popped corner for the RECO panel system. Fig. 39 shows a popped corner on a square VSL manufactured panel. Fig. 5.40 shows a larger and less typical popped corner. Sometimes a panel will have multiple popped corners.

5.3.4 Cracked Panels

As the MSE wall embankment moves, induced stresses in the panels can lead to cracking in panels as can be observed in Fig. 5.41. Further evidence of the walls
movement can be seen in the cracking of the coping on the upper left hand corner above the panel as the concrete is being crushed.

**Fig. 5.36** Buckling of 2-stage MSE wall panels (R-337-C, VSL).

**Fig. 5.37** Shows the horizontal displacement of panels along vertical joints (600 North & I-15, VSL).
Fig. 5.38 A popped corner can be seen on a MSE wall panel along with irregularities in other panel joint spacing (R-146, VSL Hex Panel).

Fig. 5.39 A typical example of a popped corner in a VSL wall panel (R-325-C, VSL).

Cracking in a MSE panel can be observed in Fig. 5.42, however, the cracking does not appear to be connected to a popped corner, but rather extends a few inches from
the end of the panel. The cracking in the MSE panel shown in Fig. 5.43 shows how continued cracking can work to degrade a panel. Fig. 5.44 displays a cracked/spalled edge along the entire vertical length of MSE panel. Fig. 5.45 shows a severe case of the cracking of an MSE Wall panel as the cracking has lead to the exposure of epoxy coated rebar.

**Fig. 5.40** A relatively large popped corner in a MSE wall panel(R-387-B, SSL or Foster).

**Fig. 5.41** A cracked panel located in the first row of cruciform panels together with cracks in the coping directly above the panel (R-365, RECO).
**Fig. 5.42** A vertical crack in panel near vertical joint (R-281, RECO).

**Fig. 5.43** Cracks in panel degrading with measuring tape showing the crack size (R-280, RECO).
Fig. 5.44 A MSE wall panel with cracking/spalling along its entire edge (R-387-B, SSL or Foster).

5.3.5 Bowing of Walls

Bowing in walls can be attributed to errors in construction or post-construction movement of the wall. For the wall shown in Fig. 5.46, the bowing of the walls can be seen as well as the varying thickness of the coping along the length of the wall. A severe case of bowing can be seen in Fig. 5.47 as the panels have separated expanding the panel joints.

5.3.6 Tears in Fabric

Irregular joint spacing and gapping can lead to the exposure of the geo-fabric placed at the panel joints. In Fig. 5.48, fabric can be observed between panels and with close inspection a difference in color near the top of the fabric in the photo reveals a tear with exposed soil. In Fig. 5.49, large joint spacing of has allowed the exposure of fabric. Movement of rip-rap at the base of the block MSE wall along the Logan River has exposed geo-fabric, as shown in Fig. 5.50.
Fig. 5.45 A cracking panel can be seen and is exposing the green epoxy coated rebar in the panels (R-442, RECO Curved Face Panel).

Fig. 5.46 Bowing (irregularly aligned) wall panels located near a bridge abutment (R-409, Foster).
Fig. 5.47 Bowing in panels exhibited by the gaps between horizontal joints (R-442, RECO Curved Face Panels).

Fig. 5.48 Tears in the black fabric between wall panels can be observed by the difference in colors between the black fabric and the gray fill (R-409, Foster).
Fig. 5.49 Exposed fabric can be seen through irregular joint spacing (R-409, Foster).

5.4 COPING AND PARAPET ISSUES

The issues discussed in the coping and parapet issues section are cracks in coping, cracks in parapets, and uneven spacing. Key indicators of wall movement are the coping and parapets, which are cast in place towards the end of construction. Hair line cracks develop in coping as part of normal concrete shrinkage. The following figures show large deformations which are indicative of wall movement. The majority of the bridge abutments throughout the state of Utah incorporate piles, caissons, or other deep foundations. The settlement of MSE walls relative to the deep foundation often leads to cracks in the coping and parapets.

5.4.1 Cracks in Coping

Figure 5.51 illustrates the fracture of concrete in MSE wall coping. Fig. 5.52 shows small cracks in the MSE coping and correspond to the cracking of a panel.
5.53 illustrates the cracking in coping as the MSE wall has bowed horizontally providing horizontal stress on the panel.

A series of small cracks has spread across a concrete section that spans an MSE approach and bridge deck joint is shown in Fig. 5.54.

