IDAHO TRANSPORTATION DEPARTMENT

RESEARCH REPORT

Your Safety • Your Mobility
Your Economic Opportunity

RP 270

Development of an Inventory and Inspection Database Framework for Asset Management of MSE Walls

By

Sunil Sharma and Ahmed Ibrahim

University of Idaho

Yang Lu

Boise State University

James Mahar and Mustafa Mashal

Idaho State University

Prepared for

Idaho Transportation Department

Research Program, Contracting Services

Division of Engineering Services

http://itd.idaho.gov/alt-programs/?target=research-program

July 2019

Standard Disclaimer

1. Report No. FHWA-ID	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Development of an Inventory and Inspection Database Framework for Asset Management of MSE Walls		5. Report Date
		6. Performing Organization Code
7. Author(s) Sunil Sharma, Ahmed Ibrahim, Yang Lu, James Mahar, and Mustafa Mashal		8. Performing Organization Report No.
9. Performing Organization Name and Address Department of Civil & Environmental Engineering 875 Perimeter Drive MS 1022 Moscow, ID 83844		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Idaho Transportation Department Division of Engineering Services, Contracting Services, Research Program PO Box 7129 Boise, ID 83707-7129		13. Type of Report and Period Covered Final Report 01/01/2018 – 07/31/2019
		14. Sponsoring Agency Code RP 270

15. Supplementary Notes

Project performed in cooperation with the Idaho Transportation Department and Federal Highway Administration.

16. Abstract

Currently, the Idaho Transportation Department (ITD) does not have an inventory of MSE walls, or procedures for their inspection and assessment. To initiate a process for compiling such information, this study collected information about MSE walls in Idaho, and assembled the material for use as a preliminary database. After considering many attributes about MSE wall, the team selected 40 for final implementation. The current database includes information on about 60 MSE walls, with plans to add more in the future. It is recommended that the database information should be added to the current ITD-GIS system, for use by ITD personnel. Additionally, the researchers reviewed the current DOT state-of-practice regarding inspections which may be used to assess the integrity of the MSE walls. Three different inspection protocols were evaluated and then applied to some of the inventoried MSE walls. A modified version of the Ohio-DOT procedure is recommended for further evaluation by ITD engineers. As no past MSE wall information was available for this study, recommendations for assessment were not possible. However, it is strongly recommended that all MSE walls should be inspected to create a baseline database which will allow assessments to be made with follow-on inspections in the future.

17. Key Words MSE walls, inventory, database, assets, inspection, attributes, GIS		18. Distribution Statement Copies available online at http://itd.idaho.gov/alt-programs/?target=research-program	
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages Add the total # of pages	22. Price None

FHWA Form F 1700.7

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.3048	meters	m
yd	yards	0.914	meters	m
mi	miles (statute)	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.4046	hectares	ha
		MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g
lb	Pounds (avdp)	0.454	kilograms	kg
T	Short tons (2000 lb)	0.907	megagrams	mg
		VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL
gal	Gallons (liq)	3.785	liters	liters
ft^3	cubic feet	0.0283	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

Note: Volumes greater than 1000 L shall be shown in m^3

Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (°F-32)	Celsius temperature	°C
		ILLUMINATION		
fc	Foot-candles	10.76	lux	lx
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2
		FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles (statute)	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
km^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.471	acres	ac
		MASS (weight)		
g	grams	0.0353	Ounces (avdp)	oz
kg	kilograms	2.205	Pounds (avdp)	lb
mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	milliliters	0.034	fluid ounces (US)	fl oz
liters	liters	0.264	Gallons (liq)	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 °C+32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	pound-force	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi

Acknowledgements

The authors would like to acknowledge support from their respective departments at the University of Idaho, Boise State University, and Idaho State University. Additionally, the University of Idaho researchers would also like to acknowledge the help provided by the staff at the National Institute for Advanced Transportation Technology (NIATT), Moscow, Idaho.

The identification and collection of MSE wall data for the inventory would not have been possible without the assistance provided by the following ITD individuals:

District 1: Jeff Drager, Charlie While, and Jerry Wilson.

District 2: Doral Hoff, David Kuisti, Curtis Arnzen, Doral Hoff, Eric Kokernak, David Kuisti, Ken Helm, Joe Shacker, and Bob Schumaker.

District 3: Michael Garz.

District 4: Scott Malone, Lynn White, and Scott Stacey.

District 5: Ed Bala, Dan Harelson, and Greydon Wright.

District 6: Ken Hahn

Technical Advisory Committee

Each research project is overseen by a technical advisory committee (TAC), which is led by an ITD project sponsor and project manager. The Technical Advisory Committee (TAC) is responsible for monitoring project progress, reviewing deliverables, ensuring that study objectives are met, and facilitating implementation of research recommendations, as appropriate. ITD's Research Program Manager appreciates the work of the following TAC members in guiding this research study.

Project Sponsor – *John Bilderback*

Project Manager – *John Ingram*

TAC Members:

John Ingram, Jim Carr, Dan Gorley, Ed Miltner, and Dave Richards.

FHWA-Idaho Advisor

Ed Miltner.

Table of Contents

List of Tables

List of Figures

List of Acronyms

AASHTO	American Association of State Highway and Transportation Officials
BSU	Boise State University, Boise
DE	District Engineer
DOR	Department of Roads
DOT	Department of Transportation
EB	Eastbound
FHWA	Federal Highway Agency
GIS	Geographic Information System
HL	Hairline
ISU	Idaho State University, Pocatello
ITD	Idaho Transportation Department
MP	Milepost
MSE	Mechanically Stabilized Earth
NB	Northbound
SB	Southbound
sUAV	Small Unmanned Aerial Vehicle
UI	University of Idaho, Moscow
WB	Westbound

Executive Summary

Introduction

MSE walls are important elements in the overall management of Department of Transportation highway assets. These walls which basically consist of reinforced earth with concrete facing panels are used in bridge approaches and for support of highway cuts and fills. The concrete panels provide confinement for the earth reinforcement which serve as the major support elements of the wall. With limited budgets, procedures need to be in place to evaluate the performance of MSE walls and where necessary, dedicate funds for the maintenance, repair or replacement of these walls. Part of the decision-making process is to have functional databases which can be used to store and retrieve information on design, construction and the time-history performance of the walls.

The first Mechanically Stabilized Earth (MSE) wall in Idaho was constructed near Hope, Idaho, in the early 1970's. Such walls contain structural and geotechnical components, each limited by its anticipated lifespan. Thus, there is a need to put all MSE walls into a database, so these assets can be properly managed with respect to maintenance, repair or replacement. Currently, ITD does not have a formal inventory of their MSE wall assets, or complete data regarding their condition. The overall intent of this project is to make recommendations of inspection protocol and database storage, and retrieval of attributes and condition surveys for asset management of ITD MSE walls.

Project Objectives and Tasks

The project tasks consisted of (1) survey of other state DOT MSE wall asset management programs, (2) in cooperation with ITD staff, develop a plan for inventory and storage of MSE wall data, (3) collection of MSE wall attribute data available in district offices, (4) formulate recommendations for inspection protocol to be used in condition surveys of ITD MSE walls (5) apply inspection protocol in field studies of typical MSE walls in Idaho, and (6) preparation of a final report to include recommendations on implementation strategy for the assembled database information.

Task 1

To initiate the study, ITD staff contacted other state DOTs to determine if they monitor their MSE wall assets and provide the monitoring data in some type of retrieval format. Of the 51 US sources surveyed, 26 responded to the questionnaire. The following is a summary of the survey responses:

- Ten (10) state DOTs have in-place procedures for MSE wall inventories.
- Nine (9) DOTs have an inventory of MSE walls: Arkansas, Arizona, Connecticut (partial), Colorado, Maine, New York, Oregon, Utah, and Vermont.
- Seven (7) DOTs have a numerical system to rate the condition of the MSE walls.

- Only four (4) states have an MSE wall database in an accessible format.
- Six (6) states have Asset Management Programs: Arkansas, Connecticut, Colorado, Maine, New York, and Oregon.

Based on the survey, the time period between inspections varied depending on wall conditions, but generally ranged between two and five years.

The researchers reviewed the literature and evaluated the current state-of-practice regarding inspection procedures used to assess the integrity of the MSE walls. The review identified at least eleven agencies with inspection procedures for retaining walls. Of these, six inspection protocols from Colorado DOT, FHWA, Nebraska DOT, North Carolina DOT, Ohio DOT, and Utah DOT were evaluated for possible use by ITD in its asset management program. After further review, the inspections procedures from Nebraska, North Carolina, and Ohio DOTs were applied to select MSE walls to investigate their usefulness in the ITD asset management program.

Task 2

The researchers conferenced with ITD staff to select an optimum database system for storage and retrieval of the MSE wall data. The discussions centered on two programs: Bridge Management Program and ArcGIS. In the last conference call of April 11, 2019, it was mutually agreed that ArcGIS would be utilized for the ITD MSE wall inventory.

Task 3

As part of Task 3, the researchers contacted the six Idaho DOT districts for design and construction information on MSE walls in their area. The available information was compiled in a preliminary database. After considering many attributes about MSE walls, the researchers selected 41 parameters for summarizing design/construction details of ITD MSE walls. The following seven general categories of MSE wall attributes were agreed on by the researchers:

1. Location
2. Wall Dimensions
3. Wall Type and Functionality
4. Historical Data
5. Structural Data
6. Drainage
7. Other

The current database includes information on about 63 MSE walls, with plans to add more in the future.

Task 4

Based on the technical literature and the experience of the researchers and the Technical Advisory Committee, inspection procedures from Nebraska, North Carolina, and Ohio DOTs were selected for further consideration. Overall, the Ohio DOT inspection procedure, with modifications, was favored by the group. This procedure considers the following four conditions: (1) Joints, (2) Wall Facing, (3) Drainage, and (4) Top of the Wall (i.e. copings, guardrails, etc.). For problem walls, detailed observations and measurements are needed to evaluate the performance of the walls. These observations and measurements are lacking in all three state protocols.

Task 5

In order to refine the other state inspection protocols, the researches carried field investigations of selected MSE walls in the six ITD Districts. A total of eighteen MSE walls were evaluated in this study, as shown in the Table below.

#	District	MSE Wall Location
1.	1	I-90, EB Exit-Ramp, MP 1.03, Post Falls
2.	1	US-95, Railroad Bridge, NW Wing-wall, MP 465.0
3.	1	US-95, SB On-Ramp, MP 475.75, Sandpoint
4.	1	SH-200, SB, MP 41.96, Trestle Creek Bridge
5.	2	US-12, WB, MP 53.12 and 53.59, near Greer
6.	2	US-12, WB, MP 67.0, Kamiah Bridge, E. Wingwall, Kamiah
7.	3	I-84, W. Eisenman Rd
8.	3	I-84 at I-184
9.	3	I-84, South Vista
10.	3	I-84, SH-69
11.	4	I-84, US-93
12.	5	Gould Street Overpass, Pocatello, Wall 4
13.	5	Gould Street Overpass, Pocatello, Wall 5
14.	5	US-30, Topaz Bridge
15.	5	US-30, Ledger Creek Bridge
16.	6	US-20 Bridge, St. Leon Exit
17.	6	SH-33 Bridge, US-20 Exit
18.	6	SH-32, Bitch Creek Bridge

The field inspection data for each case are provided in Chapter 5 of this report. MSE walls in Districts 1 to 4 as well as Topaz Bridge (US-30) are in good condition. Six of the seven MSE walls in Districts 5 and 6 should be considered for further investigation/remedial work:

US-30 Ledger Creek Bridge: concrete coping deterioration

Gould Street/First Street Overpass: west bridge abutment; structural cracks and wall rotation/settlement

Gould Street/Fourth Street Overpass: piping of MSE wall backfill beneath abutment

US-20 Bridge, St Leon Exit: erosion beneath roadway barrier

SH-33 Bridge, US-20 Exit: MSE wall panel offset/rotation

Bitch Creek Bridge, SH-32: MSE wall and abutment separation; longitudinal cracks in pavement adjacent to MSE wall built on embankment slope.

Inspection techniques using small Unmanned Aerial Vehicles (sUAVs) for high-definition photographs and Non-destructive Testing (NDT) methods with Thermography and Ultrasonic measurements were employed in some of the MSE wall field inspections. The compilation of a photographic record of wall performance is essential for long-term planning and assessment of maintenance practices. The Thermography and Ultrasonic testing have potential for evaluating the condition of MSE wall pre-cast concrete panels.

Task 6

Task 6 is submission of a final written report after review by ITD Technical Staff. The report addresses the following items:

- Literature review and state surveys
- Database framework: agreed with ITD personnel
- Inventory of MSE wall data
- Inspection protocol
- Field data for selected MSE walls
- Conclusions and recommendations for future work.

Key Findings

1. The MSE wall information was difficult to locate in most districts. Overall, District 1 had the most information available, but this is probably because many of their MSE walls were built in the last 15 years.

2. The ProjectWise system used by ITD is a useful resource for information about MSE walls. However, unless key numbers are known, it can be difficult to navigate the system and search for MSE wall data.

3. The MSE wall information can be successfully incorporated into ArcGIS, a geographic information system currently used by ITD.

4. A modified version of the Ohio DOT procedure is preferred by ITD Technical Advisory Committee for ITD needs.

5. The inspection procedures from Nebraska, North Carolina, and Ohio DOTs are based fundamentally on non-quantitative descriptions of MSE wall conditions or rely on a wide range of values to categorize wall behavior. For walls experiencing problems, measurements over time are needed for a realistic assessment of the future performance of the wall.

6. The field inspections require that the evaluators be familiar with MSE walls and the features likely to affect their performance. For implementation in Idaho, evaluators will need to be trained to perform inspections.

7. For inspecting high MSE walls, the use of sUAVs to photograph the upper portions of the wall for on-site and later viewing was a great success.

Recommendations

At the conclusion of this study, the research group offer the following recommendations:

1. A geodatabase consisting of an inventory of MSE walls, and their condition, should be implemented into its GIS system for use by ITD personnel. Additionally, each MSE wall should be assigned an “Impact” designation based on the consequences of potential failure.

2. A web-based “App” suitable for a small hand-held device should be developed for accessing, revising and adding information to the MSE wall geodatabase. This data will consist of the wall attributes, photos, and inspection records.

3. All MSE walls included in the inventory must have the following attributes assigned: (a) Route, (b) Lane direction, (c) Milepost near one end of the wall, (d) GPS coordinates near one end of the wall, and (e) Type of MSE wall. The remaining attributes may be added to the database if available.

4. A protocol for counting MSE wall at bridge abutments needs to be established for the inventory.

5. Links to information regarding contract documents, design reports, and as-built plans and specifications should be included in the assembled geodatabase.

6. ITD should commit resources towards adding walls which were not identified by this study to the MSE wall inventory database. Also, the missing attribute data should be updated in the assembled inventory by making a concerted effort to locate relevant construction and design documents.

7. A modified version of the Ohio DOT procedure, included in Appendix F, is recommended for inspecting MSE walls in Idaho. For implementation, guidelines for MSE wall inspections should be developed and workshops planned to train potential MSE wall inspectors.

8. Using the recommended inspection procedures, all ITD MSE walls in the inventory should be inspected to create a baseline report and to identify walls found to be performing below expectations. A condition survey should be completed for the poorly performing MSE walls.

9. MSE walls found to be performing below expectations, should be inspected every year, and walls which are performing well, should be inspected at least every five years.

10. Data collected during follow-on inspections should be reviewed to see if there are significant changes in the measurements and performance. With time, it may be possible to develop categories of “damage” (such as low, medium, or high) depending on the measurements and changes.

11. Inspections should be complemented by appropriately annotated HD photographs. The use of drones to photograph high walls, or walls difficult to access, should be implemented wherever possible.

12. Further use of thermal mapping or Ground Penetrating Radar (GPR) should be investigated in a future study to see if the fill and reinforcing elements behind the wall’s face can be evaluated and assessed.

13. The six MSE walls in Districts 5 and 6 which appear to be distressed should be re-inspected to evaluate their performance.

Chapter 1
Introduction

Overview and Problem Statement

Since the installation of the first Mechanically Stabilized Earth (MSE) wall in Idaho by ITD near Hope, Idaho, in the early 1970's, many similar walls have been constructed for highway projects throughout Idaho. MSE walls contain structural and geotechnical components, each limited by their anticipated lifespan. An example of a typical MSE wall configuration is shown in Figure 1.

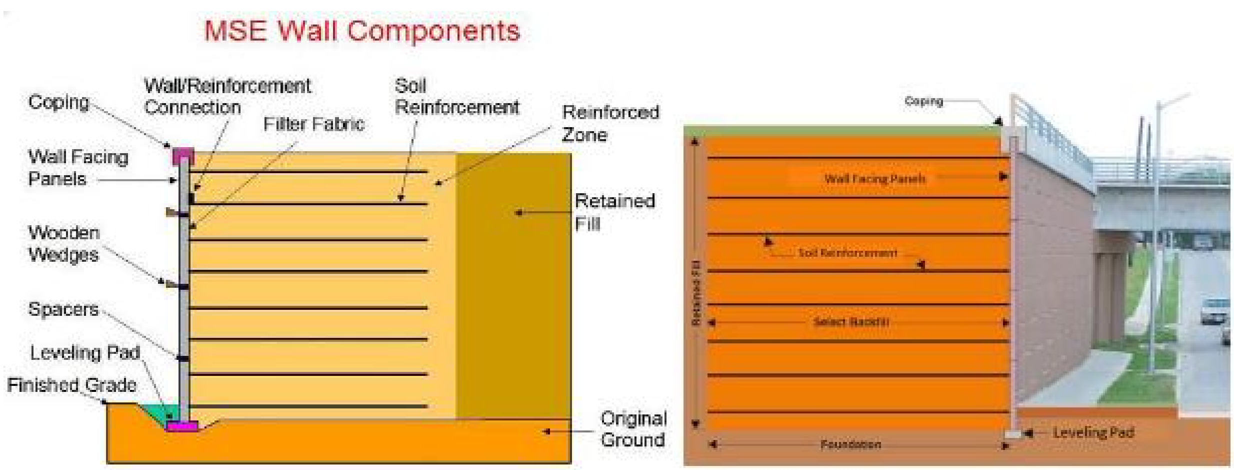


Figure 1. Typical MSE Wall Configuration [1]

Currently, the Idaho Transportation Department (ITD) does not have an inventory of MSE walls, or procedures for their inspection and assessment. An inventory of MSE walls is required as part of the overall strategy to create a complete accounting of all transportation assets. This requirement is in response to the "Moving Ahead for Progress in the 21st Century Act" (MAP-21).[2] This congressional act requires state DOTs to develop a performance-based process for building, maintaining, and managing infrastructure on the National Highway System.

As MSE walls are constructed with diverse components and techniques, there is an added need to make an effort to inspect these walls regularly to minimize potential disruptions resulting from failure and to develop budgets for future maintenance, repairs, or replacements. Essentially, the inspection process should prevent unforeseen problems, which tend to cause the greatest inconvenience.

Figure 2. MSE Wall Failure on SH-34, Soda Springs, ID, in July 2002 (3)

For example, an MSE wall which was constructed in 1978 failed in July 2002, when six precast panels "popped-out" from the 25-foot high wall.[3] This failure, shown in Figure 2, caused considerable disruption for travelers on SH-34 passing through the Soda Springs area in southeastern Idaho. The repairs were finally completed in November 2002, at a cost of nearly $2.5 million. To avoid such issues, MSE walls need to be inspected at regular intervals and their condition assessed to avoid problems.(4, 5, 6)

However, before such an inspection plan can be implemented, there is a need to inventory the location and status of existing MSE walls into a database, similar to the one assembled for ITD bridges and sign structures. Such a database will allow ITD engineers to complement the inventory details with periodic inspection information as part of a future Asset Management Program for MSE walls. This will allow ITD to focus their limited resources on optimizing the service life of MSE walls at minimal life cycle cost-matching investment with service.(2, 3) The MSE wall inventory, along with inspection information, will create a readily useable asset management program suitable for planning and managing a regular maintenance schedule.

Such an Asset Management framework will combine the inventory and inspection process to create a policy and data driven, systematic approach to identifying the optimal allocation of resources for transportation. As these MSE wall structures age, the lack of basic information, such as the location, size, and condition of the walls, may have negative impacts on both travelling public and highway operations, thus affecting safety, mobility and economic opportunity.

Objectives of the Study

The main objectives of the proposed research are to:

- Provide recommendations to guide ITD in establishing an inventory of MSE Walls. This will include identifying the data attributes for the MSE wall inventory, inspection information to be collected, and the most appropriate system for storing and tracking the data.
- Recommend an inspection protocol based on state DOT best practices for assessing the condition of MSE Walls managed by ITD. This would include proposing the inspection methods, rating criteria, inspection frequency, and the ITD personnel responsible for performing the work.
- Conduct a field assessment of the recommended inventory and inspection protocols by collecting the required data and conducting visual inspection of a few selected MSE walls. Use the results to refine the inventory and inspection recommendations.

Organization of the Report

This report contains six chapters and five Appendices.

Chapter 2 presents a summary of the information gathered from a comprehensive literature review of research and findings concerning the creation of an inventory of MSE walls, their inspection, and possible assessment of their condition. Additionally, the chapter reports on the information collected from a survey of state DOTs to learn about the status of their plans regarding the collection of similar information.

Chapter 3 concerns the selection and adoption of the MSE wall attributes needed for analyzing the performance of MSE walls and for incorporation into the proposed database. This data was selected from a combination of information gleaned from the literature review and the experience of the team members in performing previous MSE wall studies. Essentially, these attributes range from the "must-have" to many features which would be nice "to-have". This chapter also gives the inspection protocols which were identified as possible procedures for use on MSE walls in Idaho.

Chapter 4 provides information about the collection of MSE wall data and the creation of a demonstration database. Concerns and problems encountered in collecting this data from the districts are reported in this chapter.

Chapter 5 presents information about the inspection of seventeen of the inventoried MSE walls. Some of the state-of-the-art techniques, such as the use of small Unmanned Aerial Vehicles (i.e. drones) to photograph the condition of the walls and the use of thermal imaging, are discussed as suggestions for improving the inspection process.

Chapter 6 concludes the report with a summary and recommendations based on this study. Several appendices follow with special sections dedicated to details of the field inspections, thermal imaging, and a tutorial for implementing the inventory data into ArcGIS.

Chapter 2
Literature Review

Introduction

This portion of the study concerns collecting data to create an inventory of MSE walls in Idaho. This inventory will be a part of Idaho's Transportation Asset Management (TAM) system which will include information about the performance of the MSE walls. To assess performance, the MSE walls will be inspected on a regular basis to allow ITD personnel to rate their performance and make plans for future maintenance, repairs, and replacement. With these objectives in mind, a thorough review of the literature was undertaken to investigate the current state-of-practice regarding the creation of MSE wall inventories, adopted inspection procedures, and the rating of wall performance. Additionally, all state DOTs were contacted and asked to complete a survey about their current strategies for development of MSE wall inventories and inspection procedures.

MSE Wall Inventories

The construction of MSE walls in the United States is a relatively new concept, with most walls being built in the last 40 years. As a result, engineers are interested in learning from cases where the walls have performed poorly or failed. Some serious MSE wall failures have been reported in Tennessee (2000) (7), Virginia (2001) (7), Arizona (2001) (8) Maryland (2003) (9), and Texas (2004).(10) However, two failures in 2005 had significant consequences on MSE wall performance evaluation. There were considerable concerns when a 75-foot high, earth retaining wall crashed onto Riverside Drive in Manhattan, NY, causing a significant disruption of traffic flow for one week.(11) Later in the same year on December 7th, a three-lane, collector-distributor road along I-270 in northeast Columbus, OH, was closed as a large void was discovered underneath the approach slab at a bridge with MSE wall abutments.(12)

Following these failures, the DOTs took urgent action to at least start collecting data about the location of walls, which could then be followed by inspections.(12, 13, 14) To date, both the New York DOT and New York City DOT have assembled an inventory of over 4,000 retaining structures. Also, based on concerns about the MSE wall problem in Ohio in 2005, the Ohio DOT quickly located and inspected 339 walls. Ohio DOT also noted that the backfill in nearly one-third of the walls was lost through the wall joints and 13% exhibited some type of erosion problem.(15) Prior to these early studies, only the Colorado DOT had considered creation of an inventory of their retaining walls and sound barriers.(13)

With support from the Federal Highway Administration (FHWA) and American Association of State Highway Transportation Officials (AASHTO), an National Cooperative Highway Research Program (NCHRP) report titled "Guide to Asset Management of Earth Retaining Structures" was published in 2009.(5) This report focused on the development of wall inventories and inspection procedures needed to assess wall performance. Although this report covered all retaining structures, issues concerning MSE walls were also considered. Following this report, over a dozen states started work on developing inventories of their retaining walls.(18)

Table 1 presents a summary of the states and agencies actively involved with creating retaining wall inventories. For some of the agencies, the table shows the number of retaining walls in their inventories. It should be noted that these numbers are for all retaining structures and not just MSE walls. The City of Cincinnati has been very active since 1990 and has collected data on over 7,000 walls.(19)

Table 1. Agencies with Inventory and Inspection Programs (adapted from Gabr et al.(18))

Agency*	With inventory or an inspection program	With inventory and inspection program	With inventory and inspection in an asset management system	Rating scale
Alaska DOT	X	—	—	—
British Columbia Ministry of Transportation	X	X	X	—
California DOT	X	—	—	—
City of Cincinnati (7,000)	X	X	X	0 – 4
City of Seattle	X	—	—	—
Colorado DOT	X	—	—	—
FHWA and NPS (3,500)**	X	X	X	1 – 10
Kansas DOT	X	X	—	—
Maryland DOT	X	—	—	—
Minnesota DOT	X	—	—	—
Missouri DOT	X	—	—	—
New York City DOT (2,000)	X	X	—	1 – 7
New York State DOT (2,100)	X	X	—	1 – 7
Oregon DOT (500)	X	X	—	Good/fair/poor
Pennsylvania DOT	X	X	X	2 – 8
VicRoads Technical Consulting for Victoria Australia	X	X	X	1 – 4
Nebraska Department of Roads	X	X	—	0 – 9
Ohio DOT (339)	X	X	—	Yes/no
Utah DOT	X	X	—	Yes/no

*Number of earth retaining structures surveyed by each agency is shown in parenthesis, where available.
**NPS – National Park Service.

