State of Practice for Specifying and Repairing Mechanically Stabilized Earth Walls

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16. Abstract

Mechanically Stabilized Earth (MSE) walls are among the most widely used retaining wall systems in Wisconsin's highway network and across the United States; valued for cost-effectiveness, rapid construction, and ability to accommodate settlement and seismic loading. Despite a 75 or 100-year design service life, premature deterioration has been observed nationally and within Wisconsin, with some failures, defined as a total loss of service, occurring in as little as 30 years. These failures are often linked to drainage deficiencies, reinforcement corrosion, construction quality issues, and inadequate inspection or maintenance. Given the scale of WisDOT MSE wall inventory, even isolated or limited loss of service failures can result in significant safety risks, costly repairs, and major disruptions. This study reviewed national and international practices, surveyed 16 state DOTs, evaluated WisDOT manuals and specifications, and developed a vulnerability and risk-based framework for inspection and repair. The survey revealed that while most DOTs have design guidance, few have formal inspection or asset management programs specific to MSE walls. Common issues included backfill loss, panel cracking, drainage failures, and occasional reinforcement corrosion. Repair strategies to address the commonly found issues varied widely and were often reactive rather than standardized. The evaluation of WisDOT practices found good alignment with FHWA and AASHTO standards but identified gaps in geotechnical exploration, corrosion and drainage provisions, and inspection protocols. To address these, the report recommends targeted manual revisions, expanded inspection procedures, standardized repair guidance, and integration of vulnerability and risk scoring into Highway Structures Information System (HSI). By adopting these measures, the service life of the WisDOT MSE wall inventory can be extended, lifecycle costs reduced, and safety improved. The developed framework provides a basis for proactive, risk-based decision-making aligned with broader infrastructure management trends.

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EXECUTIVE SUMMARY

MSE walls are widely used across the Wisconsin Department of Transportation's (WisDOT) transportation network due to their cost-effectiveness, adaptability to poor subsurface conditions, and ability to accommodate differential settlement. Despite their advantages, MSE walls are subject to deterioration mechanisms that can compromise structural integrity and serviceability over time. These include corrosion of reinforcements, insufficient or loss of drainage, loss of backfill, panel displacement, and degradation due to other environmental exposure. While WisDOT currently designs MSE walls for a service life of 75 or 100 years, field experience and national studies show that partial and total loss of service failures can occur decades after installation, often due to factors not fully addressed in design protocols.

This report summarizes the findings for WHRP Project 0092-24-06 which include a comprehensive literature review, to evaluate the current state of practice for specifying, inspecting, and repairing MSE structures. The study identifies operational challenges, evaluates WisDOT's current documentation and inspection protocols, and proposes a risk-based framework to support long-term asset management and performance monitoring. Key results of this research project include:

Task 1: Literature Review
The literature review provides a foundational understanding of MSE wall systems, including:

- Selection criteria based on geology, topography, environmental aggressivity, seismic activity, and utility conflicts.
- Design parameters such as reinforcement length, embedment depth, and settlement tolerances.
- Component specifications for reinforced backfill, facing types (precast panels, modular blocks, welded wire mesh), and drainage systems.
- Construction sequencing and QA/QC practices.
- Common failure mechanisms and inspection strategies used by other DOTs.

These insights establish the technical basis for evaluating WisDOT's current practices and identifying opportunities for improvement.

Task 2: National Survey of DOT Practices
A survey of 16 state DOTs identified several shared attributes across state agencies:

- Most agencies have design guidance embedded in bridge, geotechnical, or construction manuals.
- Few have formal post-construction inspection protocols or maintenance procedures specific to MSE walls.
- Asset management programs for retaining walls are rare or in early development.
- Common operational issues include backfill loss, panel distress (e.g., displacement, cracking, bulging, spalling), insufficient or loss of drainage capacity, wall joint deterioration, and differential settlement. However, these issues generally occur infrequently and are addressed reactively.

The survey responses underscore the need for standardized inspection and repair protocols and highlight the opportunity for WisDOT to lead in developing a comprehensive MSE wall asset management strategy.

Task 3: Evaluation of WisDOT Manuals and Specifications
A detailed review of WisDOT's internal documentation, including the Bridge Manual (WBM), Facilities Development Manual (FDM), Construction and Materials Manual (CMM), Structure Inspection Manual (SIM), Wisconsin Bridge Manual Standard Drawings. referred to herein as Standard Plan Sheets (SPS), and Special Provisions, identified many strengths:

- Clear delineation of design responsibilities.
- Alignment with FHWA guidance and AASHTO requirements.
- Use of structure survey reports (SSR) and site investigation reports (SIR).
- Explicit requirements for temporary wall design and safety.

However, several gaps were noted:

- Inconsistent terminology and document cross-referencing.
- Limited guidance on corrosion protection, drainage design, and temporary wall inspection.
- Missing inspection criteria for ageing or overextended temporary walls.
- Lack of flowcharts and checklists to support new practitioners and field inspectors.

Recommendations include clarifying document precedence, strengthening geotechnical, repair, and corrosion guidance, and improving inspection protocols and training materials.

Task 4: Vulnerability and Risk Scoring Framework
To support proactive asset management, the report introduces a vulnerability and risk scoring framework that integrates existing WisDOT inspection data with supplemental vulnerability and risk factors which include:

Vulnerability Factors

- Construction Quality State (CQS)
- Structure Age (SA)
- Winter Highway Classification (WHC)
- Pavement Condition Index (PCI)

Risk Factors

- Functional Classification
- Supported Structures
- Wall Height
- Wall Length
- Utility Prevalence and Criticality

These factors are combined into a composite vulnerability score which is applied to element-level and structure-level condition states recorded in the Highway Structures Information System (HSI). The resulting scores enable:

- Prioritization of inspections and repairs based on both observed condition and underlying risk.
- Identification of structures with elevated vulnerability due to poor documentation, environmental exposure, or aging.
- Integration of risk ratings into WisDOT's asset management workflows.

The framework is designed to be scalable, adaptable to evolving standards, and compatible with existing WisDOT systems. It encourages digitization of construction records, supports predictive modeling, and aligns with national trends in geotechnical asset management.

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1 INTRODUCTION

Mechanically Stabilized Earth (MSE) structures, alternatively referred to as MSE walls, are a critical component of Wisconsin's transportation infrastructure. The widespread use of MSE structures is driven by favorable cost, constructability, and performance characteristics, particularly in fill applications and areas with challenging subsurface conditions. Despite their advantages, MSE walls are subject to deterioration mechanisms that can compromise structural integrity and serviceability over time, with both structural and serviceability failures observed only decades after installation; well before the end of a typical 75-year design life. These failures may result in costly repairs, safety hazards, and disruptions to the transportation network. This report consolidates findings from four key sources to evaluate the current state of practice for specifying, inspecting, and repairing MSE structures with key sources including:

- A comprehensive literature review of MSE wall design, construction, deterioration, and repair practices.
- A national survey of 16 state DOTs regarding their MSE wall guidance, inspection, and asset management protocols.
- A detailed evaluation of WisDOT manuals, specifications, and other supporting documents related to MSE walls.
- A proposed vulnerability and risk scoring framework to support future asset management and prioritization.

These sources provide a comprehensive assessment of WisDOT's current practices and identify opportunities for improvement. The report is intended to support WisDOT's efforts to improve its MSE wall management strategies, align with national best practices, and enhance long-term performance through risk-informed decision-making.

1.1 Background

Mechanically Stabilized Earth (MSE) systems and structures have become a cornerstone of modern transportation infrastructure, particularly in highway and bridge construction since their introduction in the 1970s. Their use has expanded across the United States, including Wisconsin, where they serve critical functions in grade separations, bridge abutments, wing walls, and constrained right-of-way corridors. Unlike traditional gravity or cantilever retaining walls, MSE systems rely on the interaction between select backfill materials and tensile reinforcements, typically metallic or geosynthetic, to achieve stability. This composite behavior allows MSE walls to tolerate significant differential settlement and lateral deformation, making them particularly well-suited for poor subsurface conditions and seismic zones. Additionally, MSE walls offer aesthetic flexibility through customizable facing units and can be constructed rapidly with minimal specialized labor or equipment.

As a result of these and other benefits, WisDOT has gradually expanded its inventory of MSE walls to over 1,100 structures based on the Highway Structures Information System (HSI) inventory. These structures feature a range of uses, geometries, facing units, reinforcements, drainage configurations, and geomaterials that spread over decades of design and construction since the 1990s. While commonly designed for a nominal service life of 75 or 100 years, the achieved life of these structures is primarily governed by the durability of the reinforcing elements

followed by other components including drainage systems, facing units, and foundation materials. Field experience and several regional and national studies (e.g., Koerner and Koerner (2013, 2017, 2018), MEA (2020), and Scarborough (2005)) have shown that both MSE wall serviceability and structural failures can occur during construction, shortly after installation, or decades into service; failing to meet the original design intent and performance. These failures are frequently attributable in part to factors not fully addressed in existing design protocols, design implementation (e.g., post-construction materials testing), or inspection practices, including causes such as:

- Corrosion of metallic reinforcements due to environmental exposure during service life (e.g., aggressive soil or groundwater chemistry).
- Drainage system failures leading to water pressure buildup, backfill loss, and panel displacement.
- Inadequate embedment or reinforcement length resulting in global or local instability.
- Construction quality issues such as poor compaction near the wall face or missing filter fabrics.
- Environmental exposure, including freeze-thaw cycles and deicing salt infiltration.

Often, the deterioration pertaining to these factors may go undetected until significant distress occurs, leading to costly repairs, safety hazards, and service disruptions. Early detection of deterioration related to these factors is key to prevent significant loss which is compounded by the need to develop thorough, standardized inspection protocols, maintenance procedures, and asset management frameworks specific to MSE walls across the industry and locally at WisDOT. The increasing age and inventory of MSE walls across Wisconsin's highway system would benefit a shift from reactive maintenance to proactive, risk-informed asset management approach to MSE management. However, achieving these changes requires four items:

- A clear understanding of deterioration mechanisms and performance indicators;
- consistent inspection and documentation practices;
- integration of vulnerability and risk metrics into decision-making; and
- alignment with national best practices and FHWA guidance.

Recognizing these needs, the Wisconsin Highway Research Program (WHRP) initiated Project 0092-24-06 to evaluate WisDOT's current practices and develop actionable recommendations for improving the specification, inspection, and repair of MSE walls. This report presents the findings of this project, offering a comprehensive assessment of WisDOT's MSE wall program and a roadmap for future enhancements.

1.2 Project Context and Scope

The research project includes five specific objectives completed across several key processes to fulfill the project purpose:

Objectives

1. Summarize best practices for MSE wall usage and implementation.
2. Evaluate WisDOT's current design, construction, inspections, and repair practices, critically evaluate other DOTs specifying MSE retaining walls, and prepare recommendations to maximize their service life potential.
3. Summarize best practices to identify, evaluate, maintain, and repair distressed MSE walls.

4. Prepare recommendations for specific retrofit solutions.
5. Prepare recommendations for changes to WisDOT Manuals for selecting, using, inspecting, and repairing MSE walls.

Key Processes

- Comparative analysis of MSE wall inspection and maintenance practices across 16 state DOTs, with emphasis on guidance availability, inspection protocols, and asset management maturity.
- A detailed review of WisDOT's internal documentation—including the Wisconsin Bridge Manual, Facilities Development Manual, Construction and Materials Manual, Structure Inspection Manual, Standard Plan Sheets, and Special Provisions—to assess alignment with FHWA and AASHTO guidance and identify gaps.
- Identification of common deterioration mechanisms and operational issues affecting MSE wall performance, including corrosion, drainage failure, backfill loss, and panel displacement.
- Development of a vulnerability and risk scoring framework that integrates WisDOT's existing inspection data with supplemental factors such as construction quality, structure age, winter maintenance classification, and pavement condition.
- Strategic recommendations for WisDOT to enhance inspection consistency, improve documentation, and transition toward risk-informed asset management for MSE walls.

This report synthesizes the findings of these key processes in support of the five project objectives.

1.3 Organization of the Report

The report is structured across seven sections which include:

- Section 1, Introduction: This section presents an introduction, research project scope, and supporting key processes performed in support of objective completion.
- Section 2, MSE Systems: This section presents an overview of MSE systems, their design and construction principles, deterioration mechanisms, and inspection practices. It includes information from national literature, DOT survey responses, and WisDOT documentation to as baseline for evaluating current practices and guiding future improvements.
- Section 3, National Practice Survey: This section summarizes national practices for the design, inspection, and maintenance of Mechanically Stabilized Earth (MSE) walls based on a survey of 16 state Departments of Transportation (DOTs). It identifies common operational issues, repair strategies, and prioritization approaches used across agencies, providing context for WisDOT's current practices and future enhancements.
- Section 4, WisDOT Practices: This section presents a comprehensive evaluation of WisDOT's current practices for specifying, designing, inspecting, and repairing Mechanically Stabilized Earth (MSE) walls based on referenced documents. Section content includes reviews of WisDOT's internal manuals, specifications, and standard provisions to identify strengths, gaps, and opportunities for improvement.
- Section 5, Vulnerability and Risk Framework: This section introduces a structured methodology for evaluating the vulnerability and risk of MSE walls using data available within WisDOT's HSI. The presented framework integrates observed condition states with supplemental exposure and reliability factors to produce scalable scores that support inspection prioritization, repair scheduling, and long-term asset management.

- Section 6, Repair Strategies: This section expands potential repair strategies for different defects and probable causes and outlines the difference between root causes and contributing factors for MSE structure defects, outlines the process for performing a Root Cause Analyses (RCA), and provides several repair and rehabilitation approaches for different root causes.
- Section 7, Summary of Recommendations: This section provides guidance for integrating the vulnerability and risk framework into WisDOT's existing inspection, data management, and asset planning systems. It outlines practical steps for operationalizing the scoring methodology, aligning it with current workflows, and leveraging it to support risk-informed decision-making across the MSE wall lifecycle

2 MSE SYSTEMS

2.1 Mechanically Stabilized Earth (MSE) Systems

MSE walls are composite earth retention systems that stabilize soil masses using tensile reinforcements embedded in engineered backfill. A typical MSE system consists of:

- A reinforced soil zone (backfill) constructed from select granular backfill.
- Tensile reinforcements (metallic or geosynthetic) that resist lateral earth pressures.
- Facing units (precast panels, modular blocks, or wire mesh) that retain the backfill and transfer loads.
- Drainage systems that manage water infiltration and prevent hydrostatic pressure buildup.

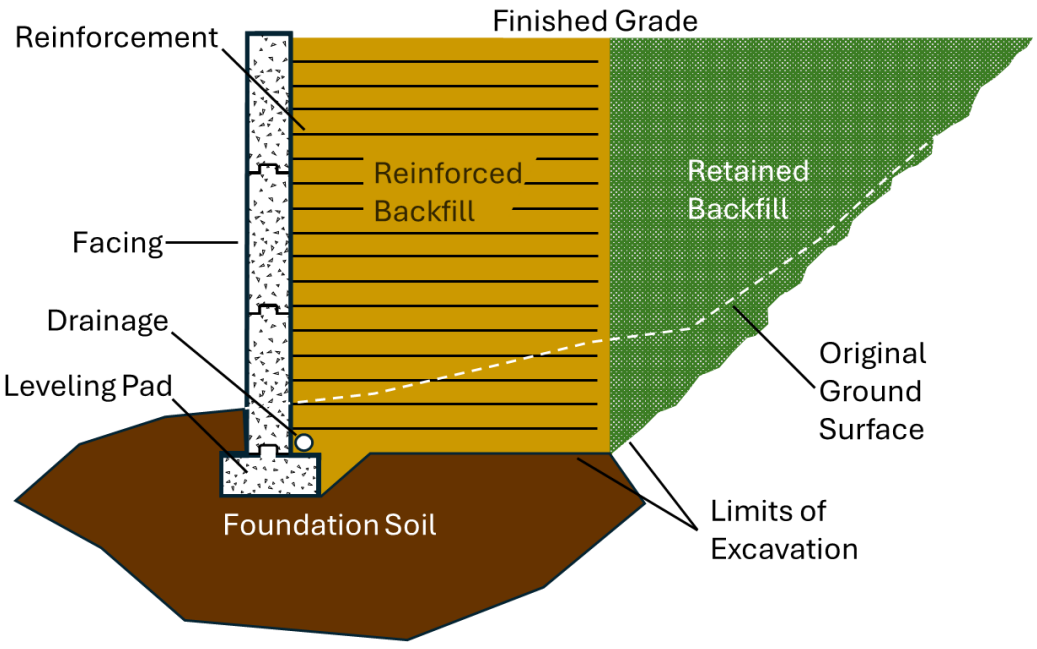

Figure 1: Components of a typical MSE wall.

The interaction between these components creates a flexible, internally stabilized mass capable of supporting significant loads and tolerating movement.

2.2 Design Life and Components

MSE walls are typically designed for a service life of 75 or 100 years. This design life is primarily governed by the durability of the reinforcement elements, especially metallic components subject to corrosion. However, other components (e.g., drainage systems, facing units, and foundation materials) may also significantly influence long-term performance and must be considered in both design and inspection. Key components shared across the majority of MSE systems include:

- Reinforced Backfill: Generally required to be free-draining, low-plasticity granular material with a minimum internal friction angle of 30° when testing data are unavailable and a nominal friction angle of 30 to 34° depending on whether grading requirements are met. Electrochemical properties (e.g., resistivity, pH, chloride/sulfate content) are critical when metallic reinforcements are used. Gradation requirements and electrochemical properties tend to be relatively uniform across governmental agencies although limitation variation may be observed in permissible gradations and electrochemical requirements as depicted in

- Table **1** through Table 3.
- Reinforcement Elements:
    - Inextensible (Metallic): Galvanized steel strips or grids, designed per AASHTO MSE specifications.
    - Extensible (Geosynthetic): Geogrids or geotextiles, selected based on tensile strength, creep resistance, and durability.
- Facing Units:
    - Cast in Place Concrete Facing: Provides a highly durable, facings with resilience comparable to that of traditional concrete retaining structures, offering resistance to vehicle impact and an aesthetic appearance similar to that of non-MSE walls.
    - Precast Concrete Panels: Offer high strength and aesthetic flexibility; and tolerate moderate differential settlement.
    - Modular Blocks: Dry-stacked units with good drainage; more sensitive to settlement.
    - Welded Wire Mesh: Lightweight and flexible; suitable for temporary or low-height applications.
- Drainage Systems: Include collector pipes, weep holes, drainage blankets, and filter fabrics. Proper drainage is essential to prevent water pressure buildup and corrosion.

Table 1: Gradation requirement of select reinforced backfill material for MSE walls.

US Sieve Size	% Passing						
	WisDOT (2025)	TxDOT (2014)	NJTA	GDOT (2023)	SCDOT (2024)	KYDOT (2019)	FHWA
4 in (100 mm)	-	-	100	100	-	100	100
3 in (75 mm)	-	100	-	-	-	-	-
2 in (50 mm)	-	-	-	80-100	-	40-90	-
1½ in (37.5 mm)	-	-	-	-	100	-	-
1 in (25.4 mm)	100	-	-	-	-	-	-
¾ in (19 mm)	-	-	30-100	-	-	-	-
No 4 (4.75 mm)	-	-	5-85	-	-	0-10	-
No 10 (2 mm)	-	-	-	20-90	-	-	-
No 40 (0.425 mm)	0-60	0-60	0-60	-	0-60	-	0-60
No 200 (0.075 mm)	0-15	0-15	0-10	0-12	0-15	0-5	0-15

Table 2: Electrochemical properties of reinforced backfill for metallic reinforcements.

Property	WisDOT (2023)	TxDOT (2014)	NJTA	VDOT (2017)	GDOT (2023)	FHWA
Resistivity	> 3000 ohm-cm	> 3000 ohm-cm	> 3000 ohm-cm	> 3000 ohm-cm	> 3000 ohm-cm	> 3000 ohm-cm
pH	5 < pH < 10	5.5 < pH < 10	5 < pH < 10	5 < pH < 10	6 < pH < 9.5	5 < pH < 10
Chlorides	< 100 ppm	< 100 ppm	< 100 ppm	< 100 ppm	< 100 ppm	< 100 ppm
Sulfates	< 200 ppm	< 200 ppm	< 200 ppm	< 200 ppm	< 200 ppm	< 200 ppm
Organic Content	< 1%	-	1% max	< 1%	-	1% max

Table 3: Electrochemical properties of reinforced backfill for geosynthetic reinforcements.

Base Polymer	Criteria		
	WisDOT (2023)	VDOT (2017)	FHWA
Polyester (PET)	4.5< pH < 9	3 < pH < 9	3 < pH < 9
Polyolefin (PP & HDPE)		3 < pH < 11	pH > 3

2.3 Selection Criteria

Selection of an appropriate MSE wall system and design components requires consideration of site-specific conditions, structural requirements, and long-term durability. Key criteria include:

- Geotechnical Conditions: MSE walls are ideal for fill applications. Cut conditions may require alternative systems due to excavation support and disposal constraints. Subsurface shear strength should exceed 2 to 2.5 times the pressure generated by the MSE volume.
- Environmental Exposure: Aggressive environments (e.g., low pH, high chloride/sulfate concentrations) accelerate corrosion. FHWA discourages metallic reinforcements in such conditions unless protective measures are implemented.
- Wall Height and Geometry: MSE walls can be designed to exceed 100 ft in height, surpassing those economically feasible by more conventional concrete and cantilever type retaining structures.
- Reinforcement Length and Embedment Depth: Reinforcement length typically ranges from 0.7H to 1.1H (where H refers to MSE wall height) depending on loading conditions (e.g., static, sloped backfill, seismic). Both embedment depth and reinforcement length are governed by local stability to limit excessive deformations. FHWA recommends minimum embedment based on slope geometry, frost depth, and scour potential.
- Utility Conflicts: Utilities within the reinforced zone complicate maintenance and may require cutting reinforcements during repair, compromising wall integrity. AASHTO discourages MSE wall use in such scenarios.
- Seismic and Settlement Tolerance: MSE walls perform well under seismic loading due to their flexibility. Facing type influences allowable differential settlement (e.g., 1/100 for precast panels, 1/200 for modular blocks, 1/50 for wire mesh). Permissible tolerances may also be established for facing unit joints, alignment, and plumbness as displayed in Table 4. Vendors and manufacturers may also provide design and system specific tolerances which are recommended for use by FHWA (FHWA-NHI-10-024).

Table 4: Precast concrete panel erection tolerances.

Criteria	**Tolerance**		
	WisDOT (2023)	**TxDOT (2014)**	**KYDOT (2019)**
Vertical and horizontal alignment along a 10-foot straightedge	≤ ¾ inch	≤ ¾ inch	≤ ¾ inch
Vertical tolerance (plumbness)	≤ ½ inch per 10 feet	≤ ½ inch per 10 feet	≤ ½ inch per 10 feet
Out of plane offset at joint	-	⅜ inch ≤ offset ≤ ¾ inch	≤ ⅜ inch
Joint gaps between panels	Within ¼ inch of design gap	-	Within ⅛ and ¼ inch of design gap

2.4 Design Parameters

Design of MSE walls must address internal, external, and global stability, as well as constructability and long-term maintenance. Key parameters, broadly generalized, include:

- **Reinforcement Length**:
    - Static loading: ≥0.7H; where H refers to MSE wall height

    - Sloped backfill: ≥0.8H
    - Seismic loading: 0.8H to 1.1H
- **Embedment Depth**:
    - Horizontal toe: H/20 to H/10
    - Sloped toe: H/10 to H/5
    - Minimum: Greater of calculated depth, frost depth, or scour depth
- **Differential Settlement Tolerance**:
    - Full height cast in place: 1/500
    - Precast panels: 1/100 (with ¾" joints)
    - Modular blocks: 1/200
    - Welded wire mesh (flexible face): 1/50
- **Drainage Design**:
    - Collector pipes ≥6" diameter
    - Drainage blankets composed of manufactured products or free-draining geomaterials and weep holes spaced per FHWA guidance
    - Filter fabric behind joints to prevent soil loss
- **Facing and Joint Design**:
    - Panel geometry and joint spacing must accommodate expected movements
    - Reactive aggregates must be avoided to prevent joint deterioration

Design must also consider corrosion protection (e.g., galvanization thickness, epoxy coatings), constructability (e.g., access, equipment), and compatibility with adjacent structures and utilities.

2.5 Construction Sequences and Quality Control

Construction of MSE walls follows a defined sequence to ensure structural integrity and performance. The general construction sequence is summarized below but may be impacted by site conditions and specific design considerations:

1. **Excavation and Foundation Preparation**: Removal of unsuitable materials and grading to design elevations.
2. **Installation of Drainage Features**: Placement of collector pipes, drainage blankets, and filter fabrics.
3. **Placement of Leveling Pad**: Typically unreinforced concrete or compacted granular material to support facing units.
4. **Facing Unit Installation**: Alignment and connection of panels or blocks, with attention to joint spacing and tolerances.
5. **Reinforcement Placement**: Installation of metallic or geosynthetic reinforcements at specified elevations and lengths.
6. **Backfill Placement and Compaction**: Use of select granular material, compacted in lifts. Lighter equipment and thinner lifts are required near the wall face.
7. **Coping and Barrier Installation**: Final structural and safety features, including guardrails and parapets.

Quality control is critical throughout construction. FHWA and state DOTs recommend inspection of reinforcement placement, backfill compaction, facing alignment, and drainage installation. QA/QC documentation should include redline drawings, material certifications, and compaction test results. Testing frequency varies considerably across state agencies with WisDOT's testing

frequency being relatively conservative for gradation testing and more liberal for electrochemical considerations as presented in Table 5.

Table 5: Testing frequencies for QC/QA for different state agencies.

Test	WisDOT (2023)	KYDOT (2019)	NEDOT (2021)	SCDOT (2024)	Reinforced Backfill with Local Material (Samtani & Nowatzki, 2021)
Gradation Test	Every 750 cubic yards of fill	Every 2000 cubic yards of fill	Determined by Engineer	Every 2000 cubic yards of fill (minimum 2 samples if backfill< 2000 cubic yards)	Every 500 cubic yards of fill
Proctor test	Every 2250 cubic yards of fill	-	-	-	One per material or source change
% Shale (at engineer's discretion)	-	Every 2000 cubic yards of fill	-	-	-
pH	-	-	-	Every 2000 cubic yards of fill (minimum 2 samples if backfill< 2000 cubic yards)	Every 1000 cubic yards of fill
Resistivity	-	-	-	Once every 15000 cubic yards of backfill (minimum 2 samples if backfill < 15000 cubic yards)	
Organic Content	-	-	-		
Internal friction angle	-	-	-		-

2.6 Failure Mechanisms and Inspections

MSE walls are subject to a range of deterioration mechanisms that can compromise performance:

- **Reinforcement Corrosion**: Accelerated by poor drainage, aggressive soils, environmental exposure, or inadequate galvanization which can lead to a loss of tensile capacity and potential structural failure.
- **Drainage Failure**: Clogged or missing components, poor grading, or infiltration causing hydrostatic pressure buildup, backfill loss, and panel displacement.
- **Backfill Loss**: Often due to missing filter fabric or joint separation resulting in voids, settlement, and pavement distress.
- **Panel Displacement and Joint Deterioration**: Caused by poor compaction, freeze-thaw cycles, or reinforcement movement which can lead to misalignment, cracking, and water ingress.
- **Foundation Instability**: Inadequate embedment or weak soils resulting in global instability and differential settlement.

Across the U.S., numerous MSE walls have failed due to the above-mentioned issues. However, the number of published case history reports that document or discuss the failure of the

MSE walls in detail are limited with causes of failure generally broadly attributed to one of the above deterioration mechanisms. Despite this, a number of authors (e.g., Athanasopoulos-Zekkos, et al., 2020, Vytiniotis et al., 2020) have worked to identify probable causes of distress and failures as displayed in Table 6. A more extensive summary of defects and probable causes is provided Appendix B: Supplemental Tables.

Table 6: MSE wall failure types and probable causes in different locations around U.S. (Athanasopoulos-Zekkos, et al., 2020).

Location	Defect (Distress)	Probable Causes
Soda Springs, ID	Popping out of six pre-cast panel	Corrosion in the reinforcement in the lower part of the wall
		Use of chemically aggressive slag as backfill
Rockville, MD	Leaning and bulging of the wall face	Improper installation of the geogrid
	12 to18 inch movement at top of the wall	Inadequate internal drainage
		Inadequate compaction of the reinforced backfill, forensic investigation revealed 81% of γ_{max}
Clearfield, UT	Vertical separation of the wall panel	Not constructing 4′ wide bench as per AASHTO specification
	Outward rotation of the top MSE Wall panels	Insufficient compaction
	Spalling of wall panel corners	Erosion of backfill material from runoff through pavement cracks
	Development of voids beneath sidewalk and pavement	
	Slope movement in the order of 1.5′	
Salt Lake City, UT	Lateral movement of MSE wall panels	Internal settlement of the backfill near wall face
		Insufficient compaction
Orem, UT	Large voids behind the back of the wall	Poor drainage and subsequent erosion
	Exposure of reinforcement	Settlement behind wall panel
Northeastern Tennessee	Movement and deformations in spread footings	Inadequate reinforcement
Southwestern Virginia	Cracking in the ground behind a parallel to the wall	Inadequate drainage
		Insufficient compaction of soil
		Use of clayey soil as backfill in the reinforced zone

Inspection practices vary across agencies to target the distresses types considered most relevant to state and local inspectors and engineers. Most inspection practices rely on visual observations during bridge evaluations or in response to observed distress. As a result, the interval of MSE inspections occasionally reflects the inspection interval established by the National bridge Inspection Standards (NBIS) for bridges but is more commonly less frequent than that for bridges. With increased inspection frequency (decreased intervals) followed only when defects are

observed or as part of regular scheduled detailed inspections. Interval recommendations for several agencies are displayed in Table 8.

NDT while less frequent, may also be used to provide useful observations of MSE wall deterioration both at the surface and within the MSE structure; areas typically inaccessible or minimally accessible as part of a visual inspection. However, NDT methods may not be consistently reliable across MSE systems and structures due to the wide range of MSE systems, variable site conditions, and applicability of individual NDT methods to potential deterioration mechanisms (i.e., selection of NDT methods, may reasonably rely on a pre-existing conception of the underlying deterioration mechanism). Further, few agencies maintain standardized inspection protocols or defect codes specific to MSE walls that could support the development of standard inspection procedures. A range of example NDT methods used in MSE inspection is summarized in Table 7.

Table 7: NDT for MSE wall monitoring (Momani, 2019).

Equipment	Application
3D robotic laser scanners	Monitor wall movement
Crack Meter	Relative movement between the precast panels
Ground Penetrating Radar (GPR)	To locate broken reinforcements, air voids or water pockets
Infrared Camera	Use thermal variation to capture gaps between concrete panel and backfill
Resistivity Imaging	Investigate ground water table and perched water zone

2.7 Performance Modeling

Due to the difficulty in identifying MSE structure deterioration in advance of visual signs, significant efforts have been made to develop reasonable and reliable performance modeling methodologies. Alternatively called distress modeling or condition modeling, these tools are intended to use a MSE structure's historical condition and performance to forecast future condition and performance. However, the development and availability of reliable models for MSE elements and full structures remain limited, restricting their practical application. For the purposes of this section, 'condition' refers to the current physical state of an element or structure, while performance refers to the service level it delivers.

It is understood that deterioration of asset condition can be continuous, with progressive failure representing a manifestation of a gradual decaying process (e.g., the corrosion of metallic reinforcements over several years). Such processes can be modeled using continuous deterioration models similar to the sketch shown in Figure 2 (left) or discrete models as shown in Figure 2 (right).