**Fig. 5.50** Exposed fabric beneath rip-rap block wall located near the Logan River (R-376-B, Genesis).

**Fig. 5.51** Cracking in coping at a MSE wall abutment and bridge deck (R-409, Foster).
Fig. 5.52 Cracking in coping which correlates with a popped corner (200 South / Center Street, Clearfield; Foster).

Fig. 5.53 Cracking along coping visible from the horizontal section of the coping (R-146, VSL Hex Panel).
5.4.2 Cracks in Parapets

Figure 5.55 shows a crack in the coping and accompanying fracture of concrete near the top of the abutment. This damage occurred above a section where underlying two-stage wall panels buckled at the 600 North interchange of I-15 in Salt Lake City. The fractured concrete section then fell to the roadway below as shown in Fig. 5.56. Finally, the view from on top of the wall of the remaining concrete and exposed rebar can be seen in Fig. 5.57. Figs. 5.55 through 5.57 are recent pictures and represents damage that has worsened since the panels below the coping and parapet were repaired. A severe case of cracking in a concrete parapet between an MSE wall and bridge abutment can be observed in Fig. 5.58.

Fig. 5.54 Small cracks in the concrete section that spans an MSE approach and bridge deck joint (R-343-41, VSL).
Fig. 5.55 Cracking in the coping and accompanying fracture of concrete near the top of the abutment (R-337-C, VSL).

Fig. 5.56 The fractured concrete section that fell to the ground below the MSE wall at 600 N and I-15 (R-337-C, VSL).
5.5 **Leveling Pad Issues**

The leveling pad can be exposed by erosion or improper burial. The inspection of leveling pads was limited to those visible at the ground surface. Issues involving leveling pads can be broken into sub-categories of exposure and cracking.

![Image of severe fracturing in the parapet with the concrete section from Fig. 60 displaced (R-337-C, VSL).]

**Fig. 5.57** Severe fracturing in the parapet with the concrete section from Fig. 60 displaced (R-337-C, VSL).

![Image of cracking in parapet can be seen at the abutment (R-343-41, VSL).]

**Fig. 5.58** Cracking in parapet can be seen at the abutment (R-343-41, VSL).
5.5.1 Exposure of Leveling Pads

Exposed leveling pads can be seen in Figs. 5.59 and 5.60, however, the mechanisms related to their exposure is quite different. Fig. 5.59 shows a typical example of an exposed leveling pad that was not buried during construction. Fig. 5.60 shows a leveling pad at the base of a MSE block wall that has been exposed due to erosion and improper burial.

Fig. 5.59 Unburied leveling pad with differing heights (R-344-9, VSL).

Fig. 5.60 Erosion along leveling pad at MSE Block bridge abutment (R-376-B, VSL).
5.5.2 Cracking of Leveling Pads

The identification of cracking in leveling pad was limited to leveling pads that were exposed. The photos shown below were taken of a leveling pad that was visible during inspection. Fig. 5.61 shows an exposed leveling pad that has experienced significant cracking. An exposed leveling pad with a series of cracks is blocked from direct view by a jersey barrier as can be seen in Fig. 5.62.

5.6 Corrosion Issues

Corrosion and/or erosion of MSE wall panels, independent of the internal reinforcement in the MSE wall backfill zone, can occur. This damage can exhibit in the concrete or in the steel reinforcement. At other times, the internal reinforcement in the backfill can corrode. A visual inspection of MSE walls does not allow an evaluation of the reinforcement buried in the backfill soil. Therefore, signs of internal corrosion must be inferred from evidence outside of the wall. However, coupons of metallic reinforcement have been placed in many MSE walls. These coupons, which are specimens of the same reinforcement materials placed at the time of construction, can be removed from the wall and evaluated for effects of corrosion. Corrosion has been separated into the following sub-categories: visible corrosion, salt deposits, and coupons.

5.6.1 Visible Corrosion

Figure 5.63 shows MSE wall panels with roughened surfaces where typically smooth concrete between fluted sections exists. This together with some uneven coloration/discoloration of the wall panels at this site at the mouth of Provo Canyon suggests that the wall panels are undergoing some amount of degradation.
Fig. 5.61 Exposed leveling pad with significant cracking (R-376-B, Genesis).

Fig. 5.62 Exposed leveling pad located behind Jersey barrier with visible cracks (R-359, Foster).
In Fig. 5.64, rust colored stains can be seen along the front of a MSE panel. Additionally, Fig. 5.65 shows the corrosion of exposed rebar in an MSE panel. Also a rust stain is visible on the face of a panel where reinforcement from within the panel has become exposed in Fig. 5.66.