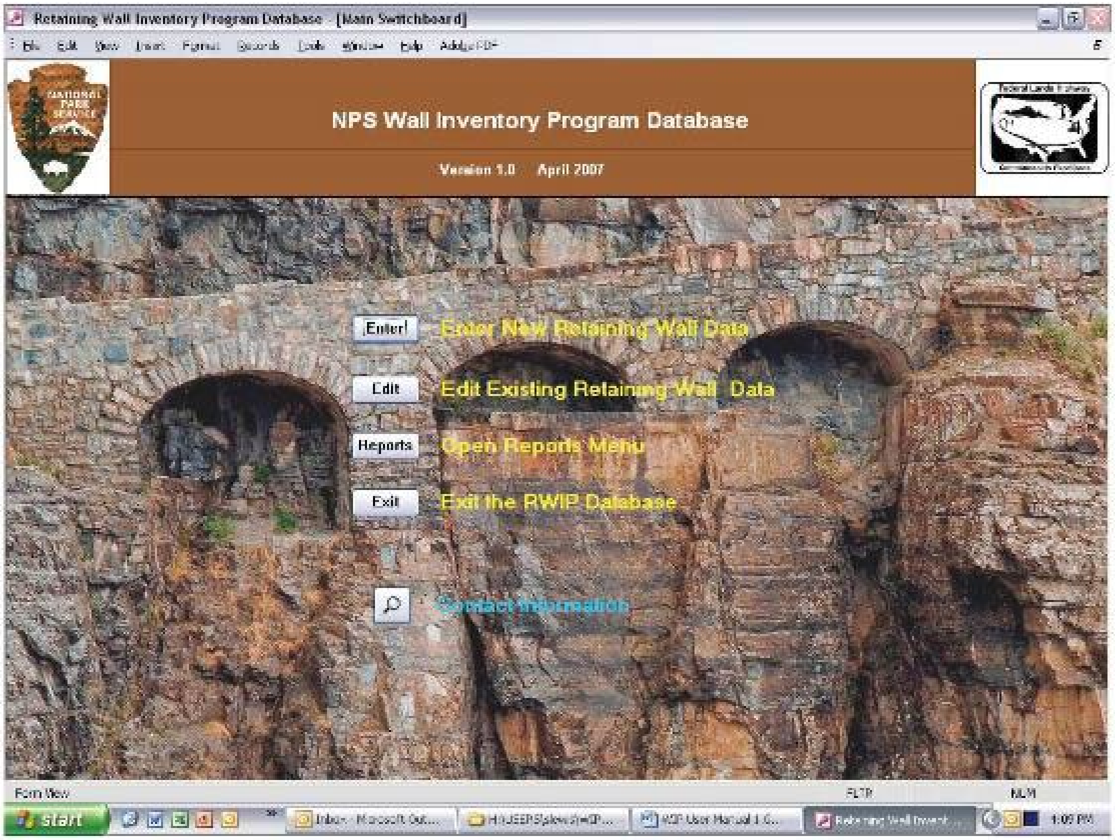


Figure 3. Opening Screen to the WIP Database [21]

The Central Federal Lands Highway Division of the Federal Highway Administration (FHWA-CFLHD) for the National Parks Service (NPS) also assembled a comprehensive inventory of more than 3,500 retaining wall assets. [20, 21] A screen shot of the interface to the "Wall Inventory Program" (WIP) database is shown in Figure 3.

WIP is supported with a procedures manual: "Retaining Wall Inventory and Condition Assessment Program (WIP): National Parks Service Procedure Manual." Alaska DOT has also developed procedures based on the WIP Manual because the manual covers many relevant retaining wall issues.

Other DOTs, such as California [22], Colorado [23], Minnesota [24], Nebraska [25], North Carolina [26, 27], Ohio [28], Oregon [29], and Utah [30, 31], and the City of Seattle [32], have formal guidelines to assist users in collecting wall data and adding to existing inventories.

Two international efforts concerning the management of retaining wall assets have been made in Australia and Canada. In 2003, the British Columbia Ministry of Transportation started adding information about retaining structures to their Bridge Management and Information system.[33] As part of this system, retaining walls were inspected and assessed within the same framework as for the bridges. In 2011, VicRoads Technical Consulting produced the "Road Structures Inspection Manual" for the State of Victoria (Australia) transportation department. This manual considered all retaining structures, including visual walls and noise walls, along with many other roadway structures including bridges and culverts in their asset management system.(34)

The present study considered many of these publications in developing wall attributes suited to MSE walls in Idaho. These attributes are discussed in the next Chapter.

MSE Wall Inspection Procedures

An effective MSE wall asset management system should "identify and gather the most useful, reliable, cost-effective information and use it to make informed decisions."(34). This entire process then uses engineering and economic principles, along with good business practices, to support decision making at the strategic, network, and project levels.(35) For MSE walls, effective decisions require complete inventories and subsequent inspections related to performance. This section reports on the literature concerning the "Inspections", as proposed and implemented by various transportation agencies.

Most of the inspection procedures were developed following MSE wall failures which adversely impacted traffic flow. Other closely related procedures were also developed to help inspectors monitor the construction of MSE walls.(1,,37, 38, 39) This implies that MSE wall observations made during post-construction inspections should be consistent with control emphasized during construction. Generally, MSE walls rarely fail completely. However, rather than failure, there is a steady degradation in their ability to retain soil as intended by the designer. Appropriate inspection procedures should thus pick up on features which indicate possible future problems which will affect the ultimate performance of the MSE wall. If some of these attribute problems are detected early enough, suitable maintenance techniques may be applied to reduce repair costs and extend the life of the wall. Also, if detected during construction through better inspection procedures, the repairs may be prevented in the first place.

Following a review of practices utilized by transportation departments, Alzamora and Anderson (40) identified ten problems which indicate possible distress in MSE walls. These ten items are:

1. geometry and wall layout,
2. obstructions,
3. wall embedment,
4. surface drainage,
5. contractor experience,
6. claims,
7. backfill placement and compaction,
8. panel joints,
9. leveling pad, and
10. durability of facing.

Most published guidelines consider these items, except for items 5 and 6, which tend to be a different quality control problem during construction.

Based on Table 1, there are at least 11 agencies in the United States with published or unpublished guidelines for conducting MSE wall inspections. As mentioned earlier, NY-DOT [13] and Ohio-DOT [14] were quick to prepare inspection guidelines following unexpected wall failures in 2005. The NY-DOT manual is really a construction inspection manual, whereas the Ohio-DOT version provides a protocol for post-construction inspection.

For inspection of retaining structures, the 2009 NCHRP study [5] identifies 22 inspection items:

1. Wall or parts of it, out of plumb, tilting or deflected.
2. Bulges or distortion in wall facing.
3. Some elements not fully bearing against load.
4. Joints between facing units (panels, bricks, etc.) misaligned.
5. Joints between panels too wide or too narrow.
6. Cracks or spalls in concrete, brick, or stone masonry.
7. Missing blocks, bricks, or other facing units.
8. Settlement of wall or visible wall elements.
9. Settlement behind wall.
10. Settlement or heaving in front of wall.
11. Displacement of coping or parapet.
12. Rust stains or other evidence of rebar corrosion.
13. Damage from vehicle impact.
14. Material from upslope rockfall or landslide adding load on wall.
15. Presence of graffiti (slight, moderate, heavy).
16. Drainage channels along top of wall not operating properly.
17. Drainage outlets (pipes/weep-holes) not operating properly.
18. Any excessive ponding of water over backfill.
19. Any irrigation or watering of landscape plantings above wall.
20. Root penetration of wall facing.
21. Tree growth near top of wall.
22. Any other observations not listed above.

After assessing the type and extent of any distress in the retaining structure, and considering consequences of failure (COF), the report suggests the following scale:

1. Low,
2. Moderate,
3. High, and
4. Urgent.

This rating is intended to assist the manager in prioritizing and scheduling follow-up inspections. For an urgent rating, the inspector is asked to discuss the responses with the supervisor.

In reviewing published inspection procedures, the Kentucky DOT assessment is one of the simplest. It provides guidelines for inspection and concludes with the assessments presented in Table 2.[38, 39] However, these are intended mainly as a preliminary assessment of MSE wall abutments used for highway bridges. Its four assessment criteria are simple but without any quantitative data and do not address individual features which may need maintenance or replacement.

Table 2. Preliminary MSE Wall Assessment by Kentucky DOT [38]

Condition	Description
Excellent	MSE wall abutment is in perfect condition without any visible damage/deterioration/deformation; without big vegetation protruding from face.
Good	MSE wall abutment is in good condition with small visible damage/deterioration/deformation; or with big vegetation protruding from face
Fair	There are non-ignorable visible damage/deterioration/deformation on MSE wall abutment and need to pay big attention on it.
Poor	There are significant visible damage/deterioration/deformation on MSE wall abutment and need to fix ASAP; otherwise, it will threaten public traffic.

The Utah-DOT [30, 31] also developed guidelines for evaluating the performance of MSE walls as part of its asset management program. Inspection data is collected using five, web-based forms. Typical examples of these data forms used for collecting the wall inspection information are shown in Tables 3 and 4. As this is a web-based collection system, the resolution of the reproduced forms in hardcopy form is unfortunately sub-standard.

Data in the Utah-DOT system is recorded as given below:

1. Drainage,
2. Wall joints,
3. Wall facing,
4. Conditions at top of wall,
5. Foundation conditions and external stability,
6. Corrosion and degradation,
7. Impact and collision, and
8. Miscellaneous issues.

These items were selected since they are strong indicators of current conditions and anticipated future performance. For each item, the inspector provides a *Yes, No, Not Applicable (N/A) or Unknown (UKN)* rating, along with an estimate of the percentage of the total wall affected by the symptom/issue. Photographic documentation is a significant part of the inspection process. Considerable resources were dedicated to the asset management effort in the early years, but the level of commitment has been very low during the past 8 years, apparently due to a lack of resources.

Table 3. Example of Web-based MSE Wall Evaluation Form 1 (Utah DOT [16])

STATE OF UTAH MSE WALL INSPECTION FORM

Compiled as Part of Research for the Utah Department of Transportation

Instructions:

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

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

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

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

Inspector Information

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

MSE WALL CHARACTERISTICS

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

Summary of Key Observations:

Table 4. Example of Web-based MSE Wall Evaluation Form 2 (Utah DOT [16])

SPECIFIC WALL CHARACTERISTICS															
DRAINAGE															
Required Tools:				Nylon Mallet-Water Bottle-Camera-Tape Measure											
Yes	No	N/A	UKN	Issue	Measurement / Explanation (If applicable)	Percentage of Wall Affected / Extent of Problem / Photo #									
Y	N	N/A	UKN	Is there an active water source near the toe of the wall (is the wall near a body of water with scour potential)?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	If applicable, are the catch basins at the base of the wall blocked?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are there culverts protruding through the wall?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are there vertical drains that travel through the backfill?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Is there erosion at the base of the wall or leveling pad?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Is there erosion along the wing walls?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are there any signs of water flow along the base of the wall?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Is there less than 15 feet between irrigation sprinklers and wall?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Does the backfill or joint fabric appear to be saturated?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Is there vegetation growing in panel joints?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are the deck drains and outlets at the top of the wall blocked?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Can water enter the wall between coping and slab (i.e., Drain appropriately)?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Is there evidence at discharge point of fill washing through drain pipes?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
MSE WALL JOINTS															
Required Tools:				Long Level-String-Camera-Tape Measure											
Yes	No	N/A	UKN	Issue	Measurement / Explanation (If applicable)	Percentage of Wall Affected / Extent of Problem / Photo #									
Y	N	N/A	UKN	Is backfill coming out of joints or are there piles of backfill at the base of the wall?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are the joints wide enough to see fabric or backfill behind panels when looking into joints? If yes, record the approximate maximum joint width in inches.		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Is exposed backfill visible in the horizontal joints?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are there visible tears in the fabric?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Is there evidence of backfill or water leaking through tears in fabric behind panels? (Do not induce additional damage to fabric)		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Do the joints have a non-uniform horizontal spacing/size? (i.e. Are some horizontal joints larger/smaller than others?)		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Do the joints have a non-uniform vertical spacing/size? (i.e. Are some horizontal joints larger/smaller than others?)		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum offset.		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%
Y	N	N/A	UKN	Does the fabric appear brittle, or appear as if it has undergone excessive UV exposure?		0-No	1%	5%	10%	25%	50%	75%	90%	95%	100%

The FHWA-CFLHD [21] forms for inspecting retaining structures are very comprehensive and require detailed investigations. The completion of a survey requires a team consisting of at least two persons, where the lead inspector is a licensed geotechnical engineer. The survey components are divided into primary and secondary wall elements as shown in Table 5.

Generally, each retaining structure is considered to have between five and ten different elements which vary somewhat based on the retaining wall type. For each element, the inspectors examine the wall and record signs of distress such as: corrosion or weathering, cracking or breaking, distortion or deflection, and lost or missing elements. Then, each element is described relative to the extent, severity, and urgency of the observable distress based on the criteria in Table 6. Finally, the elements are rated with a numerical value according to the system given in Table 7. In this rating system, lower numbers indicate a higher level of distress. After each individual element is rated, the overall rating of the wall is determined using a weighted average of all the elemental ratings. [21] The overall condition of the wall is assessed according to Table 8. Average ratings between 8 and 11 indicate good to excellent wall behavior. Typical forms used to collect retaining wall data are given in Tables 9 and 10.

Unfortunately, use of the FHWA-CFLHD procedure requires skilled inspectors and engineers to carry out the inspections. As a result, its adoption by state DOTs in MSE Wall Asset Management is unlikely because many of the elements are not part of or are not observable in MSE walls, criteria are non-quantitative and its significant expense.

Table 5. FHWA-CFLHD Primary and Secondary Wall Elements [21]

Primary Element Condition Ratings		Secondary Element Condition Rating	
Piles and Shafts	Soldier piles, sheet piles, micropiles or drilled shafts, as well as supplemental structures such as whalers, comprising part or all of the visible wall.	Wall Drains	Function and capacity of visible drain holes, pipes, slot drains, etc., that provide wall subsurface drainage.
Lagging	Structural lagging between piles and whalers.	Architectural Facing	Facing that is not relied on for structural capacity, including concrete, shotcrete, stone, timber, vegetation, etc.
Anchor Heads	All visible parts of tieback anchor, including pad (generally observed without removing cap).	Traffic Barrier or Fence	Traffic barrier or fence above or below wall, and within the influence of the wall.
Wire or Geosyn. Facing Elements	Visible facing or basket wire, soil reinforced elements, hardware cloth, geotextile or geogrids and facing stone.	Road, Sidewalk or Shoulder	Road and/or sidewalk surface above or below a wall, and within the influence of the wall.
Bin or Crib	Visible portion of cellular gravity wall.	Upslope	Ground slope area above a wall affecting wall condition and/or performance.
Concrete	Visible precast or cast-in-place concrete wall and footing elements (does not include piles, lagging, crib blocks, manufactured block or brick, and architectural facing).	Downslope	Ground slope area below the wall, distinct from the Wall Foundation Material element, affecting wall condition and/or performance.
Shotcrete	Visible shotcrete (does not include pile lagging, architectural facing or other specific elements).	Lateral Slope	Ground slope laterally adjacent to a wall affecting wall condition and/or performance.
Mortar	Visible mortar used between uncut or masoned rock, manufactured blocks or brick, or used for wall repairs.	Vegetation	Vegetation near wall or on wall face affecting wall condition and/or performance.
Manufactured Block/Brick	Manufactured blocks and bricks, including CMU's segmental blocks, large gravity blocks, etc. (does not include concrete lagging or crib wall elements).	Culvert	Culvert and inlets or outlets through, below, or adjacent to wall.
Placed Stone	Dry-laid or mortar-set *uncut* rock	Curb/Berm/Ditch	Lined or unlined surface drainage feature above or below wall.
Stone Masonry	Dry-laid or mortar cut rock	Other Secondary Wall Elements	Any secondary wall elements not listed (provide detailed narrative definition)
Wall Foundation Material	Soil or rock immediately adjacent to and supporting the wall.		
Other Primary Wall Elements	Any primary wall element not listed (provide detailed narrative definition).		

Table 6. Rating Guide for Wall Elements based on FHWA-CFLD Procedures [21]

WALL ELEMENT CONDITION RATING GUIDANCE
GOOD TO EXCELLENT **(Minor to No Distress, Minimal to No Impact, Few to No Occurrences)**
Corrosion/Weathering • No evidence of corrosion/staining, contamination or cracking/spalling due to weathering or chemical attack. • Compacted, placed or masoned rock, and associated chinking, is dense, angular, fresh, and without post- placement fracturing or chemical degradation. • No significant weathering/weakening of bedrock, softening of soil, or saturated ground conditions evident. • No impacts from vegetation noted within the wall or within adjacent elements. **Cracking/Breaking** • No evidence of element cracking, breaking, or construction/post-construction damage, opening of discontinuities in rock, or cracks or gullies in soils. • Concrete, shotcrete, and mortar is sound, durable, and shows little or no signs of shrinkage cracking or spalling. • Drains are clearly open (flowing), and in full working order. **Distortion/Deflection** • Wall elements are as constructed, and/or show no signs of significant settlement, bulging, bending, heaving, or distortion/deflection beyond normal prescribed post-construction limits. **Lost Bearing/Missing Elements** • No wall elements are missing. • Wall elements are fully bearing against retained soil/rock units. • Foundation soils/rock are more than adequate to support the wall, consistently dense, drained and strong. • No slope failures have occurred either removing or adding materials from the wall area.
FAIR **(Moderate Distress, Significant to Substantial Impact, Moderate to Multiple Occurrences)**
Corrosion/Weathering • Moderate corrosion/staining, contamination or cracking/spalling due to weathering or chemical attack. • Compacted, placed or masoned rock is not fresh or angular, showing significant weathering, post-placement fracturing, chemical degradation, and/or localized loosening. • Significant weathering/weakening of bedrock, softening of soil, or saturated ground conditions evident. • Moderate impacts from vegetation are evident within the wall or within adjacent elements. **Cracking/Breaking** • Localized element cracking, breaking, abrasion and/or construction/post-construction damage, opening of discontinuities in rock, or cracks or gullies in soils. • Concrete, shotcrete, and mortar is occasionally soft or drummy, has lost durability, and shows occasional cracking and/or spalling sufficient to intercept reinforcement. • Drains cannot be clearly determined to be fully operational. **Distortion/Deflection** • Wall elements show significant localized settlement, bulging, bending, heaving, misalignment, distortion, deflection, and/or displacement beyond normal prescribed post-construction limits (e.g., wall face rotation, basket bulging, anchor head displacement, bin displacement).
Lost Bearing/Missing Elements • Some wall elements are missing (e.g., chinking, lagging, brick-work) or non-functional. • Wall elements are generally bearing against retained soil/rock units, but localized open voids may exist along the back and top of the wall. • Foundation soils/rock are adequate to support the wall, but susceptible to shrink-swell, erosion, scour, or vegetation impacts. • Isolated slope failures have occurred either removing or adding materials from the wall area.

Table 6. Rating Guide for Wall Elements based on FHWA-CFLD Procedures [21] (continued)

POOR TO CRITICAL (Severe Distress, Failure is Imminent, Pervasive Occurrences)
Corrosion/Weathering • Metallic wall elements are corroded and have lost significant section affecting strength. • Concrete/shotcrete is extensively spalled, cracked, and/or weakened, and may show evidence of widespread aggregate reaction. • Compacted, placed or masoned rock is highly weathered, showing extensive post-placement fracturing, chemical degradation, and/or loosening within the placed volume. • Extensive weathering/weakening of bedrock, softening of soil, or saturated ground conditions evident. • Severe impacts from vegetation are evident within the wall or within adjacent elements. **Cracking/Breaking** • Extensive severe element cracking, breaking, abrasion or construction/post-construction damage, opening of discontinuities in rock, or cracks or gullies in soils. • Concrete, shotcrete, and mortar is consistently soft, drummy, or missing, has lost durability and strength, and shows pervasive cracking and/or spalling intercepting corroding/weathering reinforcement. • Drainage is missing, clearly damaged, and/or obviously clogged and non-functional. **Distortion/Deflection** • Wall elements show extensive settlement, bulging, bending, heaving, distortion, misalignment, deflection, and/or displacement well beyond prescribed post-construction limits, including loss of ground reinforcement and retention. **Lost Bearing/Missing Elements** • Many or key wall elements are missing (e.g., placed wall stone, chinking, lagging) or non-functional. • Many or key wall elements are no longer bearing against retained soil/rock units, with visible open voids evident behind a large portion of the wall. • Foundation soils/rock show signs of failure, excessive settlement, scour, erosion, substantial voids, bench failure, slope over-steepening, and/or may be adversely impacted by vegetation. • Substantial slope failures have occurred either removing or adding materials from the wall area.

Table 7. FHWA-CFLD Wall Element Condition Rating Criteria [21]

Element Condition Rating	Rating Definition
9-10 Excellent	No-to-very-low extent of very low distress. Any defects are minor and are within the normal range for *newly constructed or fabricated* elements. Defects may include those typically caused from fabrication or construction. Ratings of 9-10 are only given to conditions typically seen shortly after wall construction or substantial wall repairs.
7-8 Good	Low-to-moderate extent of low severity distress. Distress present does not significantly compromise the element function, nor is there significant severe distress to major structural elements of an element. Ratings of 7-8 indicate highly functioning wall elements that are only beginning to show the first signs of distress or weathering.
5-6 Fair	High extent of low severity distress and/or low-to-medium extent of medium to high severity distress. Distress present does not compromise element function, but lack of treatment may lead to impaired function and/or elevated risk of element failure in the near term. Ratings of 5-6 indicate functioning wall elements with specific distresses that need to be mitigated in the near-term to avoid significant repairs or element replacement in the longer term.
3-4 Poor	Medium-to-high extent of medium-to-high severity distress. Distress present threatens element function, and strength is obviously compromised and/or structural analysis is warranted. The element condition does not pose an immediate threat to wall stability and closure is not necessary. Ratings of 3-4 indicate marginally functioning, severely distressed wall elements in jeopardy of failing without element repair or replacement in the near-term.
1-2 Critical	Medium-to-high extent of high severity distress. Element is no longer serving intended function. Element performance is threatening overall stability of the wall at the time of inspection. Ratings of 1-2 indicate a wall that is no longer functioning as intended and is in danger of failing catastrophically at any time.

Table 8. FHWA-CFLD Wall Performance Rating Definitions [21]

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

Table 9. Typical MSE Wall Field Inspection Form [21]

-NPS RETAINING WALL INVENTORY PROGRAM (WIP) FIELD FORM-					
NPS Park Name		Route/Parking No.		Wall Start Milepoint	
Inspected By		Route/Parking Name		Wall End Milepoint	
Inspection Date		Side of Centerline	(R/L/P# #)	Visidata Event Milepoint	
WALL FUNCTION, DIMENSIONS, and DESCRIPTION					
Wall Function		Primary Wall Type		Architectural Facings	
Approx. Year Built		Secondary Wall Types		Surface Treatments	
Wall General Description Notes: *(e.g., wall purpose, setting, construction, consequence of failure, special design, etc.)*					
Wall Length (ft)		Wall Face Area (ft²)		Wall Start Offset (ft)	
Max. Wall Height (ft)		Vertical Offset (+/- ft)		Wall End Offset (ft)	
Photo Description/No. *(e.g., approach, elevation, wall top, alignment, face detail, deficiencies, etc.)*				Face Angle (deg)	
Park Designated Wall ID					
REPAIR /REPLACE RECOMMENDATIONS AND WORK ORDER					
Wall Condition Rating		Design Criteria		Failure Consequence	
Investigation Req'd?	(Y/N)	Cultural Concern?	(Y/N)	Action	
Brief Work Order Description *(5-10 word maximum, key work elements)*					
Repair/Replace Recommendations *(itemized description of wall repairs, methods, estimated quantities, and costs per repair item, including consideration of constructability issues such as access, traffic control, staging, safety hazards, etc.)*					
Rev. 07-10-2007				**Repair/Replace COST:**	

Table 10. Typical MSE Wall Field Inspection Form (Back Page) [21]

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

The inspection procedures proposed by VicRoads Technical Consulting [36] for the State of Victoria (Australia), uses three levels of evaluation, with each level conducted by different inspectors and at different times. The process is summarized in Table 11.

Level One only requires a routine inspection, often performed every six months, mainly to check the structural integrity and service performance of the wall. For routine inspections, inspectors observe obvious signs of defects and distress such as lateral tilting or budging, extended cracks, corrosion, spalling, heat damage, and erosion. If any distress is noted, photographs are taken for the record, and an assessment is made regarding the need for a more detailed inspection.

Level Two inspections are conducted every two to five years and are used to rate the condition of the retaining structure. The rating data in the database is used to prioritize future maintenance needs, and assess the effectiveness of past maintenance treatments, forecast future changes in condition, and estimate funds required to maintain wall performance. For Level Two inspections, current conditions are compared with past conditions recorded in photographs. The process is completed by taking new photographs and by evaluating structural elements that may need a detailed engineering inspection (level three inspection) including further monitoring, or additional review. If potentially hazardous defects are noted during Level One or Two inspections, the inspector can request a more detailed Level Three inspection.

A Level Three Inspection generally involves a more detailed assessment of specific wall elements noted as potential threats to the overall performance of the retaining structures. Level Three inspections must be performed by qualified engineers and specialists.

The City of Cincinnati has developed a very effective asset management system for more than 7,000 retaining walls. [19] The inspection information is entered directly into an electronic Excel format shown in Table 12. Once entered, the data can be readily transferred to the database and asset management system. The inspection requires a rating response to 26 questions in four categories: Structure, Drainage, Cosmetic, and Miscellaneous. An average rating for each category and an overall average is used to prioritize repairs and maintenance. This is a good rating system for retaining walls but should be modified to include actual measurements for MSE wall asset management.

One final inspection procedure worth mentioning is used for retaining walls in Seattle. In this procedure, the tilt of the retaining wall, measured using a digital protractor, is a primary component of the inspection program. [32] This measurement correlates strongly with the condition of the wall and its expected future life.

In the present study, the procedures developed specifically for MSE walls proposed by Ohio-DOT, Nebraska Department of Roads, and North Carolina DOT were selected for evaluation and potential use by ITD. Detailed information of these three procedures is given in Chapter 3. Examples of typical forms used by these three agencies are presented in Tables 13 to 16 in this report.

Table 11. Vic Roads Inspection Process for Retaining Walls [34]

	Level One (Routine Maintenance Inspection)	**Level Two** (Road Structure Condition Inspection)	**Level Three** (Detailed Engineering Inspection)
Purpose	To check general serviceability of a structure, particularly for the safety of road users and to identify any emerging problems	To assess and rate the condition of a structure and adjacent roadway and report any significant damage or defects that may require urgent repair or replacement	To undertake specific, detailed structural investigation of a specific component or element of a structure.
Entails	Brief inspection of structural elements – reporting any significant visual signs of damage, distress or unusual behavior	Inspection of road structure elements and an assessment of the condition rating for the structure as a whole using the standard condition rating system. Inspection shall start at bottom of structure and continue to the top of the structure. Inspect and rate each specified element individually. Compare photos and observations from previous inspections.	A variety of tests and inspections may occur depending on the severity and element experiencing the defect.
Recommendation	Determine if structure is in need of a more in-depth and qualified inspection.	Determine if structure is in need of a more in-depth and qualified inspection and nominate elements for closer monitoring if necessary.	
Frequency	Every 6 Months	Every new structure should be given a Level 2, Road Structure Condition Inspection within 12 months of opening and thereafter, once every 2-5 years.	As-Needed Basis
Data Sheets		Structure inventory and photographic record sheet, Condition rating sheet, Structure defect sheet (if element assessed as condition 3 or 4), Structure information sheet, Structure sketch sheet.	