Continuous deterioration models can be derived by fitting various regression models to empirical data, like that data in the HSI and reflect the natural-gradual decline in asset condition over time. These models can also be developed by analyzing the time-dependent behavior of the asset and its components using analytical models. All continuous models can be used to represent a deterministic process or a stochastic process with uncertainties as demonstrated in Figure 2 with the change in condition from time τ_0 to τ projected as moving from s_i to some condition (s) ranging

from s_9 to s_{10}. However, the interpretation and inference of continuous models as probabilistic models can be more challenging compared to discrete deterioration models.

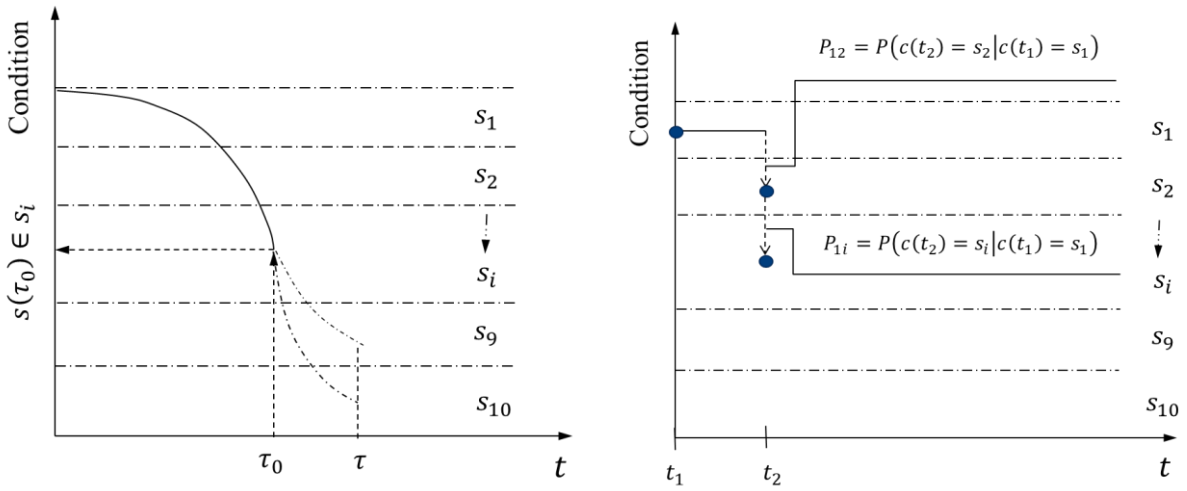

Figure 2. Schematics representing continuous deterioration in element condition state (s; y-axis) over time (τ; x-axis) (left) and a discrete representation of change in the element condition state (s; y-axis) state over time (t; x-axis) (right).

As developed, the condition states currently practiced by WisDOT follow a discrete scale with finite condition states (Figure 2, left) representing each time an asset is inspected as an individual and continuous state of being. Such a condition scale is best modelled using discrete probabilistic models. These models include the Markov Chain models and Survival models (Weibull analysis). Like condition deterioration models, the performance deterioration models can be continuous or discrete and are expected to depend on the condition deterioration models with a time lag. Given the limited historical records available for many MSE walls across the country, specific to WisDOT, and the diversity of MSE design development of these models remain challenging. As a result, many models proposed for MSE use are developed based on distress progression of other civil structures (e.g., bridges, sound walls) or from laboratory of controlled field conditions.

The research team reviewed existing literature on performance modeling of several MSE components including metallic and nonmetallic reinforcements, facing units, and other permanent components for common defects. This review found limited viable models for most MSE components and defects with metallic reinforcements having the most significant development and attention.

2.7.1 Metallic Reinforcement

The primary mechanism that induces reinforcement deterioration in inextensible reinforced MSE wall is corrosion. The design life of metallic reinforcement is determined based on the reduction in nominal cross-sectional area due to corrosion to the metallic reinforcement. Corrosion of buried metallic reinforcement is a complex mechanism and is governed by several factors, including: (1) soil moisture content; (2) soil resistivity; (3) pH value; (4) chlorides and sulfates contents; (5) presence of anaerobic bacteria; (6) soil temperature; and (7) soil aeration. Depending on the soil type and the environmental conditions the influence of these factors on corrosion rate may vary

significantly. As a result, despite significant efforts in the past, modelling corrosion rate has remained to be a challenge due to the uncertain and variable nature of the associated factors (Morsy and Ebo 2025).

The first most comprehensive corrosion model for buried metallic reinforcement was developed by Romanoff (1957). This model was generated from 47 years of data collected by U.S. National Bureau of Standards (NBS). Romanoff observed a relatively high corrosion rate in the buried steel during the early years of burial. The rate of corrosion subsequently decayed to a steady and lower rate with time. Although, the NBS model was generated for wide range of soil, it may not necessarily be applicable for the selected granular fill used as backfill of the MSE wall. Several predictive models have been developed in more recent studies to estimate the corrosion of metallic reinforcement buried in retaining wall backfill. These models were developed based on the foundation laid by Romanoff but tailored for better prediction of corrosion of metallic reinforcement buried under granular fill typically used as backfill in MSE wall. A summary of corrosion models for metallic reinforcement which may be suitable for WisDOT use is provided in Appendix B: Supplemental Tables, Table 16.

2.7.2 Nonmetallic Reinforcement

Nonmetallic polymeric reinforcements, such as geosynthetic materials, are susceptible to long-term degradation due to creep, physiochemical activities, and environmental aging. These materials may also experience damage during installation. All of these factors must be considered when designing polymeric reinforcement systems for MSE walls. To address these vulnerabilities, the ultimate tensile strength (T_{ult}) of polymeric reinforcements is reduced through the application of reduction factors. These factors account for:

- Initial construction damage;
- long-term creep and aging; and
- durability against chemical and physiochemical degradation.

This state-of-practice approach ensures that design calculations reflect the expected service conditions of the material. Geosynthetic reinforcements are particularly prone to long-term aging caused by physiochemical processes, thermal oxidation, and hydrolysis. Aging may be accelerated by extreme environmental conditions, such as wide: seasonal temperature fluctuations; consistently high temperatures, and frequent freeze–thaw cycles. These factors can significantly reduce the durability of geosynthetic reinforcement over time.

To track nonmetallic reinforcement conditions, periodic evaluation of the reinforcement is recommended. The AASHTO National Transportation Product Evaluation Program (NTPEP) suggests that certain products be tested annually, with a complete reevaluation of the reinforcement system every nine years. While the ASCE IDEA program recommends a full system reevaluation every five years. However, reinforcement testing often requires direct material exposure, which can be difficult to achieve during standard inspections.

2.7.3 Other Components

Other components and elements excluding reinforcements exhibit various types of distresses over the service life of the MSE wall. Some distresses are related to deficiencies in materials selected for use, while others are related to design deficiencies. Components may show multiple distress

types and causes of distress because of several underlying defects with other components and elements, causing a progressive decrease in overall structure condition. For example, facing unit cracking may be a function of multiple causes such as:

- Excess pore water pressure developing in the backfill due to drainage failure;
- increased lateral earth pressure due to improper compaction of the backfill; and
- development of local voids in the backfill leading to increased lateral earth pressure.

To identify the exact cause of such distress type, comprehensive forensic studies may be required to identify a root cause which can be both time consuming and expensive. Unfortunately, there is limited data available to correlate many distress types with the significant factors causing them. As a result, there are no reliable models available for predicting future distress or distress progression.

The FHWA study conducted by Berg, Samtani and Christopher (2009) summarized the relevant distresses of different components of MSE wall and associated factors that could cause distresses based on past studies. In addition, Athanasopoulos-Zekkos, et al. (2020) summarized the investigation of causes of failure of different MSE wall components and Aubeny, et al. (2014) summarized the key results of the forensic reports that highlighted the probable causes of distresses of MSE wall components located in Texas. The results of these studies are summarized in Appendix B: Supplemental Tables, Table 15, and may be used to identify probable defect and distress causes by WisDOT personnel. This information may also be used as part of a comprehensive review of WisDOT documented element defects to identify uniform MSE elements or components which should be inspected as part of routine inspection (e.g., engineered fill soil moisture).

As these defects may develop due to multiple deficiencies across multiple elements which may originate from construction or due to changes in material and site conditions over time, there are limited number of quantitative models available for modeling defect progression. The most relevant quantitative model identified was developed by Momani (2019). Momani developed a multi-linear regression model to predict the wall movement as function of reinforcement type, pore pressure, reinforcement length, reinforcement breakage/slippage, panel compressive strength, and backfill soil cohesion. Although this model was developed based on responses from a numerical simulation of MSE wall, it can be used as a framework of developing quantitative models to predict various distresses. The developed model can be expressed in the following form:

Equation 1. Momani Linear Regression Wall Movement Model

$$\log(\hat{y}_i) = \beta_0 + \beta_1 X_{i1} + \beta_1 X_{i2} + \beta_1 X_{i3} + \beta_1 X_{i4} + \beta_1 X_{i5} + \log(\varepsilon_i)$$

Where, dependent variable y is the movement of the wall in inches, X_1, X_2, X_3, X_4, and X_5 represent reinforcement type, pore pressure, reinforcement length, reinforcement slippage/breakage, and backfill soil cohesion, respectively.

3 NATIONAL PRACTICE SURVEY

To better evaluate the current national standard of care for MSE walls in the transportation sector a National Practice Survey (NPS) was performed to summarize the range of practices used by

transportation agencies across the U.S. Potential agencies were selected with assistance of the WisDOT technical panel and consisted of 16 State Departments of Transportation (DOTs) including: Florida DOT (FDOT), Iowa DOT (IADOT), Illinois DOT (IDOT), Indiana DOT (InDOT), Kansas DOT (KDOT), Michigan DOT (MDOT), Minnesota DOT (MnDOT), Missouri DOT (MoDOT), North Dakota DOT (NDDOT), Nebraska DOT (NEDOT), New Jersey DOT (NJDOT), Ohio DOT (ODOT), Oregon DOT , Texas DOT (TxDOT), Virgina DOT (VDOT), and Wisconsin DOT (WisDOT).

Selected states had extensive MSE wall experience and were preidentified as having at least evaluation procedures, maintenance, or repair programs. Questionnaires were sent to each agency to collect information to document the challenges and best practices in designing, constructing, evaluating, and managing MSE walls. The policies, practices, standard specifications, and operational issues related to the design, construction, and performance of MSE walls of the surveyed agencies were also assembled and reviewed following their provision or reference each agency.

3.1 Questionnaire

The five questions sent to participating DOTs in the form of a questionary. Questions included:

- Q1: Does your agency have project level guidance on the selection, design, and construction/ inspection of MSE walls? Where is this guidance documented?
- Q2: Does your agency have written requirements and Construction and/or routine post construction inspection procedures for MSE walls? Where is this guidance documented?
- Q3: Does your agency have written maintenance procedures for MSE walls? Where is this guidance documented?
- Does your agency have a retaining wall asset management program? Where is this guidance documented?
- Q4: Has your agency experienced post construction performance issues for MSE walls related to joint spacing, corrosion, slope stability, vertical and lateral documents (displacements or movement?) or extreme event occurrences? How common these issues are on a scale of 1 to 5, with 1 being the least common and 5 being the most common. Please provide a brief explanation of the occurrence and how it was repaired. Do you have standard MSE wall repair guidance?
- Q5. Does your agency have written standard procedures or specifications for MSE walls?

These questions were requested to be responded to in a comprehensive manner with an additional request for supplemental materials, agency documents, and other supporting rational for MSE procedures, maintenance, and repair included in questionnaire dissemination.

3.2 Agency Responses

Of the solicited DOTs, 14 provided full responses, IADOT provided a partial response, and NEDOT did not respond. Results were reviewed to summarize DOT practices, MSE operational issues, and to evaluate variability of agency practices between individual agencies. Positive agency responses on the presence of guidance documents, routine inspection post construction, presence of an asset management program, observation of performance issues (i.e., defect or distress), and availability of documents for review varied from 20 to 90%. The highest positive response rates were for having experienced post-construction performance issues and the availability of a

Standard Operating Procedure (SOP) or specification; both at 90%. The lowest positive response rate was for the use or existence of a retaining wall asset management program at 20%. Responses are summarized in Figure 3.

For operational issues responses were more varied with reported operational issues including the loss of backfill, excessive settlement, seepage, panel issues, slope stability, corrosion, joint spacing, scour or erosion, extreme events, drainage, and vehicular impacts. The highest consensus of operational issues was for loss of backfill and panel issues at 40% and 35%, respectively. Remaining operational issue responses are summarized in Figure 4.

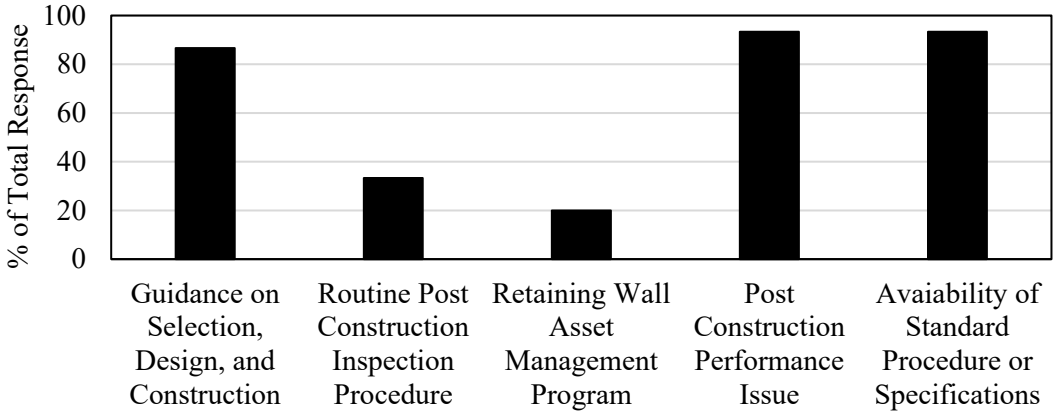

Figure 3: Summary of received positive responses from the NPS.

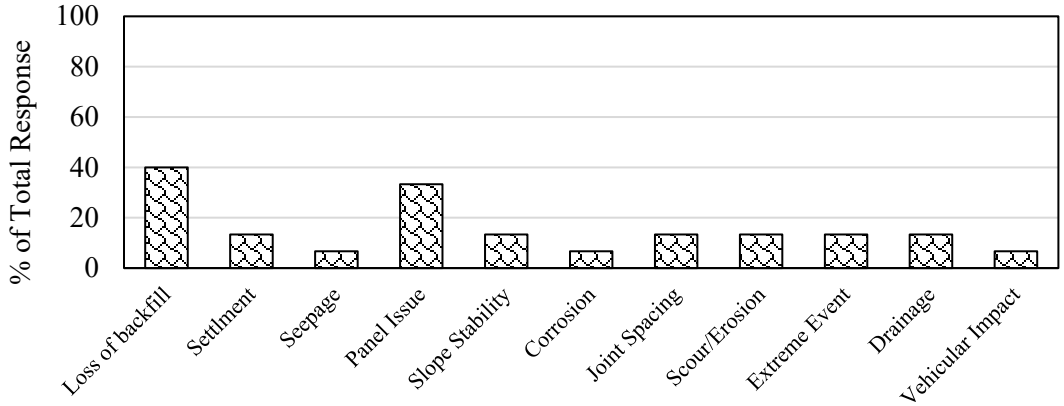

Figure 4: MSE operational issues reported the NPS.

The results of the NPS suggest that while design practices are well established, inspection and maintenance protocols remain inconsistent across agencies. It is worth noting that most DOTs embed MSE wall design guidance within bridge design manuals, geotechnical manuals, and construction specifications. With INDOT, FDOT, and MDOT supplementing these general documents with dedicated MSE-focused inspection manuals or checklists. Nearly all agencies rely on visual inspections during bridge evaluations or in response to observed distress events to trigger the inspection of MSE structures and only a few maintain formal post-construction inspection procedures specific to MSE walls. Additional insights into individual agency practices for MSE

structures are provided in the complete questionnaire responses provided in Appendix C: Survey Responses.

3.2.1 Comparison to Recent Reports

Based on survey results, the experience of respondents does not substantially vary when compared to the recent published studies and reports which evaluated common MSE operational issues/deteriorations. However, the NPS findings do not provide comprehensive insights into the potential root causes of reported operation issues. Nor does the NPS provide significant details on the frequency, consequences, or importance of individual operational issues. Recent work by Kulesza et. al. (2024), reinforces that for the same operational issue DOT-, industry-, and academic-personnel often attribute different levels of relative importance or impact to the same defect as shown in Figure **5**.

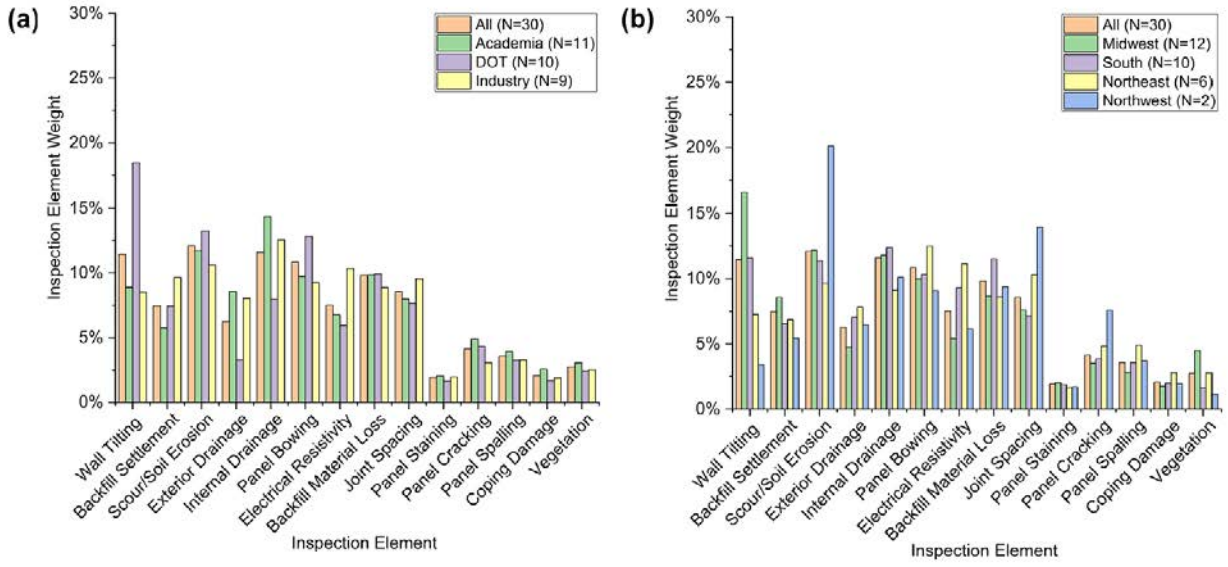

Figure 5: Element weight (relative importance) for various MSE defects by career (a) and by location (b) (Kulesza, 2024).

This variability may be attributable to a combination of factors including region, climate, asset management methods, and MSE system or repair practices in addition to personal experience and survey participant role (e.g., engineer, maintenance, owner). This demonstrates that the maintenance programs and inspection/ repair priorities can be significantly impacted by individual program developers and their professional experiences. The results from Kulesza et. al., also demonstrate that despite large individual variability in element weight, there remains prevailing industry trends. This suggests that when sufficiently reviewed by a range of professionals inspection, repair, and related vulnerability and risk rating processes are likely resilient if not optimal. More practically, this is reflected in the common recommendation to regularly review and revise agency practices, as done by this project.

3.3 Repair Strategies and Gaps

NPS responses demonstrate that repair practices across states vary widely. With the most substantial differences identified by the research team in management practices between agencies which have established standard repair processes and those which have not. This is largely attributed to repairs being addressed on a case-specific basis, with limited documentation or performance monitoring of the MSE structures before or after repairs. Long-term monitoring of repaired walls is also rare, limiting feedback into design and maintenance practices. However, both INDOT and FDOT have begun developing retrofit specifications and inspection handbooks to address these gaps and document agency asset performance standards. Common reported strategies to address operational issues across respondents include:

- Void Filling: Use of flowable fill or low-strength mortar to address backfill loss and settlement.
- Panel Replacement or Anchoring: Removal and replacement of damaged panels or anchoring displaced units in place.
- Joint Sealing: Application of sealants or installation of filter fabric to prevent soil loss and water ingress.
- Drainage Improvements: Pipe lining, polyurethane injection, or reconstruction of drainage features.
- Monitoring: Use of ground-penetrating radar (GPR) or visual surveys to assess movement and deterioration.

Additional repair strategies are outlined in Section 6, Repair Strategies.

3.4 Asset Management Systems and Repair Prioritization

A majority of respondents indicated that they do not currently have formal asset management programs or frameworks for MSE assets, with only INDOT having successfully implemented a retaining wall-specific asset management program. KDOT, NJDOT, Oregon DOT, and FDOT indicated either active efforts to develop either geotechnical asset management (GAM) programs, retaining wall asset management programs, or integration of retaining wall into their existing bridge management system. In the absence of an MSE or earth retaining system (ERS)-oriented AMS repair prioritization was driven by the severity of observed distress (e.g. settlement, displacement, corrosion), proximity to critical infrastructure (e.g., bridges, roadways), general safety risk and escalation potential, and funding and resource availability.

4 WISDOT PRACTICES

WisDOT's technical guidance for MSE walls is distributed across several core documents, including the Wisconsin Bridge Manual (WBM), Facilities Development Manual (FDM), Construction and Materials Manual (CMM), Structure Inspection Manual (SIM), WBM Standard Drawings; referred to herein as Standard Plan Sheets (SPS), and relevant Special Provisions. These documents collectively define design responsibilities, wall selection criteria, construction tolerances, and general inspection procedures.

This section presents a comprehensive evaluation of WisDOT's current practices for specifying, designing, inspecting, and repairing Mechanically Stabilized Earth (MSE) walls based on

referenced documents. Section content includes reviews of WisDOT's internal manuals, specifications, and standard provisions to identify strengths, gaps, and opportunities for improvement. Findings from document review are organized into three subsections: general commentary which addresses positive, neutral, and negative commentary of all listed documents, inspection practices which addresses the SIM and recommended revisions to WisDOT inspection processes.

4.1 Guidance Documents

The following WisDOT documents were reviewed for MSE wall-related content:

- WBM Chapter 14: Retaining Walls, including Sections 14.1–14.6, 14.12–14.16
- FDM Chapter 11, Section 55: Retaining Walls
- CMM Section 560: Earth Retaining Structures
- SIM Part 4, Chapter 4: Retaining Walls
- SPS Chapter 14: Retaining Walls
- Special Provisions SPV.0165.XX series for temporary and permanent MSE wall types
- Retaining Wall Systems – Prequalified List

Each document was evaluated for technical clarity, consistency with FHWA and AASHTO guidance, and alignment with best practices in design, construction, inspection, and maintenance. Results of this review are summarized below based on positive, neutral, and negative commentary with fully-detailed findings provided in Appendix E: Detailed Document Commentary.

4.1.1 Summary of Commentary

Positive

The current MSE wall practice demonstrates several strengths across design, documentation, and oversight. The WBM provides clear design intent and rationale, including practical examples that help reduce misapplication of standards. The use of Structure Survey Reports (SSR) and Site Investigation Reports (SIR) supports informed wall selection and layout decisions, while the Bureau of Structures (BOS) review of proprietary wall system designs adds a critical layer of quality assurance. Design responsibilities are clearly delineated between WisDOT and contractors, minimizing ambiguity and aligning with FHWA-recommended collaborative practices. Temporary walls are required to meet the same safety standards as permanent walls, and key design considerations (e.g., guardrail placement, utility coordination) are well addressed. The SIM establishes a consistent inspection interval and includes a detailed list of common MSE wall defects, while also encouraging the use of non-destructive technologies like LiDAR. In construction, the inclusion of BOS and the Structural Metals and Fabrication Quality Assurance Inspection Unit (SFU) prior to project start enhances quality control, and the CMM outlines a reasonable QA process. Additionally, WisDOT's requirement for preapproval of proprietary wall suppliers and the use of electronic submittals aligns with national best practices and supports efficient project delivery.

Neutral

WisDOT's MSE wall documentation and practices include several areas where clarification, refinement, or expansion would improve consistency and reduce ambiguity, though these do not currently pose direct risks to wall performance. Across multiple manuals, the use of permissive language such as "may" or "as appropriate" in geotechnical exploration and site characterization

introduces variability in interpretation. This can lead to inconsistent application of borings, laboratory testing, and corrosion assessments, particularly in complex or high-risk sites. Several design workflow steps outlined in the WBM are well structured but could benefit from additional guidance on environmental constraints, constructability, documentation, and iterative stability checks. Similarly, the FDM uses terminology like "barrier" that may be misinterpreted without clarification and lacks direction on how to proceed when right-of-way constraints prevent preferred wall types.

In the SIM, terminology such as "mechanically stabilized reinforced earth" and "geotechnical failure" are nonstandard or vague and would benefit from clearer definitions or examples. Inspection guidance could be strengthened by emphasizing visual indicators of drainage distress (e.g., effluent discoloration or upslope erosion) and by cautioning against uniform settlement impacts on adjacent structures. Design sections for various wall types (e.g., modular block, wire-faced, cast-in-place concrete) are generally comprehensive but omit important details such as setback tolerances, drainage layer specifications, and soil type limitations. The treatment of temporary walls is also inconsistent: corrosion and aesthetic requirements are unclear, and maintenance expectations for extended service life are not well defined.

Finally, while WisDOT's manuals reference external standards like AASHTO and FHWA, they do not consistently establish precedence or provide revision dates, which may lead to outdated or conflicting guidance. Enhancing cross-referencing, standardizing terminology, and expanding inspection and design protocols would improve clarity and alignment across WisDOT's MSE wall program.

Negative

MSE wall documentation and practices contain several critical gaps that warrant revision to reduce risk and improve long-term performance. As detailed in the Neutral Findings section, the use of permissive language such as may can result in inadequate subsurface data, especially in complex or high-risk locations. Temporary wall systems present a particular concern as designs supporting live traffic are not consistently reviewed by WisDOT. There are also no defined inspection criteria for temporary walls that remain in service beyond their intended duration. Without minimum safety standards or monitoring protocols, these structures may pose unrecognized risks.

Drainage and corrosion considerations are underdeveloped throughout the design documentation. Key sections omit guidance on soil corrosivity, drainage layer specifications, and freeze-thaw resilience, especially for wire-faced and cast-in-place concrete systems. Facing unit joint detailing, setback tolerances, and thermal expansion allowances are inconsistently addressed, increasing the likelihood of premature distress. Load assumptions for construction live loads and vehicle surcharge are outdated or insufficient. For example, the default 100 psf live load may not adequately reflect modern equipment weight, and the use of fixed surcharge values does not account for variable traffic conditions.

Construction documentation practices may also benefit from improvement. The CMM lacks explicit standards for redline documentation, including dates of changes and responsible parties. As-built records are not consistently required or standardized, limiting WisDOT's ability to assess construction quality and support future inspections. Reinforcement placement and compaction

verification are not uniformly documented, and settlement during construction is not clearly addressed; despite its potential to induce panel stress and long-term deformation.

Inspection protocols in the SIM are generally sound but do not include several recognized inspection topics which may improve MSE performance and longevity. As examples, the manual does not emphasize early indicators of distress, such as tension cracks, upslope erosion, or effluent staining. Additionally, the SIM lacks guidance on monitoring drainage effluent for discoloration or particulates, which could signal internal deterioration. Lastly, some use terms like "geotechnical failure" are vague and should be clarified with examples such as slope instability or erosion. Revision of the SIM to include these and similar items would further improve MSE inspection, repair, and reliability.

4.1.2 Recommended Revisions

For all reviewed documents it is recommended to better define references in terms of document numbers, titles, and revision dates to other WisDOT and external documents and standards (e.g., FHWA and AASHTO citations) where reasonable. This may be applied by having documents and inter-document references include at a minimum document identifiers and date of last revision to maintain consistent recommendations across the agency. This practice will aid in reducing the potential for accidental use of isolated, mismatched, or out-of-date recommendations and standards. Statements of document precedence considering WisDOT, AASHTO, FHWA, and other authoritative organizations for MSE design and construction should be addressed within WisDOT manuals to ensure current design standards are followed for all MSE projects. If no order of precedence has been determined or universal supremacy standards are not desirable by the agency, guidelines for when and how to adopt project-specific precedence clauses are recommended for inclusion into WisDOT documents.

To aid in design, construction, and inspection consider the use of MSE wall design checklists from FHWA such as those produced by Eastern Federal Lands or from well-developed state programs such as Indiana DOT (INDOT) if not already in use. A copy of the INDOT checklist has been provided in Appendix D: INDOT MSE Wall Design Review Checklist. Note that the checklist links are not intended to be functional in this example. Several additional inspection items are also recommended for inclusion into SIM to address gaps in current practice. Additional inspection items are detailed in Section 4.3.

4.2 Inspection Frequency

4.2.1 Summary of WisDOT Practice

Depending on the frequency and method of data collection, monitoring programs can be divided into two categories: (1) limited monitoring programs and (2) comprehensive monitoring programs. In limited monitoring programs, such as WisDOT's routine inspections, data is collected on a periodic basis. In comprehensive monitoring programs, data is collected continuously; a method more frequently used during construction or when a high-risk condition has been identified.

WisDOT's current routine inspection frequency (i.e., every six years) provides a suitable foundation for observing and tracking elements in good and fair condition as well as identifying defects. However, this interval may be insufficient for developing defect progression models or

regularly tracking defects. This frequency is also less than recommended by several other agencies (Table 8). It is recommended that the minimum inspection frequency employed by WisDOT be adjusted based on condition state, vulnerability, or risk. The use of condition state as a basis for inspection frequency is partially reflected in current WisDOT practice which allows inspectors to initiate damage-, interim-, or special-inspections. WisDOT also requires annual inspection for retaining walls in the severe condition state and recommends Regional Ancillary Inspection Program Managers evaluate inspection frequencies for structures in a poor condition state.

Table 8. Inspection interval recommended by various agencies (Gerber, 2012).

Authority	Inspection Interval
NBIS[1]	2 years
NYC	5 years for privately owned walls
Kansas	3 to 5 years
Oregon	5 years (good walls); more often (fair or poor walls)
California (1986-97)	5 to 10 years
PennDOT	5 years (routine)
	10 or 15 years (in-depth)
FHWA[2]	Max 10 years; more often if there are issues

[1] NBIS inspection interval is for bridge structures. This interval has been used as an inspection interval for MSE structures supporting bridges elements and auxiliary structures (e.g., wingwalls).
[2] Presented in the Retaining Wall Inventor and Condition Assessment Program (WIP); FHWA-CFL/TD-10-003 (2010).

4.2.2 Recommended Revisions

Inspection Frequency

The research team recommends that WisDOT establish a policy for performing additional targeted inspections of MSE walls during the following operations:

- Utility-related activities impacting MSE walls, including:
  - Installation
  - Repairs
  - Exposures (inspections)
- Pavement works, including:
  - Pavement system rehabilitation
  - Pavement system reconstruction
  - Sleeper slab removal

These operations provide a unique opportunity for inspectors to evaluate critical MSE elements, specifically reinforcements, drainage features, and fill geomaterials, that are typically unobservable or require significant investments in time, labor, equipment, and lane closures to inspect. Conducting inspections during these activities will:

(1) Support the early identification of defects before they appear in current HSI defect data;
(2) enable the development of defect progression models;

(3) facilitate the identification of potentially hazardous or undesirable materials and site conditions that should be considered in future projects; and
(4) reduce long-term repair costs by detecting defects early.

If WisDOT begins to incorporate these special inspections, development of SIM assessment guides for each element is recommended as presented in Section 4.3.2, Recommended Revisions.

Data Collection Methods
The type of data that must be collected to meaningfully model a defect can be obtained using several methods. While these methods typically include an aspect of visual observations like those performed as part of WisDOT routine, interim, and in-depth or special inspections, the collection of additional data using non-destructive testing (NDT) and partially destructive testing (PDT) may be required. This includes, where feasible, sampling and testing of reinforcement materials. Sampling and testing of these materials should be considered:
(1) Based on structure vulnerability and risk detailed later in this report;
(2) as part of special inspections initiated due to observed condition states; and
(3) on an as-needed basis due to other specific WisDOT concerns.