Fig. 5.63 Roughened surface of typically smooth concrete between fluted sections of a MSE wall panel (800 North and SR-189, Mouth of Provo Canyon, West Abutment).

Fig. 5.64 Rust colored staining on MSE panel face (R-346-12, VSL).
5.6.2 Salt Deposits

The use of salts to maintain the road surface during winter months can create a corrosive environment. Evidence of the salts traveling through the embankment can be
seen by Figs. 5.67, 5.68, and 5.69. A rust colored salt deposit can be seen from the underside of a bridge deck where an MSE wall embankment meets a bridge deck is shown in Fig. 5.67. The collection of salt at the base of an MSE abutment and in panel joints can be seen in Figs. 5.68 and 5.69.

Fig. 5.67 Rust and salt deposits along the underside of a bridge abutment of the approach slab (R-376-A, Genesis).

Fig. 5.68 Salt deposited at the base of a MSE wall panel (R-325-D, VSL).
5.6.3 Coupons

By removing coupons, metallic rods of similar material and placed at the same time as the original reinforcing straps, it is possible to anticipate the effects of corrosion on metal within an MSE wall. Typical panels, which contain coupons, are shown in Figs. 5.70 and 5.71. These panels have 6 holes filled with rubber stoppers, which can be removed to gain access to the coupons. No coupons have yet been pulled and tested from a MSE wall in the UDOT inventory.

Fig. 5.69 Salt collecting between MSE wall joints (R-369, RECO).

Fig. 5.70 Six coupon locations are indicated by green rubber stoppers in the panel face (R-342-11, VSL).
5.7 Stability Issues

The general stability of an MSE wall may be evaluated by a visual inspection of the following conditions: reverse batter, large deformations and/or steep slopes at the wall base, the presence or absence of a bench at the base of a wall founded on a slope, and presence of adjacent structures.

5.7.1 Reverse Batter

The reverse batter of a wall can be observed as the wall tilts outward and the degree to which this occurs can be quantified by measuring the distance of the wall from vertical. An extreme example of this can be seen in Fig. 5.72.

Fig. 5.71 Three coupons locations shown out of a possible six; located behind green rubber stoppers (R-344-7, VSL).
Fig. 5.72 Reverse batter of a MSE wall (R-442, RECO Curved Face Panels).

5.7.2 Large Deformations and/or Steep Slopes

Figures 5.73 and 5.74 show the effects of an MSE wall built along a relatively steep slope with poor soils immediately beneath the wall. The slope at the southwest corner of this MSE wall bridge abutment in Clearfield is approximately 1.5H:1V and the embankment soils are silty. Movement on the order of 1.5 feet has occurred within the slope and this movement, coupled with subsequent erosion, has undermined the wall as shown in Fig. 5.74.

5.7.3 Benches

A sufficient bench at the base of a MSE wall founded on a slope provides stability and reduces the potential erosion along the base. The required lateral width of this bench typically four feet. Figs. 5.75, 5.76, and 5.77 show benches of inadequate width. Conversely, Fig. 5.78 shows an adequate bench.
Fig. 5.73 Steep sloping of poor quality fill at base of MSE wall (200 South / Center Street, Clearfield; Foster).

Fig. 5.74 Effect of movement of fill beneath Clearfield MSE wall (200 South / Center Street, Clearfield; Foster).
Fig. 5.75 An inadequate bench at base of MSE Wall (R-369, RECO).

Fig. 5.76 Inadequate bench at base of MSE Wall (R-343-27, VSL).
5.7.4 Adjacent Structures (Excluding Bridges)

Adjacent structures can impose loads on MSE walls that can affect the stability of MSE walls. Conversely, movement of MSE walls can affect the performance of adjacent structures. Fig. 5.79 shows high tension power lines that could be adversely affected by MSE wall movements.

![Fig. 5.77 Inadequate bench at base of MSE wall situated on a steep slope (R-444, VSL).](image)

![Fig. 5.78 An adequate bench at base of a MSE wall system (R-444, VSL).](image)
Figure 5.80 shows the encroachment of a parking lot and small retaining wall into UDOT right-of-way near an MSE wall. The right-of-way fence has been taken down and the toe of the slope upon which the MSE wall is founded has been partially excavated, posing a potential stability risk to the wall. Figure 5.81 shows the placement of a new non-UDOT MSE block wall (dark red-brown in color) along the top of a previously existing UDOT MSE block wall (light grey in color).

5.8 Block Wall Issues

In reviewing block walls, the following sub-categories address items specifically related to MSE block walls: block spacing, leakage of backfill between blocks, exposure of Geogrid reinforcement, and corrosion of blocks.