Table 12. Form used by Cincinnati DOT for Retaining Wall Inspection [19]

RETAINING WALL INSPECTIONS

city of CINCINNATI TRANSPORTATION & ENGINEERING

Wall Number: ____________________

Street: ____________________

	DIVISION Structure	RATING	COMMENTS
1	Cracking----------------------		
2	Bulging-----------------------		
3	Sliding------------------------		
4	Tilt------------------------------		
5	Settlement--------------------		
6	Delamination----------------		
7	Joints-------------------------		
8	Wall Cap---------------------		
9	Stone/Block-----------------		
10	Footing-----------------------		
11	Landslide Damage-------		
12	Tree Damage--------------		
			Average Structural Condition
	Drainage		
13	Backdrains------------------		
14	Weep Holes-----------------		
15	Ditch Behind Wall---------		gutter
16	Erosion-----------------------		
17	Leakage----------------------		
			Average Drainage Condition
	Cosmetic		
18	Discoloration----------------		
19	Graffiti------------------------		
20	Gunite-------------------------		
21	Paint/Miracoat--------------		
			Average Cosmetic Condition
	Miscellaneous		
22	Brush/Undergrowth--------		
23	Railing/Fence---------------		
24	Curb----------------------------		
25	Sidewalk/Roadway--------		
26	Steps--------------------------		
			Average Miscellaneous Condition
	General Condition		
27	Overall Wall Rating		

Community No.: Community: #N/A

Inspected By:	Inspection Date:
Last Overall Wall Rating:	Change in Rating:
Last Inspection Date:	("+" = getting better / "-" = getting worse)

Retaining Wall Inspection Form (Excel) 2/1/2013

Table 13. Inspection form used by Ohio DOT [13]

STATE OF OHIO DEPARTMENT OF TRANSPORTATION

MSE WALL INSPECTION CHECKLIST

District ☐   ☐ Date Inspected   ☐ Name of Inspector

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

Instructions are on the 2nd page.

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

Revised 12/15/2005

Table 14. Inspection Form used by the Nebraska DOT Procedure (Page 1) [26]

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

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

_____ **Wall Tilting** (Panel Wall)

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

_____ **Structural Cracking**

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

_____ **Facial Deterioration**

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

_____ **Bowing of the Wall**

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

_____ **Panel Staining**

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

Table 15. Inventory Form used by North Carolina DOT [26]

Wall Identification and Data Attributes Form

Page 1

Wall ID: 910005 Date: 2/18/2014 NCDOT Reviewer(s): Cedrick Butler

Revision Date:

Picture(s):

LOCATION DATA

County: Wake Division: 5 Travel Direction: West-East

Route Number: US-70 Route Name: Glenwood Avenue Latitude: 35° 54' 05.61" Longitude: 78° 45' 56.63"

Location Description: West Wall Abutment - US 70 (Glenwood Avenue) over SR 1837 (Westgate Rd)

Bridge Association: Yes Bridge Number: 665 Culvert Association: No Culvert Number: N/A

Road System: Primary Tier: Statewide

DIMENSION DATA

Embedment (ft): 2 Max. Wall Height (ft): 25 Extension (ft): N/A Total Length (ft): 1059

Wall Batter: 90° Back Slope: N/A Front Slope: N/A Berm Dimension: N/A Distance to Stream (ft): N/A

Roadside Features:

Plan View:

Profile View:

WALL TYPE AND FUNCTION DATA

Wall Type: MSE Wall Facing Precast Panels Veneer: N/A

Construction Type: Fill Function Type: Bridge Abutment Traffic Volume: 13000

Protected Features: Roadway Purpose: Shorten Bridge Length

Table 16. Example of an Inspection Form used by North Carolina DOT [26]

ERS Field Condition Inspection Data Collection Form

Wall ID: 910005 Date: 6/5/2014 NCDOT Inspector(s): Cedrick Butler

Division: 5 County: Wake Route Number: US-70 Route Name: Glenwood Avenue

Location Description: West Wall Abutment - US 70 (Glenwood Avenue) over SR 1837 (Westgate Rd)

Latitude: 35° 54' 05.61" Longitude: 78° 45' 56.63" Wall Type: MSE

CATEGORY	OBSERVATIONS	PERCENT BY RATING 1	2	3	4	COMMENTS
Facing	Facial Deterioration	100	0	0	0	
Facing	Staining	70	30	0	0	Several discolored panels from water near the top of the wall.
Facing	Damage	70	20	10	0	Several roots penetrating the wall facing causing panels to move. Some roots were rather long.
Facing	Cracking	100	0	0	0	Counted (1) cracked panel near the base of the wall.
Facing	Joint Alignment	50	50	0	0	Evidence of misaligned facing units.
Facing	Joint Spacing	50	50	0	0	Joint spacing is too wide in several sections throughout the wall.
Facing	Material Loss	100	0	0	0	
Movement	Defection/ Rotation	90	10	0	0	There appears to be some deflection on the left side of the bridge abutment.
Movement	Bulges/ Distortion	80	20	0	0	Evidence of local bulges.
Movement	Settlement	100	0	0	0	
Movement	Heaving	100	0	0	0	
Drainage	Erosion	100	0	0	0	
Drainage	Scour	100	0	0	0	
Drainage	Internal/ External Drains	50	0	50	0	Drainage channel along the top of the wall is full of vegetation and debris.
Exterior	Wall Top Attachment	90	10	0	0	Evidence of some displacement on the right approach wall.
Exterior	Road/Sidewalk/ Shoulder	100	0	0	0	
Exterior	Vegetation	50	30	20	0	Vegetation is present all along the wall and in the drainage channel along the top of the wall. Several roots are also penetrating through the wall facing.

Inspection Frequency

In general, there was little or no information regarding the selection of an appropriate inspection cycle for retaining walls. The Oregon DOT suggested a frequency of five years for walls rated as "good", whereas those rated "fair" or "poor" are inspected more frequently, i.e. less than five years. The VicRoads Technical Consulting (33) recommends an inspection cycle of every two years and the FHWA-CFLHD (21) procedure proposes a five to seven-year return interval.

Survey of State DOTs

At the beginning of the present project in March/April 2018, 51 US DOTs were contacted to gather information about their current practices regarding MSE wall inventories and inspection procedures. By the end of May 2018, 24 responses were received, with 2 more added in June. A summary of the responses is given in Tables 17 and 18, respectively.

After reviewing the survey results concerning "MSE Wall Inventories", the following concluding observations were made:

1. Only nine DOTs have an inventory of MSE walls.
2. Only four DOTS have an MSE wall database in an accessible format.
3. MSE wall information was stored in a variety of database formats ranging from the commonly available MS-Access (part of MS Office) to more complex proprietary systems.
4. The CO-DOT and OR-DOT databases had interfaces with GIS systems. The OR-DOT system can also interface with their Bridge Management (BM) system.

With this information about current practice, it is likely that ITD will aim to develop a database which will interface with their GIS system and make the data readily accessible to ITD personnel. The ultimate goal is to collect MSE wall data in an electronic format using a small hand-held device and upload to the ITD ArcGIS system directly.

The responses for the "Inspection" portion of the survey revealed that there were only ten state DOTs with full procedures in-place for MSE wall inspections. Overall the time period between inspections varied depending on wall conditions, but generally ranged between two and five years. Only seven DOTs use the inspection data to rate the condition of the MSE wall. The existing, and available, inspection procedures were evaluated in this study for possible adoption by ITD, with appropriate modifications.

After reviewing the literature and responses from the survey, the general sense is that only a few DOTs have established a functioning protocol for assembling an MSE wall inventory which is combined with regular inspections used to rate performance. To assemble an effective asset management system for Idaho, the creation of an MSE wall inventory along with good inspection procedures for assessing performance is expected to be the best approach.

Table 17. ITD Survey Results of MSE Wall Inventories

Survey Question	Requested Response
Do you have an inventory of highway MSE walls in your State? • *Nine DOTs (CO, ME, NY, VT, UT, AK, OR, AZ) responded with "yes", one "partial (CT).* • *Three DOTs (CA, NE, and NC) did not respond to the survey, but based on past published reports, "may" have an MSE wall inventory database.* • *OH-DOT is in the "beta" testing phase for setting up a retaining wall inventory and inspection database.* • *LA-DOT is considering one.*	Yes / No
Is this inventory part of an electronic database? • *Of the ten "yes" respondents, VT-DOT does not maintain a database.*	Yes / No
If you have a database, is it available to all transportation department personnel who deal with MSE walls? • *Only four DOTs (CO, CT, AK, OR) have their databases a readily accessible format.*	Yes / No
Is this part of a GIS system or a database management system (such as the BM Program)? • Asset Management: *Six DOTs (CO, CT, ME, AK, OR, NY).* • MS-Access Database: *CT, OR, NC and NE-DOTs.* • GIS database: *CO-DOT.* • Proprietary System*: NY-DOT – also interfaces with their Bridge Management Program (BM).* Note: *OR-DOT's database interfaces with their GIS and BM systems.*	GIS, Database, or Other:
If we require additional information about your inventory, is there someone that we can contact? • *Contact information was provided by 26 respondents.*	

Table 18. Survey Results of MSE Wall Inspections used by Other State DOTs

Survey Question	Requested Response
Do you inspect your MSE walls to check on their condition? • *10 DOTs (CO, ME, NY, VT, AK, OR, IL, FL, TX and NE) have an inspection program.*	Yes / No
How often do you inspect your MSE walls? • *Results varied between 2 and 5 years for six DOTs.* • *One DOT (WA) also waited as long as 10 years between inspections.* • *Four DOTs (AK, OR, IL, and TX) have a variable time frame for inspection, depending on the condition of the wall at its last inspection.*	
Do you have a rating system that will allow the engineer to quantify the condition of the MSE wall following an inspection? • *Seven DOTs (CO, CT, ME, AK, IL, NC, NE) have a rating system.* • *NY DOT has a very general rating system for MSE Walls.*	Yes / No
If a rating system is in place, is the assessment data available to all DOT personnel? • *Four DOTs (CO, CT, NY, and IL) make data available.*	Yes / No
If a rating system is in place, are the MSE wall inspections performed in conjunction with bridge inspections? • *Five DOTs (OR, IL, FL, IA, and NH) consider walls as part of the BM program.* • *ME DOT considers MSE wall abutments, or wing-walls, as part of the bridge.* .	
If we require additional information about your rating system, is there someone that we can contact? • *Contact information was provided by 26 respondents.*	

Chapter 3
Inventory and Inspection Attributes

Inventory Attributes

In this chapter, the attributes for the MSE wall inventory will be discussed based on the literature review concerning the development of an inventory. Overall, this study identified 44 MSE wall attributes which should prove useful for asset management, future inspections, and assessments. These recommended attributes are grouped into 7 categories, as described in Table 19.

Table 19. Recommended List of Attributes for MSE Wall Inventory

#	Attributes	Values	Commentary
Location			
1.	District		1. Data used to identify MSE wall and its location. 2. Both the MP and GPS information are requested to take care of different ways currently used to identify wall locations. 3. Rather than request data for each end of the wall, the MP and GPS coordinates near one end of the wall are adequate for location. 4. The "ProjectWise" key number will allow the user to access information archived in the ITD ProjectWise system.
2.	Route		
3.	Direction		
4.	Milepost – end	End-1	
5.	GPS–end	Latitude	
6.		Longitude	
7.	ProjectWise #		
Wall Dimensions			
8.	Length of Wall		1. Typical data regarding the MSE wall dimensions. 2. Minimum and maximum height of wall. 3. Multiple heights refer to a stepped type of construction with multiple walls. 4. Distance to stream is a useful attribute for adding awareness to the potential for scour.
9.	Height – minimum		
10.	Height – maximum		
11.	Multiple heights		
12.	Wall batter angle		
13.	Back slope angle		
14.	Front slope angle		
15.	Berm height		
16.	Distance to stream		

Table19. Recommended List of Attributes for MSE Wall Inventory (continued)

#	Attributes	Values	Commentary
Wall Type & Functionality			
17.	MSE Wall Facing	Concrete Panels (CP), Concrete Blocks (CB), Wire Gabions (WG), Other facing	1. Collect data about type of wall facing. 2. Finish at top of wall provides information about its susceptibility to damage from traffic. 3. Reinforcement type information will allow assessment of potential corrosion. 4. The "Use" allows categorizing of walls and if they support the roadway (fill) or retain a slope (cut). 5. Data about traffic volume may help with assessing consequences of poor performance.
18.	Wall Top Features	Coping, cap, guardrail, etc.	
19.	Reinforcement Type	Metallic (M), Grid (G), Fabric (F), Other (O)	
20.	Use of MSE Wall	Roadway, ROW, Bridge, Culvert, Erosion, Landslide	
21.	Traffic Volume		
Historical Data			
22.	Year Built		1. Collect historical wall data, especially the expected design life of the MSE wall. 2. "Access Needs" will record information regarding the accessibility of the wall for inspection such as steep slopes or high walls. 3. Work zone requirements concern the safety aspects associated with traffic control, which may be required for inspections.
23.	Design Life		
24.	Engineer of Record		
25.	Special Access Needs		
26.	Work Zone Requirements		
Structural Data			
27.	Wall support	Concrete base (CB), Gravel base (GB), Other (O), None (N)	1. Data about the foundation supporting the wall will allow the inspectors to look for critical changes which may affect the stability of the wall. 2. The type of foundation and size, embedment and foundation soils will help with stability assessments. 3. Embedment is an important parameter for foundation stability and potential scour.
28.	Foundation – width		
29.	Foundation – thickness		
30.	Wall Embedment		
31.	Backfill Material		
32.	Foundation Material	Gravels (Gr), Sandy soils (Sa), Silty Soils (St), Clayey soils (Cl), Rock (Rk), Unknown (Un)	

Table19. Recommended List of Attributes for MSE Wall Inventory (continued)

#	Attributes	Values	Commentary
Drainage			
33.	Internal Drainage		1. Information about the construction of designed drainage features is useful for inspections. 2. Inspectors can check to see if the drainage features are performing as expected, or if maintenance is required. 3. The scour depth information is required for MSE walls constructed adjacent to flowing water, such as rivers.
34.	External Drainage		
35.	Weep Holes		
36.	Scour Depth		
Other			
37.	Site Investigation Report		1. Additional information assembled during design and construction should be recorded along with filenames, and their location within the ProjectWise system. 2. Information about the seismic zone will help with post-earthquake evaluations.
38.	As-built drawings		
39.	Design Calculations		
40.	Seismic zone		

Proposed MSE Wall Inspection Procedures

The literature review revealed 12 MSE wall inspections procedures which are used by state DOTs to evaluate MSE walls. The procedures varied from the comprehensive procedures proposed by NC-DOT to the considerably simpler one from KY-DOT.[38]

After careful deliberations, it was decided that a more capable inspection system should be selected for use in Idaho. Based on the many inspection procedures reviewed in this study, the inspection procedures from Nebraska, Ohio, and North Carolina were selected for further consideration. This was a joint decision made by the research group and the project Technical Advisory Committee. These three, selected procedures are described next.

The Ohio DOT inspection procedures, presented in Table 20, were originally developed in 2006 following an MSE wall failure. For these procedures, the inspector was asked to complete a questionnaire which concentrated on just four categories: Joints, Wall Facing, Drainage, and Top of the Wall. Only three possible responses: (1) Yes, (2) No, and (3) N/A were considered for 20 possible questions posed in the protocol. To assist with inspections, photos of relevant features were provided to help inspectors with identification and evaluation. Inspectors were encouraged to take digital photos in support of their answers. One major item missing in these procedures concerns the assessment of overall stability of the wall, as may be evidenced by wall tilt or longitudinal cracks in the overlying highway pavement. Overall, the procedure is easy to apply, but concentrates on problems which are generally reported by maintenance personnel. Following an inspection, an engineer is in a position to review the details and make a reasonable decision regarding the performance of the wall, or if a further site visit is necessary.

Table 20. Inspection Procedures from Ohio DOT [13]

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

The Nebraska Department of Roads inspection procedures were proposed in 2009. In 2017, the department changed its name to the “Nebraska Department of Transportation” (NE-DOT). In the rest of this report, these inspection procedures will be labeled Nebraska “DOT” to reflect the name change. These procedures, presented in Table 21, are very elaborate and consider 13 different categories for assessing the performance of an MSE wall. Unlike the Ohio DOT approach, the NE-DOT procedures require that the inspector report a rating value, ranging from 0 to 9, for each condition category. For the rating, lower numbers are indicative of poor performance, with “0” strongly suggesting possible failure conditions. An experienced inspector is required to perform the NE-DOT procedures. Additionally, greater effort is required to determine the various percentages required to assign the rating value.

An excellent manual has been prepared for the inspector’s use, with good photos of potential problems that may be observed in the field. Also, following an inspection, the MSE wall may be allocated a single, overall rating value. The single rating value will range from a maximum of 117 (i.e. 13 × 9) down to zero, with low numbers indicating poorer performance. The ratings may also be used to prioritize the walls for maintenance and repair according to available resources.

Table 21. Inspection Procedures from Nebraska DOT [25]

#	Items	Attribute	Value
1.	Wall Tilting	A section of the entire wall has failed due to tilting.	0
		A section of or entire wall is inclined such that separation is beginning in the wall face.	1
		A section of or the entire wall is inclined outward at 10° (2H:12V) to 15° (3H:12V).	3
		A section of or the entire wall is inclined outward at 5° (1H:12V) to 10° (2H:12V).	5
		A section of or the entire wall is inclined outward at 0° - 5° (1H:12V).	7
		There is no change in wall inclination from construction specifications.	9
2.	Structural Cracking	More than 50% of wall area shows structural cracking.	0
		Between 33 - 50% of wall area shows structural cracking.	1
		Between 20 - 33% of wall area shows structural cracking.	3
		Between 10-20% of wall area shows structural cracking.	5
		Less than 10% of wall area shows structural cracking.	7
		None or only an insignificantly small area shows structural cracking.	9
3.	Facial Deterioration	More than 50% of wall area shows facial deterioration.	0
		Between 50% and 25% of the wall area shows deterioration.	3
		Less than 25% of the wall area shows deterioration.	6
		None or only an insignificantly small area shows facial deterioration.	9
4.	Bowing of the Wall	Wall panels have bowed outward to the point where backfill loss is evident.	0
		Wall panels have bowed outward to the point where filter fabric is visible at the joints; connectors between panels have broken.	3
		Wall panels have bowed outward to where connectors between panels are visible and deforming.	5
		Wall panels have bowed outward to the point where bowing is visible standing directly in front of the wall.	7
		No signs of bowing in wall face.	9
5.	Panel Staining	More than 50% of wall area is stained.	0
		Less than 25% of the wall surface is stained.	5
		None or only an insignificantly small area of the wall is stained.	9
6.	Exposure of Fabric at Joints	Greater than 10% of the joints allow fabric to be exposed to sunlight.	0
		Fewer than 5% of joints allow fabric to be exposed to sunlight.	3
		No fabric is currently exposed at joints, but some joints appear to be increasing in width, which may allow fabric behind to become visible.	6
		Joints appear to be stable; no fabric is currently exposed.	9
7.	Loss of Backfill	Backfill loss has resulted in significant settlement of the V-Ditch, or roadway, or has affected wall inclination or alignment.	0
		Significant areas/quantities of backfill loss are visible.	3
		Backfill loss is occurring, but only minor areas/quantities of backfill loss are visible.	6
		No visual evidence of backfill loss.	9

Table 21. Inspection Procedures from Nebraska DOT [25] (continued)

#	Items	Attribute	Value
8.	Erosion: Front of Wall	Wall reinforcement is visible in several locations.	0
		Wall reinforcement is being exposed at two or more locations.	3
		Effects of erosion are visible, but no wall reinforcement has been exposed.	5
		Minor effects of erosion are visible; plant roots may be exposed or higher original soil levels on concrete structures may be indicative of erosion.	7
		There is no visual evidence that erosion is occurring behind the wall.	9
9.	Joint Spacing	Wall is not a panel wall, i.e. wall has no joints.	n/a
		Joint width appears almost totally irregular and random.	0
		Joint width varies widely across wall face.	3
		Joint width appears marginally regular, but considerable variation exists in different areas or at different heights along the wall.	5
		Joint width appears generally uniform with the exception of some discrepancies in localized areas.	7
		Joint width appears uniform across the entire wall.	9
10.	Condition of V-Ditch	The wall has no V-Ditch.	n/a
		The V-Ditch is nonfunctional due to backfill movement, cracking, etc.	0
		The V-Ditch has separated from the wall face; extensive cracking or breakup of the V-Ditch has rendered it almost nonfunctional.	3
		The V-Ditch is still attached to wall, but large cracks are developing in the V-Ditch at several locations. The V-Ditch can transport less water than intended.	5
		The V-Ditch is still attached to the wall, but minor cracks are developing; the ability of the V-ditch to transport water has not been affected.	7
		No cracks in the V-Ditch; no separation of the V-Ditch from the wall. The V-Ditch is functioning, as intended.	9
11.	Coping Deterioration	The wall has no coping.	n/a
		More than 25% of the coping shows signs of severe cracking, has become detached, or is spalling.	0
		Less than 25% of the coping shows signs of severe cracking; has become detached or is spalling.	5
		Coping shows no sign of cracking, spalling or other signs of deterioration.	9
12.	Drainage Runoff	No structure above wall to cause drainage runoff.	n/a
		Erosion is actively moving significant quantities of backfill material from the backfill to other locations	0
		Indications of erosion runoff are present; quantity of backfill material being moved appears significant.	3
		Indications of erosion runoff are present but there is no indication that the quantity of backfill material being moved is significant.	6
		No signs of erosion due to drainage runoff.	9
13.	Drainage: Front of Wall	Signs of water ponding consistently in front of the wall.	0
		Water seldom ponds in front of the wall, or only during periods of intense precipitation.	5
		Front of wall is well drained; no ponding occurs.	9
14.	Comments		

The NC-DOT inspection system, as shown in Table 22, was proposed in 2015 for inspecting retaining walls in North Carolina. MSE walls form a subset of the wall under consideration. The procedure collects information on 17 observations in four groups consisting of: (1) Facing, (2) Movement, (3) Drainage, and (4) Exterior.

Table 22. Inspection Procedures from North Carolina DOT [26]

Category Observations			Percent by Rating				Average Rating	Comments
			1	2	3	4		
FACING	1.	Facial Deterioration						
	2.	Staining						
	3.	Damage						
	4.	Cracking						
	5.	Joint Alignment						
	6.	Joint Spacing						
	7.	Material Loss						
MOVEMENT	8.	Deflection/Rotation						
	9.	Bulges/Distortion						
	10.	Settlement						
	11.	Heaving						
DRAINAGE	12.	Erosion						
	13.	Scour						
	14.	Internal/External Drains						
EXTERIOR	15.	Wall Top Attachment						
	16.	Road/Sidewalk/Shoulder						
	17.	Vegetation						

A description of each criterion and the elements that should be observed and evaluated are listed below.

FACING

1. **Facial Deterioration:** Missing facing units, spalling, delamination, weathering (splitting or rotting), other deterioration of the wall facing, or graffiti.
2. **Staining:** Discoloration of the facing of the wall from water, efflorescence, rust, or other evidence of corrosion.
3. **Damage:** Damage to the wall from vehicle impact or root penetration.

4. **Cracking:** Structural cracking that penetrates the facing of the wall.
5. **Joint Alignment:** Joints between facing units (panels, bricks, etc.) and/or adjacent wall sections that are inconsistent, misaligned, or uneven across the facing of the wall.
6. **Joint Spacing:** Joints between facing units (panels, bricks, etc.) that are too wide (exposing organic (?) material) or too narrow (removing proper spacing).
7. **Material Loss:** The loss of backfill material through the facing of the wall.

MOVEMENT

8. **Movement:** Wall or parts are visually out of plumb, tilting, or deflecting resulting in a negative or positive inclination beyond the wall's original batter.
9. **Movement:** Local bulges (outward bend or curve) or distortion in the wall facing.
10. **Settlement:** Settlement of wall, visible wall elements, or tension cracks behind wall.
11. **Heaving:** Upward movement or swelling of soil in front of wall.

DRAINAGE

12. **Erosion:** Disruption or loss of soil or backfill material over a wide area within the sphere of influence of the wall.
13. **Scour:** Evidence of localized material loss specifically at the wall or around the foundation.
14. **Internal/External Drains:** Evidence of improper passage of water through or over the facing of the wall (i.e., clogged drainage outlets such as pipes or weep-holes, or drainage channels along the top of wall that are not operating properly).

EXTERIOR

15. **Wall Top Attachment:** Displacement, misalignment, or deterioration (staining, cracking, damage, etc.) of the wall top attachment (Fence or Handrail, Coping, Concrete Barrier Rail, Guardrail, etc.).
16. **Road/Sidewalk/Shoulder:** Cracks, depressions, heaves, and any other evidence of active earth movement within the sphere of influence of the wall.
17. **Vegetation:** Evidence of excessive vegetation on or around the wall.

The NC-DOT inspection protocol adopted a rating approach based on four condition levels for each observation. The protocol rates each item as GOOD = 1, FAIR = 2, POOR = 3, and SEVERE = 4. In rating a particular item, the inspectors may also give a rating to portions of the wall. For example, 25 percent of the wall may have considerable staining at the POOR level, whereas the remaining 75 percent may be relatively unaffected and rated as GOOD. So collectively, the final rating for this item may be weighted to generate an average rating of “1.50” (i.e. 0.25 × 3 + 0.75 × 1 = 1.5). The inspector may also add comments which provide further explanation of the observed conditions.

The averaging approach adopted by NC-DOT is not a good idea as the merging of “GOOD” and POOR” grades may lead to a conclusion that the wall is in a “FAIR” condition. It is important to note that if “POOR” conditions are identified during an inspection, immediate steps should be taken for further detailed inspections with a view to scheduling maintenance at the earliest opportunity, if required.

To make this procedure work effectively, considerable resources are required to train inspectors. In North Carolina, the researchers invited participants to visit field sites to observe and practice the proposed inspection procedures.

These procedures were subsequently applied to a few MSE walls from the assembled inventory in this study. Based on the results of the field investigations, the recommendation of the team is for ITD to use the Ohio DOT inspection procedures to evaluate the performance of its MSE walls. However, the O-DOT forms provide the minimum data set needed to assess the behavior of the walls. Much more detailed observations and measurements are required for the few walls that are experiencing damage levels which exceed design expectations or are being affected by outside forces (such as erosion) that controlling the performance of the walls (see Chapter 5).

Chapter 4
MSE Wall Inventory

Introduction

The data collection phase of the project was planned during the March 12th, 2018 Project Meeting held in Boise, ID. At the meeting, it was agreed that the District Engineer (DE) in each of the six highway districts in Idaho would be contacted regarding MSE walls in their districts. An email request was sent by John Ingram (ITD, Project Manager) to the DEs in early May 2018 requesting the following information in an Excel file:

1. Route
2. MilePost
3. GPS Coordinates for ends of wall
4. MSE Wall Type
5. Wall Height: Min/Max
6. Approximate Length of Wall
7. Is there a slope above the wall?
8. Drainage: Good or Bad?
9. Any maintenance issues?
10. Do you have any photos of the wall?