These options balance the difficulty in data collection with the need to monitor long-term durability.

A comprehensive guideline for data collection of different parameters is presented in FHWA-NHI-10-025, Design of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Volume II. Other studies including Momani (Momani 2019), Athanasopoulos-Zekkos (Athanasopoulos-Zekkos, et al. 2020), and Alhasan (Alhasan, et al. 2023) have summarized different NDT technologies that have been used to collect MSE wall data. The summary of these studies based on the observed defect is presented in Appendix B: Supplemental Tables, Table 15 for consideration by WisDOT during inspection planning.

4.3 Inspection Practices

4.3.1 Summary of WisDOT Practice

In addition to the SIM document, the research team provided a thorough review of overall WisDOT's inspection practices for MSE walls and discussed inspection processes with WisDOT personnel. Inspection practices are largely documented in the SIM with inspection results, schedules, and recommended actions managed through the Highway Structures Information System (HSI). Inspections are conducted at the element level for each structure, and the HSI also serves as a repository for historical data, including design plans, as-built records, and construction documentation for select MSE walls. The HSI supports WisDOT's MSE wall inspection program by facilitating both process management and providing easy digital access to inspection records and supporting materials. Inspections are carried out at three distinct levels of intensity:

- Routine: Regular visual inspections performed per established frequency guidelines.
- Damage or Interim: Unscheduled inspections performed due to a "significant event" such as a vehicular strike or the identification of a structural concern or significant defect as part of routine or in-depth inspections.

- In-Depth (SIM) or Special (HSI): Detailed inspections used to assess structural elements not readily observed during routine inspections and for which non-destructive evaluation equipment or other material tests may be performed which are outside of the routine inspection process.

WisDOT's approach aligns with best practices employed by other DOTs with well-developed Geotechnical Asset Management (GAM) programs. These include:

- Inspection of key MSE elements,
- Thorough documentation including detailed notes,
- Photographs of significant defects, and
- The use of standardized evaluation processes for structural components.

Inspections are based on a predefined list of assessments (components) applicable across various Earth Retaining System (ERS) types, along with ERS-specific defects (elements). Each assessment and defect includes a qualitative descriptor, and in some cases, quantitative descriptors are used to classify condition states. These descriptors are updated as needed to reflect the characteristics of different wall types. For example, facing unit standards vary between flexible and precast segmental MSE walls. Current assessments and MSE specific defects incorporated into the SIM and HSI include:

- Drainage Approach (9001) - Assessment
- Aesthetic Treatments (9010) - Assessment
- Utilities (9011) - Assessment
- Signs Other (9035) - Assessment
- Structure ID Plaque (9208) - Assessment
- Decorative Rail (9335) - Assessment
- Luminaire Bases (9336) - Assessment
- Protective Screening (9337) - Assessment
- Horizontal Copings (9338) - Assessment
- Features (Roadway/Sidewalk/Etc.) to Wall (9339) - Assessment
- Drainage System (9340) - Assessment
- Stairwell (9341) - Assessment
- MSE Wall (8603) - Element
    - Masonry or Panel Displacement (1640) - Defect
    - Scour (8000) - Defect
    - Wall Movement (8902) - Defect
    - Wall Deterioration (8903) - Defect

Each applicable assessment, element, and defect is scored using a consistent rating scale of good (1), fair (2), poor (3), and severe (4). This standardized rating system, supported by descriptive criteria, ensures consistency across inspectors and facilitates comparable condition evaluations across structures. At the conclusion of each inspection, inspectors use their findings to assign an overall wall condition rating and to document necessary maintenance and repair actions. A screenshot of a typical MSE evaluation form is shown in Figure 6.

WisDOT's overall inspection processes incorporate several major MSE wall components commonly used across state transportation agencies. Although the division of these components

varies by agency, they can be broadly categorized into structural, geotechnical, hydraulic, and other classifications, with commonly included components listed in Table 9. Additional subcomponents include: barriers, guardrails, and fences under safety features; roadway condition under pavements; and vegetation and riprap under erosion and erosion control.

Assessments

Chk	Element	Defect	Description	UOM	Total	Quantity in Condition State 1	2	3	4
X	9001		Drainage - Ends of Structure	EA	2	2	0	0	0
X	9208		Structure ID Plaque located on south end	EA	1	1	0	0	0
X	9337		Protective Screening	EA	1	1	0	0	0
X	9338		Horizontal Copings 9 cracks in coping	LF	130	121	9	0	0
X	9339		Features (Roadway/Sidewalk/Etc.) to Wall	EA	1	1	0	0	0

Rating

	File	New
Overall Rating	Good	Good

Figure 6: Example of element information and details recorded as part of a MSE wall inspection as presented in the HSI.

Table 9: Common division of MSE categories and components.

	Category			
	Structural	**Geotechnical**	**Hydraulics**	**Other**
Component	Copings and Parapets	Foundations	Copings and Parapets	Utilities and Culverts
	Facing Units	Reinforced Fill	Facing Units	Safety Features
	Facing Connections	Retained Fill	Facing Connections	Pavements
	Reinforcements	General Site Fill		Erosion and Erosion Control

The inspection of these components varies across state agencies with inspection typically conducted using at least one of three frameworks which include:

1. Defect-Based Inspection: Focuses on observable defects (e.g., tilting, erosion, deterioration), then identifies affected components (e.g., observed wall tilt may indicate issues with reinforcement, reinforced fill, and facing units).
2. Element-Based Inspection: Evaluates each element individually (e.g., copings, foundations, drainage) and identifies which defects are present for each element (e.g., a facing unit may show tilt and joint spacing issues).
3. Combined Approach: Uses both defect-based and element-based strategies.

WisDOT currently follows the third approach, combining both element-oriented and MSE-specific defect-oriented inspection methods. This dual framework enables more direct identification of repair actions, as condition states are typically tied to specific constructed elements. Defect-based inspections also allow for the identification of vulnerabilities, including those not directly observable, by associating indicators of distress with potential issues. An example of this approach is the wall movement (8902) defect, which encompasses multiple types of distress, such as

settlement, bulging, bending, heaving, and distortion/deflection. The HSI provides detailed guidance on the common root causes of these conditions, the components likely to be impacted, and suggested mitigation strategies. Neither the SIM nor HSI explicitly incorporate vulnerability, risk, or consequence evaluations into MSE wall inspection as done by previously indicated agencies.

4.3.2 Recommended Revisions

As WisDOT's current practice covers many of the relevant components and uses effective inspection methods, several revisions and additions are recommended for consideration to improve MSE wall inspection and performance. Comparative assessments from agencies such as INDOT, NYSDOT, NJDOT, and NCDOT suggest opportunities for enhancement in the following areas:

- Structural – Copings and Parapets
- Structural – Facing Units
- Structural – Facing Connections
- Structural – Reinforcements
- Geotechnical – Foundations
- Geotechnical – Reinforced Geomaterials (Fill)
- Geotechnical – Retained and General Site Geomaterials (Fill)
- Hydraulics – Structure Drainage

Recommended revisions and additions to these items are listed by component and structured similar to the existing SIM guidelines. The research team recommends that WisDOT consider including these components through the establishment of new assessments and defect codes, or through revisions to current inspection protocols.

Structural – Horizontal Copings (9338)

Inclusion of displacement and detachment for copings is recommended due to the potential impact on public safety and road-user confidence. The loss of copings may also result in increased risk of displacement for underlying facing units depending on individual MSE wall design.

Revision of the current condition states are under 4.4.5.9 Horizontal Copings (9938) is recommended as displacement and detachment states generally align well with current condition states. Recommended revised condition states are below.

Condition States

- **Condition State 1 (Good):** No issues. If cracks exist, they are <1/16" in width or sealed. Copings are seated in-place and fully attached.
- **Condition State 2 (Fair):** Delamination or spalls 1" or less, or less than 6" diameter. Patches, if they exist, are sound. HL or narrow cracking may be present. Minor efflorescence may exist, but no rust staining. Abrasion, if present, is minor. Copings may be partially detached but remain in place.
- **Condition State 3 (Poor):** Spall greater than 1" deep, or 6" diameter. Patched areas are unsound or showing distress. Medium width cracks. When efflorescence is present, there is heavy build-up and/or rust staining. Abrasion, if it exists, is moderate. Copings exhibit moderate offsets of less than 1" with no copings absent.

- **Condition State 4 (Severe):** The condition warrants a structural review to determine the effect on strength or serviceability of the wall; or a structural review has been completed and the defects impact the strength and/or serviceability of the wall. Copings are displaced greater than 1" or are fully absent.

No changes to reporting methods or quantification are recommended for the changes in condition states.

Structural – Facing Units (Filler and Sealer Degradation)

Inspection and condition assessment of backer materials including geotextile and geomembranes used behind facing units and on inter-panel filler (backer) and filler sealant is recommended. These materials aid in the reduction of material loss (i.e., spill-out) between panels, guide drainage, and may reduce panel damage during extreme events. The presence of leachate from these joints may also be used to indicate excess pour water pressures or loss of drainage performance. The inclusion of backer material, filler, and filler sealants is recommended as a new defect under element MSE Wall (8603). Condition states for this defect should be like those currently used in Part 2, Bridges Appendix A, A.3.3 Joint Defects or similar.

Condition States

- **Condition State 1 (Good):** No issue. The backer materials are fully adhered to the facing panels and free of defects. Joint backer or filler and filler sealant are fully adhered.
- **Condition State 2 (Fair):** Backer materials remain free of rips or tears but may exhibit abrasions. There is minimal leakage through the joint. Minimal leakage is defined as minor or occasional leaking or water from localized areas of a joint. There is seal abrasion but without through punctures or cracks.
- **Condition State 3 (Poor)**: Backer materials may exhibit partial loss, rips, or tears for less than 50% of the total joint height. There is moderate leakage through the joint. Moderate leakage is defined as multiple areas of leaking and the passage of debris through the joint. The seal is adhered to 50% or less of the joint height but there is still some adhesion. The joint is punctured, cracked, ripped, or partially pulled out.
- **Condition State 4 (Severe):** The backer material, joint backer or filler, and filler sealant have failed and there is a free flow of water and debris through the joint. There is a complete loss of seal adhesion, or the seal is punctured, cracked, or torn completely through, pulled out, or missing.

These conditions are recommended for the linear foot unit of measure. States 3 and 4 shall have representative measurements and photographs within the report. WisDOT is recommended to consider providing examples of acceptable and unacceptable leakage, as the terms minimal, moderate, and free flow can be interpreted differently without reference standards. These standards may also vary between MSE systems and backfill materials used.

Structural – Facing Connections and Reinforcements

The inclusion of facing connections and MSE reinforcements is recommended due to the significant impact of these components on MSE structural capacity and serviceability. Based on the unique aspects of facing connections and reinforcements, it is recommended to be included into inspections as a new defect under element MSE Wall (8603); Connections and

Reinforcements. Inspection of these components would be completed as part of an in-depth, damage, or interim inspection and are not anticipated as part of the regular inspection process.

While not part of a regular inspection observation, inspection of these components is recommended during roadway rehabilitation or reconstruction efforts where the removal of the pavement surface is anticipated and schedule permits the use of soft excavation techniques such as vacuum excavation, or hydro excavation, or hand excavation. Preliminary recommendations for condition states have been provided below. ARA recommends further development of these condition states based on the results of WHRP study 0092-24-02 Investigation of MSE Wall Corrosion in Wisconsin.

Condition States

- **Condition State 1 (Good):** No issue. Facing connections, geomaterial reinforcements and other elements are free of damage and distress. Reinforcements are positioned in accordance with design drawings.
- **Condition State 2 (Fair):** Facing connections or geomaterial reinforcements exhibit minor corrosion (metallic) or abrasions (nonmetallic) which are not impactful to service life. No tears, breaks, or gouges are present. Galvanization where present has continuous coverage. Corrosion where present is uniform.
- **Condition State 3 (Poor)**: Facing connectors or geomaterial reinforcements exhibit moderate corrosion (metallic) or abrasions or reduced ductility (nonmetallic) which reduce service life but do not immediately pose a serviceability or structural risk. Metallic connections and reinforcements are free of pitting and uneven corrosion. Nonmetallic reinforcements are free of tears and breaks. Reinforcements may exhibit minor outward displacement from their original locations consistent with estimated long-term performance.
- **Condition State 4 (Severe):** Facing connections or geomaterial reinforcements exhibit significant corrosion (metallic) or abrasions, breaks, or tears (nonmetallic) which significantly and immediately reduce service life and present structural risk. Metallic connections and reinforcements may contain pitting and uneven corrosion. Reinforcements have displacement from their original locations in excess of estimated long-term performance.

Due to the infrequency of inspection of these elements all states shall have representative measurements and photographs within the report. Development of appropriate corrosion models and life expectancies are predicated in part on a better understanding of site aggravating and mitigating factors which benefit from detailed record keeping across the life of the MSE wall. The research team emphasizes that corrosion may exhibit significant spatial variability without any external sign of distress. Where performed, this inspection process is recommended to occur at different locations along the structure and at different depths to increase the likelihood of identifying the full range of present condition states.

Geotechnical – Base/Foundation (8701)

Assessment for wall foundations to include level pads, spread footings, and footings not on rock is recommended as part of regular inspections where foundations are relatively shallow due to design or where erosion has resulted in exposure of foundation elements. The inclusion of

foundation elements as part of in-depth inspections is also recommended where the partial exposure of foundations is not anticipated to generate a negative change in MSE condition. While level pads and other shallow foundations generally do not provide substantial support for facing units, poor construction practices, premature distress, and undermining or loss of support for level pads and other foundation elements may drive differential settlement resulting in reduced facing unit condition. Loss of support under foundations may also indicate an underlying cause of distress if foundations are in reasonable condition.

As foundation assessment is recommended as part of regular inspections condition states may be suitable as an individual assessment item (i.e., Base/Foundation (8701)) or as an independent MSE specific defect. If not used as an independent assessment, foundation impacts may be suitable for inclusion into an existing assessment item such as Drainage System (9340) due to erosion being a major source of foundation exposure. Preliminary condition states for an independent foundation assessment are provided below.

Condition States

- **Condition State 1 (Good):** No issue. Foundations are sufficiently embedded into soils. No differential or local settlement is observable and foundation elements where visible are free of defects.
- **Condition State 2 (Fair):** Foundation elements are not exposed but may have reduced cover due to erosion or other material loss. No lateral or vertical displacement is observable, and foundation elements remain in contact with bearing soils. Differential settlements are less than half of the recommended limits of 1/200 for prefabricated modular block facings, 1/100 for segmental precast facings, and 1/50 for flexible facings.
- **Condition State 3 (Poor)**: Foundation elements are intermittently exposed, have limited lateral or vertical displacement less than 1 inch but remain in contact with bearing soils. Foundations continue to provide partial support for facings and other supported structures. Differential settlements are greater than half of the recommended limits of 1/200 for prefabricated modular block facings, 1/100 for segmental precast facings, and 1/50 for flexible facings.
- **Condition State 4 (Severe):** Foundation elements are continuously exposed, have displaced, or are no longer in contact with bearing soils. Foundations provide no support for facings or other supported structure, or differential settlement exceed recommended limits of 1/200 for prefabricated modular block facings, 1/100 for segmental precast facings, and 1/50 for flexible facings.

These conditions are recommended for the linear foot unit of measure. States 3 and 4 shall have representative measurements and photographs within the report. In addition, the inspection of this element is recommended to indicate that observations of continued local settlement following repairs (i.e., in subsequent inspections) may act as an indicator of a poor condition state. This is due to the behavior potentially preceding structural distress.

Geotechnical – Reinforced Geomaterials

The inclusion of reinforced geomaterials (engineered fill placed within the reinforced mass of an MSE) is recommended due to the significant impact of these components on MSE structural capacity. Reinforced geomaterials are recommended to be included into inspections as a new

assessment. Inspection of this component would be completed as part of an in-depth, damage, interim, or special inspection and not anticipated as part of the regular inspection process unless access is readily available. Inspection observation of this component is recommended during roadway rehabilitation or reconstruction efforts where the removal of the pavement surface is anticipated and schedule permits. Inspection of this component may also be performed as part of excavations performed for utility work, adjacent excavation work, or other MSE and roadway repairs. Preliminary recommendations for condition states have been provided below.

Condition States

- **Condition State 1 (Good):** No issue. Geomaterial is free of deleterious materials and appears consistent with reinforced fill material specifications. Material is dry or almost dry with no signs of discoloration, settlement, or displacement. No loss of material is observable. No cracking parallel to the wall face is observed.
- **Condition State 2 (Fair):** Geomaterial appears generally consistent with reinforced fill material specifications and free of deleterious materials but may have infrequent oversized aggregates, excess fines, or signs of intermittent water intrusion. Materials are almost dry or moist. Partial discoloration due to surface contaminant intrusion may be present. No loss of material is observable. No cracking parallel to the wall face is observed.
- **Condition State 3 (Poor)**: Geomaterial is not consistent of reinforced fill material specifications having no infrequent deleterious materials and frequent oversized aggregates, excess fines, or clay portions. Signs of water intrusion are present but free of apparent surface contaminants. Material is moist. Loss of material may be observable near exterior limits of the MSE wall or along drainage features. Loss of material does not negatively impact performance and is not ongoing or recent. Fine (< 1/2 inch wide and 4 inch deep) cracks may be present parallel to the wall face.
- **Condition State 4 (Severe):** Geomaterial is not consistent of reinforced fill material specifications having frequent oversized aggregates, excess fines, clay portion, or other deleterious materials. Signs of water intrusion are present and may contain apparent surface contaminants. Material is almost saturated or saturated. Loss of material may be observable throughout the structure, near exterior limits of the MSE wall, or along drainage feature. Loss of material impact performance and may be ongoing or recent. Cracking larger than fine may be present parallel to the wall face.

Due to the infrequency of inspection of these elements all states shall have representative measurements and photographs within the report. Material sampling and laboratory testing to include corrosivity, gradations, and friction angles are recommended. Field testing to include compaction testing may be performed. Information obtained from this inspection may be supplemental to investigations into corrosion, scour, wall movement, wall deterioration, and other common defects. Where performed, this inspection process is recommended to occur at different locations along the structure and at different depths to increase the likelihood of identifying the full range of present condition states.

Geotechnical – Retained and General Site Geomaterials

The inclusion of retained and general site geomaterials (engineered or select fill placed behind the reinforced mass of an MSE or at the face of the MSE wall) is recommended due to the impact of these components on MSE structural capacity and serviceability. These materials are

recommended to be incorporated into inspections as a new assessment. Inspection of this component would be completed as part of an in-depth, damage, interim, or special inspection and may be part of the regular inspection process if accessible (unpaved). Inspection of this component may also be performed as part of excavations performed for utility work, adjacent excavation work, or other MSE and roadway repairs. Preliminary recommendations for condition states have been provided below.

Condition States

- **Condition State 1 (Good):** No issue. Geomaterial is free of deleterious materials and appears consistent with fill material specifications. Material is dry or almost dry with no signs of discoloration, settlement, erosion, or displacement. No loss of material is observable.
- **Condition State 2 (Fair):** Geomaterial appears generally consistent with fill material specifications and free of deleterious materials but may have infrequent oversized aggregates, excess fines if dictated by specification. Materials are almost dry or moist unless managed as part of a vegetative system. Partial discoloration due to surface contaminant intrusion may be present. No loss of material is observable.
- **Condition State 3 (Poor)**: Geomaterial is not consistent of fill material specifications having no infrequent deleterious materials and frequent oversized aggregates, excess fines, or clay portions if dictated by specification. Material is moist to almost saturated. Loss of material or erosion may be observable near the reinforced geomaterial zones, along the MSE wall face, or along drainage features. Loss of material does not negatively impact performance and is not ongoing or recent.
- **Condition State 4 (Severe):** Geomaterial is not consistent with fill material specifications having frequent oversized aggregates, excess fines, clay portion, or other deleterious materials if dictated by specification. Signs of water intrusion are present and may contain apparent surface contaminants. Material is almost saturated or saturated. Loss of material may be observable near the reinforces geomaterial zone, along the MSE wall face, along drainage feature, or in other impactful areas. Loss of material impact performance and may be ongoing or recent.

States 3 and 4 shall have representative measurements and photographs within the report. Material sampling and laboratory testing to include corrosivity, gradations, friction angle, and other information may be recommended by competent parties. Field testing to include compaction testing may be performed. Information obtained from this inspection may be supplemental to investigations into corrosion, scour, wall movement, wall deterioration, and other common defects.

Hydraulics – Structure Drainage

The inclusion of structure drainage, representing drainage systems design and installed specifically to service the MSE wall, is recommended due to the significant impact of this component on MSE performance. Based on the unique aspects of structure drainage features it is recommended to be included into inspections as a revised assessment of 4.4.5.1 Drainage Approach (9001) and 4.4.5.11 Drainage System (9340). Inspection of this component would be completed as part of the regular inspection process with additional in-depth, damage, or interim inspections anticipated based on identified issues. Preliminary recommendations for condition states have been provided below.

Condition States

- **Condition State 1 (Good):** No issue. Visible inlets and outlets are free of defects, erosion, and debris including discoloration or efflorescence. No vegetation is present. If water is observed draining during inspection drained material is free of silts, clay, other fines, and discoloration. Observable pipes are free from belly, cracking, disconnects and other defects. No unintended free ponding is observable within the drainage area of at drainage outlets.
- **Condition State 2 (Fair):** Visible inlets and outlets are free of defects, erosion, and debris but may include light discoloration or efflorescence. Light vegetation may be present but easily removeable by hand. If water is observed draining during inspection drained material is free of silts, clay, other fines, and discoloration. Observable pipes are free from bellying, cracking, disconnects and other defects. Limited unintended free ponding may be observable within the drainage area or at drainage outlets. Unintended ponding appears transient.
- **Condition State 3 (Poor)**: Visible inlets and outlets may have minor defects, erosion, and debris. Discoloration or efflorescence may be present. Vegetation may be present and require equipment or significant effort to remove; generally not removable by hand. If water is observed draining during inspection drained material may contain limited silts, clay, other fines but no other discoloration. Observable pipes may exhibit bellying and minor cracking but continue to function without loss of conveyed water. Minor defects may be present but no disconnects are observable. Limited unintended free ponding may be observable within the drainage area or at drainage outlets. Unintended ponding may be permanent.
- **Condition State 4 (Severe):** Visible inlets and outlets may have defects, erosion, and debris including discoloration and efflorescence. Vegetation may be present and require equipment or significant effort to remove; not removable by hand. If water is observed draining during inspection drained material may contain silts, clay, other fines and may be discolored. Observable pipes exhibit bellying, cracking, or other defects and have lost the majority of carrying capacity or lose water during conveyance. Extensive unintended free ponding may be observable within the drainage area or at drainage outlets. Unintended ponding may be permanent.

The use of linear foot unit of measure is recommended for erosion, bellying, and cracking; square footage unit of measure is recommended for efflorescence and discoloration; and per item for other defects (e.g., clogged drains, ponding, presence of material in effluent). A simplified coding process based on quantity like 9340 may also be used. States 3 and 4 shall have representative measurements and photographs within the report.

4.4 Vulnerability and Risk Scoring

4.4.1 Summary of WisDOT Practice

As previously stated, WisDOT inspection practices align with best practices employed by many other DOTs with well-developed Geotechnical Asset Management (GAM) programs. These include: the inspection of key MSE elements, thorough documentation including detailed notes, photographs of significant defects, and the use of standardized evaluation processes for structural

components. Inspections are based on a predefined list of assessments (components) applicable across various Earth Retaining System (ERS) types, along with ERS-specific defects (elements).

Each applicable assessment, element, and defect is scored using a consistent rating scale of good (1), fair (2), poor (3), and severe (4). This standardized rating system, supported by descriptive criteria, ensures consistency across inspectors and facilitates comparable condition evaluations across structures. At the conclusion of each inspection, inspectors use their findings to assign an overall wall condition rating and to document necessary maintenance and repair actions.

As established, this framework defines a performance state, representing the current observable condition and functionality of the component based on the inspected items physical condition relative to a new or like-new component of the same type, and the functional performance at the time of inspection. However, this scoring system does not fully address the vulnerability of assessed items nor the risk if a failure was to occur. As a result, the use of current performance states (HSI condition state) is limited for repair prioritization and network management.

4.4.2 Recommended Revisions

To better address the vulnerability of assessed items, and risk if a failure was to occur, the research team recommends the revision to HSI data and non-HSI condition data to better develop repair prioritization and network management schemes. This is intended to help improve overall asset management of MSE walls. These recommendations are detailed in Section 5, Vulnerability and Risk Framework.

5 VULNERABILITY AND RISK FRAMEWORK

This section introduces a structured methodology for evaluating the vulnerability and risk of MSE walls using data available within WisDOT's HSI and non-HSI structure documents. The presented framework integrates observed condition states with supplemental exposure and reliability factors to produce scalable scores that support inspection prioritization, repair scheduling, and long-term asset management.

The developed framework is designed to be modular, adaptable, and compatible with WisDOT's existing inspection workflows. It builds on national practices from agencies such as NJDOT and NYC DOT, while incorporating WisDOT-specific data sources and operational constraints.

5.1 Background

MSE assessments are typically conducted through a series of inspections that evaluate structural, geotechnical, hydraulic, and other related components. The categorization of these components varies by agency and wall type to accommodate local practices in design, construction, maintenance, operations, and engineering judgment. Most commonly, MSE walls are assessed based on visible components (e.g., facing units, drainage systems, erosion), which can be evaluated through non-intrusive field inspections. With components assessed according to their physical condition relative to a new or like-new component of the same type, and their functional performance at the time of inspection. This evaluation defines a performance state, representing the current observable condition and functionality of the component.

WisDOT currently records this data, referred to in the HSI as condition states at the element and structure levels through the HSI system as shown in Figure 6. However, this data is not fully utilized. Performance state may be manipulated using available asset data such as a structure's design, construction quality, and repair history to define a more informed asset condition state; a more expansive use of the term than is currently used in the HSI. The performance state (i.e., HSI condition state) and updated condition state may then be used to estimate the vulnerability, or likelihood of failure, of an MSE component or the entire structure. Functionally this updated condition state enables improved decision making through informed asset management. For example, two MSE walls may exhibit the same performance state, yet differ in construction quality. The wall with higher construction quality (a better condition state) will generally have a lower vulnerability, despite similar observed performance.

Vulnerability may then be further evaluated based on the consequences of failure (e.g., road closure, reduced service level, utility exposure) for each component and for the overall structure to determine a relative risk level. For instance, MSE walls associated with higher failure consequences will present greater overall risk at the same level of vulnerability. The application of vulnerability and risk as formal metrics in MSE wall evaluations is relatively new compared to other civil infrastructure assets (e.g., bridges, utilities, pavements). This is partly due to the lack of sufficiently accurate distress models capable of isolating and confirming the long-term impacts of construction quality on performance, especially when accounting for all mitigating and aggravating factors over a structure's life span. The relationship between condition states and vulnerability factors and vulnerability and risk factors is visualized in Figure 7.

The integration of vulnerability and risk into real-world DOT MSE programs has been limited until recently. This study builds upon a comprehensive review of WisDOT's current practices in MSE wall selection, design, construction, and inspection, and evaluates opportunities to incorporate historical condition state data into future MSE asset management processes. This integration is intended to support the development of risk ratings for existing WisDOT-managed MSE walls, aiding in infrastructure management and future design decisions.

This section summarizes key observations and provides recommended actions for WisDOT's consideration. These actions, while not mandated by AASHTO or FHWA, are informed by the research team's experience and reviewed documentation and are intended to support effective MSE wall management, repair, and rehabilitation. It is recommended that WisDOT evaluate whether other internal documents either support or conflict with these recommendations, particularly if such materials were not included in this review.

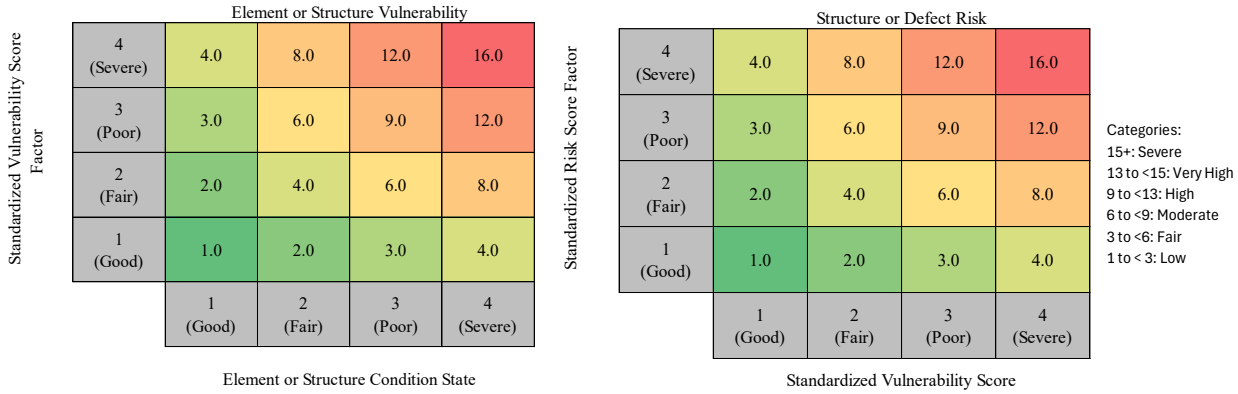

Figure 7. Representations of element – vulnerability score (left) and vulnerability – risk score matrices (right). Scores are based on composite vulnerability and risk score factors Increasing score indicates increasing vulnerability or risk.

5.2 Framework Basis

Traditional MSE wall inspections rely on visual assessments and qualitative ratings (e.g., Good, Fair, Poor, Severe) of individual components. With components assessed according to their current physical condition relative to a new, or like-new component, and functional performance at the time of inspection. While useful for documenting the current conditions or performance of a component or wall, these ratings do not account for underlying vulnerability such as construction quality, environmental exposure, or infrastructure age nor due to the potential impacts of component or wall failure. As a result, structures with similar observed conditions may have vastly different probabilities of failure, long-term performance trajectories, and impacts in case of failure. This can result in poorly optimized network management including MSE inspection, repairs, and replacement.

The vulnerability and risk framework developed for this research project addresses these limitations by introducing two quantitative metrics; vulnerability score (VS) and risk score (RS) defined below.

- **Vulnerability Score (VS)**: The quantitative measure of how susceptible an asset is to damage, failure, or degradation based on that asset's condition, design, age or deterioration state (condition state), exposure factors, construction quality, and structural redundancy.
- **Risk Score (RS)**: The quantitative measure of how severe the consequences would be to infrastructure, safety, and operations if an asset experiences complete failure (total loss of service).

These scores are applied on a 16-point range, based on a refinement of the existing 4-point condition categories used in the HSI with revised categories presented in The incorporation of VS and RS into WisDOT's MSE wall management would serve as a foundation for enhancing design and inspection practices and as a basis for advancing risk-based MSE wall management strategies. WisDOT may also use the resulting profiles of individual MSE walls and along entire corridors to inform decisions related to inspection prioritization, maintenance and repair scheduling, mitigation strategies, network planning, and adjustments to permissible roadway use, among other applications.

Table 10.

The incorporation of VS and RS into WisDOT's MSE wall management would serve as a foundation for enhancing design and inspection practices and as a basis for advancing risk-based MSE wall management strategies. WisDOT may also use the resulting profiles of individual MSE walls and along entire corridors to inform decisions related to inspection prioritization, maintenance and repair scheduling, mitigation strategies, network planning, and adjustments to permissible roadway use, among other applications.