5.8.1 Block Spacing and Leaking Backfill

The spacing between blocks in an MSE block wall is critical in keeping the backfill from leaking out of the joints. A typical example of excessive gapping in joints that has lead to the loss of backfill is shown Fig. 5.82. Another example of irregular gap spacing with leaking backfill can be seen in Fig. 5.83 and a typical example of uniform joint spacing is illustrated Fig. 5.84.
Fig. 5.79 Major power lines located on top of slope supported by MSE wall (R-442, RECO Curved Face Panels).

Fig. 5.80 Excavation of soil near MSE wall for adjacent parking lot and small retaining wall (R-383-H, SSL).
Fig. 5.81 Addition of new MSE block wall to the top of an existing MSE block wall (R-383-J, SSL).

Fig. 5.82 Excessive gapping in block spacing and joints for a MSE Block wall (R-381, Genesis).
5.8.2 Exposed Geogrid Reinforcement

Figure 5.85 shows an exposed Geogrid behind an MSE block wall at the base of bridge deck approach. Additionally, Fig. 5.86 shows Geogrid exposed at the front face of a block wall.
5.8.3 Corrosion of Block Reinforcement

Figure 5.87 shows an example of severe degradation of MSE wall block. These blocks in Provo Canyon are known to have a high gypsum content which contributed to their rapid deterioration.

Fig. 5.85 Shows eroded backfill and exposed Geogrid (R-376-B, Genesis).

Fig. 5.86 Exposed Tensar grid from construction (R-376-A, Genesis).
Fig. 5.87 Severely deteriorated MSE wall block (R-297-E).

5.9 **Summary**

This document was sent to the individual panel members to review in preparation for the panel discussion. Additionally, a summarizing presentation of this information was used as a forum for the discussion of adequacy and significance of the inspection procedure and its results.
6.1 INTRODUCTION

A panel of national experts from around the country was assembled to review the data collected from the project and produce potential failure modes of UDOT’s MSE walls on December 12-13, 2007. The panel consisted of Mike Adams (FHWA), Peter Narsavage (ODOT), Tony Allen (WashDOT), Jerry Bishop (Geotechnical Design Consultants), Keith Brown (UDOT), John Bischoff (UDOT), Jim Higbee (UDOT), Darin Sjoblom (UDOT), Grant Gummow (UDOT), Blaine Leonard (UDOT), Loren Anderson (USU), Jim Bay (USU), Travis Gerber (BYU), and members of the inspection teams. The panel made visits to several MSE Walls, reviewed documents presenting history of MSE wall failures used to produce the inspection, and a synthesis of observations and statistics from the inspection. The expert panel review produced several areas of in which they found concern and suggested improvements for the design, construction, and maintenance. This input has been organized in its considerations chronologically by short term and long term needs. Short term is defined as new construction to 15 years, and long term is defined as 25 to 75 years.

6.2 SHORT-TERM CONCERNS

The panel concerns relating to short-term performance of UDOT MSE walls can be grouped into three categories: 1) wall drainage 2) wall design, details, and specifications, and 3) retention of wall information.
6.2.1 Wall Drainage Concerns

The point was made during the failure modes discussion by Mike Adams that the three most important parts of a good MSE wall are “drainage, drainage, and drainage.” As Utah is part of the arid west, the amount of precipitation to drain from the roadway may not be as significant in number as in other parts of the country, but are no less significant in terms of its importance.

Of particular concern in drainage was the placement of vertical drain pipes through MSE wall embankments. Fig. 7.1 shows a typical drain pipe detail for an MSE wall embankment. Issues regarding the placement of drainage pipes are multifaceted. These issues can be further complicated by the lack of direct communication between the roadway drainage designer and the retaining wall designer. The geologic characteristics of the Salt Lake Valley produce challenges in the form of significant settlement. This settlement negatively affects rigid structures included as part of the soil mass. For the case of vertical pipes failing in compression, along joints, and other settlement induced failure mechanisms. These issues are difficult to identify as they are buried within the soil mass and have to be identified through secondary indicators. The significant settlements obtained throughout the lacusterine deposits of the state are accelerated by pre-staging the MSE embankments. Often the drain pipe installation timing in the construction process exposes the rigid structures to the full effects of settlement. This exposure to the full settlement creates separation issues for pipe connections and can potentially lead to breakage. These issues are compounded by multiple connections, a 90-degree elbow connection, inadequate compaction around the pipe, pipe movement in mass creating
unanticipated drainage issues and stress concentrations; these effects can lead to serious complications over the design life of the wall.