The Excel file also included some guidance regarding MSE wall terminology, MSE wall examples, and photos of typical problems which may affect MSE wall behavior. Each team received some of this information by the end of June 2018.

The three research teams started collecting MSE wall data in late May 2018. Each team was allocated two highway districts:

1. Districts 1 and 2: covered by the UI team.
2. Districts 3 and 4: covered by the BSU team.
3. Districts 5 and 6: covered by the ISU team.

The MSE wall data was extracted from electronic files, hardcopy pages, as-built paper drawings, and actual measurements of the wall in the field. The following sections report on the data collection effort and problems encountered during this phase of the study in each District.

District 1

The preliminary information about MSE walls in District 1 was received in late June and early July 2018. This data was assembled by Jerry Wilson, Operations Engineer. After receiving this data, the District 1 office in Coeur d'Alene was visited regarding additional information. Jeff Drager, District Material Engineer, and Charlie While, District Geologist, demonstrated ITD's ProjectWise system which is used to manage project documents related to design and construction. The available documents consisted of items such as "as-built" drawings, construction photos, design calculations, geotechnical reports, and inspection records. During this initial visit, MSE wall data for three projects was extracted readily from the ProjectWise system, demonstrating its usefulness as a potential resource for extracting design and construction data for additional MSE walls. Unfortunately, only data from recent projects is available through the ProjectWise system.

Having observed the ProjectWise system, it was decided that data for MSE walls in District 1 would be extracted remotely from the UI campus in Moscow, ID, rather than making frequent visits to Coeur d'Alene office, which is 90 miles north of Moscow. This would also overcome concerns that the data could only be accessed in Coeur d'Alene. For some reason, we were informed that VPN access would be required for downloading files from the ProjectWise system. VPN access was finally granted after several weeks, but we were unable to access ProjectWise to download files.

In late September 2018, we discovered that the ProjectWise system could be accessed directly through a web-based interface by using a different set of credentials provided by Beau Hansen, ITD CADD-ProjectWise Administrator. After getting access to the ProjectWise files, we were able to download some MSE wall data from the database. Although, there is a large amount of very useful data in ProjectWise, it takes considerable effort to locate information, which is often buried many layers deep. Also, it helps if the project key number used by ProjectWise is known in advance as it can be very time consuming to merely search blindly for information about MSE walls. Even though we had limited success with the ProjectWise system, we strongly feel that with familiarity more data on MSE walls may be obtained in the future. Figure 4 is an example of a drawing which was downloaded from the ProjectWise system containing information about the MSE walls constructed for the US-95 Sandpoint Bypass in 2006. This drawing along with other detailed drawings were used to extract some of the data included in the inventory.

At the end of the data collection phase, the UI team was able to find information on about 21 MSE walls out of the total of 39 MSE walls which were initially identified by Jerry Wilson, District 1 Operations Engineer.

District 2

A meeting with District 2 personnel was held on July 19th, 2018, in Lewiston. At this meeting, the attendees reviewed all major highways in the district for possible locations of MSE walls. At the conclusion of the meeting, about 20 potential MSE walls were identified for consideration by this project. Further plans were made to review these potential sites to confirm the existence of MSE walls. A list of eleven, confirmed MSE wall locations was provided by District 2 Engineering Manager, Doral Hoff, in late October 2018 and two other walls were added later for a final total of thirteen walls. The inventory data for these MSE walls was collected from "paper" plans and the ProjectWise system in early January 2019.

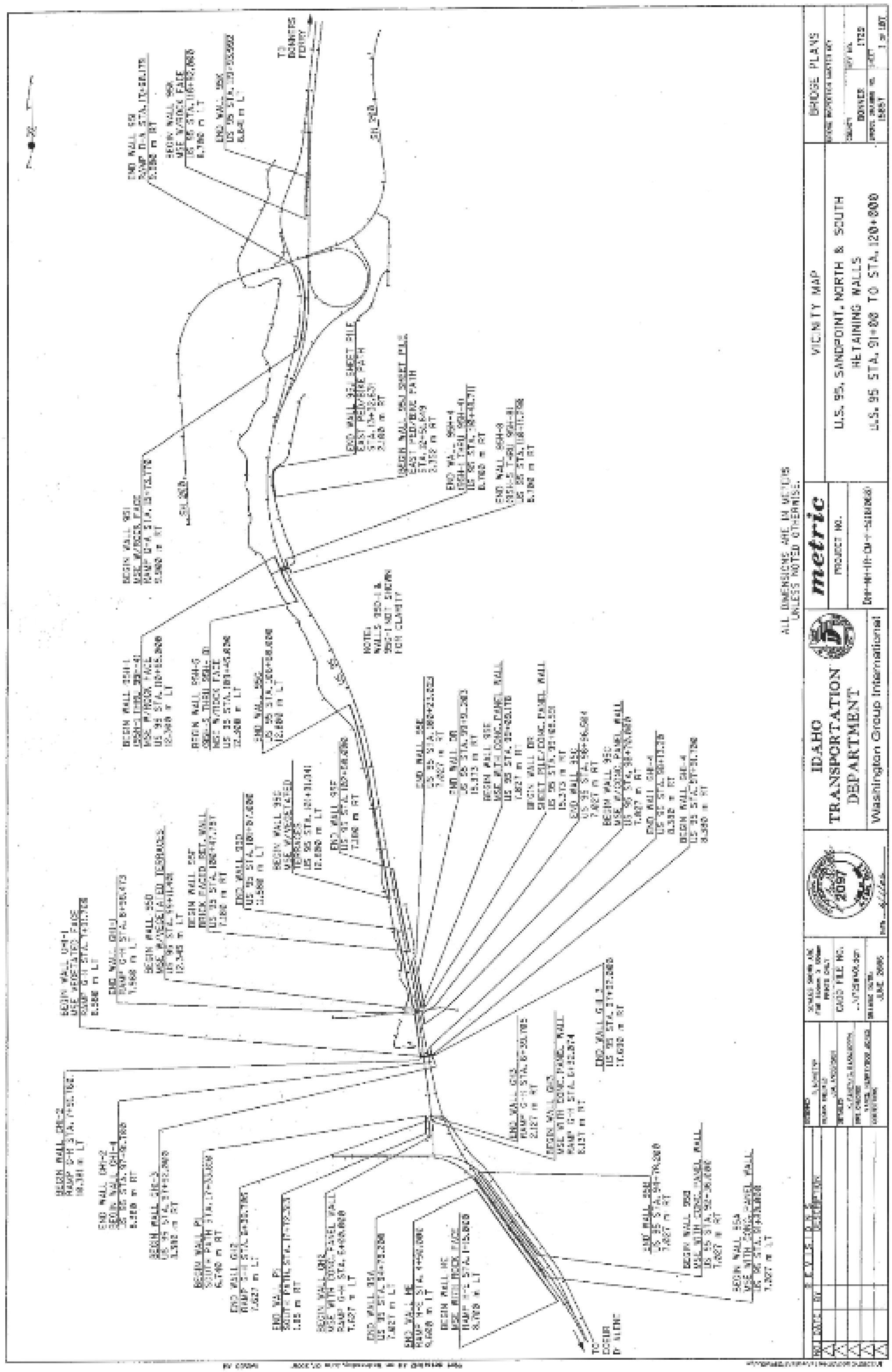


Figure 4. Construction Plans for MSE Wall Locations on US-95 Sandpoint Bypass in ProjectWise

Districts 3 and 4

The Boise State University project team worked with Michael Garz in District 3, as well as Lynn White and Scot Stacey in District 4, to identify MSE walls for this study. Both Mr. White and Mr. Stacey were very helpful in providing the available plan sheets and drawings of MSE walls. Ideally, the BSU staff would have liked to review the as-constructed drawings, but these were difficult to access even with the help of ITD engineers. Further, the data were very limited on MSE wall details regarding (1) date of construction, (2) thickness of wall, and (3) embedment depth. District 4 did provide printed plan sheets for wall D4-5 (see Chapter 5).

During the field investigation, the BSU team collected basic data on concrete panel block dimensions, wall height, wall length, and wall tilt. For condition inspections, the team conducted combined visual and thermography for each wall on service conditions, such as structural cracking, facial deterioration, bowing of wall, panel staining, joint spacing, and vegetation. Two walls were also selected for ultrasonic array inspection to detect deeper flaws in the concrete panels that cannot be detected from visual observations. The documented attribute information is included in the Excel spreadsheets of each wall. The available inventory data for the MSE walls are provided in Appendix A. Recommendations for ITD surface and subsurface investigation results, plans, specifications are given in this report.

Districts 5 and 6

ISU project staff contacted Greydon Wright in District 5 and Ken Hahn in District 6 for information on the more than 10 MSE walls considered for this study. Both Mr. Wright and Mr. Hahn were extremely helpful in providing the available plan sheets for these walls and in some cases record drawings of the walls. However, the data were very limited on MSE wall details particularly for as-constructed conditions and subsurface investigations. The available inventory data on the MSE walls studied in the field are provided in Appendix A. Recommendations for ITD storage of MSE wall design, subsurface investigation results, plans, specifications and as-built construction are provided in Chapter 6 of this report.

During the District 5 and 6 field investigation portion of the project, data was collected on outside panel dimensions, roadway drainage, as-constructed fill slopes and embankment materials, coping dimensions, wall heights above ground surface and shotcrete fiber lengths and aggregate size. This attribute information was not found in the ITD records and is included in Excel spreadsheets compiled for each wall.

Overall Summary and Conclusions

The design and construction records are extremely important in analyzing the performance of MSE walls, particularly when problems are observed or concerns for stability are identified. For MSE walls founded on slopes, geotechnical data on embankment and native subsurface conditions are extremely important when linear cracks open in the slopes or longitudinal cracks development in the pavement. Without this fundamental geotechnical and as-constructed data, it is very difficult to perform the needed slope analysis to assess the stability of the wall without expensive and perhaps unnecessary drilling and instrumentation work performed later when the problem develops. Numerous examples exist where design and construction data are critical in condition analysis. It is not sufficient to simply know the condition of the wall without understanding the reason(s) for observed behavior to make intelligent decisions on repair, stabilization or reconstruction. Identifying the reason(s) for coping concrete deterioration based at least in part on design and/or construction details will help avoid future problems.

All three team members received excellent cooperation and help from District staffs. The teams, with the help from District staff, were able to locate suitable sites for performing the condition surveys needed to fulfill the project intent. Unfortunately, the records for many of the existing MSE walls are incomplete, poorly organized and difficult to find. This situation needs to be rectified particularly in cases where the MSE walls are undergoing adverse behavior and decisions must be made on action items. As a start, design and construction records for ongoing MSE wall projects need to be archived in a manageable and retrieval geodatabase so that the records are not lost or misplaced and easily accessed. Future work would include the remaining walls, particularly those walls with one or more serious concerns. The universities involved on this project have the staff and expertise to provide this archiving service to ITD using faculty and student help.

MSE Wall Data Storage and Retrieval

The MSE wall data has been accumulated in an Excel file for use as possible input into a potential database system. Currently, ITD uses Arc-GIS, iPlan, TAMS, and AASHTOWare Bridge Management software for their many assets. The collected MSE wall data is in a format suitable for implementation into any one of the mentioned software packages except for the Bridge Management software, which is designed primarily for bridge elements only. In an 11 April 2019 teleconference with ITD staff, ArcGIS was selected as the data management tool. A tutorial to place and retrieve the MSE wall attribute and condition wall data in ArcGIS is given in Appendix E.

Chapter 5
Inspection Data Examples

Introduction

In the initial phase of this study, information used by consultants and other state agencies to inspect and rate the conditions of MSE walls was reviewed and three inspection and rating procedures were selected for evaluation. The selected procedures were published by Ohio DOT, Nebraska DOT, and North Carolina DOT. The plan was to evaluate a few representative MSE walls using these procedures, and then report on their effectiveness for future use by ITD personnel. It was also expected that by performing such field investigations, the inspection parameters could be refined for use in the ITD asset management program. Detailed field studies were conducted by the research groups on the conditions of various MSE walls along interstates and state highways in Idaho. Table 23 gives the locations of the MSE Wall condition surveys conducted by each university.

Table 23. Summary of MSE Wall Field Site Investigations

#	District	MSE Wall Location
1.	1	I-90, EB Exit-Ramp, MP 1.03, Post Falls
2.	1	US-95, Railroad Bridge, NW Wing-wall, MP 465.0
3.	1	US-95, SB On-Ramp, MP 475.75, Sandpoint
4.	1	SH-200, SB, MP 41.96, Trestle Creek Bridge
5.	2	US-12, WB, MP 53.12 and 53.59, near Greer
6.	2	US-12, EB, MP 67.0, Kamiah Bridge, E. Wingwall, Kamiah
7.	3	I-84, W. Eisenman Rd
8.	3	I-84 at I-184
9.	3	I-84, South Vista
10.	3	I-84, SH-69
11.	4	I-84, US-93
12.	5	Gould Street Overpass, Pocatello, Wall 4
13.	5	Gould Street Overpass, Pocatello, Wall 5
14.	5	US-30, Topaz Bridge
15.	5	US-30, Ledger Creek Bridge
16.	6	US-20 Bridge, St. Leon Exit
17.	6	SH-33 Bridge, US-20 Exit
18.	6	SH-32, Bitch Creek Bridge

District 1 and 2 Condition Surveys

A total of six MSE walls were inspected in Districts 1 and 2 for this study using the protocols proposed by Ohio DOT, Nebraska DOT, and North Carolina DOT. The inspected wall locations are summarized in Table 23. The inspection process consisted of recording any adverse conditions while walking from the start to the end of the wall. In some cases where the wall was on a very steep section or next to water, it was not always possible to walk along the base of the wall to complete the inspection.

The selection of potentially adverse conditions was based on the descriptions in the three inspection protocols being evaluated for this study. The evaluation, according to each protocol, was then completed using the information collected and recorded as a function of the distance along the wall.

I-90 Wall, District 1

The 960-foot long, concrete panel, MSE wall at MP 1.03 on the eastbound exit-ramp coming off I-90 was inspected with a view to evaluating the three selected inspection procedures. This MSE wall was constructed in 2012 and uses rectangular concrete panels and metallic reinforcement strips. The panels are 9.7 (W) × 4.7 (H) feet in size and have a patterned finish which has been painted dark brown. Figures 5 and 6 show the setting of the wall and a typical panel with some bulging.

The inspection was started at the western end (L = 0 feet) and looked for "blemishes" in the wall appearance moving in an eastward direction. Overall the wall is in excellent condition, with only minor items. There is some slight bulging of 1.0 to 1.5 inches in the panels located at 330, 396, and 464 feet from the western edge of the wall. Also, three panels had broken corners at 580 (2 panels) and 658 feet. It appeared that the corners at 580 feet were broken during construction, but the one at 658 feet appears to be the result of "crushing" caused by rotation of panel. A summary of the results according to the three inspection procedures is presented in Tables 24 to 26.

Figure 5. I-90 MSE Wall along the EB Off-ramp near MP 1.03

Figure 6. Rectangular Wall Panel with Bulge and Vegetation noted at L = 41 feet

Table 24. Inspection Summary of I-90 Wall – Ohio DOT Procedure

#	CONDITIONS	Yes, No, N/A
JOINTS		
1.	Is sand or gravel coming out of joints or are there piles of sand or gravel at the base of the wall?	No
2.	Is sand or gravel visible in the horizontal joints?	No
3.	Are the joints wide enough to see the sand, gravel or fabric behind the panels when looking perpendicular to the wall face using a flashlight? If yes, record the approximate maximum joint width, in inches.	No
4.	If fabric is visible in the joints, is it torn? IMPORTANT - DO NOT POKE OR CUT THE FABRIC.	N/A
5.	Do the joints have a nonuniform size, or are some joints noticeably wider than others? (see Condition Survey)	No
6.	Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum offset.	Yes 1 to 1.5 in.
7.	Is there vegetation growing in the joints? (see Condition Survey) In the Wall Facing?	Yes (at L = 41 ft)
WALL FACING		
8.	Are there cracks in more than two facing panels? (see Condition Survey) If yes, record the approximate number of panels that are cracked.	No
9.	Is the face of the wall bowed or bulged?	Yes
DRAINAGE		
10.	Are there any signs of water flow along the base of the wall?	No
11.	Is there erosion of the embankment at the base of the wall?	No
12.	If there is erosion, is the leveling pad exposed at the base of the wall?	No
13.	Are the catch basins or the catch basin outlets near the wall blocked?	N/A
14.	Is the roadway drainage system above the wall malfunctioning?	No
15.	Does water at the top of the wall collect behind the concrete coping? Top of Wall?	No

Table 25. Inspection Summary of I-90 Wall – Ohio DOT Procedure (continued)

#	CONDITIONS	Yes, No, N/A
TOP OF THE WALL		
16.	Is there settlement at the top of the wall?	No
17.	Are there any open cracks in the concrete coping (not hairline cracks)? If yes, record the approximate maximum crack width. (see Condition Survey)	No
18.	Have the construction joints in the concrete coping opened up? (see Survey)	No
19.	Is there a gap larger than 1 inch between the approach slab and the approach pavement? If yes, record the approx. max. gap size.	No
20.	At abutments, has the joint between the wall coping and the abutment opened up more than two inches?	No
21.	Comments: • Wall is in very good condition • Watch for potential erosion at edges of abutment wall	

Table 25. Inspection Summary I-90 Wall – Nebraska DOT Procedure

Nebraska Department of Transportation Procedure						
DEFECTS						
Wall Tilting	Structural Cracking	Facial Deterioration	Bowing of Wall	Panel Staining	Fabric Exposure	Loss of Backfill
9	9	9	9	9	9	9
DEFECTS						
Erosion at Front of Wall	Joint Spacing	Condition of V-Ditch	Coping Deterioration	Drainage Runoff	Drainage at Front	AVERAGE
9	9	n/a	9	9	9	**9**
Comments:						

Table 26. Inspection Summary of I-90 Wall – NC-DOT procedure

Category Observations			Percent by Rating				Average Rating	Comments
			1	2	3	4		
FACING	1.	Facial Deterioration	100				1.00	Excellent condition
	2.	Staining	100				1.00	Wall is painted dark brown
	3.	Damage	99	1			1.01	3 corners damaged
	4.	Cracking	100				1.00	None noted
	5.	Joint Alignment	100				1.00	
	6.	Joint Spacing	100				1.00	
	7.	Material Loss	100				1.00	None
MOVEMENT	8.	Deflection/Rotation	100				1.00	
	9.	Bulges/Distortion	99	1			1.01	Slight bulge, L = 41 ft.
	10.	Settlement	100				1.00	
	11.	Heaving	100				1.00	
DRAINAGE	12.	Erosion	100				1.00	
	13.	Scour	n/a				--	
	14.	Internal/External Drains	100				1.00	
EXTERIOR	15.	Wall Top Attachment	100				1.00	Coping shows no cracks
	16.	Road/Sidewalk/Shoulder	100				1.00	No cracks
	17.	Vegetation	99	1			1.01	Small plant at L = 41 ft

Westmond Railroad Bridge, District 1

The concrete paneled, wing-walls for the Westmond railroad bridge at MP 465.04 on US-95 were constructed in 2004. The NW wing-wall located at the north abutment of the SB carriageway wa inspected for damage. The wall extends about 110 feet to the abutment face and has an average height of about 10 feet. The last 20 feet plunges into the railroad cut, reaching a maximum height of about 35 feet. The wall uses cruciform-shaped concrete panels with maximum dimensions of about 53 (H) × 68 (W) inches. The panels have a cut-stone finish. The setting of this MSE wall is shown in Figure 7, along with a distressed panel in Figure 8.

For inspection, the wall features were noted in a north-to-south direction, with L = 0 feet at the north end. The inspection survey is summarized in Table 27.

Table 27. Inspection Survey of Westmond Bridge Wingwall (US-95)

Distance, L (feet)	Notes
20	Panel has rotated clockwise; joint ranges from nearly closed to 1-inch width
25	Panel has rotated clockwise; joint ranges from nearly closed to 1-inch width
30	Panel has rotated clockwise; joint ranges from nearly closed to 1-inch width (see Figure 9)
40	Panel is damaged due to crushing (see Figure 10)
45	Panel corners are damaged
60	Panel corners damaged; some crushing; vertical joint is nearly 1.5 inches wide
85	Vertical joint has widened to nearly 1.5 inches
90	MSE Wing wall ends; from 90-110 feet, wall is part of abutment
110	Bearing wall damaged; part of panel crushed and cracked (see Figure 8)

These details were subsequently used to complete the inspection according to the three procedures being evaluated by this study. The completed forms are presented in Tables 28 to 30.

Figure 7. Westmond Bridge Wingwall at US-95 SB, North Abutment

Figure 8. Typical "Cruciform" Concrete Panel and Damage in Bearing Wall at L = 110 ft

Figure 9. Rotated Panel at L = 30 feet

Figure 10. Crushed Panel at L = 40 feet

Table 28. Inspection Summary of Westmond Bridge Wall – Ohio DOT Procedure

#	CONDITIONS	Yes, No, N/A
JOINTS		
1.	Is sand or gravel coming out of joints or are there piles of sand or gravel at the base of the wall?	No
2.	Is sand or gravel visible in the horizontal joints?	No
3.	Are the joints wide enough to see the sand, gravel or fabric behind the panels when looking perpendicular to the wall face using a flashlight? If yes, record the approximate maximum joint width, in inches.	No
4.	If fabric is visible in the joints, is it torn? IMPORTANT - DO NOT POKE OR CUT THE FABRIC.	No
5.	Do the joints have a nonuniform size, or are some joints noticeably wider than others? (see Condition Survey)	Yes
6.	Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum offset.	Yes
7.	Is there vegetation growing in the joints? (see Condition Survey) In the Wall Facing?	No
WALL FACING		
8.	Are there cracks in more than two facing panels? (see Condition Survey) If yes, record the approximate number of panels that are cracked.	Yes
9.	Is the face of the wall bowed or bulged?	No
DRAINAGE		
10.	Are there any signs of water flow along the base of the wall?	No
11.	Is there erosion of the embankment at the base of the wall?	No
12.	If there is erosion, is the leveling pad exposed at the base of the wall?	No
13.	Are the catch basins or the catch basin outlets near the wall blocked?	N/A
14.	Is the roadway drainage system above the wall malfunctioning?	No
15.	Does water at the top of the wall collect behind the concrete coping? Top of Wall?	No

Table 28. Inspection Summary of Westmond Bridge Wall – Ohio DOT Procedure (continued)

#	CONDITIONS	Yes, No, N/A
TOP OF THE WALL		
16.	Is there settlement at the top of the wall?	No
17.	Are there any open cracks in the concrete coping (not hairline cracks)? If yes, record the approximate maximum crack width. (see Condition Survey)	No
18.	Have the construction joints in the concrete coping opened up? (see Survey)	No
19.	Is there a gap larger than 1 inch between the approach slab and the approach pavement? If yes, record the approx. max. gap size.	No
20.	At abutments, has the joint between the wall coping and the abutment opened up more than two inches?	No
21.	Comments: • Abutment bearing wall is damaged (see photo, Figure 8)	

Table 29. Inspection Summary Westmond Bridge Wall – Nebraska DOT Procedure

Nebraska Department of Transportation Procedure						
DEFECTS						
Wall Tilting	Structural Cracking	Facial Deterioration	Bowing of Wall	Panel Staining	Fabric Exposure	Loss of Backfill
9	7	6	9	9	9	9
DEFECTS						
Erosion at Front of Wall	Joint Spacing	Condition of V-Ditch	Coping Deterioration	Drainage Runoff	Drainage at Front	AVERAGE
9	7	n/a	9	9	5	**8.1**
Comments:						

Table 30. Inspection Summary of Westmond Bridge Wall – NC-DOT procedure

Category Observations			Percent by Rating				Average Rating	Comments
			1	2	3	4		
FACING	1.	Facial Deterioration	95	5			1.05	Some
	2.	Staining	95	5			1.05	Present
	3.	Damage	90	5	5		1.15	Some crushed
	4.	Cracking	100				1.00	None noted
	5.	Joint Alignment	90	10			1.10	
	6.	Joint Spacing	90	10			1.10	
	7.	Material Loss	100				1.00	None
MOVEMENT	8.	Deflection/Rotation	95	5			1.05	
	9.	Bulges/Distortion	95	5			1.05	
	10.	Settlement	100				1.00	
	11.	Heaving	100				1.00	
DRAINAGE	12.	Erosion	100				1.00	
	13.	Scour	n/a				--	
	14.	Internal/External Drains	100				1.00	
EXTERIOR	15.	Wall Top Attachment	100				1.00	Coping shows no cracks
	16.	Road/Sidewalk/Shoulder	100				1.00	No cracks
	17.	Vegetation	100				1.00	Under control

Sandpoint MSE Wall (95I), District 1

This MSE wall is one of the many Wire-Gabion (WG) walls which were constructed as part of the US-95 Sandpoint bypass in 2006. This wall supports SB US-95 and is located on the north side of the on-ramp near MP 476.2. This 560-foot long wall is shown in Figures 11 and 12. The gabion fill consists of material in the three to eight-inch size range. The inspection revealed that:

1. The alignment is consistently vertical without any signs of bulging or settlement;
2. The *galvanized* gabion baskets did not show any signs of corrosion, and
3. There were no areas where the rockfill had "leaked" from the gabions.

With no problems observed, it can be concluded that the wall is performing as expected.

The three inspection procedures being evaluated only address MSE walls with concrete panels. Hence, the section concerning the performance of wall panels was modified to address issues likely to affect MSE walls with wire gabions. The completed evaluations using the three protocols are included in Appendix B.

Figure 11. Wire-Gabion MSE Wall at MP 475, SB US-95 in Sandpoint

Figure 12. Wire-Gabion Configuration and Large Rockfill

Trestle Creek Wall, District 1

This is a 330-foot long, MSE concrete block wall which supports the SB lane of SH-200 near Trestle Creek. This wall was constructed in 2013 and consists of stacked concrete blocks as shown in Figures 13 and 14. The maximum height of this wall is 8.5 feet. The inspection revealed no problems with alignment, settlement, or block degradation. There was some minor staining, but there were no obvious signs of leaking backfill or drainage problems. The completed inspection forms are included in Appendix B.

Figure 13. Concrete Block Wall near Trestle Creek, SB SH-200

Figure 14. Concrete Block with "Cut-Stone" Finish used for Trestle Creek Wall

Greer MSE Walls, District 2

Western Wall

At this location, there are two wire gabion MSE walls which support the westbound lane of US-12. The walls were constructed in 2009 and are located adjacent to the Clearwater River. Figures 15 and 16 show the start of the western wall at MP 53.12, which is about 1,920 feet long and has a maximum height of about 16 feet. A woven geosynthetic mesh, as shown in Figure 16, is used to retain the finer gabion fill material.