Table 10. Vulnerability and Risk Category Descriptions

Category	Score Range		Vulnerability Description	Risk Description
Severe	15	16	Structure is at the highest probability of failure or has failed. Multiple elements or defects are in a severe category (CS = 4) and applicable vulnerability factors are at the most severe score ($Factor_{VS} = 4$).	Structure is at the highest risk in case of failure or several elements or defects exhibit failure (CS = 4). Failures will impact vital infrastructure, arterial roadway networks, adjacent structures, and other structures.
Very High	13	< 15	Structure is near the highest probability of failure. At least one element or defect is in a severe category and applicable vulnerability factors are at the most severe score ($Factor_{VS} = 4$).	Structure is near the highest risk in case of failure. Failures will impact vital or significant infrastructure, arterial roadway networks, and adjacent structures.
High	9	< 13	Structure is at a high probability of failure with at least one condition state in a poor or worse condition (CS ≥ 3); other elements if present are likely in poor or better condition (CS ≤ 3). Applicable vulnerability factors are at least to the poor ($Factor_{VS} = 3$) category.	Structure is at a high risk in case of failure. Failures are likely to impact significant infrastructure, minor arterial and major collector roadway networks, and adjacent structures
Moderate	6	< 9	Structure is at an elevated probability of failure. One element or defect may be in a poor or severe state (CS = 3, 4) while elements or defects remain in Fair (CS = 2) or better condition. Applicable vulnerability factors are generally Good to Fair.	Structure is at an elevated risk in case of failure. Failures are likely to impact significant or moderate infrastructure, minor arterial roadway networks, and limited adjacent structures.
Fair	3	< 6	Structure has a relatively low probability of failure. Elements and defects are likely Fair or better in condition. Vulnerability factors are generally Good.	Structure is at a relatively low risk in case of failure. Failures are likely to impact local or moderate infrastructure, collector roadway networks, and limited to no adjacent structures.
Low	1	<3	Structure is at the lowest probability of failure. Elements and defects are likely Good. Vulnerability factors are generally Good.	Structure is at the lowest risk in case of failure. Failures are likely to impact only a limited number of minor to moderate risk factors.

5.3 Vulnerability Scores

5.3.1 Vulnerability Assessment Factors

WisDOT currently records performance data (i.e., condition states) at the element and structure levels through the HSI system, only the incorporation of condition-related data is required to start a WisDOT based program. These revised condition states, representing potential vulnerability factors, can be customized in number and complexity as appropriate for WisDOT's operational capacity. The research team recommends the consideration of four preliminary vulnerability factors to initiate this process:

- **Construction Quality State (CQS):** Reflects the historical quality of the structure and its compliance with design and construction standards.
- **Structure Age (SA):** Indicates the wall's age relative to an assumed 75-year design service life.

- **Winter Highway Classification (WHC):** Represents the frequency and intensity of deicing salt application based on highway classification and maintenance practices.
- **Pavement Condition Index (PCI):** Indicates the general surface condition of the pavement over the wall's service life.

These four factors provide a practical basis for assessing the probability of failure when combined with existing HSI inspection data. Data for SA, WHC, and PCI are also generally available for direct incorporation or external processing, reducing time for implementation. Notably, WHC and PCI are intended to function together as a composite measure of exposure to deicing salts, particularly for metallic and masonry components.

In contrast, Construction Quality State (CQS) may require greater implementation effort due to the broad scope of data it can encompass and the time required for materials review. To manage this effort, several methods can be used to evaluate and assign CQS values:

- **Method 1:** Simple confirmation of the presence of design plans or as-built records.
- **Method 2:** Digitization and review of as-built records to evaluate conformance with design standards at the time of construction.
- **Method 3:** In-depth or special inspections, such as a new construction inspection, performed during construction and recorded in the HSI system to establish a baseline condition.
- **Method 4:** In-depth inspections conducted during MSE maintenance or corridor (roadway) reconstruction to gather missing information.

The level of detail used in the selected method should influence the range of CQS factors applied in the vulnerability evaluation. More detailed approaches provide greater nuance and differentiation across structures and elements. An example of a similar implementation is the WIP Design Criteria developed for the City of New York (NYC), which classifies construction quality into three compliance levels (Eschenasy 2024) (New York State Department of Transportation 2018):

1. **None:** Does not meet any known design standards or systematic construction methods commonly used at the time of construction;
2. **Non-AASHTO:** Does not meet AASHTO design standards, but is consistent with other structures of its type and period of construction exhibiting established construction workmanship and good performance; or
3. **AASHTO:** Appears to meet AASHTO geometric, design, materials, and construction.

NYC and other agencies have also assessed data reliability based on the quality of inspection observations and records, as part of their vulnerability scoring systems. When combined with other factors, CQS offers a flexible and comprehensive tool for condition evaluation. Based on discussions with WisDOT staff, the research team recommends a moderate implementation approach, blending Method 2 and Method 3 for preliminary use. This would involve digitization and evaluation of available records supplemented by targeted inspections. An example of a four-value scale for CQS following this approach is presented for CQS in Table 11. The presented method presents a practical starting point, leveraging available records and integration within the HSI system.

Table 11. Construction Quality States

Construction Quality State	Description	CQS Factor
1 (Good)	Design, construction, construction records, or supplemental inspections indicate the component or structure is fully consistent with selected WisDOT and national standards.	1.0
2 (Fair)	Design, construction, construction records, or supplemental inspections indicate the component or structure is predominantly consistent with selected standards. Minor non-conformances during construction were present but accepted by agency engineers. The quality of as-built, QA/QC, and other project documents had minor deficiencies or absences.	1.25
3 (Poor)	Design, construction, construction records, or supplemental inspections indicate the component or structure is moderately consistent with selected standards. Non-conformances during construction were present but accepted by agency engineers. The quality of as-built, QA/QC, and other project documents had moderate deficiencies or absences.	1.5
4 (Severe)	Design, construction, construction records, or supplemental inspections indicate the component or structure is not consistent with selected standards. Non-conformances during construction were present and were not reviewed or accepted by agency engineers. The quality of as-built, QA/QC, and other project documents had significant deficiencies or absences including no submission of as-built plans.	1.75

Condition states, associated descriptions, and corresponding factors can be progressively refined to expand the scoring range or adjust the overall influence (i.e., maximum factor value) relative to other selected vulnerability considerations, as determined by WisDOT. Detailed factor descriptions and scores for the remining vulnerability factors recommended for WisDOT use are presented in Appendix F: Vulnerability Factors.

5.4 Vulnerability Scoring

For vulnerability scoring of an individual MSE wall, applicable factors are multiplied to form a composite ($Factor_{VS}$; Equation 2) and standardized to a grading system ranging from 1 (Good) to 4 (Severe). Element-level and overall structure vulnerability scores are calculated by applying $Factor_{VS}$ to the HSI condition state (CS) for individual elements ($VS_{Element}$; Equation 3) and averaging the results across all elements to obtain a structure vulnerability score ($VS_{Structure}$; Equation 4). Vulnerability factors are also applied to HSI defects to calculate a (VS_{Defect}; Equation 5). Differences between $VS_{Structure}$ and VS_{Defect} can indicate unobservable element or site condition impacts, such as reinforcement deterioration or changes in groundwater conditions.

Equation 2. Composite Vulnerability Factor

$$\boldsymbol{Factor_{VS} = Factor_{CQS} \times Factor_{SA} \times Factor_{WHC} \times Factor_{PCI}}$$

Equation 3. Element Vulnerability Score

$$\boldsymbol{Element\ Vulnerability\ Score\ (VS_{Element}) = CS_{Element} \times Factor_{VS}}$$

Equation 4. Structure Vulnerability Score

$$\boldsymbol{Structure\ Vulnerability\ Score\ (VS_{Structure}) = \overline{CS_{Element} \times Factor_{VS}}}$$

Equation 5. Defect Vulnerability Score

$$\boldsymbol{Defect\ Vulnerability\ Score\ (VS_{Distress}) = \overline{CS_{Defect} \times Factor_{VS}}}$$

Although both $VS_{Element}$ and $VS_{Structure}$ can be developed, the use of per-element vulnerability scores is not strongly recommended. Vulnerability factors are generally broad in scope and may not be equally applicable to all elements, making them best suited for interpretation at the structure or network-wide scale.

Developed scores may be reported directly based on $VS_{Structure}$. For the factors presented here, the maximum possible score is 21.9 (i.e., the maximum $Factor_{VS}$ of 5.47 multiplied by the maximum WisDOT CS of 4). Scores may also be proportionally scaled to a preferred or existing range. For example, in Figure 7 vulnerability factors are proportionally scaled to provide a standard range of 1 (Good) to 4 (Poor) resulting in a 16-point vulnerability score window described in The incorporation of VS and RS into WisDOT's MSE wall management would serve as a foundation for enhancing design and inspection practices and as a basis for advancing risk-based MSE wall management strategies. WisDOT may also use the resulting profiles of individual MSE walls and along entire corridors to inform decisions related to inspection prioritization, maintenance and repair scheduling, mitigation strategies, network planning, and adjustments to permissible roadway use, among other applications.

Table 10.

This scaled approach simplifies the introduction of the vulnerability score concept and illustrates that a well-performing MSE wall in a well-maintained corridor will typically exhibit a condition state aligned with its vulnerability state (e.g., 1-1 or Good-Good) indicating relatively low vulnerability (1). In contrast, structures with poor documentation or located in corridors with inadequate maintenance may exhibit moderate vulnerability, even if their current condition is rated as fair. This reflects a higher vulnerability level than suggested by the condition state alone, due to reduced baseline reliability, an intuitive concept for experienced inspection personnel and engineers.

A key strength of this framework is its flexibility: vulnerability scores can be updated or revised based on the availability and quality of construction records and post-construction data. This encourages the use and preservation of construction documentation as part of asset management practices aimed at reducing structure vulnerability scores. Furthermore, detailed records and in-depth inspections are essential to support root cause analyses and distress modeling, helping to identify construction methods, materials, or specifications that may lead to increased vulnerability.

Vulnerability scoring can also help assess the impacts of changes in construction standards, design criteria, or maintenance operations. For example, if a new edition of the LRFD Bridge Design Specifications (BDS) recommends significant updates to slope stability design, MSE walls constructed under the previous standard may see their Condition Quality Score (CQS) shift from Good (1) to Fair (2). This shift reflects the wall's elevated vulnerability relative to newer walls designed under the updated standard and may justify increased inspection or monitoring. The effects of such changes are regularly discussed in engineering literature following the release of new standards (e.g., Esposito and Najim, 2010; Selladurai and Fish, 2015). Additional insights into contributing factors such as PCI and WHC are available through ongoing WisDOT research, including WHRP G24-02, Investigation of MSE Wall Corrosion in Wisconsin.

As the example illustrates, an increase in vulnerability does not account for the consequences of wall failure; it only reflects the relative risk to the wall itself when compared to past or current standards. Therefore, vulnerability ratings alone are not suitable for prioritizing inspections or treatments across different MSE wall types, heights, traffic volumes, or uses. For comparative evaluation of MSE walls, ARA recommends conducting full risk assessments and developing MSE wall risk scores.

5.5 Risk Assessment

Risk assessment, including risk scoring, is a natural extension of the vulnerability assessment process through the incorporation of failure consequences for MSE walls. These consequences may include monetary losses, injuries or fatalities, changes in serviceability, corridor and infrastructure impacts, and other factors deemed significant by the agency or its stakeholders. Agencies can use the resulting risk profiles of MSE walls to inform decisions related to inspection prioritization, maintenance and repair scheduling, mitigation strategies, network planning, and adjustments to permissible roadway use, among other applications.

5.6 Risk Assessment Factors

Consequence identification for structural failure typically relies on a combination of structure-specific and route-specific factors to assess the potential impact on the local area and the broader region. These factors include the likelihood of injuries or fatalities, traffic disruption, changes in serviceability, corridor and infrastructure impacts, route redundancy, and other considerations identified by the agency or its stakeholders (Alhasan, et al. 2023) (Adams and Nicks 2017).

The research team recommends continuing to incorporate both local and network-level impacts into the MSE risk assessment process. In particular, semi-local and network-level impacts should be evaluated using the roadway functional classification system and criteria developed with WisDOT, as detailed in *Functional Classification Criteria and Procedures* (2022). This classification system accounts for many commonly used risk assessment parameters, including:

- Network continuity
- Route usage and traffic volume
- Land use
- Route spacing
- Geographic barriers
- Roadway connections
- Redundant (parallel) routes
- Roadway characteristics
- Industrial route designation
- Seasonal demand

This single classification offers a comprehensive basis for assessing network-level risk associated with a single MSE wall failure.

As functional classification does not fully account for the local impacts of an MSE failure which may be better determined based on the geometrics and structure. The research team recommends incorporation of local impacts by considering the following factors:

- **Supported Structures (SS):** Indicates whether the MSE wall supports other transportation structures (e.g., abutments) within its influence area that would be affected in the event of failure.
- **MSE wall height (WH):** Represents the total wall height and the likely lateral extent of the failure's impact.
- **MSE wall length (WL):** Represents the total wall length and the probable horizontal extent of the failure's impact.
- **Utility Prevalence and Criticality (UPC):** Reflects the presence and redundancy of critical utilities located near the MSE wall that could be affected by failure.

Among these local impact factors, structure proximity, wall height, and wall length are available from existing HSI data. However, utility data is not readily accessible and will require coordination with local utility owners. While the development of detailed utility corridor risk assessments is beyond the scope of this project, general utility impact descriptions and preliminary ratings have been provided for future use when more information becomes available.

The recommended consequence factors are based on the team's professional judgment and referenced risk rating system publications. It is important to note that these consequence factors exclude costs related to loss of service (e.g., lane rental fees or road user costs), as well as inspection, maintenance, repair, and remediation expenses. Proposed consequence factors should be reviewed and updated on an as-needed basis to align with evolving agency and stakeholder risk concerns. Recommended factor scores are provided in Appendix G: Risk Factors.

5.7 Risk Scoring

Using a modified procedure similar to the one outlined for vulnerability scoring, all risk factors are multiplied to calculate a composite risk score factor ($Factor_{RS}$; Equation 6). Each element condition state ($CS_{Element}$) is then multiplied by $Factor_{RS}$ and averaged to generate structure risk score ($RS_{Structure;}$ Equation 7). Similarly, risk factors are also applied to each defect to calculate a defect risk score (RS_{Defect}; Equation 8).

Equation 6. Composite Risk Factor

$$\boldsymbol{Factor_{RS} = Factor_{SS} \times Factor_{WH} \times Factor_{WL} \times Factor_{UPC}}$$

Equation 7. Structure Risk Score

$$\boldsymbol{Structure\ Risk\ Score\ (RS_{Structure}) = \overline{CS_{Element} \times Factor_{RS}}}$$

Equation 8. Defect Risk Score

$$\boldsymbol{Defect\ Risk\ Score\ (RS_{Defect}) = \overline{CS_{Defect} \times Factor_{RS}}}$$

Both $RS_{Structure}$ and RS_{Defect} are evaluated on a 16-point scale, illustrated in Figure 7 with category descriptions provided in **Error! Reference source not found.**. This scale aligns with the one used for vulnerability scoring and is similar to the condition state (CS) scale used in MSE wall inspections, making the system intuitive and easy to adopt. This framework can be updated based on changes to the MSE wall, WisDOT practices, corridor characteristics, or as improved data becomes available for vulnerability or risk factors. Updates may include revised vulnerability scores, condition states, or consequence factors. As with vulnerability scoring, the difference between structure and defect scores may reflect unobservable conditions at the element or site level that impact MSE wall performance.

5.8 VS and RS Implications

As presented, vulnerability and risk scores are semi-qualitative metrics and do not incorporate the cost of failure, repairs, maintenance, or other operations. As a result, the use of these scores for life cycle cost analysis (LCCA) is limited without the inclusion or development of reasonable cost information. However, both scores are suited for use at the structure and network level for prioritization of MSE tasks.

An example of a procedure using these scores for structure and network level project planning is presented below as step-by-step process for three MSE walls. These walls are currently included in the HSI and include structures R-40-156, R-67-045, and R-67-048, located in the southeast region. Based on review of HSI records, these structures are reasonably representative of walls within the HSI and demonstrate a range of condition states and defects. Inspection reports for these structures are included in Appendix H: WisDOT Inspection Reports for R-40-156, R-67-045, And R-67-048.

Figure 8. Representative photos of MSE walls R-40-156 (left), R-67-045 (center), and R-67-048 (right).

Steps

1. An excel file is populated with structure number, inspection date, elements, defects, condition states from the HSI for each structure (Figure 9).

Structure & Inspection		Components (Structure Inspection Manual)		Condition State (CS, HSI Inspections)						
Structure Number	Inspection Date	Element	Defect	Good 1	Fair 2	Poor 3	Severe 4	N/A --	N/O --	Element CS (Average)
R40156	12-10-20	Drainage Approach (9001)		2	0	0	0			1.00
R40156	12-11-20	Aesthetic Treatments (9010)								
R40156	12-12-20	Utilities (9011)								
R40156	12-13-20	Signs Other (9035)		1	0	0	0			1.00
R40156	12-14-20	Structure ID Plaque (9208)		1	0	0	0			1.00
R40156	12-15-20	Decorative Rail (9335)								
R40156	12-16-20	Luminaire Bases (9336)								
R40156	12-17-20	Protective Screening (9337)								
R40156	12-18-20	Horizontal Copings (9338)		847	177	24	0			1.21
R40156	12-19-20	Features (Roadway/Sidewalk/Etc) to Wall (9339)		1	0	0	0			1.00
R40156	12-20-20	Drainage System (9340)		1	1	0	0			1.50
R40156	12-21-20	Stairwell (9341)								
R40156	12-22-20	MSE Wall (8603)								
R40156	12-23-20		Masonry or Panel Displacement (1640)	892	124	32	0			1.18
R40156	12-24-20		Scour (8000)							
R40156	12-25-20		Wall Movement (8902)	0	98	13	0			2.12
R40156	12-26-20		Wall Deterioration (8903)	0	26	14	0			2.35
R670045	11-11-21	Drainage Approach (9001)		2	0	0	0			1.00
R670045	11-12-21	Aesthetic Treatments (9010)								
R670045	11-13-21	Utilities (9011)								
R670045	11-14-21	Signs Other (9035)								
R670045	11-15-21	Structure ID Plaque (9208)								
R670045	11-16-21	Decorative Rail (9335)								
R670045	11-17-21	Luminaire Bases (9336)								
R670045	11-18-21	Protective Screening (9337)								
R670045	11-19-21	Horizontal Copings (9338)		175	14	2	0			1.09
R670045	11-20-21	Features (Roadway/Sidewalk/Etc) to Wall (9339)		2	0	0	0			1.00
R670045	11-21-21	Drainage System (9340)		1	1	0	0			1.50
R670045	11-22-21	Stairwell (9341)								
R670045	11-23-21	MSE Wall (8603)								
R670045	11-24-21		Masonry or Panel Displacement (1640)	0	3	2	0			2.40
R670045	11-25-21		Scour (8000)							
R670045	11-26-21		Wall Movement (8902)							
R670045	11-27-21		Wall Deterioration (8903)	0	6	1	0			2.14

Figure 9. Transcription of HSI data to excel for vulnerability and risk scoring.

2. Following transcription, vulnerability and risk assessment factors are selected reflecting HSI and external data. This includes information from the winter highway classification (Figure 10), PCI maps, and visual identification of supported structures completed via HSI photo records and online maps. Due to the lack of utility information available, “Unknown” with a 3rd quartile default value, was selected providing a uniform risk factor across all three MSE walls (Figure 11) for the utility prevalence and criticality risk assessment.

Figure 10. Example of winter highway classification for structure R-67-045 from WisDOT managed GIS database.

Structure & Inspection		Vulnerability Assessment Factors				Risk Assessment Factors				
Structure Number	Inspection Date	Construction Quality State (CQS)	Structure Age (SA)	Winter Highway Classification (WHC)	PCI Rating (PCI)	Functional Classification (FC)	Supported Structrues (SS)	Wall Height (WH)	Wall Length (WL)	Utility Prevalence and Criticality (UPC)
R40156	12-10-20	Fair	25-50	1	Satisfactory	PA	High	≥25	>500	Unknown
R40156	12-11-20									
R40156	12-12-20									
R40156	12-13-20	Fair	25-50	1	Satisfactory	PA	High	≥25	>500	Unknown
R40156	12-14-20	Fair	25-50	1	Satisfactory	PA	High	≥25	>500	Unknown
R40156	12-15-20									
R40156	12-16-20									
R40156	12-17-20									
R40156	12-18-20	Fair	25-50	1	Satisfactory	PA	High	≥25	>500	Unknown
R40156	12-19-20	Fair	25-50	1	Satisfactory	PA	High	≥25	>500	Unknown
R40156	12-20-20	Fair	25-50	1	Satisfactory	PA	High	≥25	>500	Unknown
R40156	12-21-20									
R40156	12-22-20									
R40156	12-23-20	Fair	25-50	1	Satisfactory	PA	High	≥25	>500	Unknown
R40156	12-24-20									
R40156	12-25-20	Fair	25-50	1	Satisfactory	PA	High	≥25	>500	Unknown
R40156	12-26-20	Fair	25-50	1	Satisfactory	PA	High	≥25	>500	Unknown
R670045	11-11-21	Fair	25-50	2	Fair	MA	Very High	15-25	<150	Unknown
R670045	11-12-21									
R670045	11-13-21									
R670045	11-14-21									
R670045	11-15-21									
R670045	11-16-21									
R670045	11-17-21									
R670045	11-18-21									
R670045	11-19-21	Fair	25-50	2	Fair	MA	Very High	15-25	<150	Unknown
R670045	11-20-21	Fair	25-50	2	Fair	MA	Very High	15-25	<150	Unknown
R670045	11-21-21	Fair	25-50	2	Fair	MA	Very High	15-25	<150	Unknown
R670045	11-22-21									
R670045	11-23-21									
R670045	11-24-21	Fair	25-50	2	Fair	MA	Very High	15-25	<150	Unknown
R670045	11-25-21									
R670045	11-26-21									
R670045	11-27-21	Fair	25-50	2	Fair	MA	Very High	15-25	<150	Unknown

Figure 11. Selection of vulnerability and risk assessment factors.

3. Structure vulnerability scores are reviewed for reasonableness and reported if acceptable. For the example walls, $VS_{Structure}$ are: 2.0 (R-40-156), 2.0 (R-67-045), and 2.5 (R-67-048). These scores indicate that the highest relative probability of failure is for wall R-67-048. Defect vulnerability scores as: 3.3 (R-40-156), 3.9 (R-67-045), and 3.2 (R-67-048). Indicating that the highest relative probability of failure is with wall R-67-045, followed by R-40-156, and R-67-048. The difference between $VS_{Structure}$ and VS_{Defect} generally

indicates that elements or site conditions, not part of the inspection, may be driving defects (e.g., reinforcements elongating, increased ground water elevation, excess settlement). Development of additional element inspection processes or detailed inspection may be appropriate to better capture element behavior.

4. The entire process is repeated for risk using standardized vulnerability scores and standardized composite risk score factor (Figure 13). For the example walls, structure risk scores are: 5.9 (R-40-156), 4.5 (R-67-045), and 4.3 (R-67-048). This indicates that, based on element conditions, the greatest risk is for wall R-40-156, followed by R-67-045, and R-67-048. Defect risk scores are: 9.9 (R-40-156), 8.8 (R-67-045), and 5.4 (R-67-048); consistent with the structure-based risk scores but slightly decreased for R-67-048.

Structure & Inspection		Vulnerability Factors (Value)				VS Calculations			
		CQS	AF	WSG	PCI	5.4688		Element Avg. VS	Structure Avg. VS
Structure Number	Inspection Date	(1 for N/A; Avg for Unknown)	(1 for N/A; Avg for Unknown)	(1 for N/A; Avg for Unknown)	(1 for N/A; Avg for Unknown)	Composite VS Factor CQS x AF x WSG x PCI	Standardized Composite VSF (Scores 1-4)	(For the Inspection Date)	(For the Inspection Date)
R40156	12-10-20	1.25	1.30	1.25	1.05	2.13	1.8	1.8	2.0
R40156	12-11-20								
R40156	12-12-20								
R40156	12-13-20	1.25	1.30	1.25	1.05	2.13	1.8	1.8	2.0
R40156	12-14-20	1.25	1.30	1.25	1.05	2.13	1.8	1.8	2.0
R40156	12-15-20								
R40156	12-16-20								
R40156	12-17-20								
R40156	12-18-20	1.25	1.30	1.25	1.05	2.13	1.8	2.1	2.0
R40156	12-19-20	1.25	1.30	1.25	1.05	2.13	1.8	1.8	2.0
R40156	12-20-20	1.25	1.30	1.25	1.05	2.13	1.8	2.6	2.0
R40156	12-21-20								
R40156	12-22-20								
R40156	12-23-20	1.25	1.30	1.25	1.05	2.13	1.8	2.1	3.3
R40156	12-24-20								
R40156	12-25-20	1.25	1.30	1.25	1.05	2.13	1.8	3.7	3.3
R40156	12-26-20	1.25	1.30	1.25	1.05	2.13	1.8	4.1	3.3
R670045	11-11-21	1.25	1.30	1.15	1.10	2.06	1.7	1.7	2.0
R670045	11-12-21								
R670045	11-13-21								
R670045	11-14-21								
R670045	11-15-21								
R670045	11-16-21								
R670045	11-17-21								
R670045	11-18-21								
R670045	11-19-21	1.25	1.30	1.15	1.10	2.06	1.7	1.9	2.0
R670045	11-20-21	1.25	1.30	1.15	1.10	2.06	1.7	1.7	2.0
R670045	11-21-21	1.25	1.30	1.15	1.10	2.06	1.7	2.6	2.0
R670045	11-22-21								
R670045	11-23-21								
R670045	11-24-21	1.25	1.30	1.15	1.10	2.06	1.7	4.1	3.9
R670045	11-25-21								
R670045	11-26-21								
R670045	11-27-21	1.25	1.30	1.15	1.10	2.06	1.7	3.7	3.9

Figure 12. Calculation of the composite vulnerability score factor and application to elements and defects prior to averaging vulnerability scores for each.

5. Comparing vulnerability scores to risk scores demonstrates that the vulnerability of each wall does not directly correspond with risk. For the example, R-40-156, had the second lowest VS_{Defect} and the highest RS_{Defect}. Under a risk-based process, R-40-156 would likely be given higher priority for inspection and treatment. An agency may also use this information to calculate cumulative or average vulnerability and risk scores along a corridor (i.e., multiple MSE walls). This would allow impact evaluation of grouped MSE wall repairs or single repairs on corridor or network.

Structure & Inspection		Risk Factors (Value)					Risk Calculations			
		CF	SS	WH	WL	UPC			Element Avg. RS	Structure Avg. RS
Structure Number	Inspection Date	(1 for N/A; Avg for Unknown)	(1 for N/A; Avg for Unknown)	(1 for N/A; Avg for Unknown)	(1 for N/A; Avg for Unknown)	(1 for N/A; Avg for Unknown)	Composite RS Factor FC x SS x WH x WL x UPC	Standardized Composite VSF (Scores 1-4)	(For the Inspection Date)	(For the Inspection Date)
R40156	12-10-20	2.00	1.10	1.10	1.10	1.44	3.83	3.0	5.2	5.9
R40156	12-11-20									
R40156	12-12-20									
R40156	12-13-20	2.00	1.10	1.10	1.10	1.44	3.83	3.0	5.2	5.9
R40156	12-14-20	2.00	1.10	1.10	1.10	1.44	3.83	3.0	5.2	5.9
R40156	12-15-20									
R40156	12-16-20									
R40156	12-17-20									
R40156	12-18-20	2.00	1.10	1.10	1.10	1.44	3.83	3.0	6.4	5.9
R40156	12-19-20	2.00	1.10	1.10	1.10	1.44	3.83	3.0	5.2	5.9
R40156	12-20-20	2.00	1.10	1.10	1.10	1.44	3.83	3.0	7.9	5.9
R40156	12-21-20									
R40156	12-22-20									
R40156	12-23-20	2.00	1.10	1.10	1.10	1.44	3.83	3.0	6.2	9.9
R40156	12-24-20									
R40156	12-25-20	2.00	1.10	1.10	1.10	1.44	3.83	3.0	11.1	9.9
R40156	12-26-20	2.00	1.10	1.10	1.10	1.44	3.83	3.0	12.3	9.9
R670045	11-11-21	1.50	1.25	1.05	1.00	1.44	2.83	2.3	3.9	4.5
R670045	11-12-21									
R670045	11-13-21									
R670045	11-14-21									
R670045	11-15-21									
R670045	11-16-21									
R670045	11-17-21									
R670045	11-18-21									
R670045	11-19-21	1.50	1.25	1.05	1.00	1.44	2.83	2.3	4.3	4.5
R670045	11-20-21	1.50	1.25	1.05	1.00	1.44	2.83	2.3	3.9	4.5
R670045	11-21-21	1.50	1.25	1.05	1.00	1.44	2.83	2.3	5.8	4.5
R670045	11-22-21									
R670045	11-23-21									
R670045	11-24-21	1.50	1.25	1.05	1.00	1.44	2.83	2.3	9.3	8.8
R670045	11-25-21									
R670045	11-26-21									
R670045	11-27-21	1.50	1.25	1.05	1.00	1.44	2.83	2.3	8.3	8.8

Figure 13. Calculation of the composite risk score factor, and application to elements and defects prior to averaging vulnerability scores for the entire structure and all defects.

6. Assuming a structure level assessment, if R-40-156 is determined to be too high risk, a repair may be recommended. The impacts of repairs or changes may be evaluated using estimated post-action conditions states and assessment factors. For R-40-156, a repair to the wall face, reducing deterioration (8903) to the good condition with no other changes results in a reduction for both VS_{Defect} and RS_{Defect}. If the repair is performed, R40-156 would move to a lower RSDefect of 7.5 and R-40-156 would move to the highest risk score as are shown in Table 12 and
7. Figure **14**.

Table 12. Summary of Example wall CS, VS, and RS Results

Structure Number	Average Structure CS		Average Distress CS		Average Structure VS		Average Defect VS		Average Structure RS		Average Defect RS	
R-40-156	1.1	(Fair)	1.9	(Fair)	2.0	(Very Low)	3.3	(Fair)	5.9	(Fair)	9.9	(High)
R-67-048	1.6	(Fair)	2.0	(Poor)	2.5	(Low)	3.2	(Fair)	4.3	(Fair)	5.4	(Fair)
R-67-045	1.1	(Fair)	2.3	(Poor)	2.0	(Very Low)	3.9	(Fair)	4.5	(Fair)	8.8	(Moderate)
R-40-156 (Repaired)	1.1	(Fair)	1.4	(Fair)	2.0	(Very Low)	2.5	(Low)	5.9	(Fair)	7.5	(Moderate)
R-40-156 Change	0.0	None	0.5	None	0.0	None	0.8	1 Cat.	0.0	--	1.4	1 Cat.

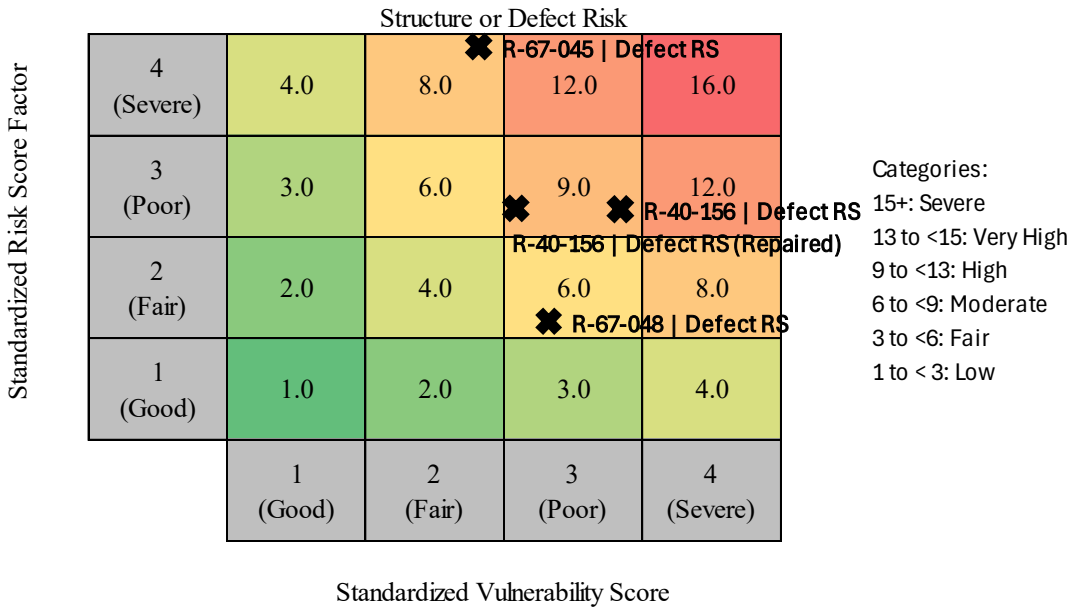

Figure 14. Visual representation of calculated defect risk scores relative to vulnerability and risk score factors for examined walls and for wall R-40-156 following repair.