Inadequate drainage design creates unnecessary maintenance issues with the drain pipes in the backfill can create issues within the wall. The drainage detail shown in Fig. 6.1 shows a discharge pipe, making a 90-degree angle at the base of the wall. This angle can increase the incidence of blockage, and amplify the effects of settlement in the wall. Debris found along the roadway, which finds its way into the catch basin, and then into the drain pipes can also lead to blockage. The 90-degree angle facilitates a blockage at the elbow. If this occurs, as little as seven feet of vertical water head exceeds the joint capacity for ABS pipe and can lead to joint leakage or a bursting joint. These possible complications are exemplified by Fig. 6.2, which shows water leaking from behind panel faces onto the roadway. It should be noted that Fig. 6.1 is the drainage detail used in the MSE wall shown in Fig. 6.2. The panel recommended an examination of this detail and possible alterations by changing the angle of the drain pipe, implementing a drop structure for areas requiring a vertical drop, or draining off the roadway surface through the parapet onto the side embankment.

Another issue identified was water collection along the top of the roadway, particularly during the winter months due to the freezing and thawing of the roadway drainage. As snow is collected from the roadway surface and diverted to the shoulders by machinery, the melting and freezing creates “water ponding” near the roadway parapet as can be seen in Fig. 6.3.
The “water ponding” at the roadway surface makes its way into the catch basins or other openings in the wall and refreezes, which then blocks drains and creates potential issues within the drain pipe. An example of this is shown in Fig. 6.4.

The final area identified regarding drainage is erosion at the base of the wall. This erosion comes as a result of inadequate drainage of the roadway or nearby water sources, which leads to erosive flow along the faces of the retaining walls. This erosion compromises the stability of the wall in two general ways. The erosion of fill can continue back under the parapet, moment slab, and even roadway surface. This condition is exemplified by Figs. 6.5, 6.6, and 6.7.

Fig. 6.1 Shows the drain pipe detail for wall (R-349-2, VSL).
**Fig. 6.2** Water draining through the MSE backfill and panels onto the roadway during a rain storm (R-349-5, VSL).

**Fig. 6.3** Snow collected from the roadway diverted to the shoulder (R-349-5, VSL).
**Fig. 6.4** Water frozen over drain to roadway drain (R-349-5, VSL).

**Fig. 6.5** Slope of wall, with erosion taking place near the top of the wall beneath the roadway (R-343-42, VSL).
Fig. 6.6 Erosion working behind the panel and beginning to work under the moment slab (R-343-42, VSL).

Fig. 6.7 View of the eroded section and remaining fill from inside the eroded area (Panel to the left and moment slab above section shown) (R-343-42, VSL).
This erosion process has been observed in wall failures and has lead to issues ranging from cracking of the roadway to collapse. Alternatively, it can work to erode beneath the retaining wall exposing the leveling pad to excess stresses, which can led to failure of the leveling pad and the unzipping of the MSE system. An example of this is shown in Fig. 6.8.

6.2.2 Wall Design Details and Specifications- Single-Stage Walls

A key item came out of the review and discussion of the state’s specifications in light of the data collected was that the specifications supplied by vendors are not adequate. Experience indicates that the manufacturer’s requirements for the construction of the walls are often inadequate, and more prescriptive specifications should be required in some cases. Specifically, it was identified that the compaction immediately behind the panels or the use of self-compacting fills near the wall face, is a critical detail for wall stability. This detail becomes increasingly important as wall height increases.

Fig. 6.8 Erosion of leveling pad below block wall base due to surface runoff and stream flow (R-407-D, Genesis).
Additionally, the union of the coping, parapets, and moment slab into one monolithic structure, without expansion joints, creates stress on panels and leads to cracking. An example of this is shown in Fig 6.9.

In the past, emphasis was placed on having a four foot bench or slope break at the base of the wall; however, panel input and finite element analysis associated with this project encouraged sufficient embedment of three feet into the subsurface rather than a bench. This embedment will lead to increased stability of the overall wall and has been shown through finite element modeling to aid in construction through reducing tipping and bowing.

Fig. 6.9 A generic detail for the coping, parapet, and moments slab for the I-15 reconstruction.
Due to the geological nature of the metropolitan centers in Utah that being largely composed of largely compressible clays, this issue of settlement is a challenge for any earth structure. The use of deep foundation methods to support bridge decks in Utah coupled with MSE wall supported approaches, leads to complications in differential settlement. In attempts to mitigate this settlement issue, a two-stage MSE system has been used in areas of with significant settlement.