Only a small portion of the wall could be inspected due to the terrain next to the Clearwater River. The gabions, made of Corten-steel, have developed the expected coating of rust. There were no signs of excessive corrosion or leakage of gabion fill materials. The state of light rusting of the Corten steel in front of the woven geosynthetic mesh is illustrated in Figure 16.

Starting the inspection from the eastern end (L = 0 ft), Table 31 presents the items noted during the evaluation process. The completed inspection forms for the eastern wall are included in Appendix B.

Table 31. Inspection Survey of Western Greer Wall (US-12)

Distance, L (feet)	Notes
350	Vegetation has started to grow in the gabion.
1210	Top of wall drops about two feet, creating a 30° to 45° slope to the highway.
1250	The sloping fill above the wall is loose and possibly unstable, reaching angles up to 45°.
1920	End of wall.

Eastern Wall

Figures 17 and 18 show the start of the eastern wall at MP 53.59, which is about 650 feet long and has a maximum height of about 15 feet. As in the western wall, a woven geosynthetic mesh is used to retain the finer gabion backfill, as shown in Figure 18. These gabions are also made of Corten-steel which has developed the typical rust coating.

Only the edges of the wall could be accessed for inspection due to the steep, vegetated terrain next to the Clearwater River. There were no signs of excessive corrosion or leakage of gabion fill materials, and no adverse observations noted during the site visit.

Figure 15. Western Wire Gabion MSE Wall at MP 53.00, WB US-12

Figure 16. View of Western Wall and Corten-steel Gabions from Clearwater Riverbank

Figure 17. Eastern Wire Gabion MSE Wall at MP 53.59, WB US-12

Figure 18. View of Eastern Wall and Corten-steel Gabions from Clearwater Riverbank

Kamiah Bridge Eastern MSE Wall, District 2

The final field inspection was carried out on a concrete panel, MSE wall which supports a section of the EB lane of US-12 at the eastern abutment of Kamiah Bridge. This 848-foot long wall was part of the replacement bridge constructed in 2000. Its height ranges from about 9 to 23 feet and it is located next to the Clearwater River, as shown in Figures 19 and 20. The concrete panels are cruciform shaped.

The wall was only viewed from the bridge deck as direct access was not possible due to the proximity of the Clearwater River, the presence of rip-rap rock placed at the base of the wall, and heavy vegetation growth, as seen in Figures 19 and 20. Hence the condition survey was limited to observations made from the bridge-deck (Figure 20) and from the photo (Figure 19) of the wall taken from across the river.

Overall the MSE wall is in good condition, with only minor staining, no obvious distress in the concrete panels, and all panel joints have uniform spacing. The rip-rap (up to 3-feet in diameter) placed at the base of the wall is performing well as there were no obvious signs of erosion due to scour. The wall did not have any vegetation growth in the panel joints and only limited vegetation growth on the road side of the coping. The inspection forms for this MSE wall are not included as the wall is performing very well and no adverse features were observed during the field investigation.

This wall is an excellent candidate for future condition surveys performed by sUAV ("drone") technology due to its inaccessibility adjacent to the Clearwater River.

Figure 19. View of Kamiah Bridge Eastern MSE Wall, EB US-12, from across the River

Figure 20. Closer View of Eastern MSE Wall of Kamiah Bridge from the Deck

Summary of District 1 and 2 Condition Surveys

The inspection of the four selected MSE wall sites in District 1 were completed in one day. The time taken to complete the condition surveys for each MSE wall as follows:

1. I-90 MSE Wall: 90 minutes,
2. Westmond Bridge: 75 minutes,
3. Sandpoint MSE Wall: 90 minutes, and
4. Trestle Creek Wall: 45 minutes.

The above survey times were relatively short as the walls were easily accessible and the walls are in good condition. The 20-foot high southern section of the Westmond Bridge wall towards the abutment and railroad was very steep and the inspection had to be completed from the higher terrace. To complete the inspection, a special access permit would have been required from the railroad company.

For District 2, the conditions of three walls along US-12 were surveyed in one day. The time taken to complete the condition surveys for each MSE wall were as follows:

1. Western Greer MSE wall: 90 minutes,
2. Eastern Greer MSE wall: 60 minutes, and
3. Kamiah Bridge West Abutment: 30 minutes.

Access to examine the Greer MSE walls was very difficult due to the proximity of the Clearwater River, vegetation growth, and the presence of large boulders for scour protection near the base of the walls. Thus, only parts of the walls near their edges could be viewed for inspection. The rest of the inspection consisted of a walk along the top of the walls to look for cracks in the pavement and possible erosion of the fill between the highway edge and the wall. All three walls are good candidates for future surveys using sUAVs to record the condition of the entire wall in HD video.

The District 2 condition surveys were completed by walking along the wall and looking for features which may indicate potential problems as described in the three selected inspection protocols from Ohio, Nebraska, and North Carolina DOTs. If any problem was observed, its description and location (measured from the end of the wall) were noted and photographs taken of the features. These notes were used to complete the pages for the inspection protocols. Approximately, 1-hour was spent in the office for organizing the notes, forms, and photographs for each inspected wall.

Supplementary inspection data for the District 1 and 2 MSE walls are provided in Appendix B. For future condition surveys, notes may be taken as a voice recording, but should be supplemented by handwritten notes. Similarly, any photos taken may be annotated by a short audio description along with handwritten notes.

District 3 and 4 Condition Surveys

Introduction

Funded by Idaho Transportation Department (ITD), Boise State University (BSU) has conducted condition surveys on 5 Mechanically Stabilized Earth (MSE) walls in Districts 3 and District 4. In addition to the condition surveys, BSU staff investigated two nondestructive testing methods (NDT) (infrared thermography and ultrasonic) for use in MSE wall surveys. The preliminary results indicate that these methods may be useful in detecting defects in the MSE wall concrete panels. Additional work using infrared thermography and ultrasonic techniques is needed on MSE walls to verify the results.

Project outcomes

The BSU group conducted a series of field inspections and on-site tests to contribute to Task 5 in the ITD Contract. The intent was to illustrate the inspection protocol and evaluate the condition ratings used in other state DOT practice.

The following data have been collected for the MSE walls in Districts 3 and 4:

1. Wall defects and condition state based on the wall condition parameters used Nebraska DOT.
2. Visual images of the wall defects.
3. Thermal images of surface and shallow sub-surface defects.
4. Ultrasonic data of sub-surface anomalies and reinforcement in concrete panels (two walls).

The results of the thermal image and ultrasonic studies are given in Appendix C of this report.

Methodology

The MSE wall system consists of the original ground, concrete leveling pad, wall facing panels, coping, soil reinforcement, select backfill and any loads and surcharges acting on the wall. All of these items can have an effect on the performance of the MSE wall and should be taken into account in the integrity assessment. However, in most cases one or two of the parameters control the performance of the wall. Wall panels come in a few shapes and sizes. The panels are typically pre-cast, reinforced concrete. The front faces of the panels observed in this study can have rough or smooth finishes, irregular or planar shapes, and fine or exposed aggregate textures. This section focuses on interpretation of MSE wall performance data and the use of this data in asset management decisions. The methods of inspection and the significance of the data that are acquired using each method are described in the following sections of this report.

The first step in evaluating the performance of the MSE walls was to carry out a visual inspection of the overall condition of the wall. After the general inspection, the observations focused on the site-specific, attributes and features such as wall size and location, accessibility of the wall for inspection, panel dimensions, panel/coping surface cracks, vegetation, irregular spacing between panels, wall tilt and surface erosion.

Anomalies such as cracks, uneven spacing between adjacent panels and facial deterioration were measured using a caliper. The wall profile such as its length/height and panel dimensions were measured using a self-retracting metal tape. The anomalies were documented by taking visual images, which were stored in their respective folders for future reference and review.

For safety, BSU staff always wore orange vests while performing the site inspections. Only sections of the sites with walkways were chosen so that safe access was provided to the study area.

MSE Wall Rating System

Staff from BSU investigated five MSE walls: 4 in District 3 and 1 in District 4. Visible observations of MSE wall conditions included wall tilt, structural cracking, facial deterioration, wall bowing, panel staining, panel joint opening and vegetation. Three different rating systems: (1) Nebraska DOT, (2) Ohio DOT, and North Carolina DOT, were considered to characterize the conditions of MSE walls. After a review, only the Nebraska DOT system [25] was selected for use in the Districts 3 and 4 studies (see Table 21 in this report). The results of the BSU studies on the selected walls are given in Table 32.

Table 32. MSE Wall Condition Survey in Districts 3 and 4 using NE-DOT Rating System

MSE Wall	Defects							Average
	Wall Tilting	Structural Cracking	Facial Deterioration	Bowing of Wall	Panel Staining	Joint Spacing	Vegetation	
D3-5	7	9	9	7	9	7	9	8.1
D3-10	9	7	6	9	9	9	9	8.3
D3-11	9	7	9	9	9	9	9	8.7
D3-14	9	9	9	9	9	9	7	8.7
D4-5	9	9	9	9	9	9	9	9.0

As described in Nebraska DOT procedures (Table 21), the ratings range between “9” (good condition) to “0” (serious condition). The average value given in the last column is the average of all seven condition parameters for each MSE wall. All parameters were given equal weight in the analysis. The inspection results show that the MSE study walls are in good condition although some defects are present in the walls. Moreover, all 5 MSE walls were rated as being in good condition. Supplementary inspection procedures carried out by BSU staff for District 3 and 4 MSE walls are provided in Appendix C.

During the inspection process, additional information such as the type of wall, coordinate location, approximate height and length (feet), panel shape and size (inches) and presence of erosion were recorded. Inspection notes for the study walls are given as follows:

Wall D3-5:	Joint gap is between 0.75" to 1.5";
	0.5-inch outward offset of some joints;
	One panel is bowed outward.
Wall D3-10:	Panel joint spacing is 1.5 inches;
	5 to 6 panels have surface cracks.
Wall D3-11:	Panel joint spacing is 1.5 inches.
Wall D3-14:	Small face deterioration present;
	Small amount of vegetation present between some panels.

Although all three rating systems were considered, the NE-DOT classification was selected to be most appropriate for characterizing the District 3 and 4 MSE Walls because of the semi-quantitative nature of the rating system. However, some interpretation is needed because performance levels are based on ranges in percentages of affected portions of the wall and not on individual problem areas. Further, structural cracking and the nature of panel deterioration are not defined. Quantitative values for various damage levels are given for wall tilt. In some cases, the observed deficiencies such as the presence of small vegetation or hairline cracks may not be cause for action items. Conversely, a given defect may be present only in one limited section of the wall but may be a serious concern for the overall integrity of the wall.

The MSE Wall studies carried out by BSU were highly successful; the inspections themselves were performed in less than 1 day. Additional time was needed to perform the non-destructive testing but the results in identifying potential defects in the concrete panels were well worth the effort. The main concern was for safety and portions of some walls were not observed because of traffic volume and restricted access. In the future, some form of traffic control should be considered to allow inspection of the full length of the walls.

District 5 and 6 Condition Surveys

The basic approach used in the ISU study of MSE walls in Districts 5 and 6 is summarized as follows:

1. Located potential study sites.
    - Surveyed condition of MSE walls during drive-by inspections.
2. Carried out detailed site inspection of selected walls.
    - General survey of existing conditions.
        - Identified specific features controlling behavior/performance of walls.
    - Performed comprehensive damage investigations.
        - Documented observations and measurements of important features (see Appendix D).
        - Recorded digital and sUAV photographs of walls and roadway surface.
        - Logged time to complete site inspection (see Appendix D).
3. Summarized results in an Excel spreadsheet.
4. Illustrated critical conditions in drawings and photos.
5. Filled out the Ohio DOT rating system forms for each wall.
6. Developed a tutorial for placing observations and measurements into an ArcGIS geodatabase (see Appendix E).

The procedures used and information recorded on MSE wall conditions in the ISU study were based on more than 50 years-experience on performance and damage evaluation of numerous structures including bridges and MSE walls. The measurements and observations carried out in this study are at baseline levels of existing conditions. Future site inspections can then focus on measured changes in the initially observed conditions of critical features which control or impact the performance of the walls. Development of any new conditions affecting performance would be noted and baselined for future investigation and evaluation.

The Ohio and Nebraska DOT MSE wall methodologies were used in this study to meet the intent of tasks proposed for this study. In consultation with ITD staff, the Ohio DOT protocol was the preferred method for use by ITD maintenance staff for MSE wall inspections. Further discussions of the Ohio, Nebraska, and North Carolina DOT inspection protocols are provided in the conclusion section of the report.

Site Selection

Study sites used to test condition survey protocols in Districts 5 and 6 were selected to represent the range of conditions present in MSE Walls in southeast Idaho. Prior to selection, MSE walls along Interstate I-15 between the Utah and Montana borders, along Interstate I-86 between Pocatello and American Falls, along US-20 between Idaho Falls and the Montana border and US-30 between Pocatello and the Utah border were identified and visually observed.

A summary of MSE wall locations in District 5 and 6 is given in Table 33. In addition, MSE walls supporting the Gould Street overpass in Pocatello, the UPRR overpass in Soda Springs and the Bitch Creek Bridge on SH-32 were also considered for investigation. The intent was to identify walls with little or no visible damage, walls with intermediate damage levels, walls with significant panel cracks/offsets, and MSE walls founded in embankments above original ground as well as on level ground. A total of 7 MSE walls were selected for further investigation (see Table 34).

Table 33. MSE Wall Locations in Districts 5 and 6 considered for Study.

#	Highway	Wall	District	Latitude	Longitude	Elevation
1.	I-86	Hiline Rd	5	42.912619	112.450892	4,522 ft
2.	I-15	Rose Rd North	5	43.261631	112.308894	4,533 ft
3.		Pocatello Creek	5	42.897361	112.435506	4,590 ft
4.		Clark Street	5	42.875733	112.425047	4,650 ft
–		Siphon Road[1]	5	42.934167	112.439722	4,600 ft
5.	East Gould St. (Pocatello)	Wall 4	5	42.874853	112.459225	4,466 ft
6.		Wall 5	5	42.873253	112.462264	4,478 ft
7.	US-30	Topaz Bridge	5	42.623844	112.120425	4,931 ft
8.		Soda Springs	5	42.656883	111.594842	5,800 ft
9.		Ledger Creek Bridge	5	42.647544	112.575783	5,853 ft
10.	I-15	Humphrey Rd	6	44.487411	112.235362	6,545 ft
11.		Pancheri	6	43.489233	112.055503	4,737 ft
12.	US-20	St Leon Exit	6	43.542903	112.004944	4,788 ft
13.		N 25 E Hitt Road	6	43.569422	111.984608	4,801 ft
14.		E 145 N	6	43.626431	111.944094	4,845 ft
15.		N 4200 E/Lorenzo	6	43.724528	111.874775	4,876 ft
16.		Thornton	6	43.762075	111.844582	4,858 ft
17.		SH-33 Rexburg	6	43.762583	111.748983	4,890 ft
18.		Salem Church Road	6	43.875286	111.756989	4,903 ft
19.	SH-33	Exit at US-20	6	43.883586	111.748983	4,909 ft
20.	SH-32	Bitch Creek Bridge	6	43.938333	111.178506	5,902 ft

[1] Approximate coordinates for new MSE wall planned for 2019.

Table 34. MSE Walls Selected for District 5 and 6 Condition Surveys

Location	District	Latitude	Longitude
E. Gould Street Overpass Wall 4	5	42.874853	112.459225
E. Gould Street Overpass Wall 5	5	42.873253	112.462264
US-30, Topaz Bridge	5	42.623844	112.120425
US-30, Ledger Creek Bridge	5	42.647544	112.575783
US-20, St Leon Exit	6	43.542903	112.004944
SH-33 Exit, US-20	6	43.883586	111.748983
SH-32, Bitch Creek Bridge	6	43.938333	111.178506

MSE Wall Survey Methodology

In the field studies conducted by ISU staff, detailed damage surveys were carried out on one or two walls at each selected bridge site. The first step was to perform an overall assessment of each MSE wall at the site. Once the individual wall was identified, a 100-ft long tape was laid out along the wall alignment. Stations were marked on the wall every 50 ft. At each damage observation, the feature was identified using an abbreviation (e.g. CS for compression spall) and given a sequential number scribed on blue masking tape (see Figure 21). All features were consecutively numbered for identification purposes and noted in the record. The station, vertical height above the ground surface and dimensions of the feature were logged and sometimes mapped. Slope distances were recorded if the MSE wall was part of an embankment. Still photos and sUAV videos were taken of all walls. The blue masking tape served to identify the features in the photos of the wall. Wall settlement was estimated using a level line along common panel edges. Occasional tilt measurements of the smooth wall panels were made using a 4-ft level.

Typically, it took two to four hours to conduct a full field investigation, including detailed damage mapping of one wall. The longest section of mapped wall (482 ft) was along the south side of the western approach to the Topaz Bridge on US-30.

Figure 21. Numbered Open/Tight Joints and Compression Spall in MSE Wall Panels

MSE Wall Condition Survey Observations/Measurements

Detailed observations and measurements of damage conditions were made at all seven MSE wall study sites (see Appendix D for more details). The data recorded in the field was then summarized in Excel spreadsheets (see Table 35). Where a specific condition was absent at the site (such as erosion along the south MSE wall in the west abutment of Topaz Bridge), it is simply not recorded in the spread sheet. The focus of the investigations was on the important conditions affecting the performance/behavior of the MSE walls and adjoining bridges and pavements.

Table 35. Condition Survey of South MSE Wall/East Abutment, Ledger Creek Bridge, US-30

Ledger Creek Bridge, US-30	42.647544	EL 5859 ft		10-Jul-18
South Wall/East Abutment	112.575783	11:18 TO 15:38		
STATION	**CONDITION**	**HEIGHT ABOVE GROUND**	**DIMENSION**	
			LATERAL	**VERTICAL**
0+00	East End/South Wall			
0+06	Broken Corner	72 in.	5 in.	8.5 in.
0+24	Broken Corner	48 in.	4 in.	2.5 in.
0+24	Broken Corner	105 in.	2.5 in.	2.5 in.
0+28.5	Broken Corner	Below Coping	8 in.	14 in.
0+35	Broken Corner	108 in.	2.5 in.	2 in.
END SURVEY: 0+50.8				
MSE WALL PANEL CRACKS				
STATION	**ORIENTATION**	**HEIGHT**	**WIDTH**	
0+10	Diagonal	30 in.	HL	
0+15	Polygonal	90 in.	HL	
0+18	Diagonal	62 in.	HL to 1/16 in.	
0+24.5	Diagonal	73 in.	HL to 1/16 in.	
0+32	Diagonal/Horizontal	75 in.	HL to 1/16 in.	
0+38	Polygonal	204 in.	HL to 1/32 in.	
0+43.2	Diagonal	192 in.	HL	
0+46.2	Diagonal/Horizontal	121 in.	HL	
VEGETATION GROWTH				
0+41.8	Above Coping Near Abutments			
PANEL STAINS				
0+25 TO 0+40				
COPING DAMAGE	**WIDTH**			
Deteriorated Concrete				
Wall Sections Missing				
Reinforcing Steel - Exposed				
Horizontal/Vertical Cracks	HL to 3 in.			

The results of the MSE Wall field investigations are summarized as follows:

E. GOULD STREET OVERPASS WALL 4

1. Significant water/soil flow from abutment face (see Figure 22).
2. Hairline (HL) panel cracks: 2 out of 180 exposed panels (1%).
3. Compression spalls/broken panel corners: 20 out of 180 exposed panels (11%).
4. Dry backfill loss: 3 panels.

E. GOULD STREET OVERPASS WALL 5

1. Severe MSE Wall damage beneath abutment (see Figure 23).
    - HL to $^{3}/_{16}$ in. wide panel cracks.
    - outward rotation/lateral displacement at top.
    - vertical coping offset.
2. Compression spalls/broken corners: 13 out of 88 exposed panels (15%).
3. Backfill loss: 2 panels.

US-30, TOPAZ BRIDGE

1. HL to $^{1}/_{32}$ in. wide vertical cracks in shotcrete (see Figures 24 and 25).
    - few cracks up to $^{1}/_{16}$ in. wide.
    - shrinkage cracks primarily along construction joints.
    - cracks present in 46 out of 80 panels: (58%).
    - damage levels: acceptable - no concern.
2. Animal burrows in one area at base of wall.
3. No ground cracks in embankment supporting MSE wall.
4. Discontinuous transverse separations/cracks on ends of approach slab.

US-30, LEDGER CREEK BRIDGE

1. Severe concrete deterioration along coping (see Figure 26).
    - coping sections missing.
    - reinforcing steel exposed.
2. Concrete deterioration in one concrete panel (see Figure 27).
3. HL to $^1/_{32}$ in. wide, vertical, horizontal and polygonal cracks in 7 out of 34 exposed panels: (21%).
4. Broken corners: 5 out of 34 exposed panels (15%).
5. Diagonal/transverse separations in approach slab.

US-20, ST LEON EXIT

1. Erosion above and along east and west sides of south MSE Walls (Figure 28).
    - Eroding pavement and undermining of barrier walls.
    - shallow embankment erosion south of MSE walls.
2. HL to $^1/_{32}$ in. wide, vertical cracks in coping.
3. Broken/cracked corners: 2 out of 28 exposed panels (7%).

SH-33 EXIT, US-20

1. Severe lateral displacement/rotation of two MSE Wall panels adjacent to southeast abutment (see Figure 29).
    - lateral displacement greater than 3 in.
    - panel braced with steel channel.
    - anchor bolts in adjacent panels.
2. Irregular spacing (tight to 1 in.) in panel joints within 20 ft of abutment.
3. HL to $^1/_{16}$ in. wide, horizontal cracks in 2 out of 30 exposed panels: (7%).
4. Iron-stained along panel interfaces.
5. Numerous HL to ⅛ in. wide cracks in coping.
    - Coping is iron-stained.
6. Broken corners/compression spalls: 5 out of 30 exposed panels (17%).

SH-32, BITCH CREEK BRIDGE

1. Significant lateral displacement/rotation of MSE Wall at south abutment interface (see Figures 30 and 31).
   - lateral displacement: 1⅛ in.
   - rigid body rotation: 1⅝ in. over 6.8 ft.
   - placed pavement overlay in approach (see Figure 32).
2. Major lengths of foam-filled gap between MSE wall and coping.
3. HL to $^{1}/_{16}$ in. wide, horizontal cracks in 4 out of 103 exposed panels: (4%).
4. Broken corners/compression spalls: 13 out of 103 exposed panels (13%).
5. Slope erosion below catch-basin outlets.
6. Animal burrows in embankment next to MSE Wall.
7. Tight contacts and spalling between MSE wall panels.
8. Longitudinal cracks and depressions in long sections of pavement above east and west MSE walls (see Figure 33).
9. No evidence of slope movement adjacent to east MSE wall.

Further MSE wall condition survey details are provided in Appendix D. The MSE Wall location and elevation data in the Excel spreadsheets are given at Station 0+00 on the wall.

In damage classification systems, compression spalls develop where the edges of the panels were in contact, whereas broken corners occur where there is a gap along the sides of the adjacent panels (see Figure 21, for example). Compression spalls indicate panel displacement whereas broken corners typically occur during wall construction. In the MSE wall study, the field investigations focused on the visual observations and measurements of the conditions including the exposed panel surface damage, loss of MSE wall backfill, erosion, settlement, slope/base wall instability and pavement performance above MSE walls. The data obtained in this study was not only useful in evaluating other state MSE wall inspection procedures but also in providing ITD with baseline observations and measurements on some of damaged or vulnerable MSE walls in Districts 5 and 6 for future inspections.