5.8.1 Impacts of Vulnerability Scores on Risk Scoring

While vulnerability scores can enhance risk assessments and ratings, they are not explicitly required under the framework recommended for WisDOT. WisDOT may determine that developing practical vulnerability scores for MSE elements and structures is not feasible. In such cases, a Condition Quality Score (CQS) of 1.0 could be applied, with existing condition states (e.g., good [1], fair [2], poor [3], severe [4]) used directly as the vulnerability values. However, relying solely on a CQS of 1.0 is not recommended. Incorporating and assessing vulnerability scores based on construction data and other records plays a critical role in validating design and construction practices. It also promotes the maintenance of consistent and reliable MSE performance data.

5.8.2 Other Risk and Vulnerability Factors

As management, site conditions, design, materials, and construction all influence the consequences of an MSE wall failure, there is a wide range of vulnerability and risk factors which may be identified throughout the MSE life cycle. The research team recommends that WisDOT regularly review and revise assessment factors and their corresponding scores to ensure they remain appropriate with an initial three-to-five-year review cycle anticipated to be suitable. In particular, developing vulnerability factors based on repair methods, repair method efficacy, and reliability may prove especially useful. Additional vulnerability factors could be based on specific products (e.g., reinforcement types, facing units, or brands), construction practices, or site features such as overload traffic potential, soil types, soil variability, and corrosivity. It is also advisable to develop vulnerability factors for rare and extreme events which may include vehicle impacts, flooding, wildfire, earthquakes, malicious acts against infrastructure, and other impactful factors as they are identified

For persistent distresses, the research team recommends incorporating a vulnerability factor based on the likelihood of recurrence; that is, the probability that a specific defect will reappear at regular intervals. Pavement Condition Index (PCI) and other pavement-related distresses are examples of recurring defects. Given that pavement life cycles typically range from 15 to 25 years, an MSE system is expected to be exposed to the PCI cycle at least three times, and likely up to five times. This iterative decline in PCI may intermittently increase soil chloride content, potentially accelerating distress in reinforcement and facing units. The impact may manifest as a stepped or prolonged increase in chloride concentrations.

As few suitable distress models currently exist for use in developing vulnerability and risk factors. Developing viable models will depend on collecting and analyzing reliable, consistent data from a wide range of MSE walls, a process WisDOT has already begun through the HSI system.

5.9 Use of Vulnerability and Risk Scores

5.9.1 Risk Based Management

The 16-point vulnerability and risk scores presented can be used to guide prioritization of data collection, field operations, and both structure-specific and network-level planning, with the goal of enhancing overall performance. Risk-based considerations are already partially integrated into WisDOT practices through the SIM, specifically in Section 4.4.7, Maintenance & Repair Items. This section outlines default priorities for maintenance and repair activities, assigning lower priority to items with relatively low consequences—such as aesthetic concerns, vegetation removal, or minor structural defects like delamination (Figure 15).

Category	Repair/Maintenance Item	Default Priority
Improvement	Imp – Rehab/Major Repair	---
	Imp – Replace Structure	---
Miscellaneous Maintenance	Misc. – Cut Brush	Low
	Misc. – Other Work	---
	Misc. – Remove Vegetation (Spray)	Low
	Misc. – Remove/Monitor Loose Concrete	Medium
	Misc. – Repair/Replace Fence or Railing	Medium
	Misc. – Sign Remove/Reset/Replace	Low
	Misc. – Utility Repair/Notify Utility	Low

Figure 15. Example of part of an existing WisDOT maintenance, repair, and monitoring priority table.

The research team recommends that WisDOT update this SIM section and related documents to formally incorporate vulnerability and risk scores as influencing factors in determining maintenance, repair, and monitoring priorities. This would ensure alignment with broader asset management goals and reflect current best practices in risk-informed decision-making. WisDOT may also elect to take direct action based on risk scores alone. This is a valid approach, as current scoring methodology incorporates WisDOT condition states directly into the vulnerability and risk calculations. In effect, a high risk score can only result from at least one element or defect being rated in a severe condition state. Table 13 provides an example framework for potential action strategies corresponding to different risk score categories, reflecting the likely severity and impact of failure.

Table 13. Example Risk Score Category Actions

Risk Score Category	Score Range		Actions
Severe	15	16	Immediate assessment of the structure is recommended. Consider full road closure until vulnerabilities and risk concerns are addressed. Review and evaluate structure documents to identify and treat risk factors if present.
Very High	13	< 15	Immediate assessment of the structure is recommended. Consider lane closures nearest defect or element failures if full closures are not required for safety until vulnerabilities and risk concerns are addressed. Review and evaluate structure documents to identify and treat risk factors if present.
High	9	< 13	Plan a special or in-detail assessment of the structure in the near-future. Consider repair actions to reduce defect or element condition state scores. Review and evaluate structure documents to identify and treat risk factors if present.
Moderate	6	< 9	Increase inspection frequency and consider repair of elements or defects with the highest condition states; CS exceeds 3. Consider reviewing documents to identify and treat risk factors if present.
Fair	3	< 6	Maintain regular inspection and maintenance practices. Consider treatment of elements and defects when permitted by schedule unless CS exceeds 3.
Low	1	<3	Maintain standard MSE inspection and maintenance practices.

5.9.2 HSI and Asset Management Integration

The research team recommends integrating vulnerability and risk scores into existing asset management systems, such as the HSI. Where feasible, these assessments should be linked directly to WisDOT-managed databases and GIS services to streamline data access and enhance accuracy. Cross database integration minimizes the potential for data entry errors, enables error-checking of existing records (e.g., automated HSI score and score trend confirmation), and reduces the time required to develop recommended scores.

It is further recommended that current HSI entries, along with the proposed vulnerability and risk scores, be structured to support time-oriented data visualization, such as presenting risk scores for 2019, 2022, and 2025 together. Because element and defect conditions typically deteriorate over time, a time-based view can serve as an early warning system for emerging issues. Additionally, temporal tracking enhances root cause analysis of defects and provides a valuable quality control mechanism by flagging inconsistencies or unexpected trends in historical data.

6 REPAIR STRATEGIES

This section expands potential repair strategies for different defects and probable causes. Due to the variety of MSE designs in service it is strongly recommended that repairs and remediation beyond minor repairs be developed on a case-by-case basis by a qualified engineer. This section outlines the difference between root causes and contributing factors for MSE structure defects, outlines the process for performing a Root Cause Analyses (RCA), and provides several repair and rehabilitation approaches for different root causes.

6.1 Root Causes and Contributing Factors

Root causes and contributing factors play different roles in the understanding of MSE structure performance. A root cause is the fundamental, underlying condition or mechanism that directly leads to the observed failure or distress. It is the underlying factor that if removed or corrected, would prevent the problem from recurring. In retaining structures, root causes are often conditions that compromise the structure internal or external stability (e.g., inadequate drainage design, insufficient compaction, insufficient reinforcement length).

Contributing factors are secondary influences that worsen the situation but are not solely sufficient to cause poor performance (e.g., defects and distress). These may include poor surface water management, vegetation growth, minor construction deviations, or limited increased loading from adjacent development. Contributing factors may accelerate or exacerbate the effects of the root cause. If eliminated, these factors alone would not resolve the underlying performance concerns. For example, clogged drainage holes may increase hydrostatic pressure, but if the root cause is an inadequate drainage system, clearing the weep holes only provides temporary relief.

Distinguishing between root causes and contributing factors impacts the effectiveness of remediation strategies. As addressing only contributing factors may lead to recurring problems, while targeting the root cause is likely to result in durable and resilient performance improvements.

6.2 Root Cause Analysis (RCA)

RCA should begin with a systematic review of the desired structure. This includes a review of design and as-built data, inspection history, and a visual inspection for individual HSI assessments and defects (e.g., wall movement, cracking, settlement, backfill loss). In this preliminary step RCA focuses on documenting patterns and extents of distress, which can help form initial hypotheses about potential failure mechanisms. Probable causes should be identified based on the inspectors' expert knowledge and experience and available reports or guidelines such as those in this report and the HSI.

Based on identified probable causes, targeted data collection and diagnostic testing are used to further define subsurface and structural conditions. This may include soil borings, moisture and density testing, groundwater evaluation, and monitoring. Monitoring may include both surface and embedded instrumentation such as inclinometers, porewater pressures sensors, flowmeters, or settlement markers. NDT (Table 7 and Table 17) and PDT methods may also be used in this process. Depending on the defect condition state and failure impact a comprehensive forensic study may also be warranted. This targeted data collection is intended to identify drivers of distress (e.g., water infiltration from utilities, softening of soils, or land-use changes) which may not be apparent during visual inspection alone.

Supplemental information should be reviewed by a qualified party and used to integrate field data, design reviews, and support analysis (e.g., modeling and design calculations) to identify the causal chain behind the distress. A key focus of this process should be isolating and documenting contributing factors and the underlying root cause(s). Identification of the underlying mechanism supports the development of targeted, risk-informed repair and remediation strategies while remaining aware of the impact of contributing factors which may continue to affect the MSE structure after repair.

While RCA does not directly evaluate the vulnerability or risk of an MSE structure it may be used to better define the structure condition state. For example, an RCA for tilting panels at a single structure may result in digitalization and review of previously unidentified as-built records and identification of a large diameter watermain or other critical utility within the influence area of the structure. Resulting in changes to the construction quality state vulnerability factor ($Factor_{CQS}$) and the utility prevalence and criticality risk factor ($Factor_{UPC}$).

6.3 Repair Strategies

An effective repair strategy should reasonably match the intervention (i.e., repair method) to the root cause, not just the visible symptoms. The process starts with a clear understanding of the structure condition and the mechanisms driving the distress provided by the RCA to determine whether the issue stems from internal stability, external stability, global stability, surface-level deterioration, or other less-frequent factors. This strategy is important to reduce the likelihood of defect recurrence.

Repair options should be reviewed based on feasibility, risk, and long-term performance considering prior experiences, recent process improvements, and impacts of contributing factors. This includes considering constructability constraints (e.g., traffic, utilities, access), the wall's structural role, and the consequences of partial versus full reconstruction. For example, if the distress is driven by inadequate drainage, improving subsurface and surface water management may be more effective than reinforcing the facing. If the issue is reinforcement corrosion or global instability, a more robust intervention such as soil nails, ground improvement, or staged reconstruction, may be more suitable.

Repair strategies should also be evaluated based on durability, maintainability, and current WisDOT standards; choosing repairs that solve the immediate problem and reduce the likelihood of recurrence. This often includes considering long-term repair performance, material compatibility, expected and remaining service life, and the ability to monitor the repaired structure over time. Selected strategies should be documented with clear design assumptions, construction sequencing, and monitoring plans so ensure that the repair is both technically sound and operationally sustainable. As-built plans and other construction records should also be prepared and recorded as part of the repair process. With these documents supporting WisDOT's expansion of HSI guidance on common root causes, impacted components, and suggested mitigation strategies based on the successes or failures of repair strategies for different MSE systems. Preparation of case studies for internal and external reference is also recommended.

To aid in development of WisDOT specific repair strategies, the project team has prepared a summary table of repair strategies for fourteen total defects across copings and parapets, facing units, facing joints, and overall MSE structures. Each defect includes a brief list of probable causes anticipated to be experienced by WisDOT and several repair strategies which may be used to temporarily or permanently repair each defect. Repair strategies may be used individually or in combination. Limitations and commentary by the research team for individual repair strategy are also provided along with primary references. The entire repair strategies table is presented in Table **18**, Appendix B: Supplemental Tables. An sample of this table limited to three defects is presented as Table 14.

Table 14. Example defects, probable causes, and repair strategies.

Category	Defect	Probable Cause(s)	Repair Strategies	Limitations and Commentary	References
Copings and Parapets	Displacement and Tipping	• Differential settlement between facing and reinforced soil mass • Inadequate bearing surfaces or poor connection detailing • Freeze–thaw cycles and water infiltration weakening bedding • Construction tolerances leading to long-term misalignment	• Reset displaced units and clean and level bearing surfaces • Reseal joints to limit moisture infiltration • Installation of anchors or dowels may be used to reduce displacement between units but may increase stress transfer to facing units.	• Temporary stabilization may be required if settlement is ongoing • The use of a flexible non-cementitious sealant (e.g., polyurethane) may improve joint performance if not previously used • Long-term performance requires addressing underlying settlement or drainage issues	Berg, Christopher and Samtani 2009 Elias, Christopher and Berg 2001 CMHA 2024 INDOT 2025 Uretek 2025
Facing Units	Displacement – Outward	• Increased hydrostatic pressures from saturated backfill or clogged drains • Insufficient (short) reinforcement lengths or poor connection performance • Differential settlement behind the wall	• Repair or improve drainage, or install pressure-relief measures which may include permeable joint seals, weep drains, or horizontal relief drains • Reconstruct localized facing and reinforced zones • Installation of restraint and reinforcement systems	• Vertical drains may also be used but may require active pumping • Reconstruction with longer reinforcement may be necessary if deficiencies are systemic • Restraint and reinforcement systems include buttress walls, soil nails, tiebacks, and tiebacks and walers	Berg, Christopher and Samtani 2009 CMHA 2024 TxDOT 2024 INDOT 2025 Hall and Afkhami 2014
Facing Units – Joints	Alignment – General Misalignment	• Construction tolerances and uneven bearing surfaces • Differential settlement between adjacent panels • Thermal expansion/contraction shifting joints • Equipment impacts during construction	• Reset panels and adjust shims; grout pads may be used to correct alignment • Install joint fillers and sealants rated for large displacements	• Misalignments may indicate settlement and should be monitored for recurrence or condition state progression • Persistent and reoccurring misalignments may require localized reconstruction	Berg, Christopher and Samtani 2009 CMHA 2024 INDOT 2025

7 SUMMARY OF RECOMMENDATIONS

This section provides guidance for integrating the vulnerability and risk framework into WisDOT's existing inspection, data management, and asset planning systems. It outlines practical steps for operationalizing the scoring methodology, aligning it with current workflows, and leveraging it to support risk-informed decision-making across the MSE wall lifecycle.

7.1 WisDOT Practice Documents

The comments provided by the research team reflect their experience in the selection, design, construction, inspection, and repair of MSE walls and conformance to general industry practice, professional project experience, previous project deliverables, design guidelines, industry design documents, and U.S. federal design documents. Provided commentary and recommendations should be reviewed and integrated into WISDOT practice where feasible. WisDOT is recommended to consider if any other internal or external agency referenced documents may contradict or confirm these recommendations but were not considered in this review.

7.2 Risk-Based Management Strategy

The vulnerability and risk framework allows WisDOT to shift from condition-based maintenance to a risk-based management approach that prioritizes structures based on exposure, reliability, and potential consequences in addition to observed distress. This strategy helps identify high-risk walls before visible deterioration occurs, promotes consistent prioritization across regions and wall types, supports efficient allocation of inspection and repair resources, and improves long-term planning and budgeting. Recommended actions include using vulnerability and risk scores to guide inspections, repairs, and replacements, integrating these scores into maintenance and capital improvement programs, and establishing thresholds to trigger special inspections when necessary.

7.3 Integration with HSI and Asset Management Systems

Integrating the vulnerability and risk framework into WisDOT's HSI will enable automated scoring, reporting, and decision support for wall management. This process involves linking relevant datasets to HSI wall records, adding key scoring fields, and developing a scoring module to automatically calculate vulnerability and risk scores from inspection and exposure data. Visualization tools such as dashboards and risk maps will help display and prioritize structures by region, wall type, or age, while exported lists will support inspection and repair scheduling. A feedback loop will ensure that scores are updated after each inspection or repair, allowing WisDOT to monitor changes over time and assess the effectiveness of maintenance interventions.

7.4 Inspection and Data Collection Enhancements

To improve the accuracy of vulnerability scoring and long-term performance tracking, WisDOT should strengthen its inspection and data collection procedures. Recommended actions include expanding the SIM to cover component-level assessments tied to vulnerability factors, standardizing defect codes and condition descriptors for MSE-specific issues, and training

inspectors to document construction quality indicators. Where feasible quantifiable values for conditions and distresses are recommended to be developed such as specific crack diameters and lengths, when supported by practice and their impact on asset performance can be justified. Additionally, WisDOT should incorporate NDT methods such as GPR and LiDAR for subsurface evaluations when appropriate and promote the digital submission of redline drawings and as-built records to enhance construction quality scoring.

7.5 Organizational Roles and Responsibilities

Successful implementation of the vulnerability and risk framework depends on coordinated efforts across several WisDOT units. While determination of application structure is wholly the responsibility of WisDOT the research team recommends the following potential organizational structure and responsibilities: The Bureau of Structures oversees scoring methodology, design review, and quality assurance integration, while regional inspection teams will handle field data collection, condition assessments, and defect documentation. The Asset Management Group will incorporate scores into planning and budgeting processes, IT and Data Systems will develop scoring tools and dashboards, and Maintenance and Operations will carry out prioritized repairs and monitor high-risk walls. Clearly defining these roles and workflows will ensure consistent application and long-term sustainability of the framework.

7.6 Pilot Implementation Strategy

To verify the effectiveness of the vulnerability and risk framework, WisDOT should implement a phased pilot rollout. The research team recommends a three-phase approach. In Phase 1, a prototype will be developed by selecting 10 to 15 representative MSE walls, assigning preliminary scoring values, and comparing calculated vulnerability and risk scores to historical data. Phase 2 will focus on field validation through targeted inspections of high-risk walls, refining scoring accuracy, and updating protocols based on findings. Finally, Phase 3 will involve a statewide rollout, including staff training, full integration of scores into the HSI system, and using the results to guide inspection and repair planning over a one- to three-year period.

7.7 Long-Term Integration and Expansion

Once established WisDOT can enhance the vulnerability and risk framework by incorporating additional factors such as soil chemistry, groundwater conditions, revised traffic loading, and seismic exposure. The framework can also evolve to include predictive modeling that forecasts deterioration and optimizes maintenance timing, as well as cross-asset integration to apply similar scoring methods to other geotechnical assets like slopes and embankments. Additionally, using vulnerability scores to guide performance-based design standards and contractor quality assurance will strengthen overall system reliability. These advancements will position WisDOT as a leader in geotechnical asset management and promote ongoing improvements in MSE wall safety and performance.

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APPENDIX A: SUPPLEMENTAL FIGURES

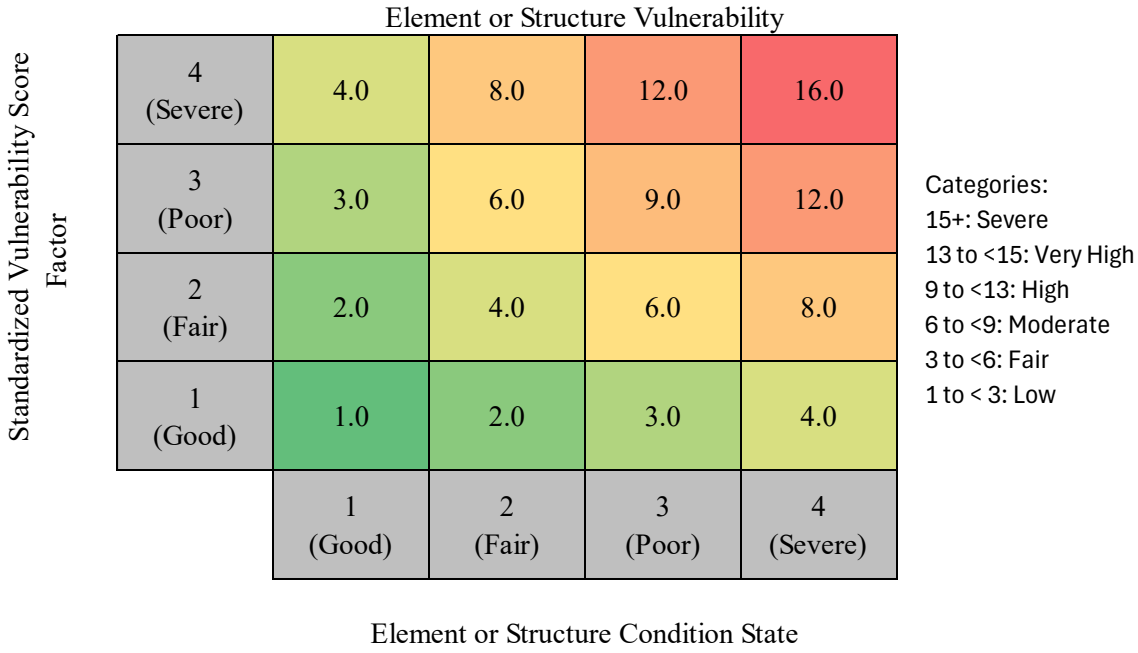

Figure 16. Element and structure vulnerability scores based on the composite vulnerability score factor (Factor$_{VS}$) and element or structure condition states. Increasing score indicates increasing vulnerability.

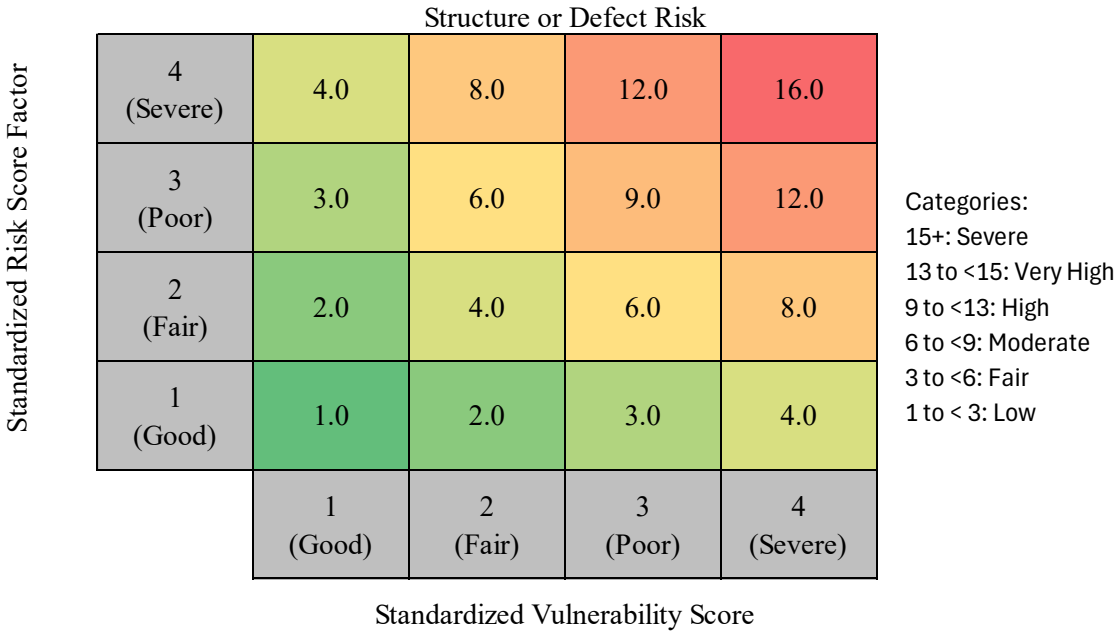

Figure 17. Structure and defect risk scores based on the composite risk score factor (Factor$_{VS}$) and defect or structure vulnerability score. Increasing score indicates increasing risk.

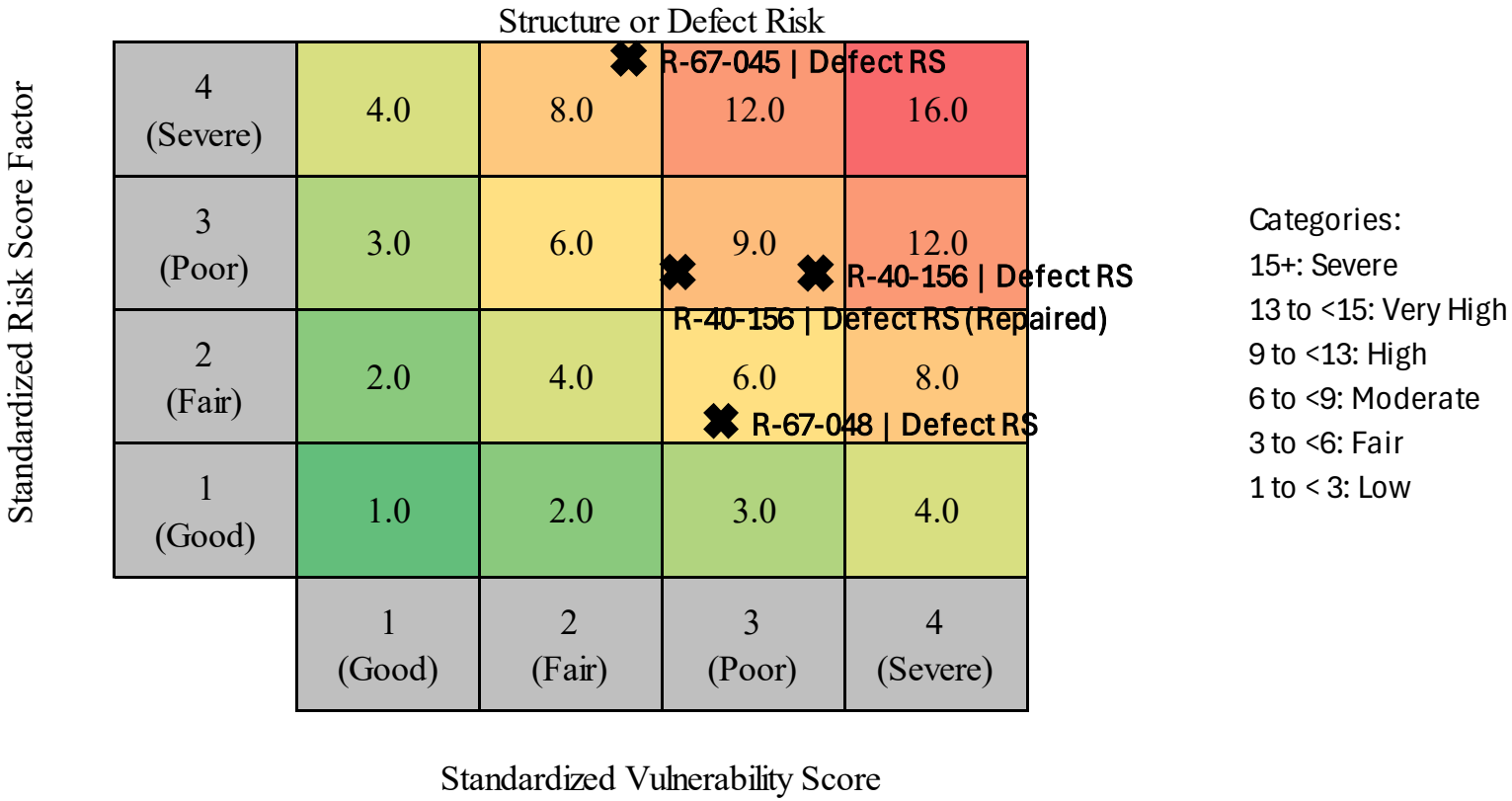

Figure 18. Visual representation of calculated defect risk scores relative to vulnerability and risk score factors for examined walls and for wall R-40-156 following repair.

APPENDIX B: SUPPLEMENTAL TABLES

Table 15. Probable causes of various distresses of different components of MSE walls.

Element	Defect (Distress)	Probable Cause(s)	Reference
Facing Wall	Differential settlement or low spot in wall.	• Foundation (subgrade) material too soft or wet for proper bearing • Poor Fill materials or inadequate compaction	Berg, Samtani and Christopher, 2009
	Overall wall leaning beyond vertical alignment tolerance.	• Foundation (subgrade) material too soft or wet for proper bearing • Poor Fill materials or inadequate compaction	Berg, Samtani and Christopher, 2009
	Wall out of vertical alignment tolerance (plumbness) or leaning in.	• Excessive batter set in panels or offset in modular block units for select granular backfill material being used • Inadequate compaction of backfill • Possible bearing capacity failure	Berg, Samtani and Christopher, 2009
		• Internal settlement due to insufficient compaction	Athanasopoulos-Zekkos, et al., 2020
	Wall out of vertical alignment tolerance (plumbness) or leaning out.	• Panel not battered sufficiently • Oversized compaction equipment working within 3 ft of wall facing panels • Backfill material placed wet of optimum moisture content. Backfill contains excessive fine materials • Backfill material pushed against back of facing panel before being placed and compacted above reinforcing elements • Excessive compaction of uniform, medium-fine sand • Backfill material dumped close to free end of reinforcing elements, then spread toward wall face, causing displacement of reinforcements and pushing panel out • Shoulder wedges not seated securely • Shoulder clamps not tight • Slack in reinforcement to facing connections • Inconsistent tension of geosynthetic reinforcement to facing • Localized over-compaction adjacent to MBW unit	Berg, Samtani and Christopher, 2009
		• Improper geogrid installation • Inadequate drainage • Inadequate compaction	Athanasopoulos-Zekkos, et al., 2020
	Wall out of horizontal alignment tolerance, or bulging.	• Backfill material placed wet of optimum moisture content • Backfill contains excessive fine materials • Backfill materials pushed against facing panels before being placed and compacted above reinforcing elements • Excessive compaction of uniform, medium-fine sand • Backfill saturated by heavy rain or improper grading of backfill after each day's operations	Berg, Samtani and Christopher, 2009
Facing Panel	Spalling, chipping, or cracking, and bulging out of facing units	• Foundation (subgrade) material too soft or wet for proper bearing • Stones or concrete pieces between facing units (e.g. units not clean or used to level face units) • Poor Fill materials or inadequate compaction • Inadequate spacing in horizontal and vertical joints • Use of improper bearing pads • Stones or concrete pieces between facing units (e.g. units not clean or used to level face units)	Berg, Samtani and Christopher, 2009
	Water stain on facing panels and joints	• Drainage failure	

Element	Defect (Distress)	Probable Cause(s)	Reference
	Panels do not fit properly in their intended locations.	• Panels are not level • Differential settlement • Panel cast beyond tolerances	Berg, Samtani and Christopher, 2009
	Large variations in movement of adjacent panels.	• Backfill material not uniform • Backfill compaction not uniform • Inconsistent setting of facing panels	Berg, Samtani and Christopher, 2009
	Loss of backfill through panel joints	• Presence of excessive fines • Poor drainage	Aubeny, et al., 2014
	Rust staining at the crack	• Excessive corrosion	Janacek, 2013
	Changes in panel joint spacing / growth of vegetation	• Poor drainage	Janacek, 2013
Reinforced Backfill	Cracking in the ground surface behind the wall	• Inadequate drainage • Insufficient compaction of the backfill • Presence of clayey soil in the reinforced backfill	Athanasopoulos-Zekkos, et al., 2020
	Backfill erosion	• Presence of excessive fines • Poor drainage	Aubeny, et al., 2014
	Large void in the backfill	• Poor drainage and subsequent erosion	Aubeny, et al., 2014; Athanasopoulos-Zekkos, et al., 2020
Other Components	Movement of spread footing foundation	• Inadequate reinforcement • Presence of clayey soil	Athanasopoulos-Zekkos, et al., 2020
	Pavement cracking, depression near the approach as departure side of MSE wall	• Unsuitable backfill materials • Poor drainage • Presence of clayey soil under the foundation	Aubeny, et al., 2014
	Lateral movement or dislocation of traffic rail/barrier on the top of MSE wall	• Unsuitable backfill materials • Poor drainage • Presence of clayey soil under the foundation	Aubeny, et al. ,2014; Janacek, 2013

Table 16. Description of commonly used corrosion models for buried metallic reinforcement of MSE wall.