6.2.3 Wall Details and Specifications
Two-Stage Walls

The two-stage system allows for additional settlement using metal reinforcement and geosynthetic fabric to support the soil mass before panels are placed on the exterior reducing the stresses from settlement deformation on the panels. The duration of this exposure is determined by the time it takes for the soil mass to reach a predetermined settlement, which can often take months. The staged construction of the two-stage system exposes the geosynthetic fabric to the element and over extended periods, as seen in Utah, can lead to UV degradation, tearing, and the loss of fill, which can contribute to potential failure of wall over time. The loss of fill and the general state of the fabric over time is difficult to ascertain, as it is covered with panels, but it remains a serious concern for the long-term stability of the wall. Additionally, without the rigid protection of the concrete panels, additional damage can be done to the wall from the construction process. This is evident in Fig. 6.10 in which a two-stage embankment nearing the completion of its settlement time is shown, with exposed geosynthetic, disturbed reinforcement wire, and leaking backfill. The cause of the reinforcing wire and fabric disturbance is unknown, but the effects of the disturbance could potentially lead to a wall issues.
Additionally, the reliability of the two-stage wall system was discussed regarding the panel-wall facing connections as a concern in seismic loading, construction, and corrosion. The nature of the steel panel-reinforcement connection can be seen in Fig. 6.11, with the steel reinforcement linking the panels and steel reinforcement. Panel discussion called into consideration the ability of the panel wall connections to absorb significant seismic loadings as are anticipated along the Wasatch Front. The racking and dropping of panels during an earthquake creates safety issues in roadway general stability. Furthermore, making reliable panel-wall connections during construction by developing consistent and adequate tension in the varying panel-reinforcement connection types produces a degree of unreliability. As well, the long-term wall settlement that continues after the placement of the panels leads to unanticipated stresses in the connections. Additionally, the air space between the wall and panels provides a convenient location for drainage from the roadway. The roadway discharge during winter months high in salt concentration and other reactive contaminants is concentrated and passes through the metal wall-panel connections leading to corrosion and possible failure of the connections.

After further consideration and panel discussion, the use of a segmented two-stage wall using a wall-panel connection was questioned. It was suggested that the use of architectural shotcrete to cover the wall and reduce the space for contaminant flow along the panels should be considered for standard practice. Minimally, the void space between the wall and panels could be filled in order to reduce the aforementioned potential issues.
Fig. 6.10 Two-stage MSE wall with exposed geosynthetics and wire reinforcement (Legacy Parkway).

Fig. 6.11 Multiple wall panel connections with wall covered in snow (Legacy Parkway).

6.2.4 Maintaining Wall Information

The information collected as part of this survey was intended to provide a snapshot of the current status of the MSE walls in the state of Utah, gather time sensitive information of institutional knowledge, disappearing documentation (drawings, wall location, etc), and alert UDOT of walls in peril. However, through the collection of
available wall drawings and information of the walls, it became apparent that much of the
information regarding the walls in the state (wall location, wall numbers, wall drawings,
institutional knowledge, etc.) had been lost over time. The purpose of the database
construction was to supply a means, by which electronic information could be stored for
long-term use, with minimal expense and effort. The specific concern of those associated
with MSE walls was providing the means and motivation to continue the collection and
storage of this information. The resolution of this complication remains to be seen;
however, it is the hopes of this project that the careful consideration and development of
this project and database will encourage and facilitate its use and update. The information
provided as part of this database could prove invaluable in the case of a wall defect or
issues associated with a specific wall type or manufacturer that is replicated throughout
the state.

Furthermore, during the course of the inspection several distressed walls were
observed and arrangements were made to both visit and mitigate inspected issues. Federal
funding provides for a bridge inspection program; however, the embankments which
support these bridges go uninspected. The expenses of a MSE inspection program could
be potentially offset by savings gained through catching and mitigating developing issues
before they lead to failure. For the case of Utah, the programs and methods of wall
documentation can be updated with minimal expense and effort and will serve the state
well in its geotechnical asset management to document.