Figure 22. Soil/Water Flow (Piping) from MSE Wall 4 West Abutment Face, E. Gould Street Overpass

Figure 23. Severe Damage in MSE Wall 5 Beneath West Abutment of E. Gould Street Overpass

Figure 24. Steel-fiber Reinforced Shotcrete MSE Wall at Topaz Bridge, US-30

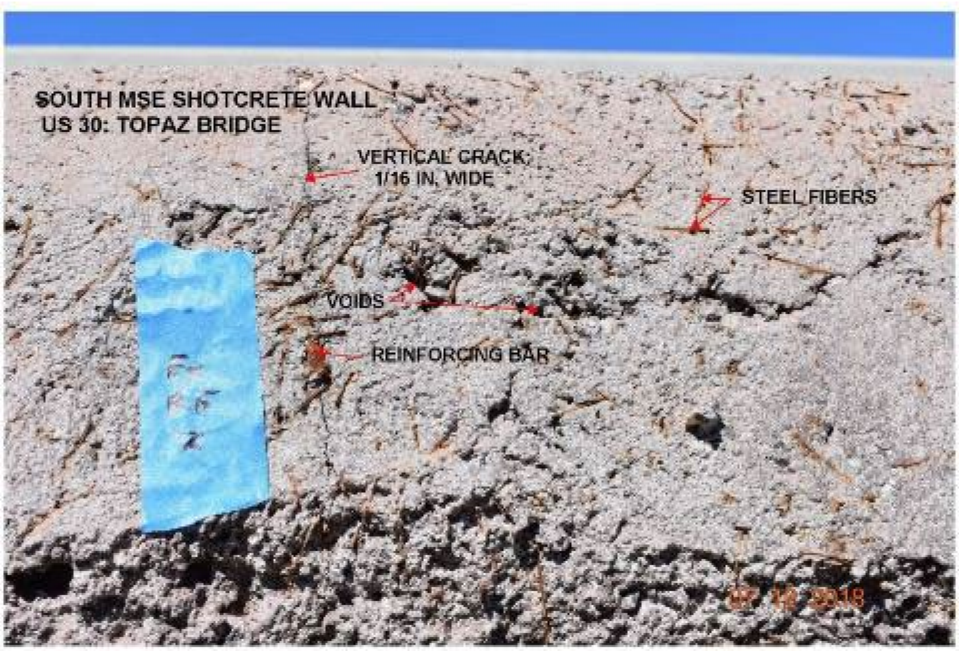


Figure 25. Vertical Cracks and Small Voids in Fiber-reinforced Shotcrete at Topaz Bridge

Figure 26. Severe Concrete Deterioration of MSE Wall Coping on Ledger Creek Bridge

Figure 27. Concrete Deterioration and Diagonal Cracks in MSE Wall at Ledger Creek Bridge

Figure 28. Erosion Along and Behind MSE Wall Coping and Concrete Barrier at US-20, St Leon Exit

Figure 29. Lateral Displacement and Outward Rotation of MSE Wall Panels with Open and Tight Joints in Southeast MSE Wall at SH 33 Exit, US-20

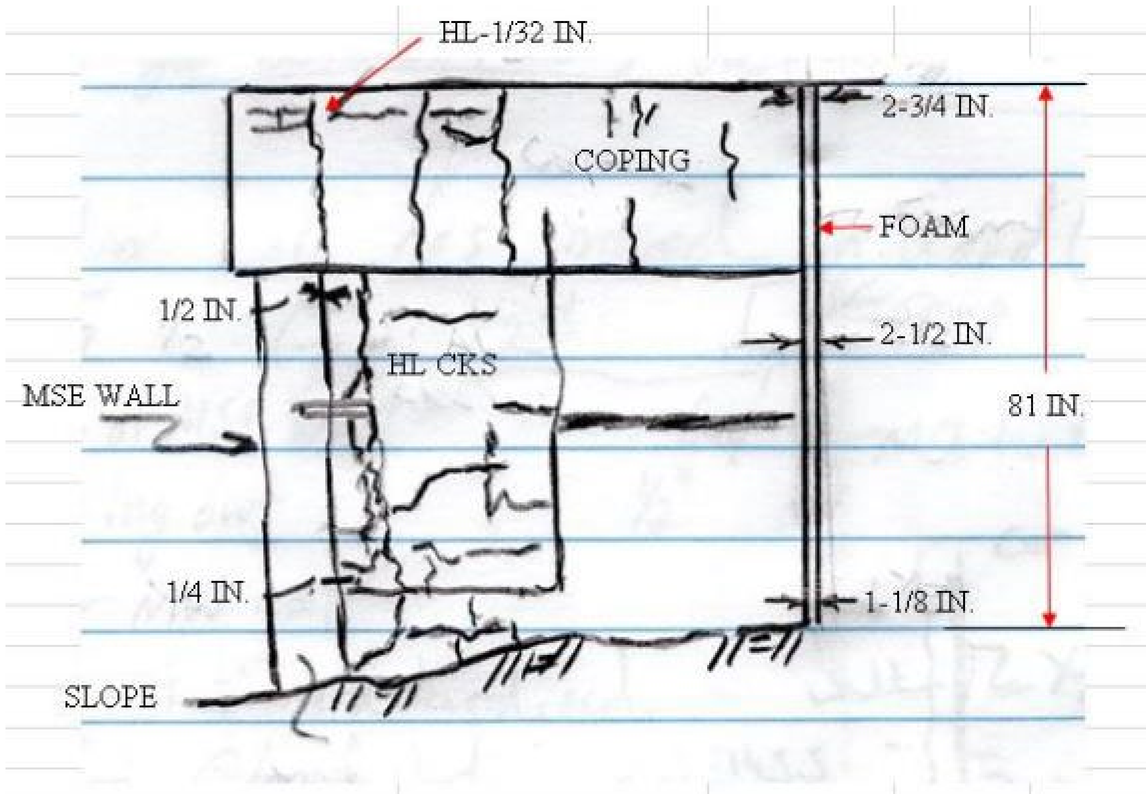


Figure 30. Damage Map of East MSE Wall at South Abutment of Bitch Creek Bridge, SH-32

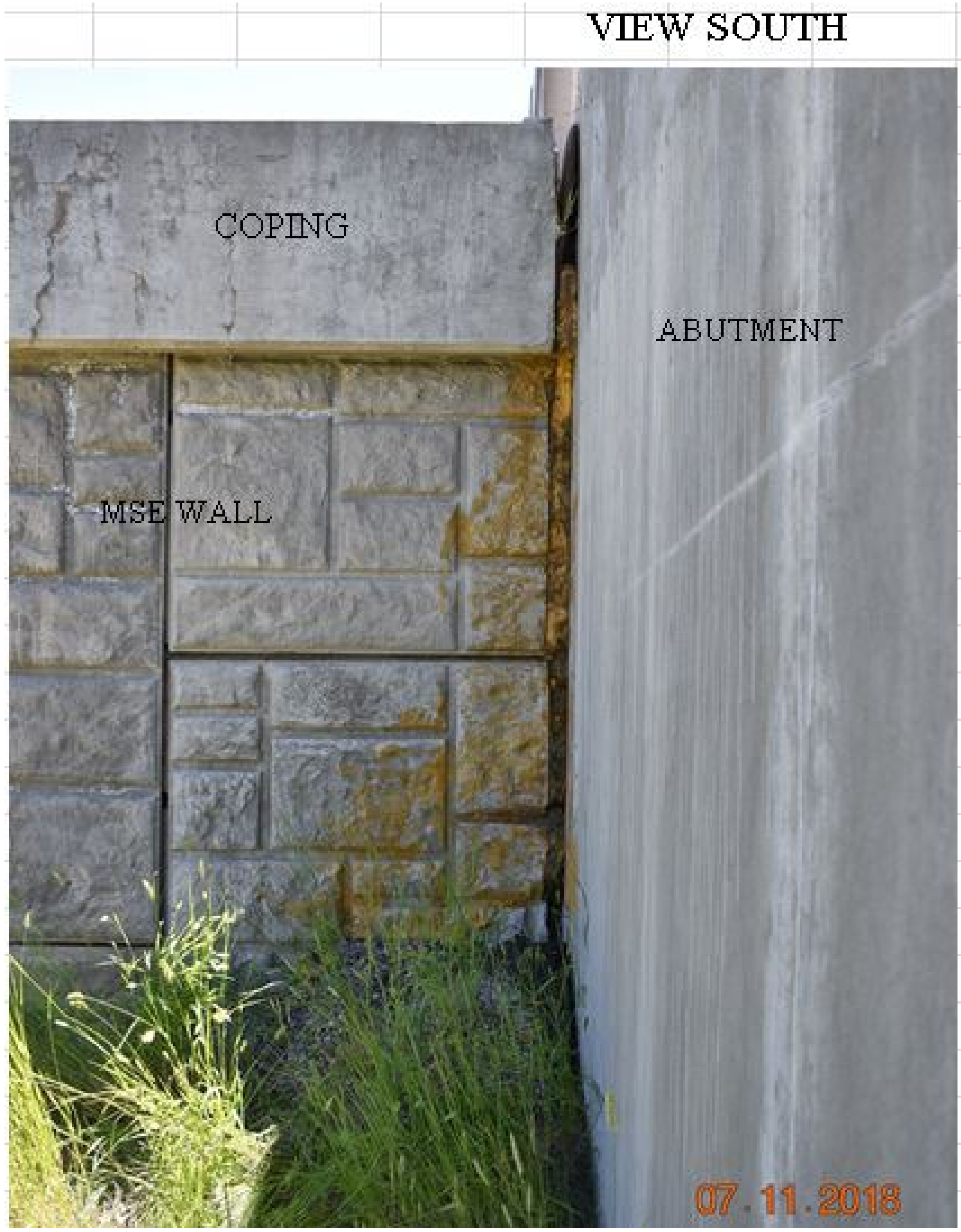


Figure 31. Photo of MSE Wall Damage at Interface with SE Abutment of Bitch Creek Bridge, SH-32

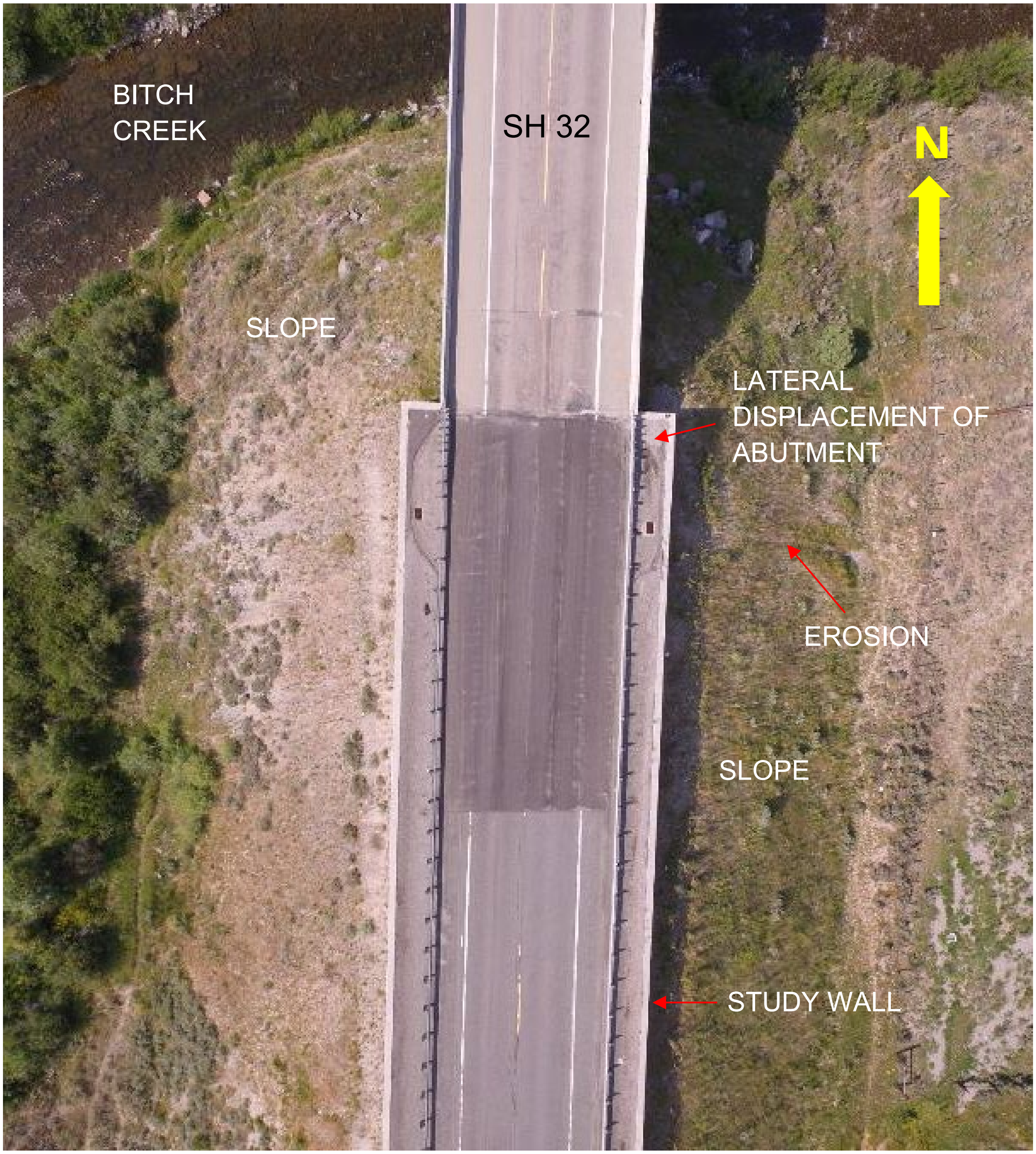


Figure 32. sUAV Photo of Pavement Overlay in Area of MSE wall/Abutment Movement on Approach to Bitch Creek Bridge

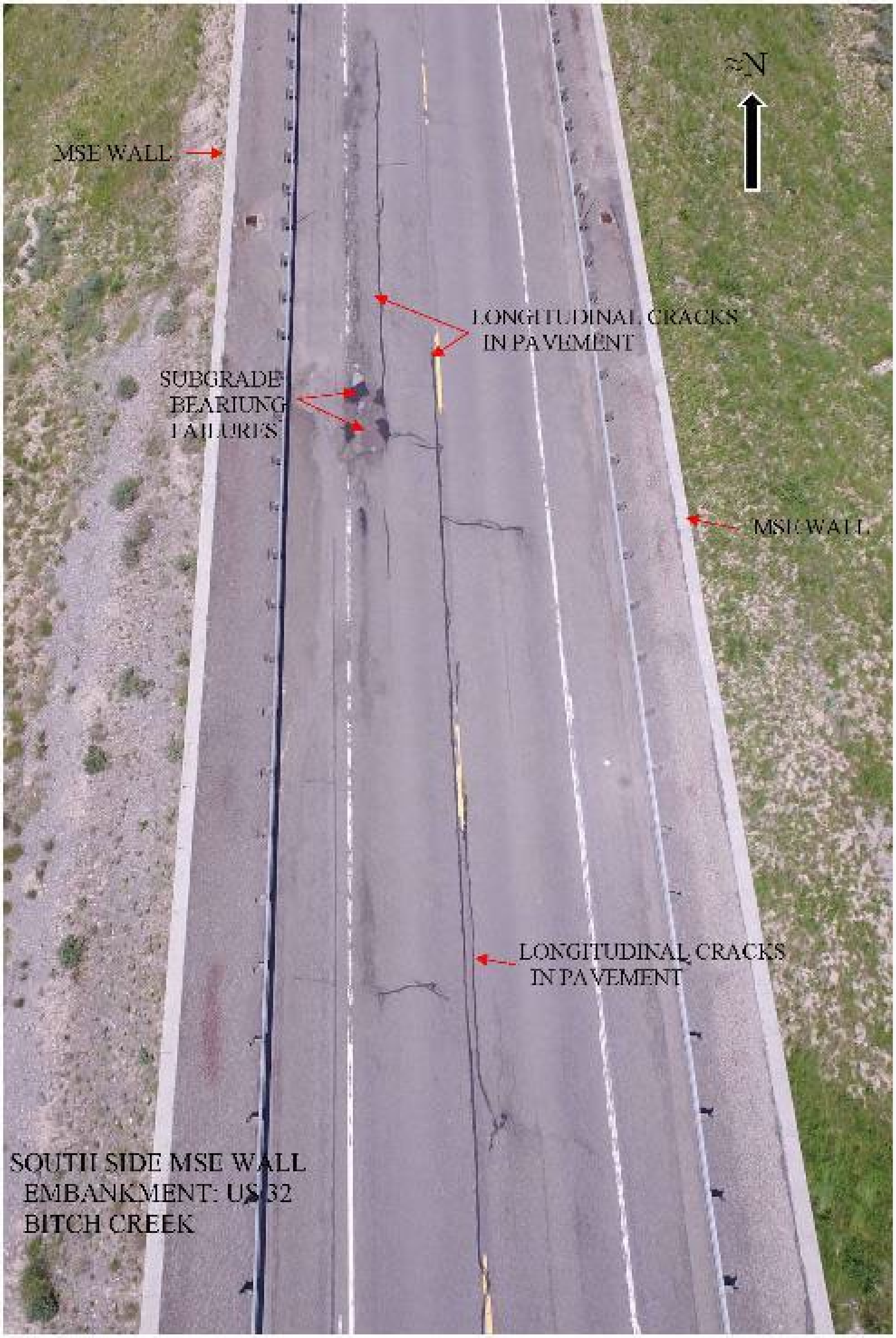


Figure 33. sUAV Photo of Longitudinal Cracks in Pavement due to Lateral Slope Movement, Bitch Creek Bridge

Based on the ISU field investigations, six of the seven MSE wall sites should be considered for some future added investigation and remedial work:

1. Ledger Creek Bridge, US-30: concrete coping deterioration.
2. E. Gould Street/Fourth Street Overpass, Wall 4 — lost MSE wall backfill.
3. E. Gould Street/First Street Overpass, Wall 5 — MSE wall damage below the western bridge abutment.
4. St Leon exit, US-20 — erosion along back and end of south MSE walls.
5. SH-33 Exit, US-20 — severe lateral displacement and rotation of MSE wall panels.
6. Bitch Creek Bridge, SH-32 — MSE wall and abutment separation; longitudinal cracks in pavement adjacent to MSE wall built on embankment slope.

Further, some additional investigation should be carried out to explain the longitudinal cracks and depressions in the pavement above the MSE walls on the southern approach to Bitch Creek Bridge on SH-32. One likely explanation is lateral movement of the walls and/or slope.

In all cases, only one or two conditions have the greatest influence on the asset management decisions. An excellent example is the east and west MSE Walls supporting the south abutments of the US-20 bridge at the St Leon exit, where the only concern is erosion along the back sides and ends of the walls. The erosion is compromising the backfill, removing the shoulder, and undermining the adjacent concrete barriers. Otherwise, all four MSE Walls are in excellent condition.

In order to meet the ITD protocol preference, the Ohio DOT MSE wall inspections forms were filled out for each study wall in Districts 5 and 6. The form for the south MSE wall of the Ledger Creek Bridge, US-30, is given in Table 36. The remaining forms are included in Appendix D.

The only significant condition affecting the performance of the wall is concrete deterioration in the coping and one panel at Survey Station 0+24. However, the remaining observation and measurement data although not showing adverse conditions are important baselines for evaluating the future behavior of the MSE wall. The survey line was established, and the detailed field measurements were completed in less than 2 hours, not including travel time. The damage was obvious and the methodology to map the conditions well established based on prior experience in damage surveys. The remaining Ohio DOT forms for the other study walls are included in Appendix D.

Table 36. Ledger Creek Bridge Condition Survey – Ohio DOT Procedure

#	CONDITIONS	Yes, No, N/A
JOINTS		
1.	Is sand or gravel coming out of joints or are there piles of sand or gravel at the base of the wall?	No
2.	Is sand or gravel visible in the horizontal joints?	No
3.	Are the joints wide enough to see the sand, gravel or fabric behind the panels when looking perpendicular to the wall face using a flashlight? If yes, record the approximate maximum joint width, in inches.	No
4.	If fabric is visible in the joints, is it torn? IMPORTANT - DO NOT POKE OR CUT THE FABRIC.	NA
5.	Do the joints have a nonuniform size, or are some joints noticeably wider than others? (see Condition Survey)	No
6.	Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum offset.	No
7.	Is there vegetation growing in the joints? (see Condition Survey) In the Wall Facing?	Yes Sta 0+41.8
WALL FACING		
8.	Are there cracks in more than two facing panels? (see Condition Survey) If yes, record the approximate number of panels that are cracked.	Yes 7
9.	Is the face of the wall bowed or bulged?	No
DRAINAGE		
10.	Are there any signs of water flow along the base of the wall?	No
11.	Is there erosion of the embankment at the base of the wall?	No
12.	If there is erosion, is the leveling pad exposed at the base of the wall?	No
13.	Are the catch basins or the catch basin outlets near the wall blocked?	N/A
14.	Is the roadway drainage system above the wall malfunctioning?	No
15.	Does water at the top of the wall collect behind the concrete coping? Top of Wall?	Yes

Table 36. Ledger Creek Bridge Condition Survey – Ohio DOT Procedure (continued)

#	CONDITIONS	Yes, No, N/A
TOP OF THE WALL		
16.	Is there settlement at the top of the wall?	No
17.	Are there any open cracks in the concrete coping (not hairline cracks)? If yes, record the approximate maximum crack width. (see Condition Survey)	Yes 3 in.
18.	Have the construction joints in the concrete coping opened up? (see Survey)	Yes
19.	Is there a gap larger than 1 inch between the approach slab and the approach pavement? If yes, record the approx. max. gap size.	No
20.	At abutments, has the joint between the wall coping and the abutment opened up more than two inches?	No

21.	Comments:
	Concerns: see Condition Survey
	• major concrete deterioration in coping
	  ○ full length of coping
	  ○ reinforcement exposed
	  ○ sections of coping missing
	• concrete cracks and deterioration in MSE wall panel
	  ○ Station 0+24, see photo
	Other Observations/Measurements:
	• cracks open to 1/16 in. in 3 MSE Wall panels
	• broken corners in 5 MSE Wall panels
	• slight erosion in area between pavement and top of wall	

Use of sUAV for MSE Wall Investigation

At the end of the damage survey, all of the MSE walls as well as the pavement surface at the bridge sites were video recorded using a small Unmanned Aerial Vehicle (sUAV) operated by Chris Baker (Figure 34). Mr. Baker is a licensed uUAV operator pilot (FAA 107 UAV) who performs commercial asset management services and was a student at ISU at the time of the MSE wall investigations. The sUAV used in the study is a DJI Phantom 4 Pro. Prior to performing the sUAV flights, overhead power lines and light poles were identified, and a plan developed to conduct the survey safely. In the Ledger Creek investigation, aviation personnel at the small airport west of the bridge site were contacted to obtain clearance to fly the MSE wall alignment.

The sUAV provided excellent photos of the MSE walls, bridges and appurtenant assets such as lighting and signage. One of the most significant advantages of using the sUAV was that the overhead videos of the crack patterns in the pavement surface allowed the ISU team to assess the behavior of the approach structure and pavement along adjoining walls (see Figures 35 and 36). Use of a sUAV is also very beneficial in surveying walls greater than 10 ft in height such as along the north wall on the west side of Topaz Bridge on US-30. (Figures 36 and 37). Flight times to document the wall/pavement conditions typically varied between 30 and 45 minutes depending on the wind direction/velocity and on the aerial coverage.

Figure 34. Photo of sUAV used in the ITD MSE Wall Investigation

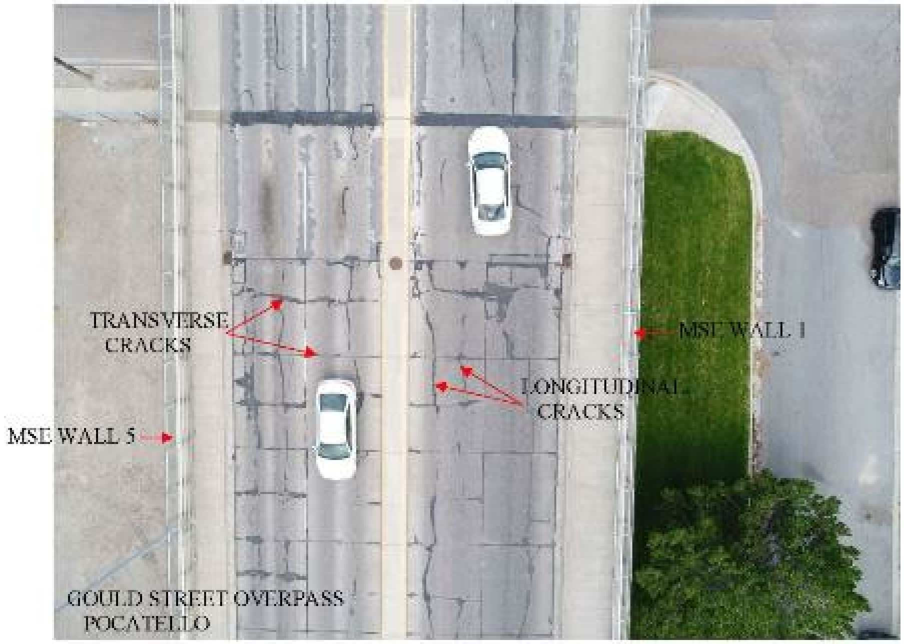


Figure 35. sUAV Pavement Survey above MSE Wall 5 along E. Gould Street Overpass

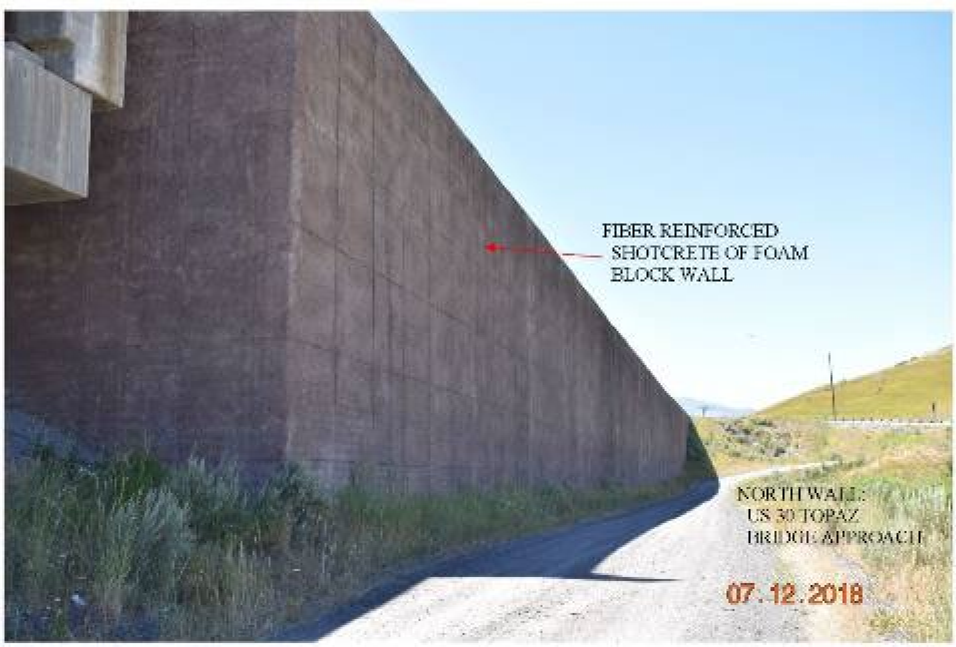


Figure 36. sUAV Survey of 30-ft High North Wall of Topaz Bridge Approach

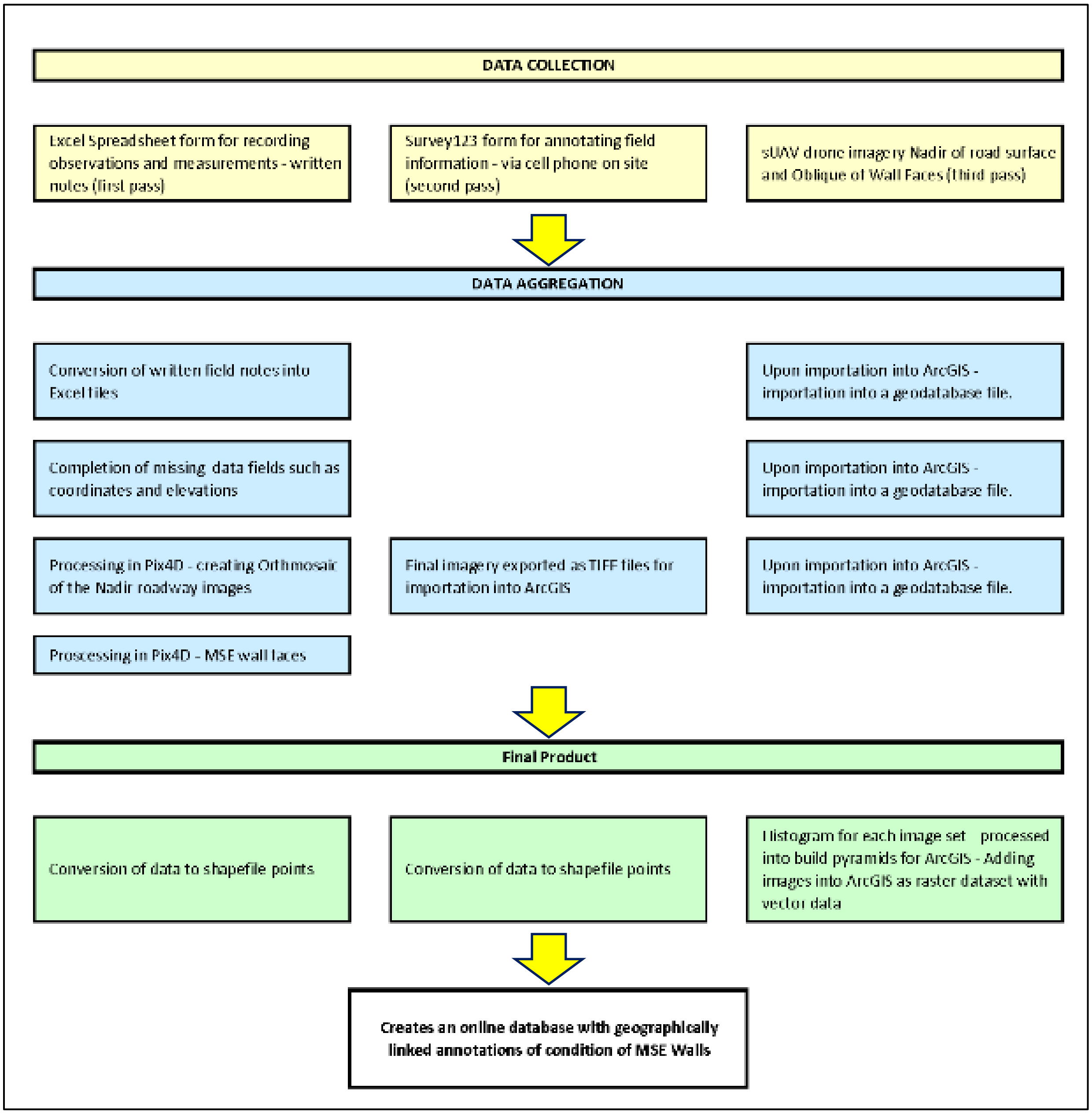
Figure 37. sUAV Survey Photo at Top of 30-Ft High North Wall of Topaz Bridge, US-30

The sUAV unit in the ISU MSE wall study can be used to make measurements of crack/panel joint opening, settlement, wall bulge and tilt. In order to add a measurement component to the sUAV surveys, coordinate and elevation control must be established along the wall. This experimental work was performed along MSE Wall 5 on the East Gould Street Overpass. Survey control was provided by the ISU College of Technology using their base station and Trimble R10 GPS receiver. Gaps between wall panels, crack widths and settlement can be measured to the nearest centimeter.