Model	**Model Description**	**Form** [1, 2]	**Applicability**
(Darbin, Jailloux and Montuelle 1988)	Model was developed from 20 years of data from controlled conditions - electrochemical test specimens & samples buried in soil box. This model assumes that the loss of steel reinforcement occurs after the depletion of zinc coating.	$X = 50 * t_f^{0.65} - 2 * z_i \quad for\ t_f > \left(\frac{z_i}{25}\right)^{1.54}$ $X = 0 \quad for\ t_f < \left(\frac{z_i}{25}\right)^{1.54}$	Galvanized steel buried under backfill of MSE wall that has resistivity greater than 1000 Ω-cm.
(Elias 1990)	Mainly based on Romanoff (1957). The model coefficient was calibrated to predict corrosion on plain steel. The model provides a conservative estimate of metal loss buried in MSE wall fill.	$X = 80 * t_f^{0.80}$	Plain steel buried in granular backfill in MSE wall.
(Rehm 1980)	Also known as Stuttgart model. It is a linearized form of Romanoff/Darbin model. For galvanized steel, the module assumes that the steel loss occurs after the zinc layer is depleted. The model also assumes that zinc layer depletion rate is highest during first 2 to 4 years and then the rate is reduced significantly.	Low salt content Galvanized $X = 9\left(t_f - 2 - \frac{z_i - 12}{2}\right)$ Plain steel $X = 90 + 9(t_f - 2)$ High salt content Galvanized $X = 12\left(t_f - 3 - \frac{z_i - 51}{2}\right)$ Plain steel $X = 160 + 12(t_f - 2)$	Galvanized or plain steel buried in granular backfill in MSE wall.
AASHTO	This model is similar to Stuttgart model but considers more conservative approach in defining the rate of corrosion. This model also assumes that the steel reinforcement corrosion will only occur after zinc layer is depleted.	$X = 12\left(t_f - 2 - \frac{z_i - 30}{4}\right)$	Applicable for fill with: - pH = 5-10 - Resistivity >= 3000 Ω-cm - Chlorides <= 100 ppm, - Sulfates <= 200 ppm, and - Organic content <= 1%
Caltrans (Jackura, Garofalo and Beddard 1987)	This model was developed based on the data collected from MSE sites located in California. The model assumes a higher rate of metal loss over the design period. The model also assumes that the zinc layer exists until 10 years with initial thickness of 2 oz/ft2.	$X = K(t_f - C_{yrs})$ K and C varies with solid type	Applicable for fill with: - pH = 5.5-10 - Resistivity >= 2000 Ω-cm - Chlorides <= 250 ppm, - Sulfates <= 500 ppm, and

[1.] X is corrosion thickness loss in mm.
[2.] z_i is zinc depletion in mm; and t_f is time in years

Table 17. Available techniques to determine the condition of MSE walls.

Defect or Concern	**Monitoring Methods**
Drainage behavior of backfill	• Visual observation at outflow points • Open standpipe piezometers
Horizontal movements of face	• Visual observation • Surveying methods (LiDAR) • Horizontal control stations • Tiltmeters
Horizontal movements within overall structure	• Surveying methods • Horizontal control stations • Probe extensometers • Fixed embankment extensometers • Inclinometers • Tiltmeters
Vertical movements of the overall structure	• Visual observation • Surveying methods (LiDAR) • Benchmarks • Tiltmeters
Local movements or deterioration of facing elements	• Visual observation • Check gauges (cack meters)
Vertical movements within the mass of the overall structure	• Surveying methods • Benchmarks • Probe extensometers • Horizontal inclinometers • Liquid level gauges
Lateral earth pressure at the back of facing elements	• Earth pressure cells • Strain gauges at connections • Load cells at connections
Stress distribution at base of structure	• Earth pressure cells
Stress in reinforcement OR Stress distribution in reinforcement due to surcharge loads	• Resistance strain gauges • Induction coil gauges • Hydraulic strain gauges • Vibrating wire strain gauges • Multiple telltales
Relationship between settlement and stress-strain distribution OR Stress relaxation in reinforcement	• Same instruments as for: • Vertical movements of surface of overall • Structure vertical movements within mass of overall structure • Stress in reinforcement, and • Earth pressure cells
Total stress within backfill and at back of reinforced wall section	• Earth pressure cells
Pore pressure response below structures	• Open standpipe piezometers

Defect or Concern	Monitoring Methods
	• Pneumatic piezometers • Vibrating wire piezometers
Temperature	• Thermocouples • Thermistors • Resistance temperature devices • Frost gauges
Rainfall	• Rainfall gauge
Barometric pressure	• Barometric pressure gauge
Backfill Resistivity	• Resistivity Imaging
Void, air pockets, reinforcement condition	• Ground penetrating radar (GPR)
Pavement cracks, dislocation of traffic rail	• Visual Inspection
Gaps between concrete panel and backfill	• Infrared thermometer

Table 18. Selected defects, probable causes, and repair strategies for MSE structures.

Category	Defect	Probable Cause(s) [1]	Repair Strategies	Limitations and Commentary	References
Copings and Parapets	Displacement and Tipping	• Differential settlement between facing and reinforced soil mass • Inadequate bearing surfaces or poor connection detailing • Freeze–thaw cycles and water infiltration weakening bedding • Construction tolerances leading to long-term misalignment	• Reset displaced units and clean and level bearing surfaces • Reseal joints to limit moisture infiltration • Installation of anchors or dowels may be used to reduce displacement between units but may increase stress transfer to facing units.	• Temporary stabilization may be required if settlement is ongoing • The use of a flexible non-cementitious sealant (e.g., polyurethane) may improve joint performance if not previously used • Long-term performance requires addressing underlying settlement or drainage issues	Berg, Christopher and Samtani, 2009 Elias, Christopher, and Berg, 2001 CMHA, 2024 INDOT, 2025 Uretek, 2025
	Detachment	• Corrosion or deterioration of connectors and bedding materials • Water infiltration weakening mortar or grout beds • Impact loads from vehicles or snowplows • Stiffness incompatibility between parapets and flexible MSE facings	• Reinstall or replace connectors and reset coping or parapet elements • Add supplemental anchorage where feasible • Apply sealants or waterproofing membranes to improve connection and reduce freeze-thaw cycle impact	• Connection details may require redesign if movement persists • The use of a flexible non-cementitious sealant (e.g., polyurethane) may improve joint performance if not previously used	Berg, Christopher and Samtani, 2009 CMHA, 2024 INDOT, 2025 Uretek, 2025
Facing Units	Displacement – Outward	• Increased hydrostatic pressures from saturated backfill or clogged drains • Insufficient (short) reinforcement lengths or poor connection performance • Differential settlement behind the wall	• Repair or improve drainage, or install pressure-relief measures which may include permeable joint seals, weep drains, or horizontal relief drains • Reconstruct localized facing and reinforced zones • Installation of restraint and reinforcement systems	• Vertical drains may also be used but may require active pumping • Reconstruction with longer reinforcement may be necessary if deficiencies are systemic • Restraint and reinforcement systems include buttress walls, soil nails, tiebacks, and tiebacks and walers •	Berg, Christopher and Samtani, 2009 CMHA, 2024 TxDOT, 2024 INDOT, 2025 Hall and Afkhami, 2014
	Displacement – Inward	• Settlement or consolidation of retained soils • Loss of confinement due to erosion or void formation • Poor compaction or presence of compressible soils • Rebound after removal of surcharge loads	• Recompact or replace backfill behind facing (reconstruction) • Install flowable fill or pressure-grout void; the use of structural polyurethane foams and resins may also be suitable • Installation of restraint and reinforcement systems may be an suitable alternative to pressure grouting	• Restraint and reinforcement systems include buttress walls, soil nails, tiebacks, and tiebacks and walers	Elias, Christopher, and Berg, 2001 CMHA, 2024 INDOT, 2025 TSPWG, 2015 Uretek, 2025 Hall and Afkhami, 2014
	Cracking or Spalling	• Freeze–thaw cycles and moisture infiltration • Poor concrete quality or inadequate curing • Thermal stress and restrained movement • Impact loads or corrosion of embedded hardware	• Patch with polymer-modified mortars or inject epoxy to stabilize crack defects • Replace severely damaged units • If moisture infiltration originates from the wall face apply sealers to reduce moisture penetration; if excess moisture infiltration originates from behind the wall repair or improve drainage or install pressure-relief measures • Replace panels when deterioration is structural or widespread	• The ability to replace severely damaged units depends on MSE facing material and connection facing connection method • This repair is most practical near the top of MSE structures and in areas where limited reconstruction is permissible	Berg, Christopher and Samtani, 2009 CMHA, 2024 INDOT, 2025
	Scaling or Delamination	• Freeze–thaw cycles and deicing salt exposure • Weak surface paste or low air-entrainment • Entrapped moisture expanding during freezing • Poor vibration or curing in precast units	• Remove loose material and apply bonded overlays • Patch deeper delamination with polymer-modified mortars • Severe delamination may require panel replacement • Apply protective sealers to reduce environmental exposure to deicing chemicals	• Drainage improvements above the MSE wall may be used to reduce exposure to excess moisture and deicing chemicals	Berg, Christopher and Samtani, 2009 CMHA, 2024
Facing – Joints	Alignment – General Misalignment	• Construction tolerances and uneven bearing surfaces • Differential settlement between adjacent panels • Thermal expansion/contraction shifting joints • Equipment impacts during construction	• Reset panels and adjust shims; grout pads may be used to correct alignment • Install joint fillers and sealants rated for large displacements	• Misalignments may indicate settlement and should be monitored for recurrence or condition state progression • Persistent and reoccurring misalignments may require localized reconstruction	Berg, Christopher and Samtani, 2009 CMHA, 2024 INDOT, 2025
	Alignment – Out of Plane	• Panel rotation from uneven compaction or backfill pressure • Differential settlement causing tilt or twist • Poor connection performance allowing excessive movement	• Minor misalignments may be corrected with grout pads or shims while panels remain in-place • Moderate to significant misaligned require partial disassembling and reconstruction of affected areas	• Temporary bracing or unloading of the MSE through surficial soil removal may be used to facilitate repairs • Reinforced soil mass movement must be stabilized if present	Elias, Christopher, and Berg, 2001 CMHA, 2024 INDOT, 2025

		• Hydrostatic pressure pushing panels outward	• For hydrostatic induced movements repair or improve drainage, or install pressure-relief measures which may include permeable joint seals, weep drains, or horizontal relief drains		
	Void Formation / Loss of Backfill	• Erosion or migration of fines through joints or geotextiles • Poor drainage or concentrated water flow paths • Improper compaction near the facing • Burrowing animals or utility trenching	• Use flowable fill or pressure-grout to fill voids • Improve drainage and seal joints; joint filler may be semi-permeable if joint drainage is desired • Excavate and reconstruct severe void areas	• Correct drainage and erosion sources for long-term stability	Elias, Christopher, and Berg, 2001 CMHA, 2024 INDOT, 2025 FDOT, 2012 TSPWG, 2015
	Free-Flow of Water (Leachate)	• Clogged drains or inadequate filter layers • Surface runoff concentrating behind the wall • Poor joint sealing or missing backer rods • Freeze–thaw cycles worsening leakage paths	• Inspect and repair drainage • Regrade the ground surface and crack seal pavements to improve surface water management • Seal joints with impermeable filler and sealant • Improve drainage, or install pressure-relief measures which may include permeable joint seals, weep drains, or horizontal relief drains if flow continues	• Joint sealing should be performed after correcting drainage to avoid increases in hydrostatic pressure	Berg, Christopher and Samtani, 2009 CMHA, 2024 INDOT, 2025
Overall Structure	Differential or Local Settlement	• Variable foundation soils or inadequate compaction • Consolidation of soft subgrades • Poor drainage weakening foundation soils • Erosion or loss of backfill creating depressions	• Stabilize foundation soils using pressure-grout or structural polyurethane foams and resins • Fill and compact surficial voids • Removal and replacement of near-surface soils with lightweight alternatives along with partial reconstruction of the MSE wall may be used to reduce loading on soft subgrades • Reconstruct severely impacted all sections	• Grouting programs tend to be more successful for uniform sites experiencing localized settlement; large-scale grouting plans require extensive monitoring to evaluate structure response and secondary grouting programs • Long-term performance requires addressing underlying drainage issues if weakened foundation soils are the root cause	Berg, Christopher and Samtani, 2009 CMHA, 2024 TxDOT, 2024 INDOT, 2025 Uretek, 2025
	Displacement – Outward	• Increased hydrostatic pressures from saturated backfill or clogged drains • Inadequate reinforcement length or global stability issues • Weak foundation soils allowing rotation or sliding • Excessive loading triggering outward movement	• Repair or improve drainage, install pressure-relief measures which may include permeable joint seals, weep drains, or horizontal relief drains • Add soil reinforcement or external stabilization • Rebuild sections with longer reinforcement	• Full reconstruction may be required for deep-seated instability or in cases of exceedingly weak subsoils • Restraint and reinforcement systems include buttress walls, soil nails, tiebacks, and tiebacks and walers	Elias, Christopher, and Berg, 2001 CMHA, 2024 TxDOT, 2024 Hall and Afkhami, 2014
	Displacement – Inward	• Settlement or softening of retained soils • Erosion or loss of confinement behind the wall • Poor compaction or compressible soils • Rebound of underlying soils after surcharge removal	• Use flowable fill or pressure-grout to fill voids; the use of structural polyurethane foams and resins may also be suitable • Recompact or replace retained soils	• Correct drainage and erosion sources for long-term stability • Restraint and reinforcement systems include buttress walls, soil nails, tiebacks, and tiebacks and walers	Elias, Christopher, and Berg, 2001 CMHA, 2024 INDOT, 2025 TSPWG, 2015 Uretek, 2025
	Void Formation / Loss of Backfill	• Erosion or water infiltration behind the wall • Migration of fines through joints or drainage layers • Poorly installed geotextiles or clogged drains • Surface runoff or animal activity creating voids	• Seal joints • Use flowable fill or pressure-grout to fill voids; the use of structural polyurethane foams and resins may also be suitable • Repair or improve drainage, install pressure-relief measures which may include permeable joint seals, weep drains, or horizontal relief drains • In cases of severe loss of backfill, excavation and replacement of backfill may be required (reconstruction)	• Correct drainage and erosion sources for long-term stability	Elias, Christopher, and Berg, 2001 CMHA, 2024 INDOT, 2025

[1] Refer to Table 6 and Table 15 for probable cause references.

APPENDIX C: SURVEY RESPONSES

Q1: Does your agency have project level guidance on the selection, design, and construction/ inspection of MSE walls? Where is this guidance documented?

State	Response
KDOT	*Wall design and layout is a multi-disciplinary process involving, as a minimum, the Geotechnical, Road Design and Bridge Design Sections. In addition, many other functional units within the agency may have input regarding use of these structures. The Project Manager (The Bureau of Road Design or Consultant) coordinates with all of the design units involved in a project. This guidance is documented in the Bridge Design Manual and Bridge Construction Manual. Minimum requirements for MSE wall geotechnical investigations are documented in the Geotechnical Manual.*
INDOT	*Yes, guidance is available in Section 7.31 of the Indiana Standard Specification 2024, Chapter 410 of the Indiana Design Manual, and MSE Wall Construction Inspection Manual. In addition, there are feasibility checklists that are used at different steps of the design and construction phases. All this information can be found on the INDOT website.*
NJDOT	*Selection of MSE wall versus other wall types is recommended by NJDOT's designer and approved by NJDOT. The design requirements are depicted in the NJDOT Bridge Design Manual. The construction is controlled by the contract documents (Design plans and specifications), working drawings by the wall designer/supplier, and QA/QC of suppliers (i.e. RECo Construction Installation Manuals).*
MoDOT	*For project level guidance on the selection and design of MSE walls, see 751.24 LFD Retaining Walls - Engineering_Policy_Guide (modot.org). We do not have specific guidance regarding construction and inspection. Some of the basic construction requirements are addressed in our standard specifications, see link in answer 5.*
NDDOT	*We have a standard special provision that has requirements for the construction of the wall and the manufacturer portion of the design. We update the SP as necessary internally and attach it to projects. We do not have guidance on selection or design.*
Oregon DOT	*Chapter 16 of the ODOT Geotechnical Design Manual includes guidance for selection of retaining wall system type and design methods and requirements for MSE retaining walls. Section 00596A of the Oregon Standard Specifications for Construction specifies submittals, materials, labor, construction, tolerances requirements for the contractor to follow and the construction inspector to ensure compliance. The ODOT Non-Field-Tested Materials Acceptance Guide is organized by specifications section numbering and lists documentation and testing responsibilities for material acceptance.*
TxDOT	*a. Yes, the requirements for designers exist within our Geotechnical Manual https://onlinemanuals.txdot.gov/TxDOTOnlineManuals/txdotmanuals/geo/geo_lrfd.pdf* *b. The requirements for inspection exist in Item 423 of the Standard Specifications https://www.txdot.gov/content/dam/docs/specifications/2024/spec-book-0924.pdf*

State	Response
VDOT	*Yes. Selection and design criteria are in the S&B Manual. Construction criteria are in our Special Provision for MSEW.*
WSDOT	*Yes, available on the website.*
FDOT	*Yes. Standard Plans - FY 2024-25 (fdot.gov). In particular, see Standard Index No. 548-020*
MnDOT	*Mostly, we rely on NHI document 132042, "Design and Construction of MSE Walls". We also provide some direction in our special provisions. We have additional state specific guidance which is being to be developed for inclusion in our LRFD Bridge Design Manual. The special provisions we have been developed are attached.*
IDOT	*Guidance on the selection and design is discussed in the IDOT Bridge Manual. Design and construction is discussed in Article 522 of the IDOT Standard Specifications for Road and Bridge Construction.*
ODOT	*Yes; Microsoft Word - MSE Wall Shop Drawing Checklist (rev 3).docx (ohio.gov)*
IADOT	*Design: https://iowadot.gov/design/dmanual/200F-03.pdf*
MDOT	*General criteria to guide in the selection of retaining wall types is included in Table 16 of the MDOT Geotechnical Manual (https://www.michigan.gov/mdot/-/media/Project/Websites/MDOT/Programs/Bridges-and-Structures/Geotechnical-Services/Geotechnical-Manual.pdf?rev=230780ad19a74ee6956b7c81729c8506&hash=B68B7B0D10617FD014AAB47E1368C330).* *Design requirements that the Engineer of Record and Geotechnical Engineer are responsible for as well as detailing information for MSE walls are outlined in Section 7.03.12 of the MDOT Bridge Design Manual (https://mdotjboss.state.mi.us/stdplan/getStandardPlanDocument.htm?docGuid=3c008b88-0fa1-4a0f-b9a8-56e57482af24).* *Design requirements that the MSE wall supplier is responsible for is outlined in the Special Provision for Mechanically Stabilized Earth Retaining Wall System (20SP-706B-02) (https://mdotjboss.state.mi.us/SpecProv/getSSSPDocumentById.htm?projNum=704577&fileName=20SP-706B-02.pdf).* *Material, fabrication, and construction requirements for MSE walls are outlined in the Special Provision for Mechanically Stabilized Earth Retaining Wall System (20SP-706B-02) (see the link in the bullet point above).* *Guidance for the inspection of the construction of MSE walls is included in Section 719 of the MDOT Construction Manual (https://mdotwiki.state.mi.us/construction/index.php?title=719_-_Earth_Retaining_Structures).* *Requirements for verifying the compaction of the soil placed during the construction of a project is outlined in the MDOT Density Testing and Inspection Manual (https://www.michigan.gov/mdot/-/media/Project/Websites/MDOT/Business/Construction/Standard-Specifications-Construction/CFS-Manuals/Density-Testing-Inspection-Manual.pdf?rev=a07cccb9b9904c7ab28a9f885ad5a43c&hash=B72BD47368755B67482D7FF00B282052).*

Q2: Does your agency have written requirements and Construction and/or routine post construction inspection procedures for MSE walls? Where is this guidance documented?

State	Response
KDOT	*No*
INDOT	*We have a written construction inspection manual but routine post-construction inspection procedures for MSE walls are still under development. However, field inspections are performed as part of the bridge inspection program that identifies MSE Walls that need retrofit work. We also do not have standalone written maintenance procedures for MSE walls. However, we have an on-going IDIQ Contract that includes design specifications for the retrofit work.*
NJDOT	*Wall acceptance criteria are set in the contract documents. Wall inspection procedure is currently under development*
MoDOT	*No*
NDDOT	*No*
Oregon DOT	*Due to variations between proprietary MSE retaining wall systems, we do not have a single comprehensive construction inspection manual for MSE retaining walls. The Retaining Wall Engineer has provided "Hands-on Just-in-time training assistance" during construction utilizing the manufacturer's construction manual and the contract special provisions.*
TxDOT	*a. Requirements for inspections are covered in the Standard Specifications listed above.* *b. Material testing frequency is covered by the Guide Schedule https://ftp.dot.state.tx.us/pub/txdot/mtd/dbb-guide/guide_schedule-0719.pdf*
VDOT	*No*
WSDOT	*No*
FDOT	*Yes. Standard Specifications Standard Specifications Library (fdot.gov) and MSE Wall Inspector's Handbook Documents and Publications (fdot.gov)*
MnDOT	*We do not have these requirements recorded.*
IDOT	*No*
ODOT	*Yes, see answer to question 1, as well as Supplemental Specification 840*
IADOT	-

State	Response
MDOT	*a. Material, fabrication, and construction requirements for MSE walls are outlined in the Special Provision for Mechanically Stabilized Earth Retaining Wall System (20SP-706B-02) (see the link in the bullet point above).* *Guidance for the inspection of the construction of MSE walls is included in Section 719 of the MDOT Construction Manual (https://mdotwiki.state.mi.us/construction/index.php?title=719_-_Earth_Retaining_Structures).* *Guidance for the post construction inspection of MSE walls that are part of a bridge substructure are outlined in Section 5.17.03 and 5.17.04 of the Michigan Structure Inspection Manual (https://www.michigan.gov/mdot/-/media/Project/Websites/MDOT/Programs/Bridges-and-Structures/Inspections/MISIM/Chapter-5-Inspection-Procedures.pdf?rev=760063f9ae3c4e22b464ea87433d93bd&hash=ADCFF36F29C7353646F4B707962139CC).* *Guidance for the post construction inspection of MSE walls that are functioning as retaining walls away from bridge abutments are outlined in Section 8.3 of the Michigan Ancillary Structures Inspection Manual (https://www.michigan.gov/mdot/-/media/Project/Websites/MDOT/Programs/Bridges-and-Structures/Structure-Preservation-Management/Ancillary-Structures/Resources/MiASIM.pdf?rev=afb31537042848d9a243b789e8332b9d&hash=3EFA42A8BD630CDF4B6BEEF062A7E635).*

Q3: Does your agency have written maintenance procedures for MSE walls? Where is this guidance documented? Does your agency have a retaining wall asset management program? Where is this guidance documented?

State	Response
KDOT	*KDOT's Geotechnical Asset Management program is in its infancy. Our mission is to begin evaluating walls regularly and implementing necessary maintenance if warranted. This will be documented in a database once it is developed.*
INDOT	*We do not have standalone written maintenance procedures for MSE walls. However, we have an on-going IDIQ Contract that includes design specifications for the retrofit work. Yes, we have the retaining wall asset management program, and we are in the process of preparing a complete guideline. A draft inventory collection and distress rating manual is attached.*
NJDOT	*No maintenance procedures. Retaining wall asset management is under development*
MoDOT	*No retaining wall maintenance procedures. No asset management program.*
NDDOT	*No*
Oregon DOT	*We do not have a specific manual for MSE retaining wall maintenance procedures. The Highway Division Maintenance Leadership Team Operational Notice, MG-Activities-1, requires structural repairs to retaining walls greater than 4-feet high measured from the base of the footing to the top of the wall and any wall with a surcharge load be evaluated and designed by a licensed professional. We have had one agency position developing a retaining wall asset management program sporadically over past years and created an inventory database of more than 1,600 retaining walls of various types. The MSE retaining walls are subdivided by facing type. The database was created from contract plans, and not all walls have had site visit documentation. Walls that did have site visits recorded photographs and data on location, and observations to look for wall deformation (localized facing, wall horizontal or vertical alignment change, distress above and below the wall (scour, settlement, pavement cracking, distress in coping). The retaining wall asset management guidance document is in draft, it is not a final, published document.*
TxDOT	*a. No, we do not. Wall maintenance issues are often handled by our group and repair is case specific. b. We do not.*
VDOT	*No*
WSDOT	*No*
FDOT	*As for the portions we attribute to a bridge:* *MSE walls are mentioned in our bridge inspection procedures (850-010-030-k).* *o This language will be updated with the last sentence reading: "…of the MSE walls within 30 feet of the structure or to the end of the approach slab, whichever is greater."* *MSE walls are not found in our BMS Coding Guide and so are not given an NBI rating on the inspection reports.* *On inspection reports they are listed via their Element Code: 8478, a length is given for the wall, and then a defect and condition state as appropriate per our Field Guide.* *As for repairs upon discovery of an issue during a bridge inspection, see attached.*

State	Response
	Each District Maintenance Office has their own Procedure and Quality Control Plan. The attached is an excerpt that gives a good description of the process for dealing with issues found in the field. Panel replacements are discussed in section 5.13 of our Bridge Maintenance and Repair Handbook as a reference.
MnDOT	*We do not have these requirements published at this time.*
IDOT	*No*
ODOT	*No*
IADOT	-
MDOT	*a. MDOT does not currently have written maintenance procedures for MSE walls. b. General work recommendations intended to extend the life of abutments, including MSE walls, are included in Section 5.17.07 of the Michigan Structure Inspection Manual (see the link above). c. General work recommendations intended to extend the life of retaining walls are included in Section 8.3.3 of the Michigan Ancillary Structures Inspection Manual (see the link above).*

Q4: Has your agency experienced post construction performance issues for MSE walls related to joint spacing, corrosion, slope stability, vertical and lateral documents (displacements or movement?) or extreme event occurrences? How common these issues are on a scale of 1 to 5, with 1 being the least common and 5 being the most common. Please provide a brief explanation of the occurrence and how it was repaired. Do you have standard MSE wall repair guidance?

State	Response
KDOT	*It is rare, so I estimate this as a 1. Typically monitoring is done via routine surveys and instrumentation. In a few instances, grout has been used to counter loss of material and vertical displacement of approach slabs where MSE walls wrap around the abutment.*
INDOT	*Yes, post construction performance issues for MSE walls are common. We found the most common issue is the leakage of backfill soil from the walls due to seepage action. It causes a void behind the wall that results in a loss of straight alignment of the wall and settlement/deformation of the top pavement layer. After finding an issue in the MSE wall such as, settlement/depression in the top pavement layer, movement in the MSE wall panels, widening of the wall joints, sedimentation of the backfill soil outside the wall, and other wall distresses, a visual inspection is done to evaluate the severity, identify causes, and look for possible repair strategies. GPR is used to evaluate the underneath soil condition and investigate if there is any void created due to the soil loss. Continuous monitoring is performed to see if the problem becomes worse over time. It should be mentioned that the repair strategy depends on the MSE wall type and degree of severity. In common, the voids are filled with flowable fill materials, and we install soil nails if they are needed. Necessary work is also done to improve the overall drainage facility regarding the MSE wall.*
NJDOT	*Yes, we have observed several performance issues over the years. They are typically we see loss of material (Score =1), damages of panels and foundation by trees (2), corrosion are rare given the age of the walls, extreme slope stability (I-295 wall failure) (1), and several failures due to flooding failure (3).*
MoDOT	*We are not aware of any major issues. I would say "1". We do not have standard MSE wall repair guidance.*
NDDOT	*We have had some vertical deformations in one location that I know of.*
Oregon DOT	*Post construction performance issues of concern have not been a common experience – estimated least common value of 1. There is no standard repair guidance, when a problem is observed, staff is assigned to investigate the source of problem, evaluate the wall condition, the cause for the issue and design repair for the specific situation.*
TxDOT	*a. Joint Spacing – 2: Often these issues do not cause major problems, but if the joints are allowing material to pass through. We often try to seal the joints. b. Slope Stability – 2: Advanced slope/wall stability issues are rare, but when they do occur, they often require buttressing or full removal/replacement. c. Displacements – 1: Local panel displacements may be addressed with partial removal/replacement. Repair need likely depends on the cause of the movement. d. Extreme Event Occurrences – 1: There are not many of these outside of the*

State	Response
	categories above, as most of the walls in state are not subject to "extreme event" conditions.
VDOT	*VDOT has experienced a few isolated post-construction MSEW performance issues. They are 1 for how common. Issues vary including differential settlement and undermining due to scour. Internal and external stability generally have not been an issue. VDOT does not have standard MSEW repair guidance.*
FDOT	*Yes, with a rating of 1 (not very common). Issues have been related to leaks in drainage pipes, usually repaired with polyurethane injection and lining of the drainage feature, or re-construction.*
MnDOT	*Regarding question 4, yes Joe and I have seen some wall movements affecting joint spacing but I would not say it is common. I have not seen any global stability issues with this type of wall or other lateral and vertical movements being we have a pretty good foundation drilling program and geotechnical reporting for our walls. I would say Consultants have improved their work as well for the work they do on local State Aid types of projects that I review. Mass Transit (light rail and rapid buss) projects have seen a few problems, mostly with construction issues (uniformity of compaction and such). Some isolated instances of reactive aggregate in the precast panels have been seen in some older walls causing some minor "rust" discoloration and/or "pop-out" of a few stones (mostly just cosmetic issues it would appear).*
IDOT	*a) Yes - We've experienced several issues: Select MSE fill material spilling out of joints between panels due to failure/lack filter fabric behind joints (3 on the scale) – we sealed the joints along with grouting any voids as necessary; damaged panels (2 on the scale) we've replaced the panel or anchored in place if fractured; panels that have moved out laterally (1 on the scale) – we anchored the panel in place.* *b) No, we have no standard repair guidance.*
ODOT	*Primary post construction performance issue is leaking joints and vegetation growing in joints. We have had few occurrences of substantial loss of select granular backfill, for which void space was backfill with low strength mortar. We have occasional occurrences of panels deteriorating, for which patching is performed, as long as the reinforcement isn't compromised. We have occasional occurrences of deformation occurring, but in every case (judging from memory) we have just monitored the situation to determine the movement didn't compromise the performance of the wall. On a scale of 1-5, we are estimated to be in the 1-2 range. Our MSE wall repair guidance is attached.*

State	Response
WSDOT	*Post construction issues due to internal or external design considerations have been negligible. We haven't tracked numbers, but probably less than 1% of all constructed walls have had post construction issues. It's likely that the high-quality gravel backfill (WSDOT Standard Specification 9—3.14(4)) and high seismic demands result in robust designs.* *Only known failure of a MSE wall was due to scour. A stream migrated from its channel during a storm event and undermined the facia of a panel faced MSE and washed out the backfill. Wall was removed and a soldier pile wall constructed.* *One other wall was damaged by scour during a flood event. Several feet of backfill behind the fascia and several panels displaced vertically be approximately one foot. Void was filled with a controlled low strength material and is still in service. The panels were not jacked back in to position, they were just left in place and the gap filled with concrete.* *Most MSSE walls are tolerant of some settlement. Enclosed drainage in the backfill is not. We've had leaking joints from storm drain systems wash the backfill out of a MSE wall and cause deformation of the wall face.* *Most potential issues have manifested themselves during construction. WSDOT field inspectors either notice the work is not in accordance with specifications, or there is visible displacement of the wall face that triggers additional investigation. Poor control of stormwater runoff and failure to follow manufacturer's construction details have been the cause of most known issues. Some examples:* *Vibratory rollers on a saturated backfill will liquefy the soil. Loss of pullout resistance resulted in significant wall face deformation.* *It is important that blocks are pushed forward to engage connectors on some wall systems. Pulling the blocks back to correct batter does not work. The earth pressure will eventually push the blocks forward until they engage the connectors.* *It is actually important to put the bolt in the connection for RECo walls. We've actually had contractors fail to do so.*
IADOT	-
MDOT	*a. We do not have a standard MSE wall repair guidance.* *b. The most common issue that MDOT has is sand leaking through joints in the MSE wall panels, which isn't common (1). Typically, these are repaired by placing backer rods in the joints that are having issues.* *c. We don't have issues with corrosion, slope stability, vertical or lateral displacements, or extreme event occurrences.* *d. We have had a few MSE walls be hit by vehicles outside of the clear zone. Because of that we have recently changed the requirement to have all MSE wall panels designed for vehicular impact loads. The repair of damaged panels has varied from just epoxy crack injection to full panel replacement, depending on the severity of the damage. This is a rare occurrence (1).*

Q5. Does your agency have written standard procedures or specifications for MSE walls.