6.3 Long-Term Concerns

The panels concerns relating to long-term performance of UDOT’s MSE
inventory centralized on the effects of corrosion of the retaining wall systems. Metallic
reinforced MSE wall systems face unique challenges in their long-term durability in the State of Utah. The majority of precipitation for the state falls during the winter months in the form of snow. This precipitation coupled with cold temperature creates challenges for maintenance crews working to protect the roads from snow and ice. The state of Utah has a Dry Road policy, in which road maintenance uses salt in whatever quantity necessary to maintain the state’s roads safety. The particular challenge the state faces is the corrosive conditions that are formed by using salt in large quantities. This issue is further compounded by the greater part of the state’s precipitation falls during times when the salt concentrations are the highest. Generally the application of salt has not been a significant contributor throughout the country as it is diluted and washed out of the wall by additional precipitation throughout the year. However, the precipitation patterns for the state of Utah introduce the high concentration of salt into the wall, but do not remove it as well as in other parts of the country that get more precipitation. The fact that this salt is moving through the walls was established during the inspection process, by visual confirmation of salt collecting along joints. This can be observed by Figs. 6.12 and 6.13. Fig. 6.12 shows salt, observed by a white crystallized stain collected along a vertical joint in wall panels, whereas Fig. 6.13 shows salt collected along a horizontal joint.
As part of a site visit by the panel members, it was observed that the clearing of the roadway of snow concentrates salt and water along the roadway shoulder. This is seen in Fig. 6.14. This water is highly concentrated in salt and then ponds on the roadway surface increasing the opportunity for seepage into the backfill.
The effect that the heavy salting is having on the corrosion rates for the metallic reinforcement remains to be seen and warrants additional investigation. The reconstruction of the I-15 corridor through Salt Lake required the placement of test wires or coupons to monitor the effects of corrosion. However, initial or baseline measurements were not taken, or were final placement of the test wires recorded. Through the inspection of these walls the majority of these test wires were located. The panel concluded that it is a high priority item to extract the wires and assess their status. Each test wire panel contains room for six test wires and by pulling and documenting current status it would help create a baseline for future extractions.

After review of the available information by panel members, it was concluded that corrosion will be a significant consideration for the long term health of the MSE wall systems in the state. A recommendation was made for the extraction of test wires and based on the degree of corrosion observed; an alternative to protect the wall systems by placing an impermeableGeomembrane over the retaining wall and beneath roadway
surface was suggested. This alternative may not be appropriate as a standard for the entire
state, but for areas that see a significant amount of salting, such as canyons or popular
destinations for winter recreation, the membrane would add a degree of reliability for
long term performance.

Consequently, a well constructed and compacted wall will decrease the incident
of corrosion within the soil mass. The previously mentioned suggestion of required
compaction near the face of the wall is important for stability, but also plays a significant
role in corrosion protection. Backfill significantly compacted will decrease the amount of
water that can enter the fill and will be forced to find its way around the compacted fill
and buried reinforcement.

6.4 OTHER CONCERNS

The panels concerns relating to long term performance of UDOT MSE walls can
be grouped into two categories: 1) Improved training for state inspectors and contractors
and 2) Partnerships with other department of transportation entities.

6.4.1 Improved Training for State Inspectors
and Contractors

A significant number of MSE walls were constructed during the I-15
reconstruction period. A general trend was observed throughout the inspection of the
retaining walls, being that chronologically the appearance and overall health of the MSE
walls has improved with time. After discussion it was determined that many of the
problems that existed were due to a lack of experience in constructing MSE walls. As
contractors, engineers, and state inspectors partnered on series of walls, their expertise
was augmented and the wall construction improved. The experience gained during the I-
15 construction has served as a valuable resource for the reliability of MSE walls in the state over time. This observation suggests that through better informing, training, and recording of lessons learned, data will prove valuable for future walls constructed in the state. The most efficient method to improve the reliability of UDOT’s MSE walls is to construct them well initially, reducing risks in the future. The proper design and construction will minimize the potential losses/costs in maintenance, service-use losses, service life, and reconstruction. The panel concluded that the state could largely benefit from additional training and certification for contractors, inspectors, and maintenance employees who work on MSE walls.

6.4.2 Partnerships with other Department of Transportation Entities

Many of the suggestions on mitigating observed issues came directly from specifications used in other Department of Transportation entities shared during the conference. The sharing of these specifications could prove mutually beneficial in improving the current and future status of MSE walls. The dissemination of this information could be facilitated through partnerships with other Department of Transportation entities. This partnership would facilitate improvement in specifications, design and construction, and reducing costs associated with wall loss and maintenance.