MSE Wall Data Storage and Retrieval

The typical workflow consists of “Data Collection” followed by “Data Aggregation” before creating files for use in ArcGIS. This procedure was used to create an online database with geographically linked annotations of MSE wall conditions. A flow chart of the MSE wall data collection and storage in the ArcGIS geodatabase is given in Table 37. A user-friendly tutorial for locating and importing the MSE wall asset data is given in Appendix E of this report.

Table 37. Flow Chart for MSE Wall Data Collection and Storage



MSE Wall Asset Management Rating Systems

Based on team review of other states such as Nebraska, Ohio and North Carolina, rating systems have been developed for asset management of MSE walls. In the Nebraska and North Carolina systems, numerical values are assigned to each condition based primarily on non-quantitative criteria observed along the walls and decisions are made regarding maintenance, repair, or replacement of MSE wall elements. The results of these rating systems are difficult to evaluate based on only one site inspection because of the problem of discerning the differences between construction impacts and later performance of the completed wall.

In all cases investigated by ISU staff, only one or two conditions governed the overall behavior and stability of the wall. For example, lateral displacement and rigid body rotation of MSE end Wall 5 on the East Gould Street Overpass is a serious concern for the stability of the abutment supporting the bridge (see Figure 23, for example). The remainder of Wall 5 is in good condition and is performing satisfactorily. Similarly, lateral displacement and rotational movement of the MSE wall at abutment in conjunction with the pavement overlay indicate potential movement of the embankment slope supporting the east MSE wall along the south side of the Bitch Creek Bridge. The remainder of the MSE wall outside the abutment area shows little or no sign of distress.

In consultation with ITD staff, the Ohio DOT protocol was the preferred method for carrying out and performing the condition surveys. However, the Ohio DOT, Nebraska DOT and North Carolina DOT inspection protocols are useful in providing information on some of the important features, such as erosion and wall tilt, in MSE wall condition surveys. Blank forms for completing these inspections are included in Appendix F.

However, most of the criteria used to evaluate the performance of the walls are non-quantitative or use broad ranges of values in assigning performance ratings. For example, the Ohio DOT inspection protocol has a non-quantitative "yes/no/N/A" (not applicable) rating system. Except for a few measurements such as number of cracked panels more than two (without specifying crack width or origin), the procedures are non-quantitative. Moreover, it is difficult to draw any conclusions on the behavior of an MSE wall if the box labeled settlement is checked "yes" for multiple site visits without site specific, settlement measurements. Further, the North Carolina DOT condition surveys involving "Good, Fair, Poor and Severe" ratings are very subjective and highly dependent on the experience and education of the inspector.

If ITD chooses to use the Ohio DOT or any other rating system, it is recommended that the staff quantify the important features (such as slope crack: length, width and offset or erosion: depth, width or elevation above the leveling pad) controlling the behavior of the individual wall. In such cases, baseline values are needed in the areas of greatest concern in monitoring the performance of the wall. In many cases, such as the East Gould Street Wall 5, these areas may constitute a very small portion of the wall. For the remaining non-critical parameters (such as the shrinkage cracks in Topaz Bridge shotcrete facing), rating systems such as used by the Ohio DOT can serve as an index of the overall wall condition provided baseline values are recorded first.

The best way for evaluating the behavior and need for remediation is to study measured changes in the condition(s) of the wall which occur between two or more site visits. During each site visit, the important features identified during previous visits are re-measured for changes such as added wall tilt, panel displacement, widening and lengthening of structural cracks, further concrete deterioration and/or deeper erosion scars. One of the best tools for evaluating MSE wall performance is to analyze increases and particularly any acceleration in the rate of movement. It is the detailed study and assessment of the critical feature(s) and not the assigned numerical values in the existing protocols that should govern the decision-making process.

Other conditions which are absent or make up a small portion of the wall are not significant but should be baselined in the event of significant changes observed in follow-on surveys. One of the best means for conducting multiple MSE wall surveys is to compare the conditions in present and past sUAV surveys during and after the site visit. However, use of the sUAV surveys does not eliminate the need for real-time observations and measurements of critical parameters controlling the performance of the wall.

Conclusions

One of the primary concerns in using the existing state protocols is the lack of condition-specific observations and measurements which allow direct assessment of changes with increasing time. The existing protocols are either non-quantitative or have such large ranges in criteria that they are limited in making an assessment of MSE wall performance. For example, the lateral displacement/rotation of the upper three panels at the top of MSE Wall 5 in the abutment of the East Gould Street Overpass constitute only 3.5 percent of the 88 panels along the length of the wall. Based on the Nebraska DOT system, Wall 5 has a good to excellent performance rating or 7 to 9 for Structural Cracking and Wall Tilt (see Table 21). Even though other records such as photographs would assist in the evaluation process, the performance rating itself masks the serious problem in the bridge support. Giving average values such as in the North Carolina MSE wall inspection protocol further dilutes the assessment process.

Based on project studies, the following inspection and evaluation process should be considered for evaluating MSE walls:

1. Initial Inspection
   (a) perform field inspections using the proposed ITD procedure to determine overall condition of the MSE walls in the inventory.
   (b) identify features, if any, that are affecting the stability of MSE walls.
   (c) For MSE wall features performing at below expected levels, establish site specific baseline observations and measurements. This condition survey data may be recorded in a form such as the one shown in Table 38, and included in Appendix F.
2. Follow-on Inspections of MSE Walls Identified as Performing Poorly
   (a) Take new measurements of the critical conditions identified by previous inspection(s).
   (b) Note any new adverse conditions likely to affect the performance of the MSE wall.
3. Assessment
   (a) Review changes in measurements and impact of any new damage observations. Are conditions becoming more adverse as a function of time?
   (b) Compare the behavior with expected performance assumed in design.

Table 38. Recommended Form for MSE Wall Damage Survey

MSE WALL INSPECTIONS – Form B

WALL INFORMATION

Route	US-20, St Leon Exit	Date	13 July 2018
MSE Wall Location	West Wall/South Abutment	GPS - Latitude	43.54290°
Milepost	311.35	GPS - Longitude	112.00490°
ProjectWise #		Direction	NB

Report on the following adverse conditions along the wall; take photos for documentation.

1. Excessive Joint widths
2. Joint offsets
3. Panel Cracks
4. Shotcrete Spalls
5. Gabion Corrosion
6. Backfill Loss
7. Verticality of wall
8. Bowing of Wall
9. Erosion near base
10. Drainage
11. Ground Cracks
12. Coping or Guardrail

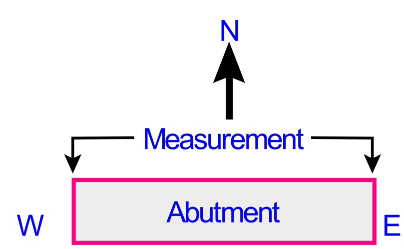
OBSERVATIONS:

Distance Along Tape	Offset	Notes
0 + 00	Top of wall	Embankment erosion behind wall; affecting pavement and concrete barrier. See photo in Figure 28 and condition survey.

COMMENTS/DIAGRAMS/PHOTOS:

Erosion Condition Survey: 13 July 2018

Wall	Width	Depth	Length
West Side	2.6 ft	1.2 ft	3.7 ft
East Side	1.7 ft	0.5 ft	2.2 ft



Chapter 6
Summary, Conclusions, and Recommendations

Summary

The first Mechanically Stabilized Earth (MSE) wall in Idaho was constructed near Hope, Idaho, in the early 1970's. Such walls contain structural and geotechnical components, each limited by its anticipated lifespan. Thus, there is a need to assess the condition of these walls to evaluate their performance and anticipated future life. Currently, ITD does not have a formal inventory of their MSE wall assets or data regarding their condition. The project tasks consisted of (1) evaluation of inspection procedures used by other state DOTs, (2) collection of ITD MSE wall data attributes, (3) inspection of sample walls, (4) recommendations on ITD inspection protocols, and (5) recommendations concerning the implementation strategy for the assembled database information.

Inventory of ITD MSE Wall Assets and Attributes

Based on the literature review and information available in the design and construction records in ITD files, a table was developed to summarize useful MSE wall attributes (properties). A total of 40 MSE wall attributes were selected in seven general categories: (1) location, (2) wall dimensions, (3) wall type and functionality, (4) historical data, (5) structural data, (6) drainage, and (7) other features. These were discussed in Chapter 3.

After identifying MSE walls, attribute data was collected, where available, for each wall. Researchers contacted district office personnel to obtain design and construction details on the MSE walls (see Chapter 4). ITD District staff introduced the researchers to the ProjectWise system used to manage project documents. Although the ITD ProjectWise system was useful in finding data, the process was very time consuming. Similarly, access to the "as-built" drawings was always difficult as it required considerable help, which was provided by ITD personnel. Where lacking, attribute data was supplemented by observations made at the selected study sites.

This study compiled information on 58 MSE walls from the six ITD Districts, as shown in Table 39. The research team reviewed records and visited the sites of several MSE walls identified during the investigation to collect data on as many attributes as possible. As a minimum, information about the route and location in the form of milepost data and/or GPS coordinates was included in the inventory. The attribute data for the ITD MSE walls was assembled in Excel and is given in Appendix A of this report.

MSE walls used for bridge abutments were also included in this inventory. However, there was some uncertainty on how such walls should be counted for the proposed inventory as sometimes there could be as many as six distinct walls, as in the case for the Bitch Creek bridge on SH-32.

Table 39. MSE Walls identified in the six ITD Highway Districts

District	1	2	3	4	5	6
No. of Walls	21	13	4	1	9	10

MSE Wall Data Storage and Retrieval

In an April 11, 2019, project meeting with ITD staff, ArcGIS was selected as the data management tool. A tutorial to place and retrieve the MSE wall attributes and condition data into an ArcGIS geodatabase is given in Appendix E.

MSE Wall Asset Evaluation Practices

To develop recommended inspection procedures for ITD, the team started with an investigation of practices used by other government agencies in assessing the performance of MSE walls. The literature search included technical publications on retaining wall structures including MSE walls as well as manuals and checklists used by other States, FHWA, and overseas agencies. The focus of the study was two-fold: identification of important features governing performance and the nature of rating systems used to monitor MSE walls. The features identified in the literature as affecting the performance of MSE walls were generally consistent in the numerous documents reviewed by the project team. The general categories of MSE wall inspection features include the wall and coping, leveling pads, backfill, erosion, drainage and appurtenant structures at the top of the wall.

Checklist and rating system forms used by ten city, state and Federal agencies are discussed in Chapter 2 of this report. Of the protocols reviewed by the project team, three were considered for use by ITD: Nebraska DOT (2009), North Carolina DOT (2015), and Ohio DOT (2007). These procedures range from simple observations to measurements and record keeping, as discussed in Chapter 3. In all three protocols, descriptions are given for MSE wall conditions. The descriptions themselves provide useful information on MSE wall parameters which affect behavior. However, most of the descriptions are non-quantitative, and if measurements are made, broad ranges of values are used to categorize levels of performance. None of the methods use actual measurements or rates of change to evaluate or rate the performance of the walls.

In the Nebraska and North Carolina systems, numerical values are assigned to each descriptive condition. In the North Carolina protocol, ratings are good (value of 1), fair (2), poor (3), and severe (4), and are assigned to percentages of the affected area of the wall. Area-weighted average values are then calculated for each condition. These ratings are highly dependent on the experience and education of the inspector. Moreover, average values often mask the true condition of the wall.

The Nebraska DOT procedures are made up of 13 categories of wall performance to which values of 0 to 9 are assigned by the inspector. Ranges of values are given for condition (attribute) descriptions (most commonly percentage of wall affected) to assign a numerical rating value. Many of the ranges are wide with no differentiation between intermediate values. For example, in Category 1 “Wall Tilting”, the range of tilt difference corresponding to changes in ratings is 5 degrees. For a 20-ft high wall, a 5-degree interval is equivalent to 20 inches of lateral displacement at the top of the wall.

Based on input provided by the ITD Technical Advisory Committee, the Ohio DOT procedures are the preferred method for conducting MSE wall performance investigations. In the Ohio DOT inspection system, a list of 20 condition descriptions are used to evaluate the performance of the wall. However, the Ohio DOT procedure has some serious limitations. Except for a few conditions, such as the number of cracked panels greater than two, the descriptions are not quantitative. Moreover, it is difficult to draw any conclusions on the performance of the wall if the box for settlement is checked “yes” for multiple year site inspections without supporting details regarding the magnitude or rate of change in the vertical displacement.

With help from ITD, a questionnaire was sent to all 51 states requesting information on their MSE wall inventories and performance evaluation practices. Twenty-six state DOTs responded to the survey, the results of which are summarized in Chapter 2. Compilation of the survey results show limited state DOT effort in MSE wall asset evaluation. Of the 26 responses: 10 states inspect MSE wall conditions, 9 states have inventories of MSE walls, 7 states have a system for rating MSE walls and only 4 states have accessible MSE wall databases.

Field Investigations of ITD MSE Walls

To evaluate existing MSE wall inspection and rating systems and make recommendations to ITD, the researchers carried out field studies on selected MSE walls. A total of 18 walls were studied in the six ITD districts and data was collected on the condition of the walls, and surrounding areas. Observation and measurement data, as well as photographs, were assembled in Excel format for the District 5 and 6 surveys. The data was used to evaluate the Ohio, Nebraska and North Carolina DOT inspection procedures and ratings.

In Districts 1 and 2, the evaluated MSE study walls are in good condition and had high Nebraska, Ohio and North Carolina performance ratings. For example, the I-90 wall at MP 1.03 had an average value of 9 (highest) in the Nebraska DOT system and a rating of 0.99 to 1.00 (good condition) in the North Carolina procedure. Locally, some slight bowing/bulging, panel offset, compression spalls, joint opening and slight cracking near the abutment were observed in the 6 MSE walls in the Districts 1 and 2. In essence, the rating systems matched the performance of the walls which were all in good condition.

Similar good conditions were observed for the five MSE walls surveyed in Districts 3 and 4. Nebraska DOT ratings for 7 conditions ranged between 7 and 9 and averaged 8.1 to 9.0. Again, local joint openings, slight offsets, and minor vegetation were found in four of the five MSE walls.

In Districts 5 and 6, six of the seven MSE walls have marginal or serious conditions, which places them in the highest category for additional investigations, repair or replacement. In each case, only one or two adverse conditions were affecting the performance of the wall. The other assessment conditions were absent or performing satisfactorily. In all six cases, the other state protocols were deficient and could lead to wrong conclusions on the conditions of the walls or adjoining features. For example, checking "yes" in Box 8 for the presence of cracks in two or more panels in the Ohio DOT procedures is unlikely to alert ITD staff to the major problems with the MSE wall supporting the west abutment of the East Gould Street Overpass. Similarly, a rating of 7 to 9 in the NE-DOT system for structural cracking where 10% or less of the panels are cracked does not represent the extent of the serious condition in the overpass.

The North Carolina, Nebraska and Ohio DOT inspection procedures and rating systems are suitable for MSE walls that have little or no damage and are behaving as expected, such as the I-90 wall at MP 1.03 in District 1. However, these and other state protocols are inadequate for assessing the behavior of walls with adverse conditions, such as Wall 5 supporting the west abutment of the East Gould Street Overpass. In these cases, observations and measurements are needed to evaluate the performance of the walls and for making intelligent decisions regarding the need for remedial actions.

To establish a process for MSE wall inspections, the first stage is to inspect the conditions of all MSE walls and identify and record features that are impacting the performance of the wall (such as erosion or panel/coping concrete deterioration). The Ohio DOT procedures, with modifications, are suitable for initial MSE wall inspections. However, if adverse conditions are noted, baseline measurements of the distressed areas should be started as part of the regular inspections. This will allow follow-on inspections to determine if the previously noted adverse conditions are stabilizing, or if the rate of change requires plans for maintenance, repair, or replacement.

Recommended Inspection Procedures

To create an effective evaluation process, the condition of all MSE walls should be initially assessed using the proposed modified version of the Ohio DOT procedures. This initial review should identify and record features that are impacting the performance of the wall (such as erosion or panel/coping concrete deterioration).

If an MSE wall is experiencing adverse conditions, initial baseline observations and measurements must be made to allow follow-on inspections to assess changes. The form presented in Table 38 may be used to record details of problem areas, providing focus for more detailed observations and measurements during follow-on inspections. The comparison of multi-year measurements will provide quantitative data which may be used to commit resources for maintenance, repair, or replacement. With time and experience, it is possible that such measurements will allow ITD to develop criteria for unacceptable damage levels, allowing ITD to formally rate MSE walls that are performing poorly.

Conclusions

Following a review of literature and state DOT practices as well as the field surveys, the following conclusions are made:

1. Adequate MSE wall data is available to create an inventory as part of an asset management program for its MSE walls. Information about the type of MSE wall and its location is a minimum requirement for the inventory.
2. Although MSE Wall attribute data are available in ITD files, considerable effort is required to extract the necessary information for all 40 attributes selected for the inventory database.
3. The information collected for the MSE wall inventory is in a suitable format for use with the ArcGIS system.
4. As much data as possible was collected for the MSE wall inventory. However, information for many attributes could not be located within the time dedicated to the project.
5. A modified version of the Ohio DOT procedure is preferred by ITD Technical Advisory Committee for ITD needs.
6. The North Carolina, Nebraska and Ohio DOT inspection procedures and rating systems are applicable for MSE walls that have little or damage and are behaving as expected. The inspection procedures are not suitable for evaluating MSE walls with deteriorating conditions which require repair or replacement.
7. The inspection procedures are based fundamentally on non-quantitative descriptions of MSE wall conditions or rely on a wide range of values to categorize wall behavior. In other words, there is no apparent connection between the rating criteria and the expected performance of the individual MSE walls. For walls experiencing problems, measurements over time are needed for a realistic assessment of the future performance of the wall.
8. MSE walls may be inspected and their conditions assessed by experienced personnel. However, evaluations regarding future performance and design life can only be made after adequate baseline information has been collected to monitor changes with time.
9. ArcGIS should be used as the geodatabase storage information system. ITD ArcGIS staff are capable of assist with the process of placing attribute and condition survey information into ArcGIS. Example procedures for importing data and subsequent access using ArcGIS are included in the Appendix E.
10. The use of sUAVs (i.e. drones) to capture HD video and photographs of walls in District 5 and 6 was very successful. Examples of such surveys are included in Appendix D.
11. The assessment of internal MSE wall elements, such as voids and degradation of reinforcing elements, may be possible using thermal imaging and ground penetrating radar. The use of thermography is discussed in Appendix C.

Recommendations

At the conclusion of this study, the research group offer the following recommendations:

14. A geodatabase consisting of an inventory of MSE walls, and their condition, should be implemented into its GIS system for use by ITD personnel. Additionally, each MSE wall should be assigned an "Impact" designation based on the consequences of potential failure.
15. A web-based "App" suitable for a small hand-held device should be developed for accessing, revising and adding information to the MSE wall geodatabase. This data will consist of the wall attributes, photos, and inspection records.
16. All MSE walls included in the inventory must have the following attributes assigned: (a) Route, (b) Lane direction, (c) Milepost near one end of the wall, (d) GPS coordinates near one end of the wall, and (e) Type of MSE wall. The remaining attributes may be added to the database if available.
17. A protocol for counting MSE wall at bridge abutments needs to be established for the inventory.
18. Links to information regarding contract documents, design reports, and as-built plans and specifications should be included in the assembled geodatabase.
19. ITD should commit resources towards adding walls which were not identified by this study to the MSE wall inventory database. Also, the missing attribute data should be updated in the assembled inventory by making a concerted effort to locate relevant construction and design documents.
20. A modified version of the Ohio DOT procedure, included in Appendix F, is recommended for inspecting MSE walls in Idaho. For implementation, guidelines for MSE wall inspections should be developed and workshops planned to train potential MSE wall inspectors.
21. Using the recommended inspection procedures, all ITD MSE walls in the inventory should be inspected to create a baseline report and to identify walls found to be performing below expectations. A condition survey should be completed for the poorly performing MSE walls.
22. MSE walls found to be performing below expectations, should be inspected every year, and walls which are performing well, should be inspected at least every five years.
23. Data collected during follow-on inspections should be reviewed to see if there are significant changes in the measurements and performance. With time, it may be possible to develop categories of "damage" (such as low, medium, or high) depending on the measurements and changes.
24. Inspections should be complemented by appropriately annotated HD photographs. The use of drones to photograph high walls, or walls difficult to access, should be implemented wherever possible.
25. Further use of thermal mapping or Ground Penetrating Radar (GPR) should be investigated in a future study to see if the fill and reinforcing elements behind the wall's face can be evaluated and assessed.
26. The six MSE walls in Districts 5 and 6 which appear to be distressed should be re-inspected to evaluate their performance.

References

1. Passe, P.D. "Mechanically Stabilized Earth Wall Inspector's Handbook." Florida Department of Transportation, Tallahassee, FL, 47 pages, September 2000.
2. MAP-21. "Moving Ahead for Progress in the 21st Century Act (MAP-21)." Pub. L. No. 112- 141, 126 Stat. 432-434 §1106, 2012.
3. Armour, T.A., J. Bickford, and T. Pfister. "Repair of Failing MSE Railroad Bridge Abutment." GeoSupport 2004: Drilled Shafts, Micropiling, Deep Mixing, Remedial Methods, and Specialty Foundation Systems, ASCE, GSP 124, pp. 380-394, 2004.
4. AASHTO. "Asset Management Data Collection Guide." AASHTO-AGC-ARTBA Task Force 45, AASHTO, Washington, D.C., 100 pages, 2006.
5. Brutus, O. and G. Tauber. "Guide to Asset Management of Earth Retaining Structures." National Cooperative Highway Research Program. Transportation Research Board. Project 20-07. Task 259. Washington DC. 120 pages, October 2009.
6. Shannon & Wilson, Inc., Spy Pond Partners, LLC, Iowa State University, and University of Missouri. "Geotechnical Asset Management for Transportation Agencies: Research Overview. Pre-publication draft of NCHRP Research Report 903, Volume 1." Transportation Research Board, Washington, D.C., September 2018.
7. Scarborough, J.A. "A Tale of Two Walls: Case Histories of Failed MSE Walls", Geotechnical Special Publications GSP 140, Slopes and Retaining Structures under Seismic and Static Conditions, presented at the Geo-Frontiers 2005 Conference, Austin, TX, 12 pages, 2005.
8. Samtani, N.C. and D. Alexander. "Remediation of a Failing MSE Wall by Jet Grouting." Geotechnical Special Publications GSP 136, Innovations in Grouting and Soil Improvement, Proceedings of the Geo-Frontiers 2005 Congress, Austin, TX, 2005.
9. Hossain, Md. S. and V. Omelchenko. "Failure Analysis of a Mechanically Stabilized Earth (MSE) wall in Maryland." 86th Annual Meeting of TRB, Paper #07-0450, 20 pages, 2007.
10. Chen, D. H., S. Nazarian, and J. Bilyeu. "Failure Analysis of a Bridge Embankment with Cracked Approach Slabs & Leaking Sand", Journal of Performance of Constructed Facilities, ASCE, Vol. 21(5), pp. 375-381, 2007.
11. New York City Department of Buildings. "Board of Inquiry Report: Castle Village Retaining Wall Collapse". (on May 12, 2005). April 2007.
12. Keller, T. "MSE Wall Inventory and Inspection Program." Unpublished, Inter Office Memo, Ohio Department of Transportation, 2 pages, December 2005.
13. Ohio Department of Transportation. "MSE Wall Inspection Checklist", Ohio Department of Transportation, Columbus, 11 pages, 2007.
14. New York State Department of Transportation. "Mechanically Stabilized Earth System Inspection Manual", Geotechnical Engineering Manual 16, Albany, 05 pages, 2007.
15. Narsavage, P., "MSE Walls Problems and Solutions," presented at Ohio DOT Geotechnical Workshop, Columbus, Apr. 11, 2006.

16. Gerber, T. "Assessing the Long-term Performance of Mechanically Stabilized Earth Walls." NCHRP Synthesis 437, *National Cooperative Highway Research Program.* Transportation Research Board. Washington DC, 211 pages, 2012.

17. Hearn, G. "Feasibility of Management Systems for Retaining Walls and Sound Barriers". Report Number CDOT-DTD-200-3, Colorado Department of Transportation Research Branch, Boulder, 106 pages, 2003.

18. Gabr, M.A., W. Rasdorf, D.J. Findley, C.J. Butler, and S.A. Bert. "Comparison of Three Retaining Wall Condition Assessment Rating Systems." J. Infrastruct. Syst., ASCE, 24(1), DOI: 10.1061/(ASCE)IS.1943-555X.0000403, 11 pages, 2017.

19. Sundararajan, L. "Retaining Wall and Landslide Stabilization Audit." Department of Transportation and Engineering, City of Cincinnati, 32 pages, October 2017.

20. DeMarco, M., R. Barrows, and S. Lewis. "NPS Retaining Wall Inventory and Assessment Program (WIP): 3,500 Walls Later." *Proceedings of the 2010 Earth Retention Conference.* American Society of Civil Engineers. Bellevue, Washington. (August), 8 pages, 2010.

21. DeMarco, M., D. Keough, and S. Lewis. "Retaining Wall Inventory and Condition Assessment Program (WIP): National Parks Service Procedure Manual." *Central Federal Lands Highway Division.* Federal Highway Administration. Lakewood, Colorado. FHWA Publication Number FHWA-CFL/TD-10-003. (August), 188 pages, 2010.