State	Response
KDOT	*Yes. These are included primarily in the KDOT Standard Specifications, and secondly in the Bridge Design Manual, and the Geotechnical Manual.*
INDOT	*Yes, guidance is available in Section 7.31 of the Indiana Standard Specification 2024, Chapter 410 of the Indiana Design Manual, and MSE Wall Construction Inspection Manual. In addition, there are feasibility checklists that are used at different steps of the design and construction phases. All this information can be found on the INDOT website.*
NJDOT	*Yes, https://www.nj.gov/transportation/eng/specs/2019/Division.shtml*
MoDOT	*See 751.24 LFD Retaining Walls - Engineering_Policy_Guide (modot.org) for standard procedure and Missouri Standard Specifications for Highway Construction | Missouri Department of Transportation (modot.org) section 720 for MSE walls.*
NDDOT	*We have a standard special provision that has requirements for the construction of the wall and the manufacturer portion of the design. We update the SP as necessary internally and attach it to projects. We do not have guidance on selection or design.*
Oregon DOT	*ODOT has Standard Specifications and Special Provisions boilerplates available electronically.* *https://www.oregon.gov/odot/Business/Pages/Standard_Specifications.aspx*
TxDOT	*a. Specifications are listed in #1 above* *b. We also have MSE wall standard sheets that are inserted into contract plans* *i. https://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/RW-MSE-22.pdf* *ii. https://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/RW-MSEDD-22.pdf*
VDOT	*Special Provision for MSEW, which is a stand alone spec.*
WSDOT	*Available in the website*
FDOT	*Yes. Standard Specifications. Standard Specifications Library (fdot.gov)*
MnDOT	*Yes, see attached.*
IDOT	*Yes – in our IDOT Standard Specifications foe Road and Bridge Construction.*
ODOT	*Yes, see question #2.*
IADOT	*https://www.iowadot.gov/erl/current/GS/content/2432.htm*
MDOT	*a. MSE walls are covered by the Special Provision for Mechanically Stabilized Earth Retaining Wall Systems (20SP-706B-02). A link to this special provision has been included in the responses above.*

APPENDIX D: INDOT MSE WALL DESIGN REVIEW CHECKLIST

MSE WALL DESIGN REVIEW CHECKLIST

INSTRUCTIONS

This checklist should be completed by the Engineer of Record (EOR) and submitted to the Geotechnical Services Division for review at MSEWallShopDrawings@indot.IN.gov, in accordance with IDM Chapter 14.

A link to frequently used abbreviations and acronyms is provided here.

The following tables should be filled out by the party listed in parenthesis.

PROJECT INFORMATION (EOR)

Contract No.	
Des. No. (associated with MSE wall details)	
Route(s)	
Feature Crossed (if applicable)	

DESIGNER (EOR) and GEOTECHNICAL EOR INFORMATION

Name of EOR	
EOR Consulting Firm or INDOT Location	
Name of Geotechnical EOR	
Geotechnical EOR Consulting Firm or INDOT Location	

INDOT GEOTECHNICAL REVIEWER INFORMATION (Geotechnical Engineering Division)

Name	
Date Received	
Date Returned to EOR	
Is a resubmittal required?	

NOTES FOR CHECKLIST

1. The following information/material should be referenced while completing the checklist:
   a. Project documents (final plan set, *Standard Specifications*, Standard Drawings, special provisions, project geotechnical report)
   b. FHWA/NHI manual ("Mechanically Stabilized Earth Walls and Reinforced Soil Slopes," Publications. FHWA NHI-10-024 Vol I and NHI-10-025 Vol II, December 2009; Authors: Ryan R. Berg, Barry R. Christopher and Naresh C. Samtani)
   c. Applicable version of AASHTO *LRFD Bridge Design Specifications*, including interims referenced on the plans.
2. Each question must have a "Yes", "No" or "N/A" box checked. Add any pertinent project specific questions to the checklist under "Place comments here. If NO or N/A is checked comments are required," as necessary. Additional sheets may be used if more space is required.
3. The documents listed under the "Reference" column in the checklist are not intended to be a complete list of documents. Rather, the most common documents are listed where guidance/information related to the question in the checklist may be found. More stringent criteria may exist in other project documents (e.g., special provisions, etc.) that may be relevant to a given question. In such an event, the governing document should be noted in the "Comments/Action Required" column of the checklist.

CHECKLIST

I. INITIAL FEASIBILITY REVIEW FOR PROJECT SITE				
QUESTION	REFERENCE	YES	NO	N/A
1. Has the MSE Wall been submitted to INDOT Geotechnical Services Division for evaluation of suitability? [place date of submittal in comments below]	IDM Ch. 14	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				
II. DESIGN CRITERIA				
QUESTION	REFERENCE	YES	NO	N/A
1. Are all acute angles greater than 70 degrees?	IDM 410-5.01(06)	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				
2. Are the radii of curves in the horizontal alignment of the wall greater than 100 ft for standard 10 ft wide panels, and greater than 50 ft for 5 ft wide panels?	IDM 410-5.01(06)	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				

II. DESIGN CRITERIA (Continued)				
QUESTION	REFERENCE	YES	NO	N/A
3. Are utilities located within the reinforced zone? Where utility placement in the reinforced zone is unavoidable, future access must be provided to the utility without disrupting the reinforcement.	IDM 410-5.01(06)	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				
4. Are utilities located under the wall? Where utility placement under the wall is unavoidable, they should be placed deep enough to minimize the effect of failure as per IDM.	IDM 410-5.01(06)	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				
5. Are culverts located within the reinforced zone? If so, slip joints should be provided. If the culvert is at skew, the skew should not affect the placement of reinforcement as per IDM.	IDM 410-5.01(06)	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				
6. Is the wall embedment per LRFD, but not less than 3 ft from final grade to top of leveling pad, unless founded on rock.?	LRFD 11.10.2.2, Spec 731.03 IDM 410-5.01(05)	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				
7. Is the top of leveling pad at least 1 ft above ordinary high water and groundwater elevation?	IDM 410-5.01(05)	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				
8. Is coarse aggregate No. 8 used behind the wall instead of structure backfill up to the Q100 high-water elevation?	IDM 410-5.01(05)	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				
9. Has a horizontal bench with a min. width of 4 ft been provided in front of walls where the back slope is steeper than 4H:1V?	IDM 410-55.01(05), Spec 731.03	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				

II. DESIGN CRITERIA (Continued)				
QUESTION	REFERENCE	YES	NO	N/A
10. Is the embedment and bench day-lighted and riprapped??	Spec 731.03	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				
11. Does the MSE wall drainage system show the required drain outlets?	IDM 410-5.01(07)	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				
12. Has moment slab been placed adjacent to the MSE wall coping, and not on top of the coping?	Standard Drawings Series E 706-MSRW	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				
13. Has guardrail been located so that the posts will be located outside the limits of the MSE wall reinforced zone?	IDM 410-5.01(05)	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				
14. Have the piles been located a minimum of 4 times the diameter of pile between the back of the wall panels and the center of the piles?	IDM 402-6.02(02)	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				
15. Has a minimum of 6 in. been provided between the MSE coping and face of end bent.?	IDM Fig. 409-2G	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				
16. Have integral end bents and semi-integral end bent diaphragms been isolated from the MSE wall system for calculated thermal movements?	IDM Fig. 409-2G	☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				

III. PLAN DETAILS				
QUESTION	REFERENCE	YES	NO	N/A
1. Have the following been shown in the Elevation View?				
a. Wall envelope including control lines 1, 2, and 3	IDM 410-5.01(07), PGR	☐	☐	☐
b. Minimum embedment from top of leveling pad to the final ground line		☐	☐	☐
c. Undercut and soil improvement requirements		☐	☐	☐
d. Leveling pad steps level and in 2.5 ft increments		☐	☐	☐
e. Obstructions that protrude through the wall face		☐	☐	☐
f. Obstruction, such as utilities, pipes, or culverts, placed below the leveling pad		☐	☐	☐
g. Factored bearing resistance from Geotechnical Report		☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				
2. Have the following been shown in the Plan View?				
a. Obstructions within reinforced or retained backfill zones, including station and offset to the back of wall panel. [due diligence is expected to avoid placing obstructions within the reinforced backfill zone]	IDM 410-5.01(07), PGR	☐	☐	☐
b. Station and offset relative to survey centerline to the back of the wall panel and all such information for turn point locations		☐	☐	☐
c. Flow direction arrows for surface water coming from the bridge, ramp and/or road above the MSE wall and being directed away from the reinforced backfill area of the wall		☐	☐	☐
d. Wall construction limits relative to temporary and permanent ROW		☐	☐	☐
e. Internal wall drainage details with outlet locations		☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				

III. PLAN DETAILS (Continued)				
QUESTION	REFERENCE	YES	NO	N/A
3. Have the following been shown in the Section Views?				
a. Estimated dimensions of reinforced and retained backfill	IDM 410-5.01(07), PGR	☐	☐	☐
b. Slope of ground above the top and in front of wall		☐	☐	☐
c. Distance between the back of the wall face and piles or pile sleeves		☐	☐	☐
d. Undercut and soil improvement details		☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				
4. Have the following Special Wall Details been shown?				
a. Architectural treatments	IDM 410-5.01(07), PGR	☐	☐	☐
b. Special facing elements where connecting to existing wall systems		☐	☐	☐
c. Tiered walls detail in accordance with project criteria, including bench widths, aesthetics within benches, etc.		☐	☐	☐
d. Instrumentation details		☐	☐	☐
Place comments here. If NO or N/A is checked comments are required.				

ABBREVIATIONS / ACRONYMS

Construction Plans	Final plan set for the project as advertised, with all associated revisions.
EOR	Engineer of Record. Professional Engineer who stamped the construction plans
FHWA	Federal Highway Administration
Geotechnical EOR	Geotechnical engineer (in charge of the geotechnical investigation)
IDM	*Indiana Design Manual* https://www.in.gov/indot/design_manual/design_manual_2013.htm including INDOT Design Memorandum No. 17-03 available at https://www.in.gov/indot/files/17-03MSEwalls.pdf
LRFD	AASHTO *LRFD Bridge Design Specifications, including interims referenced on the plans.*
PGR	Project Geotechnical Report
Spec	INDOT *Standard Specifications* and any applicable special provisions (refer to contract documents for applicable spec year)
USP	Project specific unique special provision

APPENDIX E: DETAILED DOCUMENT COMMENTARY

WISCONSIN BRIDGE MANUAL (WBM)

Review of the WBM included chapters and sections related to mechanically stabilized earth (MSE) systems. This included Chapter 14 and Sections 14.1 through 14.6, 14.12, and 14.13 through 14.16. Comments are provided on a per-section basis with general comments provided where applicable and sub-sections referenced as-required for clarity.

General

The WBM provides several examples and explanations on the intent behind requirements (e.g., 4-ft bench in front of MSE required to prevent local instability near the toe). These examples and explanations are likely to reduce errors and misapplication of design standards. Where beneficial, the WBM also provides external references, including FHWA guidance documents. However, several tables are provided for design values; the inclusion of these tables without reference to precedence order compared to AASHTO may result in a discrepancy if the AASHTO tables are updated before the WBM.

Section Specific

Section 14.1

Positive comments include:

- Requiring roadway barrier for walls susceptible to damage from vehicular impact is a reasonable method to reduce risk of panel and wall system damage.
- The WBM emphasis collaboration and communication between project parties including iterative collaboration between WisDOT entities is recommended by FHWA to improve project efficiency and increase owner influence on project outcomes.
- Preparation of a Structure Survey Report (SSR) with preliminary evaluation of wall type, location, and height including preliminary layout plan is an effective tool to improve project efficiency and are supported by a site investigation report (SIR).
- Clear declaration of supplier/contractor responsibilities including structural design, internal and final external stability of proprietary wall systems reduces role ambiguity.
- Design, shop drawing, and computations of proprietary wall systems are reviewed by Bureau of Structures (BOS), reducing the risk of errors and insufficient wall designs.

Neutral comments include:

- SIR contents are well balanced as an initiation site investigation, larger projects or complex site may require supplemental geotechnical explorations. Language should clearly indicate that explorations may be an iterative process if determined appropriate by the designer.
- WisDOT should consider specifying minimum standards for preliminary geotechnical and hydraulic analyses, including thresholds for when additional site exploration is required for consultant produced SSRs and SIRs.
- Contractor design responsibility of temporary walls may improve project efficiency by allowing an increase in material, method, and design freedom. However, reasonable precautions may be appropriate including:
    - WisDOT review of temporary plans to confirm minimum performance and safety standards. This is most relevant when temporary wall systems are supporting active

traffic. WisDOT is encouraged to review these designs to confirm their performance relatively to all regulatory and safety requirements.
    - Evaluation of long-term impacts if actual schedules exceed planned schedules and temporary walls remain in place longer than initially planned or designed for.

Negative comments include:

- The use of 'may' regarding explorations and ERS borings is recommended to be changed to 'shall' (i.e., explorations shall be needed). Appropriate design of MSE walls require borings within the proposed wall area and influenced soils.
- Temporary wall systems pose a risk if plans and calculations are not submitted for review. It is recommended that temporary MSE walls be submitted for review by WisDOT prior to the start of construction whether designed by a consultant, supplier, and contractor.
- Development of minimum safety standards or inspection criteria for temporary walls which have exceeded their planned service life is recommended. These standards may include occurrences such as wall damage due to construction equipment impacts or general wear and tear.
- Inclusion of a flowchart indicating roles of different WisDOT departments and key contact personnel would improve clarity and communication for new practitioners, contractors, and suppliers.

Section 14.2

Positive comments include:

- Clear distinctions are provided between wall categories and classifications.

Neutral comments include:

- MSE description states 'selected soil mass' excluding most LWFs, cellular concrete, and other geomaterials. This may limit design options and affect MSE performance.
- Table 14.2-1, below, should be considered for modification with a column used to indicate which wall types WisDOT considers suitable for temporary applications. Providing a column indicating cut or fill construction may also aid in design selection.

Wall Category	Wall Sub-Category	Wall Type	Typical Construction Concept	Proprietary
Gravity	Mass Gravity	CIP Concrete Gravity	Bottom Up (Fill)	No
	Semi-Gravity	CIP Concrete Cantilever	Bottom Up (Fill)	No
	Reinforced Earth	MSE Walls: • Precast Panels • Modular Blocks • Geogrid/ Geo-textile/Wire- Faced	Bottom Up (Fill)	Yes
	Modular Gravity	Modular Blocks, Gabion, Bin, Crib	Bottom Up (Fill)	Yes
	In-situ Reinforced	Soil Nailing	Top Down (Cut)	No
Non-Gravity	Cantilever	Sheet Pile, Soldier Pile, Tangent/Secant	Top Down (Cut) /Bottom Up (Fill)	No
	Anchored	Anchored Sheet Pile, Soldier Pile, Tangent/Secant	Top Down (Cut)	No

Table 14.2-1
Wall Classification

Table 14.2-1, Wall Classification as presented in WisDOT WBM.

Negative comments on Section 14.2 include:

- While the manual states that temporary walls are designed for the greater of 3 years or the project duration, it lacks emphasis on ensuring adequate design robustness if the project duration exceeds 3 years. For longer-term projects, this could lead to temporary walls that are inadequately designed , especially if they are designed with less restrictive standards.

Section 14.3

Positive comments include:

- The intent of site characterization is clearly described which may help with appropriate exploration planning (Section 14.3.1.3).
- Requiring all right of way (ROW) segments to be under WisDOT control reduces potential long-term maintenance access issues and construction conflicts (Section 14.3.1.5).

Neutral comments include:

- The phrase "site characterization should be performed, as appropriate" can create ambiguity. "As appropriate" might lead to variability in interpretation, resulting in incomplete or inconsistent site characterizations (Section 14.3.1.3)

- Corrosion potential of the soil is not listed (Section 14.3.1.3).
- Drainage considerations and corrosion resistant material selection are missing from design considerations. The addition of a corrosion discussion is recommended to focus on durable material selection and design considerations to minimize long-term maintenance (Section 14.3.1.4). A drainage discussion should also be added.

Negative comments include:

- Recommend replacing "as appropriate" with a clear requirement for site characterization in all retaining wall projects or “as determined by a licensed geotechnical engineer”.
- Section 14.3.1.3 is recommended to indicate that laboratory testing may be required to determine soil properties, and that testing will be specified by WisDOT’s Geotechnical Engineering Unit as the entity responsible for completing the investigation and analyses for all in-house wall design work.
- Section 14.3.1.3 does not discuss soil corrosion potential, as an important design consideration this is recommended for inclusion.

Section 14.4

General comments include:

Section 14.4 is well structured and detailed referring several times to external sources including direct references to AASHTO . Potential further enhancements are provided in the sections below and generally focus on improving documentation, project compliance, and construction feasibility.

Positive comments include:

- WisDOT precedence clearly established in ambiguous areas and standards (Section 14.4.2).
- Clear statement of temporary walls being designed for the entire life of the project and safety requirements must meet those of a permanent wall excluding corrosion and aesthetics; see neutral comments regarding corrosion and aesthetics (Section 14.4.3).
- Required use of walk behind compactor within 3-ft of the wall is a reasonable precaution to reduce the risk of overstressed reinforcement and panel damage (Section 14.4.5.4.3).
- Provided differential settlement tolerances are a reasonable range (Section 14.4.7.2.1).
- Requirement to obtain utility agreements for encapsulated utilities is a reasonable, consider defining or providing typical agreement requirements if possible (Section 14.4.7.9).
- Guardrail placement through MSE and impacts on design are well established in the provided manual (Section 14.4.7.10).

Neutral comments include:

- The provided design workflow and description of tasks is well developed. Several additional steps are suggested to further improve this workflow (Section 14.4.1). These include:
    - Step 1: Indicate environmental impact assessment and site-specific constraints such as soil corrosivity and groundwater conditions which could influence wall selection and design.

    - Clarify Step 5 and Step 7 to indicate adjustments may be needed based on stability and movement checks, reenforcing the iterative design process.
    - Step 7: Identify 'settlement' as part of the iterative design review.
    - Add a step or note to emphasize documentation of design calculations, assumptions, and checks performed. Consider inclusion of guidance on internal and external reviews and approvals by relevant stakeholders.
    - Add a step to review construability including installation, accessibility, and required equipment / knowledge.
    - Add a step or note for final design review and compliance checks including project, local, DOT, and AASHTO code / requirements.
- Consider the use of MSE wall design checklists from FHWA such as those produced by Eastern Federal Lands or from well-developed state programs such as Indiana DOT (INDOT) if not already in use. A copy of the INDOT checklist has been attached to this report for reference, please note that the checklist links are not intended to be functional in this example.
- Corrosion and aesthetic requirements are unclear are unclear for temporary structures, maintenance of temporary structures for corrosion and aesthetics is also unclear (Section 14.4.3).
- Consider clarifying the purpose of each limit state for a more complete understanding (i.e., service limit states address deformations and extreme event limit states account for extreme events such as earthquakes) (Section 14.4.4)

Negative comments include:

- The use of 'may' regarding explorations and ERS borings is recommended to be changed to 'shall' (i.e., explorations shall be needed). Appropriate design of MSE walls require borings within the proposed wall area and influenced soils (Section 14.4.4).
- Recommend referring to AASHTO 10.6.2.4.2, 10.6.2.4.3, and 11.10.4.1 for service limit states and AASHTO 11.10.4.1 for differential settlement. Acceptable deformations should also be confirmed with the project structural engineer (Section 14.4.5).
- Consider the use of AASHTO specific vehicle load recommendations as a replacement for 2-ft of 120 pcf soil surcharge or the greater of the two. The use of AASHTO specific load recommendations will better reflect the range of potential loading on MSE systems across all traffic conditions (Section 14.4.5.4.2).
- Recommend the revision of construction live loads to require the greater of 100 psf or the calculated construction loading for walls without traffic as 100 psf may not be sufficient for many projects (Section 14.4.5.4.2).
    - 'Walls without traffic shall be designed for the greater of a live load of 100 psf or the anticipated construction loading generated by construction equipment including vehicle traffic, heavy equipment, crane loads, and other construction equipment.'
- Recommend a revision to language relating to embedment depth, below, to incorporate 'site-specific' conditions including freeze, shrink-swell, etc. (Section 14.4.7.5).
    - "The final footing embedment depth shall be based on the required geotechnical bearing resistance, wall settlement limitations, and all internal, external, and overall (global) wall stability requirements in AASHTO LRFD and the Bridge Manual".

- The use of the term 'pervious' is poorly defined and should be clarified, consider either a set permissible range, a performance standard, or inclusion of language like that in the WisDOT roadway specification (Section 14.4.7.6).
- For MSE systems which must be installed in areas with utilities, if no other options are available, provide either case scenarios or minimum specifications for their installation (Section 14.4.7.9).

Section 14.5

No comments were prepared for Section 14.5.

Section 14.6

General comments include:

Section 14.6 is generally well written and provides well-developed documentation of responsibilities for project parties (i.e., owner and consultant). Explicit statements on several key design areas reduce the risk of miscommunication of project requirements and performance criteria. The section may be further improved by inclusion of additional documentation requirements for non-WisDOT designs including design submittals for WisDOT acceptance, corrosion guidance, and drainage design guidance.

Positive comments include:

- A clear outline delineation of analysis and design responsibilities between the state and the contractor is provided.
- Explicit requirement of compliance with AASHTO Section 14.4.2. in combination with external FHWA guidance documents for geometrically complex MSE systems provides a comprehensive basis of design.
- Inclusion of supporting structure and the use of smaller wall panels for larger settlements reduces risk and increases likelihood of long-term effectiveness (Section 14.6.1).
- Explicit statement on requiring corrosion of the wall anchors that connect soil reinforcement to the wall face being considered is well received and frequently overlooked (Section 14.6.2.2).
- Restrictions on panel widths based on wall radii are reasonable and the requirement for galvanized reinforcement for CIP concrete facing is well explained and reasonable (Section 14.6.2.3).
- The concrete modular block facing section is comprehensive but excludes drainage and setback tolerances; see negative comments (Section 14.6.2.3).
- The MSE wire-faced section covers several important aspects including bulging limits and differential settlements but excludes soil type limitations and lacks galvanization details; see negative comments (Section 14.6.2.3).
- Cast-in-place (CIP) concrete facing information is comprehensive but excludes drainage and thermal expansion considerations; see negative comments (Section 14.6.2.3).
- Clear statement of MSE wall protection from vehicle impacts reduces structure risk and is a reasonable approach (Section 14.6.3.1).
- Requires submittal of internal and local stability design drawings and calculations for acceptance by the BOS (Section 14.6.3.2).

- Clear inclusion of abutment loads, internal wall design, and external stability (Section 14.6.3.2).
- Influence factors, epoxy protection, and other design factors are generally clearly stated.
- Inclusion of common sources of aggressive environments in Wisconsin (e.g., salt spray, areas near storm pipes) are very useful for designers (Section 14.6.3.8.12).

Neutral comments include:

- Explicit list of restrictions to avoid common issues is very useful, however the provided list excludes conditions which may lead to drainage issues (e.g., flooding, water table fluctuation). Inclusion of potential drainage conditions is recommended for inclusion (Section 14.6.1.1).
- Division of design responsibilities appear fair, submittal of additional consultant engineer calculations to WisDOT for acceptance may be prudent; see negative comments (Section 14.6.3.2).
- Design steps derived from FHWA NHI-10-24 and provide a reasonable basis for most designs; consideration should be given to including environmental factors (e.g., snow loads) in Step 1 and overturning movement in Step 7 (Section 14.6.3.3).
- Statement on extensible reinforcements described in Section 14.6.3.8.2 are better describe on pdf page 86, consider revision to Section 14.6.3.8.2 language.
- Requirement for 6" collector diameter is generally acceptable, consider inclusion of when alternative diameters such as concurrent lower diameter drains, or larger diameter drains may be considered by WisDOT (Section 14.6.3.9).

Negative comments include:

- Inclusion of drainage considerations (i.e., weep holes or panel joint design for thermal expansion and contraction) is recommended due to Wisconsin's climate and the prevalence of freeze-thaw cycles (Segmental Precast Panels, Section 14.6.2.3).
- Additional details on drainage requirements and considerations including drainage aggregate, weep holes, weep layers, drainage blankets, etc. are recommended for all MSE types presented (Section 14.6.2.3).
- Inclusion of setback angle tolerances is recommended for concrete modular block facing (Section 14.6.2.3).
- The MSE wire-faced section is recommended to include soil type limitations or preferred types as fill type will impact wall performance (Section 14.6.2.3).
- The MSE wire-faced section is recommended to additional details on corrosion protection systems for permanent wire-faced walls (Section 14.6.2.3).
- CIP concrete information should include discussion of thermal expansion impacts on join design to reduce the risk of premature panel distress (Section 14.6.2.3).
- Required submission of external stability, overall stability, and settlement calculations to WisDOT for acceptance if completed by a consultant designer is recommended to improve oversite and confirm designer assumptions (Section 14.6.3.2).
- Bearing resistance is recommended to refer to AASHTO LRFD (excerpt below); in particular if soils are soft/compressible the flexibility of the MSE wall may not adequately distribute pressures uniformly (Section 14.6.3.5.4)

    - "The bearing resistance check shall be performed in accordance with LRFD [11.10.5.4]. Provisions of LRFD [10.6.3.1] and LRFD [10.6.3.2] shall apply. Because of the flexibility of MSE walls, an equivalent uniform base pressure shall be assumed."
- Settlement of the MSE system including panels and fills during construction is not clearly denotes as required or recommended. During construction settlement may induce significant panel stresses and is recommended to be calculated prior to construction and monitored during construction (Section 14.6.3.6).

Section 14.12
No comments were prepared for Section 14.12.

Section 14.13
No positive or neutral for Section 14.13 were generated as part of this review.

Negative comments include:

- Step 10: Project Monitoring, is recommended to specify a CMM section being referenced. The table of contents in the CMM does not explicitly show which chapter this information can be found. The full paragraph text is provided below (Section 14.13.1).
    - "Step 10: Project Monitoring It is the responsibility of the project manager to verify that the project is constructed with the previously accepted contract proposal. Refer to the Construction and Materials Manual for monitoring material certification, construction procedures and material requirements."

Section 14.14
Positive comments include:

- Well documented standard requirements.

No neutral or negative comments for Section 14.14 were generated as part of this review.

Section 14.15
Positive comments include:

- The use of inclusive 'to be provided' items from the contractor reduces the risk to the owner.

No neutral or negative comments for Section 14.15 were generated as part of this review.

Section 14.16
Positive comments include:

- Submittal of detailed structural plans as a prerequisite for preapproval is reasonable and appropriate (Section 14.16.3).
- Required explicit statement of wall system limitations is reasonable (Section 14.16.3).

No neutral or negative comments for Section 14.16 were generated as part of this review.

FACILITIES DEVELOPMENT MANUAL (FDM)

FDM review included Chapter 11 Design, Section 55 Special Features, Subsection 5 Retaining Walls.

General

The FDM appears generally consistent with the WBM. Limited referrals to outside federal (FHWA) guidance documents help to reinforce WisDOT recommendations and requirements. Based on the number of comments positive, neutral, and negative comments have been provided below with referenced sections provided in parentheses.

Positive comments include:

- Required preapproval of proprietary wall suppliers is appropriate and consistent with industry best practices and the WBM (Section 5.1).
- BOS review of structural aspects of design and construction prior to the start of construction and the use of electronic submittals is consistent with industry best practices and FHWA guidance (recommended push to digital records) (Section 5.1).
- A clear statement of limitations for minor retaining walls (MRW) is provided (i.e., no traffic, slopes steeper than 2.5H:1V, exclusion of tiered walls) (Section 5.2).

Neutral comments include:

- The term 'barrier' as used may cause some confusion with FHWA terminology when used in relation to vehicle traffic, a clarifying note that the term barrier as used does not include roadway traffic barriers may prevent errors during design (Section 5.3)

Negative comments include:

- The statement, "If sufficient right of way cannot be obtained for a particular type of wall, then specify a different type of wall." does not specify what needs to be done in cases where sufficient right of way cannot be obtained. Clarification should be provided on the decision or design process and potential contacts for discussion / resolution for these conditions should be provided (Section 5.4)

CONSTRUCTION AND MATERIALS MANUAL (CMM)

CMM review included Section 560. Due to the length of this section comments are limited and provided under the General heading, below.

General

The CMM appears generally consistent with the WBM. Based on the number of comments positive, neutral, and negative comments have been provided below with referenced sections provided in parentheses.

Positive comments include:

- Required inclusion of the BOS and Structural Metals and Fabrication Quality Assurance Inspection Unit (SFU) prior to the start of construction is a reasonable method to reduce risk and improve MSE performance.

- CMM implements a reasonable QA process including timely review.

No neutral comments were generated during the review of CMM documents.

Negative comments include:

- Additional explicit minimum redline documentation standards including the add dates of changes and signatures of individuals responsible for documenting and assessing changes is recommended.

STRUCTURE INSPECTION MANUAL (SIM)

SIM review included Part 4 – Ancillary Structures, Chapter 4 – Retaining Walls.

General

The SIM appears generally consistent with the WBM and external referral to the AASHTO Manual for Bridge Element Inspection acts as a reasonable basis of inspection. If WisDOT practices deviate from the AASHTO MBEI explicit indication of deviations is recommended to reduce the potential inspections being performed in non-compliance of WisDOT requirements.

Section Specific

Part 4.4.1

Positive comments include:

- Inspection frequency of 6 years is consistent with previous recommendations.
- Provides a list of factors impacting inspection interval through referral to SIM Part 4 Chapter 1.

Neutral comments include:

- The use of the terms ‘mechanically stabilized reinforced earth’ is atypical and ‘reinforced’ is recommended for removal (Section 4.4.1.2).

Negative comments include:

- The use of the term ‘geotechnical failure’ is vague and should be better defined or revised for clarity. Examples of geotechnical failures such as slope instability, settlement, bearing capacity failure, erosion, etc. may provide further explanation to the term and intent.
- Inclusion of additional cut and fill areas of concern including differential settlement, freeze-thaw damage, and erosion are recommended (Section 4.4.1.2).

Part 4.4.2

Positive comments include:

- Common causes of MSE failure reflect those presented in FHWA guidance documents.
- Provided lists of common defects and deteriorations is well detailed (Section 4.4.2.2)

Neutral comments include:

- Inclusion of additional caution on uniform settlement impacts on piles and other nearby structures may be warranted (Section 4.4.2.1).

No negative comments were identified for Part 4.4.2.

Part 4.4.3

Positive comments include:

- Inspection recommendations are generally reasonable and consistent with industry practice.
- Inspection recommendations also include the use of NDT technologies such as LiDAR which may improve inspection quality (Section 4.4.3.1).