6.5 Non-Panel Conclusions

MSE walls remain a spatially and fiscally efficient retaining system and satisfy their applications in the State of Utah. The inspection of these walls produced a few immediate issues that have been advised and recommended for mitigation. However, the
relative youth of MSE walls in their design life and the fact that many of the failure mechanisms are difficult to observe as part of a buried structure is not conducive to advanced warnings of failure. This is particularly true for corrosion, where it is strongly recommended that test wire extractions be performed. Additionally, as MSE walls continue to age, the benefits of periodic inspection and documentation of MSE wall construction and issues increase and offset losses in time, serviceability, cost, and potentially lives.

Similarly, the effects of drainage impact all aspects of the wall design and communication must exist between all different facets of roadway design with the designers of MSE wall systems. The particular challenges of settlement found in the state of Utah require specific consideration regarding roadway drainage and landscape irrigation in the design and construction of MSE structures.

Unfortunately, with the increased demand for the allocation of resources in the transportation sector, the challenges of creating means to properly assess, maintain, and improve MSE walls is limited. This creates a dire situation in which until a crisis occurs the priority of MSE inspection will not receive its due attention. State officials and departments must remain vigilant in their efforts to make the most of these limited resources to ensure the functionality and reliability of MSE walls. For these reasons currently, without an MSE wall inspection program, similar to that of bridges, the improvement of specifications, design, inspection, wall documentation, and construction remain the most fiscally responsible course to minimize potential losses in the future. However, as this ‘snapshot’ of the current status of MSE walls has revealed, potentially costly losses can be mitigated by inspection even within a periodic time table. UDOT has
made a significant contribution to the increased understanding and improvement of reliability in MSE walls as a Department of Transportation through its facilitation of this project. The products of the work performed and information gained have put UDOT at the forefront of research in managing MSE walls as geotechnical assets. The continued success of MSE walls and their primary position as efficient retaining wall systems is dependent on the partnership of the client, constructor, and designer. To the degree that this relationship is viewed as mutually beneficial will determine the continued success and popularity of MSE wall systems.
REFERENCES


Appendix A. MSE Wall Inspection Form
### STATE OF UTAH MSE WALL INSPECTION FORM

#### Instructions:
- Field data recorded by the MSE Wall Inspector and Wall Characteristics.
- Inspect the wall using the attached form. Questions that require a "Yes" answer should be documented by noting the nature of the problem in the rightmost column and photo-documenting. Photos document visual defects and should be submitted to the appropriate authority. Photos should be labeled with the inspector's name and date.
- Photos should be taken to document the wall in its current condition. Photos should be taken to document the presence of any defects. Photos should be taken to document the wall in its current condition.

#### Inspector Information

<table>
<thead>
<tr>
<th>Region</th>
<th>Names Of Inspectors</th>
<th>Identifying Road/Intersection</th>
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#### MSE WALL CHARACTERISTICS

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<th>Bridge Number (if applicable)</th>
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<td>Surrounding Features</td>
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<td>Metropolitan Region (PAR-5)</td>
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<td>Terminal &amp; Exit Features</td>
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<td></td>
<td>One Stage, Two Stage or Blind Wall</td>
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<td>Other Details (if applicable)</td>
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<td>Intersecting Mile Length (WMI)</td>
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<td>Preferable Soil Region</td>
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<td>Type, Size of Clearance</td>
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#### OTS Options

- WGS/84, NAD/83, or NAD/27
- Other (please specify)

#### Summary of Key Observations:

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### Specific Wall Characteristics: Drainage

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<th>Required Trait</th>
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<th>Measurement/Explanation (of defect)</th>
<th>Percentage of wall affected/Extent of Problem/Photo Number</th>
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<tr>
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<td>No</td>
<td>UNKN</td>
<td>A drain is present within one centimeter from the base of the wall or a vent of more than five centimeters (Percentage of wall affected)</td>
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<tr>
<td>Yes</td>
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<td>A drain is present within one centimeter from the base of the wall or a vent of more than five centimeters (Percentage of wall affected)</td>
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<tr>
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### MSE Wall Joints

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<td>UNKN</td>
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<td>UNKN</td>
<td>A joint is present within one centimeter from the base of the wall or a vent of more than five centimeters (Percentage of wall affected)</td>
<td>0%</td>
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### WALL FACINGS

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<th>Facade Code</th>
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<th>Percentage of wall affected</th>
<th>Result of Failure</th>
<th>Notes</th>
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### MORTAR OF WALL

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### FOUNDATION CONDITIONS AND EXTERNAL STABILITY

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<tr>
<td>Year</td>
<td>Region</td>
<td>Occupation</td>
<td>Percentage of Full-Time</td>
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RETAIL AND COLD STORAGE

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MERCHANDISE

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Appendix B. MSE Database & Software
(Attached to back cover in pocket)