Neutral comments include:

- Visual inspection of drainage systems and drainage effluents for volume, discoloration, and particulates may improve timely identification of drainage issues

Negative comments include:

- Inclusion of language on the identification of tension cracks parallel to the wall on the upslope side and erosion within drainage paths on the upslope side of MSE walls is recommended.

Part 4.4.4

No comments were prepared for Part 4.4.4.

STANDARD PLAN SHEETS (SPS)

SPS inspection review included Chapter 14 – Retaining Walls and Sections.

General

Provided designer notes and inclusion of test borings into plans (Sheet 14.03) is consistent with FHWA general guidance. The reviewers also recommend the inclusion of instrumentation locations and monitoring points within plan sheets if not provided under separate cover. If provided under separate cover, reference to instrumentation and monitoring documents is recommended for inclusion into plan sheets. The inclusion of retained fill and cut slope markers (Sheets 14.11 and 14.12) is also recommended with a note on determining cut slope geometry.

SPECIAL PROVISIONS

Special provision review included three special provisions including SPV.0165.XX Temporary Wire Faced MSE, SPV.0165.XX Wall Concrete Panel MSE, and SPV.0165.XX Wall Modular Block MSE.

General

Provided general comments are applicable to all reviewed special provisions. While comments are generated based on special provisions, application of comments resolutions may also be suitable for other WisDOT documents such as the WBD or CMM.

Positive comments on all special provisions include:

- Reviewed special provisions are generally consistent with the current WBM, FHWA design guidance, and AASHTO design manuals.
- Quality control protocols are consistent with FHWA guidance including the use of quality verification (QV) and independent assurance (IA) roles which are often overlooked in MSE construction.
- Outlined dispute resolution process is clear and consistent with FHWA guidance.
- Special provisions establish timelines, standards, and responsible parties for the preapproval and design process.
- Required use of certified independent labs is a recommended best practice.

Neutral comments on all special provisions include:

- Special provisions are also recommended to include a last revision date to reduce the risk of out-of-date provisions being used during design and construction.
- Special provisions reasonably outline the material certificate age limits and retest requirements, however clarifications of the term ‘change’ regarding backfill characteristics or examples of material changes would improve understanding and clarity for designers and constructors.
- As-written provisions appear to exclude the use of common alternative lightweight fills (LWFs) and other geomaterials which may provide a more effective MSE design. Consideration to including language on the use of LWFs and other geomaterials is recommended is permitted by WisDOT.
- The use of the simplified stiffness method is LRFD calibrated and may provide more efficient designs, inclusion of the simplified stiffness method as outlined in the 2020 AASHTO LRFD Bridge Design Manual should be considered.

Negative comments on all special provisions include:

- Special provisions do not include commentary on survey or monitoring including monitoring methods, survey points, or post-construction performance monitoring. Inclusion of survey and monitoring details are recommended for consideration directly or through referencing to other WisDOT documents.
- The use of 2-ft of 120 pcf soil surcharge is recommended to be replaced by the greater of 2-ft of 120 pcf soil surcharge and AASHTO specific vehicle load recommendations. The use of AASHTO specific load recommendations will better reflect the range of potential loading on MSE systems across all traffic conditions.

- ‘Critical wall stations’ is recommended to be better defined and to include a minimum number of sections to be evaluated along with a range of conditions which are considered as indicating a critical wall station (e.g., tallest wall segment, highest water table, presence of a potential slip surface).
- The use of vertical batter for obstructions and planned inclusions such as drainage is not clearly addressed. Inclusion of limits of vertical batter and distance from the back of wall are recommended.

SPV.0165.XX Temporary Wire Faced MSE

General

Special provision SPV.0165.XX Temporary Wire Faced MSE includes those comments provided in Section 0. Additional provision specific comments are limited to the following:

- Inclusion of additional details on acceptable corrosion protection methods (e.g., hot-dipped galvanizing, epoxy coating) may be beneficial for designers.
- Inclusion of construction specific loading requirements is recommended to reduce the risk of during-construction failure. These loads may include heavy equipment or crane loads exceeding those represented by the current 2-ft of 120 pcf soil surcharge.

SPV.0165.XX Wall Concrete Panel MSE

General

Special provision SPV.0165.XX Wall Concrete Panel MSE includes those comments provided in Section 0.

Positive comments include:

- Required use of leveling pads will result in improved long-term performance.

Neutral comments include:

- Inclusion of a panel storage, lifting, and placement procedure may reduce the risk of panel cracking during handling and placement.

Negative comments include:

- Panel inspection and rejection criteria including potential cost-share schedule for rejected panels is recommended for inclusion.
- Special provision is missing information on precast panel material testing. FHWA NHI-10-024 states, “Agencies should check the raw materials, mix design, and precasting operation as they do for other precast, structural items.”

SPV.0165.XX Wall Modular Block MSE

General

Special provision SPV.0165.XX Wall Modular Block MSE is generally accepted with comments including those provided in Section 0. An additional positive comment included the inclusion of material testing of blocks which is consistent with FHWA guidance and important to successful use of Modular Block MSE.

RETAINING WALL SYSTEMS – PREQUALIFIED

General

The prequalified retaining wall systems are like other prequalified lists maintained by several state DOTs providing prequalified suppliers for MSE systems by facing type. This list provides reasonable limitations for individual suppliers, where established by WisDOT, and no recommended revisions or considerations are recommended. Due to the length of the document no section specific comments or recommendations are provided.

APPENDIX F: VULNERABILITY FACTORS

Table 19. Vulnerability Factor: Construction Quality States

Construction Quality State	Description	CQS Factor
1 (Good)	Design, construction, construction records, or supplemental inspections indicate the component or structure is fully consistent with selected WisDOT and national standards.	1.0
2 (Fair)	Design, construction, construction records, or supplemental inspections indicate the component or structure is predominantly consistent with selected standards. Minor non-conformances during construction were present but accepted by agency engineers. The quality of as-built, QA/QC, and other project documents had minor deficiencies or absences.	1.25
3 (Poor)	Design, construction, construction records, or supplemental inspections indicate the component or structure is moderately consistent with selected standards. Non-conformances during construction were present but accepted by agency engineers. The quality of as-built, QA/QC, and other project documents had moderate deficiencies or absences.	1.5
4 (Severe)	Design, construction, construction records, or supplemental inspections indicate the component or structure is not consistent with selected standards. Non-conformances during construction were present and were not reviewed or accepted by agency engineers. The quality of as-built, QA/QC, and other project documents had significant deficiencies or absences including no submission of as-built plans.	1.75

Table 20. Vulnerability Factor: Structure Age

Construction Quality State	**Description**	**SA Factor**
1 (New Construction)	Structure age less than 25 years.	1.0
2 (Mid Life)	Structure age from 25 and up to 50 years.	1.3
3 (Near End of Life)	Structure age from 50 and up to 75 years.	1.65
4 (End of Life)	Structure age exceeds design life; greater than 75 years.	2.0

Table 21. Vulnerability Factor: Winter Highway Classification Group

WHC Category	Description [1]	Factor
5 and LMR	All other two-lane highways. The driving lane will be maintained primarily by plowing with minimal salting. Local Maintenance Responsibility: Local streets and roads that carry state highway travel through cities and villages. Connecting highway aids help local governments maintain these streets and roads at state trunk highway (STH) system standards, and help compensate local governments for the incremental costs of through-traffic routed over municipal streets.	1
4	Most high-volume two-lane highways (AADT >= 5,000) and some two-lanes (AADT < 5,000) The driving lane will be maintained with emphasis on plowing and sensible salting.	1.05
3	All other four-lane highways (AADT< 25,000) All lanes and ramps will be maintained with emphasis on plowing and sensible salting. However, the driving lanes and ramps will receive preferential treatment. The passing lane will receive less attention. Plowing with less salting will be done on the passing lane.	1.08
2	High-volume four-lane highways (AADT* >= 25,000 and some four-lane highways (AADT < 25,000) and some six-lane highways All lanes and ramps will be maintained equally with emphasis on plowing and sensible salting.	1.15
1	Major urban freeways and most highways with six lanes and greater. All lanes and ramps will be maintained to the highest level practical.	1.25

[1] Descriptions are as presented in the Wisconsin DOT, *Winter Maintenance Databases*, updated September 11, 2024. Winter Maintenance

Table 22. Vulnerability Factor: Pavement Condition Index

PCI Category	Description	Factor
1 (Good)	PCI is greater than 85.	1.0
2 (Satisfactory)	PCI is greater than 70 and up to 85.	1.05
3 (Fair)	PCI is greater than 55 and up to 70.	1.1
4 (Poor)	PCI is greater than 40 and up to 55.	1.15
5 (Very Poor or Below)	PCI is less than 40.	1.25

APPENDIX G: RISK FACTORS

Table 23. Risk Factor: Functional Classification

Functional Classification [1]	**Description** [2]	**Factor**
Non-Transportation	Supports pedestrian or non-transportation systems such as bike-paths, land, viewing areas, or non-roadway road separations at a service level below the local functional classification.	1.0
Local (LOC)	The bottom of the functional classification hierarchy, even though they comprise the largest percentage of all roadways in the state. Their role is to provide access to homes and businesses. They have low speed limits and offer limited mobility for through traffic.	1.05
Minor Collector (MIC)	Similar to that of Major Collectors, but they connect Arterials and Local Roads over shorter distances and serve lower density areas. Generally, they have lower speed limits and serve smaller communities than Major Collectors do. Rural Minor Collectors provide service to smaller population clusters not already served by a Collector or Arterial, link the locally important traffic generators, and are spaced to collect traffic from Local Roads and bring developed areas within a reasonable distance of a Collector road.	1.1
Major Collector (MAC/COL)	Circulate traffic and provide access to local businesses or homes. They distribute trips between Local Roads and Arterials over greater distances than Minor Collectors. Major Collectors generally have fewer driveways, higher speed limits, higher VMT, more travel lanes, and are spaced at greater intervals than Minor Collectors. In rural areas they provide service to small-to-moderate sized communities and other intra-area traffic generators and link those generators to nearby larger population centers (cities, villages, and towns) or Arterials. Many rural Major Collectors are also county highways.	1.25
Minor Arterial (MA)	Connect and support the system of Principal Arterials, serving trips of moderate length. In rural areas they provide links between cities, while in urban areas, Minor Arterials often support other transportation modes, such as bus travel, and typically have lower speeds than Principal Arterials. All Minor Arterials provide opportunities for direct access to adjacent land uses.	1.5
Principal Arterial (PA)	The highest level of the highway functional classification system. They provide a high level of mobility, have high speed limits, carry high traffic volumes, and allow for long-distance, uninterrupted travel. Rural Arterial roadways connect states, regions, and urban centers, may have multiple lanes, and provide limited access, such as at interchanges. Urban Arterials serve the major activity centers within the urban area and are its highest traffic volume corridors.	2.0

[1.] Functional category to be determined by the higher of the supported roadway and adjacent roadways which would be impacted by an MSE failure (e.g., a minor collector supported by an MSE and passing over a principal arterial should be rated as a principal arterial).

[2.] Descriptions excluding Non-Transportation are as presented in the Bureau of Planning and Economic Development, *Functional Classification Criteria and Procedures*, 2022.

Table 24. Risk Factor: Supported Structures

Classification	Description	Factor
Low	Supported structures are limited to the wall structure alone and	1.0
Moderate	Supported structures are limited to the wall structure, roadway, and ground level pedestrian paths or structures.	1.05
High	Supported structures include roadways, abutments, or elevated pedestrian paths or structures.	1.1
Very High	Supported structures include abutments, bridge piers, other non-pedestrian structures, or other retaining walls.	1.25

Table 25. Risk Factor: Wall Height

Wall Height (ft)	Description	Factor
< 15	Wall height is less than 15 ft.	1.0
15 to 25	Wall height is from 15 to 25 ft.	1.05
> 25	Wall height is greater than 25 ft.	1.1

Table 26. Risk Factor: Wall Length

Wall Length (ft)	Description	Factor
< 150	Wall length is less than 150 ft.	1.0
150 to 500	Wall length is from 150 to 500 ft.	1.05
> 500	Wall length is greater than 500 ft.	1.1

Table 27. Risk Factor: Utility Prevalence and Criticality (modified after AECOM, 2016)

Classification	Description	Factor
Sub-Local	No utilities are present beyond those constructed to supported the retaining structure.	1.0
Local	No vital or major utilities are present. Local utilities present; considered as permitting for loss of service during an emergency. Utilities include those which are low risk, low value, or are considered able to be reasonably replaced. Utilities are not critical to essential services. Examples include gas distribution, residential distribution lines, water distribution, and collector sewers.	1.05
Moderate	No vital or major utilities are present. Moderate utilities present; considered as permitting for loss of service during an emergency. Utilities include those which are low to moderate risk, low to moderate value, or are considered able to be reasonably replaced. Utilities may be critical to essential services but have multiple redundant routes. Examples include gas distribution, commercial and industrial distribution lines, water distribution, and collector sewers.	1.15
Significant	No vital or major utilities are present. A maximum of five significant utilities; considered as permitting for limited loss of service during an emergency. Utilities include those which are moderate risk, moderate value, or are considered difficult to replace. Utilities may be critical to essential services but have a viable redundant route. Examples include medium pressure gas transmission, commercial and industrial distribution lines, water transmission, and collector sewers.	1.25
Major	At least one utility which serves a single regions and is considered major; being required to function to the fullest extent after an emergency. Utilities include those which are high risk, high value, or are considered irreplaceable and are critical to essential services and have no viable redundancy. Examples include high pressure gas transmission, high voltage gas-filled transmission, high-pressure and high-volume water transmission, and trunk sewers.	1.5
Vital	At least one utility which serves multiple regions and is considered vital; being required to function to the fullest extent after an emergency. Utilities include those which are high risk, high value, or are considered irreplaceable and are critical to essential services and have no viable redundancy. Examples include high pressure gas transmission, high voltage gas-filled transmission, high-pressure and high-volume water transmission, and trunk sewers.	1.75

APPENDIX H: WISDOT INSPECTION REPORTS FOR R-40-156, R-67-045, AND R-67-048

STATE OF WISCONSIN
DEPARTMENT OF TRANSPORTATION

Inspection Report for

R-40-156

IH 43 SB
Dec 10,2020

Type	Prior	Team Leader	Frequency (mos)	Performed
Routine - Retaining Wall	10-29-15	Zippel, William J (9605)	72	X

	Start Coordinates	End Coordinates (optional)
Latitude	43°07'06.70"N	43°06'55.92"N
Longitude	87°55'07.89"W	87°55'07.59"W

Owner	STATE HIGHWAY DEPT	Maintainer	STATE HIGHWAY DEPT

Time Log	Hours	Minutes	Team members
	1	0	Bryan Schaller
Weather	Temperature (f)	Condition	
	49	Sunny	

Inspector	Name	Number	Signature	Signature Date
	Pawlak, John	9661	John Pawlak E-signed by John A Pawlak(japawlak)	01-11-21

BRIDGE INSPECTION REPORT
Wisconsin Department of Transportation
DT2007 2003 s.84.17 Wis. Stats.

Identification & Location

Retaining Wall Type: MSE- PRECAST PANEL FACING	Section Town Range: S29 T08N R22E	Structure Number: R-40-156
Nearest Feature Under: IH 43 SB	County: MILWAUKEE	
Location 60 FT S JCT SILVER SPRING DRIVE	Municipality: GLENDALE	Structure Name:

Geometry & Inventory

Functional Type: Fill		Top Railing (if applicable)	
Foundation Type: SPREAD FOOTING	Piling Type Code(if applicable):	Primary Wall Material: CONCRETE	Installation type: Ground Mounted
Overall Length(ft): 1048.0	Max Height(ft): 34.5	Max Wall Exposure Height(ft): 30.65	Avgerage Wall Thickness(ft): 0.83
Vegetation Notes: Highway Face=5%			

Construction History

Year	Work Performed	FOS id
1991	NEW STRUCTURE	1228-01-72

Maintenance Items

Item	Priority	Recommended by	Status	Status change
STRUCTURAL- STABILIZE WALL	HIGH	Pawlak, John (9661)	IDENTIFIED	01/11/21
Repair shifted 4th panel from the north end.				
DRAINAGE- SEAL VERTICAL JOINTS OR CRACKS	MEDIUM	Pawlak, John (9661)	IDENTIFIED	01/11/21
DRAINAGE- SEAL HORIZONTAL JOINTS OR CRACKS	MEDIUM	Pawlak, John (9661)	IDENTIFIED	01/11/21
STRUCTURAL- INVESTIGATE CAUSE OF MSE FILL LOSS	MEDIUM	Pawlak, John (9661)	IDENTIFIED	01/11/21

BRIDGE INSPECTION REPORT
Wisconsin Department of Transportation
DT2007 2003 s.84.17 Wis. Stats.

Structure No.:**R-40-156**

Elements

Chk	Element	Defect	Description	UOM	Total	Quantity in Condition State 1	2	3	4
X	331		**Reinforced Concrete Bridge Rail**	LF	1,048	707	333	8	0
		1080	Delamination - Spall - Patched Area 20 LF Scattered CS2 Spalls. 78 LF Scattered CS2 Delaminations, Typically Along Top of Rail. 8 LF Scattered CS3 Spalls.	LF		0	98	8	0
		1130	Cracking (RC) 235 LF CS2 Narrow Vertical Cracks	LF		0	235	0	0
X	8603		**MSE Wall** North end of wall starts at the the back of B-40-584 south abutment.	LF	1,048	892	124	32	0
		1640	Masonry or Panel Displacement Top Panel at the 4th Panel Column From the North is Out 1.5" - 5 LF CS3	LF		0	0	5	0
		8902	Wall Movement 43 LF Scattered CS2 Vertical Joints with Leaking Backfill 55 LF Scattered CS2 Horizontal Joints with Leaking Backfill (11 - 5 LF Panels) 13 LF CS3 Wide (2"-3") Vertical Joints Near the Tops of the Wall.	LF		0	98	13	0
		8903	Wall Deterioration 11 LF Scattered CS2 Panel Corner Spalls, 12 LF Scattered CS2 Panel Corner/Edge Delaminations, 8 LF Scattered CS3 Panel Spalls. 3 LF CS2 Narrow Vertical Cracks in Panels, 6 LF CS3 Medium	LF		0	26	14	0

BRIDGE INSPECTION REPORT
Wisconsin Department of Transportation
DT2007 2003 s.84.17 Wis. Stats.

Structure No.:**R-40-156**

Assessments

Chk	Element	Defect	Description	UOM	Total	Quantity in Condition State 1	2	3	4
			Drainage - Ends of Structure	EA	2	2	0	0	0
X	9001		North End: Joint with Adjacent Structure in Good Condition, South End: Spall at Adjacent Barrier Wall, No Erosion Issues.						
			Signs - Other	EA	1	1	0	0	0
X	9035		Mile Marker Sign Mounted to Parapet						
			Structure ID Plaque	EA	1	1	0	0	0
X	9208		Located at Inside of Parapet at the North End of the Wall.						
			Horizontal Copings	LF	1,048	847	177	24	0
X	9338		CS1 HL Vertical Cracking at 3 FT Average Spacing - 349 LF CS1 CS2 Narrow Vertical Cracking at 10 FT Average Spacing - 105 LF CS2 72 LF Scattered CS2 Delaminations Typically at Expansion Joints. 24 LF Scattered CS3 Spalls Typically at Expansion Joints.						
			Features (Roadway/Sidewalk/Etc.) to Wall	EA	1	1	0	0	0
X	9339		Roadway On Top of Wall is in Good Condition.						
			Drainage System	EA	2	1	1	0	0
X	9340		Top: 2 Deck Drains, 1 is Partially Plugged with Debris Bottom: Maintained Lawn.						

Rating

	File	New
Overall Rating	Fair	Fair

Structure Specific Notes

Name plate is at north end. Wall is the south west wingwall for B-40-584 and abuts R-40-611 on the north end.

Inspection Specific Notes

Inspector Site-Specific Safety Considerations

Routine - Retaining Wall Specific Procedures

Access from along the side of the ramp.

Special Requirements

Chk	Hours	Cost	Comments

Retaining Wall Item 1

Typical Delaminations Along Top of Rail at Middle of Wall.	 r40-156_20_Wd6.jpg
Linked Element(s): Reinforced Concrete Bridge Rail	

Retaining Wall Item 2

CS3 Spalls at Sides of Junction Box Near South End of Wall.	 r40-156_20_Wd5.jpg
Linked Element(s): Reinforced Concrete Bridge Rail	

Retaining Wall Item 3

At 4th Panel Column From the North End The Top Panel is Out 1.5" with an Adjacent CS3 Spall at a Panel Corner.	 r40-156_20_Wd1.jpg
Linked Element(s): MSE Wall	

Retaining Wall Item 4

Typical CS3 Wide (3") Panel Joint Near North End.	 r40-156_20_Wd2.jpg
Linked Element(s): MSE Wall	

Retaining Wall Item 5

Medium Horizontal Crack in Panel Near Middle of Wall.	 r40-156_20_Wd3.jpg
Linked Element(s): Reinforced Concrete Bridge Rail	

Retaining Wall Item 6

Typical CS2 Leaking Vertical Joint Near North End.	 r40-156_20_Wd4.jpg
Linked Element(s): MSE Wall	

Retaining Wall Item 7

Large Spall in Adjacent Barrier at the South End.	 r40-156_20_Wd9.jpg
Linked Element(s): Drainage - Ends of Structure	

Retaining Wall Item 8

Typical CS3 Spall in Coping Near South End.	 r40-156_20_Wd7.jpg
Linked Element(s): Horizontal Copings	

Retaining Wall Item 9

Typical CS2 Delamination Near South End.	 r40-156_20_Wd8.jpg
Linked Element(s): Horizontal Copings	

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STATE OF WISCONSIN
DEPARTMENT OF TRANSPORTATION

Inspection Report for

R-67-045 (REINFORCED EARTH PANEL WALL)

IH 94 WB
Sep 22,2021

Type	Prior	Team Leader	Frequency (mos)	Performed
Routine - Retaining Wall	11-24-15	Zippel, William J (9605)	72	X

Start Coordinates		End Coordinates (optional)	
Latitude	43°03'03.40"N	Latitude	43°03'03.40"N
Longitude	88°18'11.40"W	Longitude	88°18'14.00"W
Owner	STATE HIGHWAY DEPT	Maintainer	STATE HIGHWAY DEPT

Team members

Time Log	Hours	Minutes
	0	30
Weather	Temperature (f)	Condition
	62	Overcast

Inspector	Name	Number	Signature	Signature Date
	Rozmenoski, Wyatt	9706	Wyatt Rozmenoski E-signed by Wyatt Rozmenoski(wrozmenoski)	11-11-21

BRIDGE INSPECTION REPORT
Wisconsin Department of Transportation
DT2007 2003 s.84.17 Wis. Stats.

Identification & Location

Retaining Wall Type:	Section Town Range:	Structure Number:
MSE- PRECAST PANEL FACING	S19 T07N R19E	R-67-045
Nearest Feature Under:	County:	
IH 94 WB	WAUKESHA	
Location	Municipality:	Structure Name:
1.1 MI W JCT CTH G	PEWAUKEE	REINFORCED EARTH PANEL WALL

Geometry & Inventory

Functional Type:		Top Railing (if applicable)	
Cut			
Foundation Type:	Piling Type Code(if applicable):	Primary Wall Material:	Installation type:
		CONCRETE	Ground Mounted
Overall Length(ft):	Max Height(ft):	Max Wall Exposure Height(ft):	Avgerage Wall Thickness(ft):
191.0	18.47	16.83	1.08
Vegetation Notes:			
Some vegetation overhanging coping and front face at west end (5-10'). Vegetation is relatively light (ie weeds, vines)			

Construction History

Year	Work Performed	FOS id
9999	NOT BUILT	1060-51-71
2000	NEW STRUCTURE	2723-02-70

Maintenance Items

Item	Priority	Recommended by	Status	Status change
STRUCTURAL- JOINT REPAIR OR REPLACEMENT	MEDIUM	Rozmenoski, Wyatt (9706)	IDENTIFIED	09/30/21

Comment:
Repair vertical joints at bridge abutment. Seal joints to prevent backfill loss through wall.

Maintenance priority decreased from high to medium due to new bridge approach slab which minimizes water from roadway from getting behind wall.

Status Comment:

BRIDGE INSPECTION REPORT
Wisconsin Department of Transportation
DT2007 2003 s.84.17 Wis. Stats.

Structure No.:**R-67-045**

Elements

Chk	Element	Defect	Description	UOM	Total	Quantity in Condition State 1	2	3	4
X	8603		MSE Wall	LF	189	177	9	3	0
			Few locations of rust staining at front face						
			Masonry or Panel Displacement	LF		0	3	2	0
		1640	CS2: panel shifting at east end, panel shifting at joint adjacent to abutment ends (3 LF CS2) CS3: Wide joint between wall and abutment ends (2 LF CS3)						
			Wall Deterioration	LF		0	6	1	0
		8903	6 LF CS2 corner spalls in precast panels. 1 LF CS3 corner spall in precast panel at west end of abutment.						

Assessments

Chk	Element	Defect	Description	UOM	Total	Quantity in Condition State 1	2	3	4
X	9001		Drainage - Ends of Structure	EA	2	2	0	0	0
			East-OK, steep but stable. West-OK						
X	9208		Structure ID Plaque	EA	1	0	0	0	1
			No Name Plate						
X	9338		Horizontal Copings	LF	191	175	14	2	0
			1 LF shallow pall at west end,13 LF narrow vertical cracks (14 LF CS2) 2 LF large spall with exposed rebar at west end of bridge abutment (2 LF CS3)						
X	9339		Features (Roadway/Sidewalk/Etc.) to Wall	EA	2	2	0	0	0
			Top: loss of soil at ends of abutment and at median CTH SS. Loss of soil appears to be from erosion rather than settlement (CS1) Bottom; good						
X	9340		Drainage System	EA	2	1	1	0	0
			Bot-OK slope protection under bridge Top- eroded holes at ends of abutments due to old replaced bridge approach slab. Wide opening at abutment/wall joint allows for water to pass thru joint. Grading and new bridge approach slab are mitigating potential for water to find its way to eroded hole at back of wall. Vegetated.						

Rating

	File	New
Overall Rating	Fair	Fair

Structure Specific Notes

Wall has no name plate. Wall retains north abutment of B-67-267

Inspection Specific Notes

Inspector Site-Specific Safety Considerations

Routine - Retaining Wall Specific Procedures

Special Requirements

Chk	Hours	Cost	Comments

Retaining Wall Item 1

CS2 spall at west end of wall coping	 r67-045_21_Wd1.jpg

Retaining Wall Item 2

CS2 panel movement at east end of wall	 r67-045_21_Wd2.jpg

Retaining Wall Item 3

Wide joint at east end of bridge abutment	 r67-045_21_Wd3.jpg
Linked Element(s): MSE Wall	

Retaining Wall Item 4

CS2 spall at panel, typ	 r67-045_21_Wd4.jpg

Retaining Wall Item 5

CS3 spall at panel at west end of bridge abutment	 r67-045_21_Wd5.jpg
Linked Element(s): MSE Wall	

Retaining Wall Item 6

CS3 spall at coping west end of bridge abutment	 r67-045_21_Wd6.jpg
Linked Element(s): Horizontal Copings	

STATE OF WISCONSIN
DEPARTMENT OF TRANSPORTATION

Inspection Report for

R-67-048

IH 94 EB
Sep 22,2021

Type	Prior	Team Leader	Frequency (mos)	Performed
Routine - Retaining Wall	11-24-15	Zippel, William J (9605)	72	X

Start Coordinates		End Coordinates (optional)	
Latitude	43°02'57.00"N	Latitude	43°02'58.00"N
Longitude	88°17'20.00"W	Longitude	88°17'26.00"W
Owner	STATE HIGHWAY DEPT	Maintainer	STATE HIGHWAY DEPT

Team members

Time Log	Hours	Minutes
	0	50
Weather	Temperature (f)	Condition
	62	Overcast

Inspector	Name	Number	Signature	Signature Date
	Rozmenoski, Wyatt	9706	Wyatt Rozmenoski E-signed by Wyatt Rozmenoski(wrozmenoski)	11-11-21

BRIDGE INSPECTION REPORT
Wisconsin Department of Transportation
DT2007 2003 s.84.17 Wis. Stats.

Identification & Location

Retaining Wall Type:	Section Town Range:	Structure Number:
MSE - MODULAR BLOCK FACING	S19 T07N R19E	R-67-048
Nearest Feature Under:	County:	
IH 94 EB	WAUKESHA	
Location	Municipality:	Structure Name:
OFF RAMP TO CTH G 950 FT E JCT CTH G	PEWAUKEE	

Geometry & Inventory

Functional Type:		Top Railing (if applicable)	
Cut			
Foundation Type:	Piling Type Code(if applicable):	Primary Wall Material:	Installation type:
		MASONRY	Ground Mounted
Overall Length(ft):	Max Height(ft):	Max Wall Exposure Height(ft):	Avgerage Wall Thickness(ft):
425.0		10.01	1.33
Vegetation Notes:			
One spot location with growth/vine overhanging front face of wall. Vine growth present on chain link fence behind wall.			

Construction History

Year	Work Performed	FOS id
1999	NEW STRUCTURE	1065-10-71

Maintenance Items

Item	Priority	Recommended by	Status	Status change
Misc - Cut Brush	MEDIUM	Rozmenoski, Wyatt (9706)	IDENTIFIED	09/30/21

Comment:
Remove tree growing at backface of wall

Status Comment:

BRIDGE INSPECTION REPORT
Wisconsin Department of Transportation
DT2007 2003 s.84.17 Wis. Stats.

Structure No.:**R-67-048**

Elements

Chk	Element	Defect	Description	UOM	Total	Quantity in Condition State 1	2	3	4
X	8603		MSE Wall Salt staining/leaching typical on surface.	LF	425	399	25	1	0
		1640	Masonry or Panel Displacement 4 LF wide joints (1/2"+) not leaking.	LF		0	4	0	0
		8903	Wall Deterioration CS2 = 19 LF shallow spall blocks, 2 LF cracked/split blocks (21 LF CS2) CS3 = 1 LF CS3 spalled block, exposing interior of cell at near west end (1 LF CS3)	LF		0	21	1	0

Assessments

Chk	Element	Defect	Description	UOM	Total	Quantity in Condition State 1	2	3	4
X	9001		Drainage - Ends of Structure East - OK, Steep but no erosion. West - OK, vegetated	EA	2	2	0	0	0
X	9208		Structure ID Plaque No name plate	EA	1	0	0	0	1
X	9337		Protective Screening Chain link fence is mounted behind wall, imbedded into ground	EA	1	1	0	0	0
X	9339		Features (Roadway/Sidewalk/Etc.) to Wall Top wall: no settlement Bottom wall: no settlement	EA	2	2	0	0	0
X	9340		Drainage System Front Face - good Back Face/Along top - good	EA	2	2	0	0	0

Rating

	File	New
Overall Rating	Fair	Fair

Structure Specific Notes

Wall has no name plate.

Inspection Specific Notes

Inspector Site-Specific Safety Considerations

Recommend inspecting fence and drainage at back of wall from south side of fence.

Routine - Retaining Wall Specific Procedures

Special Requirements

Chk	Hours	Cost	Comments

Retaining Wall Item 1

Typical salt staining/leaching at front face wall	 r67-048_21_Wd1.jpg

Retaining Wall Item 2

CS2 cracked block unit	 r67-048_21_Wd2.jpg

Retaining Wall Item 3

CS2 cracked block unit	 r67-048_21_Wd3.jpg

Retaining Wall Item 4

CS2 spalling at block units	 r67-048_21_Wd5.jpg

Retaining Wall Item 5

Spalling at west end of wall	 r67-048_21_Wd6.jpg

Retaining Wall Item 6

CS3 spall exposing interior cell of block	 r67-048_21_Wd7.jpg
Linked Element(s): MSE Wall	

Retaining Wall Item 7

Tree growth at BF wall	 r67-048_21_Wd9.jpg

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