22. California Department of Transportation. "MSE Structure Inspection Element Extraction Procedure, California Department of Transportation, Sacramento, 23 pages, 2004.

23. Walters, B.X., M.P. Collins, N.E. Funk, M.J. Vessely, B.L. Widman, J.W. Koonce, M.J. Garlich, and P.D. Thompson. "Colorado Retaining and Noise Walls Inspection and Asset Management Manual." Version /.0, Denver, CO, Colorado Department of Transportation, 300 pages, April 2016.

24. CTC and Associates. "Asset management for retaining walls." Minnesota Dept. of Transportation, St. Paul, MN, 42 pages, 2013.

25. Jensen, W. "Inspector's Manual for Mechanically Stabilized Earth Walls." Nebraska Department of Roads, University of Nebraska-Lincoln, Technical Report Number SPR-P1 (09) P320, 36 pages, 2009.

26. Rasdorf, W., M.A. Gabr, C.J. Butler, D.J. Findley, and S.A. Bert. "Retaining Wall Inventory and Assessment System." NCDOT Project 2014-10, North Carolina Department of Transportation, 273 pages, September 2015.

27. Butler, C.J., M.A. Gabr, W. Rasdorf, D.J. Findley, J. Chang, and B. Hammit. "Retaining wall field condition inspection, rating analysis, and condition assessment." J. Perform. Constr. Facil., 10.1061/(ASCE)CF .1943-5509.0000785, 04015039, 12 pages, 2016.

28. Ohio DOT. "ODOT Retaining Wall Inventory Manual (Draft)." Ohio Department of Transportation, 49 pages, June 2018.

29. Turner, D. "A Retaining Wall Management System for ODOT Asset Management," presented at 34th Northwest Geotechnical Engineers Workshop, Springdale, Utah, 2008.

30. Maw, R.B. "Development of Mechanically Stabilized Earth (MSE) Wall Inspection Plan and Procedure for Failure Mode Analysis and Risk Assessment." MS Thesis, Utah State University, 266 pages, 2009.

31. Swenson, A. “Evaluation and Analysis of Utah Department, of Transportation MSE Wall Performance.” MS thesis, Brigham Young University, Provo, Utah, 116 pages, 2010.

32. Molla, A. “City of Seattle Retaining Walls Condition Assessment”, Unpublished, 4 pages, 2009.

33. BC MOT. “Responsibility for identification, structure number assignment, inspection, maintenance, rehabilitation, and setting of standards for retaining wall structures.” Technical Circular T-05/03, British Columbia Ministry of Transportation Engineering Branch, 2003.

34. VicRoads Technical Consulting. “Road Structures Inspection Manual.” *State Government of Victoria.* Victoria, Australia. 296 pages, April 2011.

35. Kim, Y., J. Hummer, M. Gabr, D. Johnston, S. Underwood, D. Findley, and C. Cunningham. “Asset management inventory and data collection.” FHWA/NC/2008-15.2009, Federal Highway Administration, Lakewood, CO, 287 pages, October 2009.

36. Flintsch, G.W. and J. W. Bryant, Jr. “Asset Management Data Collection for Supporting Decision Processes.” FHWA, 97 pages, March 2009.

37. Castellanos, J.F, "Mechanically Stabilized Earth Wall Inspector’s Handbook." Revised 2000 Edition, Florida Department of Transportation, Tallahassee, FL, 45 pages, June 2012.

38. Sun, C. and C. Graves. “Evaluation of Mechanically Stabilized Earth Walls for Bridge Ends in Kentucky; What Next?” Report KTC-13-11/SPR443-12-1F, Kentucky Transportation Center, Lexington, KY, 60 pages, July 2013.

39. Sun, C. and C. Graves. “Inspection Guidelines for Construction and Post-Construction of Mechanically Stabilized Earth (MSE) Wall.” Kentucky Transportation Center, Lexington, KY, 51 pages, Summer 2013.

40. Alzamora, D.E., and S.A. Anderson. “Review of Mechanically Stabilized Earth Wall Performance Issues.” TRB 2009 Annual Meeting CD-ROM, 2009.

41. Tarawneh, B., A.B. Wassel and Masada, T. “Inspection and Risk Assessment of Mechanically Stabilized Earth Walls Supporting Bridge Abutments.” Journal of Performance of Constructed Facilities, Vol 32(01), ASCE, 6 pages, 2018.

42. Golrokh A. J., Y. Lu, and X. Gu. “A real-time thermal imaging-based system for asphalt pavement surface distress inspection and 3D crack profiling.” submitted to Journal of Nondestructive Evaluation.

43. Lu, Y., A. J. Golrokh, and MD. A. Islam. “Concrete pavement service condition assessment using infrared thermography.” Advances in Materials Science and Engineering, Article ID 3829340, 8 pages, 2017.

44. Golrokh, A.J. et al. “An experimental study of environmental effects on concrete pavement surface cracking using infrared thermography.” under review for TRB publication.

45. Golrokh, A. J. and Y. Lu. “An experimental study of environmental effects on concrete pavement surface cracking using infrared thermography.” Pavement Analysis Workshop (PAWS), 98th Annual Meeting of TRB, 21 pages, 2019.

46. Berg, R.R., B.R. Christopher, and N.C. Samtani. Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, FHWA NHI-10-024, Volume I and NHI-10-025 Volume II, U.S. Department of Transportation, FHWA, Washington, D.C., 306 pages (Vol I) and 380 pages (Vol II), November 2009.

47. Bligh, R.P., J-L. Briaud, K. Kang-Mi, and A. Abu-Odeh. "Design of Roadside Barrier Systems Placed on MSE Retaining Walls." Texas Transportation Institute, College Station, 2009.

Appendix A
Listing of MSE Wall Inventory

Table 40. MSE Wall Data for District 1

MSEW #:	D1-1	D1-2	D1-3	D1-4	D1-5
Location					
1. District	1	1	1	1	1
2. Route	SH-5	SH-200	SH-200	I-90	I-90
3. Direction (E, W, N, S)	W	E	W	E	E
4. Mile post (End-1)	8.77	42.19	60.18	0.91	11.24
5. GPS-end-1 Latitude	47.347415	48.282506	48.095000	47.700020	47.699684
6. GPS-end-1 Longitude	116.725336	116.349416	116.105000	117.022304	116.80778
7. ProjectWise #	A013(410)	BR-STP-5120(107)			IM-90-1(190) 10
Dimensions					
8. Length of Wall	390	340	360	960	114.8
9. Height - minimum	3.5	5	3	0	0
10. Height - maximum	13.8	10	13	20	13
11. Multiple Heights					
12. Wall batter angle	none	3.58 deg		none	none
13. Back Slope angle	none	4H:1V		2H:1V	2H:1V max
14. Front Slope angle		none		none	
15. Berm Height		n/a			
16. Distance to stream		n/a			
Wall Type & Functionality					
17. MSE Wall Facing	CP	CB	CB	CP	Stone Facing
18. Wall Top Feature	Coping	Guardrail		Coping	Coping
19. Reinforcement Type	G	G		M	F
20. Use of MSE Wall	Rwy	Rwy		Rwy	Rwy
21. Traffic Volume					
Historical Data					
22. Year Built	2016	2013		2012	2001
23. Design Life	75 years	75 years		75 years	75 years
24. Engineer of record	John P. Vaudreuil	Colin J. Meehan			Steven C. Hutchinsor
25. Special Access Needs					
26. Work Zone Requirements					
Structural Data					
27. Wall support	None	CB		CP	CP
28. Foundation - width	Det. By Designer	4 ft		12 inches	0.75 * Height
29. Foundation - thickness		6 in			
30. Wall Embedment	2 ft minimum	2 ft minimum			3 ft minimum
31. Backfill Material	3/4 in Type A	Free Draining backfill			
32. Foundation Support	Un	Silt/Gravel	Un	Un	Un
Drainage					
33. Internal Drainage	1 ft minimum	2 ft minimum			
34. External Drainage	12 inch perf. drain				
35. Weep Holes					
36. Scour Depth	n/a	n/a	n/a	n/a	n/a
Other					
37. Site Inv. Report Available		Yes		Yes	
38. As-built drawings					
39. Design Calculations	Yes	Yes			
40. Seismic zone	0.097g	0.10 to 0.15g	0.10 to 0.15g	0.10 to 0.15g	0.10 to 0.15g

Table 40. MSE Wall Data for District 1 (continued)

MSEW #:	D1-6	D1-7	D1-8	D1-9	D1-10
Location		HE	95A	95B	GH2
1. District	1	1	1	1	1
2. Route	US-95	US-95	US-95	US-95	US-95
3. Direction (E, W, N, S)	S	S	S	S	S
4. Mile post (End-1)	465.00	473.53	473.63	473.66	473.94
5. GPS-end-1 Latitude	48.157496	48.267686	48.268166	48.268302	48.271251
6. GPS-end-1 Longitude	116.600405	116.540423	116.540779	116.540664	116.544682
7. ProjectWise #	BRF-5110(107)		DHP-NH-IR-CM-F-5116(068)	DHP-NH-IR-CM-F-5116(068)	DHP-NH-IR-CM-F-5116(068)
Dimensions					
8. Length of Wall	110	1100	978.3	795	130
9. Height - minimum	5		0		
10. Height - maximum	30	15	20		20
11. Multiple Heights					
12. Wall batter angle	none				
13. Back Slope angle	none				
14. Front Slope angle	none				
15. Berm Height					
16. Distance to stream					
Wall Type & Functionality					
17. MSE Wall Facing	CP	CP	CP	CP	CP
18. Wall Top Feature	Coping	Coping	Coping	Coping	Coping
19. Reinforcement Type	Unknown		Unknown		
20. Use of MSE Wall	Rwy	Rwy	Br		Rwy
21. Traffic Volume					
Historical Data					
22. Year Built	2004	2006	2006	2006	2006
23. Design Life		75 years	75 years	75 years	75 years
24. Engineer of record		Richard L. Novotny	Richard L. Novotny	Richard L. Novotny	Richard L. Novotny
25. Special Access Needs					
26. Work Zone Requirements					
Structural Data					
27. Wall support			CP	CP	
28. Foundation - width					
29. Foundation - thickness					
30. Wall Embedment			3.6 ft		
31. Backfill Material			MSE Backfill	MSE Backfill	MSE Backfill
32. Foundation Support	Un	Un	Un	Un	Un
Drainage					
33. Internal Drainage			0.6 ft Drainage Layer		
34. External Drainage					
35. Weep Holes					
36. Scour Depth	n/a	n/a	n/a	n/a	n/a
Other					
37. Site Inv. Report Available		Yes	Yes	Yes	Yes
38. As-built drawings					
39. Design Calculations					
40. Seismic zone	0.10 to 0.15g	0.10 to 0.15g	0.10 to 0.15g	0.10 to 0.15g	0.10 to 0.15g

Table 40. MSE Wall Data for District 1 (continued)

MSEW #:	D1-11	D1-12	D1-13	D1-14	D1-15
Location	95C	95D	95E	95F	95I
1. District	1	1	1	1	1
2. Route	US-95	US-95	US-95	US-95	US-95
3. Direction (E, W, N, S)	N	S	N	N	S
4. Mile post (End-1)	474.05	474.08	474.08	474.16	475.11
5. GPS-end-1 Latitude	48.274053	48.274105	48.274363	48.276403	48.287547
6. GPS-end-1 Longitude	116.54509	116.545342	116.545159	116.546096	116.549735
7. ProjectWise #	DHP-NH-IR-CM-F-5116(068)	DHP-NH-IR-CM-F-5116(068)	DHP-NH-IR-CM-F-5116(068)	DHP-NH-IR-CM-F-5116(068)	DHP-NH-IR-CM-F-5116(068)
Dimensions					
8. Length of Wall	85	640	375	665	650
9. Height - minimum					2
10. Height - maximum	11	22	20	8	30
11. Multiple Heights					
12. Wall batter angle			none		none
13. Back Slope angle			none		3H:1V
14. Front Slope angle			none		none
15. Berm Height			n/a		N/A
16. Distance to stream			n/a	N/A	N/A
Wall Type & Functionality					
17. MSE Wall Facing	CP	WG	CP	Brick	WG
18. Wall Top Feature	Coping	Coping	Coping	Coping	Guardrail
19. Reinforcement Type					M
20. Use of MSE Wall	Br		Rwy		Rwy
21. Traffic Volume					
Historical Data					
22. Year Built	2006	2006	2006	2006	2006
23. Design Life	75 years	75 years	75 years	75 years	75 years
24. Engineer of record	Richard L. Novotny	Richard L. Novotny	Richard L. Novotny	Richard L. Novotny	Richard L. Novotny
25. Special Access Needs					
26. Work Zone Requirements					
Structural Data					
27. Wall support			CB		none
28. Foundation - width					n/a
29. Foundation - thickness					n/a
30. Wall Embedment					2 ft
31. Backfill Material	MSE Backfill	MSE Backfill	MSE Backfill	MSE Backfill	MSE Backfill
32. Foundation Support	Un	Un	Un	Un	Un
Drainage					
33. Internal Drainage					0.6 ft Drainage Layer
34. External Drainage					none
35. Weep Holes					none
36. Scour Depth	n/a	n/a	n/a	n/a	n/a
Other					
37. Site Inv. Report Available	Yes	Yes	Yes	Yes	Yes
38. As-built drawings					
39. Design Calculations					
40. Seismic zone	0.10 to 0.15g	0.10 to 0.15g	0.10 to 0.15g	0.10 to 0.15g	0.10 to 0.15g

Table 40. MSE Wall Data for District 1 (continued)

MSEW #:	D1-16	D1-17	D1-18	D1-19	D1-20
Location	95K				
1. District	1	1	1	1	1
2. Route	US-95	US-95	US-02	US-02	US-02
3. Direction (E, W, N, S)	S	S	W	W	W
4. Mile post (End-1)	475.31	476.19	5.96	6.15	6.23
5. GPS-end-1 Latitude	48.291163	48.296454	48.180000	48.180000	48.180000
6. GPS-end-1 Longitude	116.549073	116.548783	116.913000	116.907000	116.907000
7. ProjectWise #	DHP-NH-IR-CM-F-5116(068)	NH-IR-F-5116(049)			
Dimensions					
8. Length of Wall	335	550	860	280	95
9. Height - minimum	4		3	0	0
10. Height - maximum	15	30	8	9	9
11. Multiple Heights					
12. Wall batter angle	none				
13. Back Slope angle	none				
14. Front Slope angle	none				
15. Berm Height	N/A				
16. Distance to stream	N/A				
Wall Type & Functionality					
17. MSE Wall Facing	WG	WG	CP	CP	CP
18. Wall Top Feature	Coping	Guardrail	Coping	Coping	Coping
19. Reinforcement Type	Unknown				
20. Use of MSE Wall	Br	Rwy			
21. Traffic Volume					
Historical Data					
22. Year Built	2006				
23. Design Life	75 years				
24. Engineer of record	Richard L. Novotny				
25. Special Access Needs					
26. Work Zone Requirements					
Structural Data					
27. Wall support	CB				
28. Foundation - width					
29. Foundation - thickness					
30. Wall Embedment	3.6 ft				
31. Backfill Material	MSE Backfill				
32. Foundation Support	Un	Un	Un	Un	Un
Drainage					
33. Internal Drainage	0.6 ft Drainage Layer				
34. External Drainage					
35. Weep Holes					
36. Scour Depth	n/a	n/a	n/a	n/a	n/a
Other					
37. Site Inv. Report Available	Yes				
38. As-built drawings					
39. Design Calculations					
40. Seismic zone	0.10 to 0.15g	0.10 to 0.15g	0.10 to 0.15g	0.10 to 0.15g	0.10 to 0.15g

Table 40. MSE Wall Data for District 1 (continued)

MSEW #:	D1-21				
Location					
1. District	1				
2. Route	US-02				
3. Direction (E, W, N, S)	E				
4. Mile post (End-1)	23.58				
5. GPS-end-1 Latitude	48.250000				
6. GPS-end-1 Longitude	116.650000				
7. ProjectWise #					
Dimensions					
8. Length of Wall	150				
9. Height - minimum	1				
10. Height - maximum	7				
11. Multiple Heights					
12. Wall batter angle					
13. Back Slope angle					
14. Front Slope angle					
15. Berm Height					
16. Distance to stream					
Wall Type & Functionality					
17. MSE Wall Facing	CB				
18. Wall Top Feature	Coping				
19. Reinforcement Type					
20. Use of MSE Wall					
21. Traffic Volume					
Historical Data					
22. Year Built					
23. Design Life					
24. Engineer of record					
25. Special Access Needs					
26. Work Zone Requirements					
Structural Data					
27. Wall support					
28. Foundation - width					
29. Foundation - thickness					
30. Wall Embedment					
31. Backfill Material					
32. Foundation Support	Un				
Drainage					
33. Internal Drainage					
34. External Drainage					
35. Weep Holes					
36. Scour Depth	n/a				
Other					
37. Site Inv. Report Available					
38. As-built drawings					
39. Design Calculations					
40. Seismic zone	0.10 to 0.15g				

Table 41. MSE Wall Data for District 2

MSEW #:	D2-1	D2-2	D2-3	D2-4	D2-5
Location					
1. District	2	2	2	2	2
2. Route	SH-3	US-12	US-12	US-12	US-12
3. Direction (E. W. N, S)	E	W	W	E	E
4. Mile post (End-1)	0.43	53.12	53.59	66.69	66.92
5. GPS-end-1 Latitude	46.475725	46.372020	46.366324	46.230020	46.230778
6. GPS-end-1 Longitude	116.769147	116.173401	116.167898	116.019595	116.016105
7. ProjectWise #	STP-4170(101)	NH-SB-4200(139)	NH-SB-4200(139)	BRF-4200(101)	BRF-4200(101)
Dimensions					
8. Length of Wall	997	1920	650	280	848
9. Height - minimum	3	1	1	2	9.5
10. Height - maximum	36	16	10	15	23
11. Multiple Heights					
12. Wall batter angle	No data found	No angle	No angle	No angle	No angle
13. Back Slope angle	No data found	variable	variable	none	2.0:1
14. Front Slope angle	No data found	variable	variable	none	1.5:1
15. Berm Height	No data found	none	none	None	None
16. Distance to stream	29 ft (Average)	0 to 30 feet	0 to 30 feet	0 to 30 feet	0 to 30 feet
Wall Type & Functionality					
17. MSE Wall Facing	WG	WG	WG	CP	CP
18. Wall Top Feature	Guardrail	Guardrail	Guardrail	Cap	Cap
19. Reinforcement Type	G	F	F	F	F
20. Use of MSE Wall	Rwy	Rwy	Rwy	Br	Br
21. Traffic Volume					
Historical Data					
22. Year Built	1999	2005	2005	2000	2000
23. Design Life	75 years	75 years	75 years	75 years	75 years
24. Engineer of record	Blake Rindlisbacher	Joe Schacher	Joe Schacher	Douglas J. McAtee	Douglas J. McAtee
25. Special Access Needs	None noted	River bank	River bank	None noted	None noted
26. Work Zone Requirements	None noted	Drone	Drone	None noted	None noted
Structural Data					
27. Wall support	None noted	None noted	None noted	Gravel Base	Gravel Base
28. Foundation - width	Varies	None noted	None noted	5.9 ft	5.9 ft
29. Foundation - thickness	None noted	None noted	None noted	5.9 ft	5.9 ft
30. Wall Embedment	None noted	3 ft	3 ft	5.9 ft minimum	5.9 ft minimum
31. Backfill Material	No Data Found	Backfill	Backfill	Rock Riprap	Rock Riprap
32. Foundation Support	Un	Un	Un	Rk	Rk
Drainage					
33. Internal Drainage	No Data Found	None	None	No Data Found	No Data Found
34. External Drainage	No Data Found	None	None	No Data Found	No Data Found
35. Weep Holes	No Data Found	None	None	No Data Found	No Data Found
36. Scour Depth	n/a	No Data Found	No Data Found	No Data Found	No Data Found
Other					
37. Site Inv. Report Available					
38. As-built drawings	1999	2005	2005	2000	2000
39. Design Calculations					
40. Seismic zone	0.09g	0.09g	0.09g	0.09g	0.09g

Table 41. MSE Wall Data for District 2 (continued)

MSEW #:	D2-6	D2-7	D2-8	D2-9	D2-10
Location					
1. District	2	2	2	2	2
2. Route	US-12	US-95	US-95	US-95	US-95
3. Direction (E. W. N, S)	N/S	S	N	S	S
4. Mile post (End-1)	76.82	210.04	230.31	231.41	319.85
5. GPS-end-1 Latitude	46.142344	45.599613	45.832272	45.833203	46.475691
6. GPS-end-1 Longitude	115.941677	116.271328	116.241877	116.240607	117.039286
7. ProjectWise #	A013(884)	A010(446)	A013(003)	NH-4110(137)	NH-4110(133)
Dimensions					
8. Length of Wall	507	610	750	4785	312
9. Height - minimum	6	5	8	4	6
10. Height - maximum	10	20	13.5	10	16
11. Multiple Heights			8,9,12 13.5 ft	4,6,8,10 ft	
12. Wall batter angle	80.0:1	50.0:1	6.0:1	6.0:1	12.0:1
13. Back Slope angle	2.0:1	1.0:1	Varies	Varies	2.0:1
14. Front Slope angle	1.5:1	1.0:1	1.0:1	1.0:1	No angle
15. Berm Height	No data found	No data found	No data found	No data found	No data found
16. Distance to stream					
Wall Type & Functionality					
17. MSE Wall Facing	WG	WG	WG	WG	WG
18. Wall Top Feature	Cap	Cap	Guardrail	Cap	None noted
19. Reinforcement Type	F	F	F	F	Unknown
20. Use of MSE Wall	Br	Ls	Rwy	Rwy	Er
21. Traffic Volume					
Historical Data					
22. Year Built	2018	2010	2015	2009	2010
23. Design Life	75 years	75 years	75 years	75 years	75 years
24. Engineer of record	Joe Schacher	Curtis J. Arnzen	Curtis J. Arnzen	Curtis J. Arnzen	Gregory Holder
25. Special Access Needs	None noted	None noted	None noted	None noted	Bottom of steep hill
26. Work Zone Requirements	None noted	None noted	None noted	None noted	None noted
Structural Data					
27. Wall support	None noted	None noted	None noted	None noted	None noted
28. Foundation - width	varies	4 ft	None noted	1.75 ft	Contractor design
29. Foundation - thickness	None noted	Varies	None noted	2 ft	Contractor design
30. Wall Embedment	2 ft minimum	4 ft	3 ft minimum	Unknown	Contractor design
31. Backfill Material	Compacting Backfill	Compacting Backfill	Compacting Backfill	Granular Backfill	Native Material
32. Foundation Support	Un	Un	Un	Un	Contractor design
Drainage					
33. Internal Drainage	No Data Found	No Data Found	No Data Found	No Data Found	Contractor design
34. External Drainage	No Data Found	No Data Found	No Data Found	No Data Found	Contractor design
35. Weep Holes	No Data Found	No Data Found	No Data Found	No Data Found	Contractor design
36. Scour Depth	No Data Found	n/a	n/a	n/a	n/a
Other					
37. Site Inv. Report Available					
38. As-built drawings	2018	2010	2015	2009	2010
39. Design Calculations					
40. Seismic zone	0.09g	0.09g	0.09g	0.09g	0.09g

Table 41. MSE Wall Data for District 2 (continued)

MSEW #:	D2-11	D2-12	D2-13		
Location					
1. District	2	2	2		
2. Route	US-95	US-95	US-95		
3. Direction (E. W. N, S)	N	N	N		
4. Mile post (End-1)	349.77	350.00	350.13		
5. GPS-end-1 Latitude	46.796523	46.800177	46.801944		
6. GPS-end-1 Longitude	116.995170	116.996890	116.998047		
7. ProjectWise #	11031	11031	11031		
Dimensions					
8. Length of Wall	240	270			
9. Height - minimum	3	3	3		
10. Height - maximum	16	16	16		
11. Multiple Heights					
12. Wall batter angle					
13. Back Slope angle					
14. Front Slope angle					
15. Berm Height					
16. Distance to stream					
Wall Type & Functionality					
17. MSE Wall Facing	WG	WG	WG		
18. Wall Top Feature	Guard Rail	Guard Rail	Guard Rail		
19. Reinforcement Type					
20. Use of MSE Wall	Rwy	Rwy	Rwy		
21. Traffic Volume					
Historical Data					
22. Year Built	2009	2009	2009		
23. Design Life	75 years	75 years	75 years		
24. Engineer of record					
25. Special Access Needs					
26. Work Zone Requirements					
Structural Data					
27. Wall support					
28. Foundation - width					
29. Foundation - thickness					
30. Wall Embedment					
31. Backfill Material					
32. Foundation Support					
Drainage					
33. Internal Drainage	none	none	none		
34. External Drainage					
35. Weep Holes	none	none	none		
36. Scour Depth	n/a	n/a	n/a		
Other					
37. Site Inv. Report Available					
38. As-built drawings					
39. Design Calculations					
40. Seismic zone	0.09g	0.09g	0.09g		

Table 42. MSE Wall Data for Districts 3 and 4

MSEW #:	D3-3	D3-5	D3-11	D3-13	D4-5
Location					
1. District	3	3	3	3	4
2. Route	Hwy 26	I-84	I-84	I-84	I-84
3. Direction (E. W. N, S)	NW	NW	NW	NW	NW
4. Mile post (End-1)	47	60	54	47	174
5. GPS-end-1 Latitude	43.622446	43.507789	43.5712437	43.5964555	42.6417984
6. GPS-end-1 Longitude	116.243193	116.143441	116.2153286	116.3548537	114.445898
7. ProjectWise #					
Dimensions					
8. Length of Wall	116	110	204	115	61.75
9. Height - minimum					
10. Height - maximum	45	14.5	19.5	38	11.9
11. Multiple Heights					
12. Wall batter angle					
13. Back Slope angle					
14. Front Slope angle					
15. Berm Height					
16. Distance to stream					
Wall Type & Functionality					
17. MSE Wall Facing	CP	CP	CP	CP	CP
18. Wall Top Feature					
19. Reinforcement Type	F				
20. Use of MSE Wall	Rwy	Br	Br	Br	Br
21. Traffic Volume					
Historical Data					
22. Year Built					
23. Design Life					
24. Engineer of record					
25. Special Access Needs					
26. Work Zone Requirements					
Structural Data					
27. Wall support					
28. Foundation - width					
29. Foundation - thickness	`				
30. Wall Embedment					
31. Backfill Material					
32. Foundation Support					
Drainage					
33. Internal Drainage					
34. External Drainage					
35. Weep Holes					
36. Scour Depth					
Other					
37. Site Inv. Report Available					
38. As-built drawings					
39. Design Calculations					
40. Seismic zone	0.08 to 0.1g	0.08 to 0.1g	0.08 to 0.1g	0.08 to 0.1g	0.08 to 0.1g

Table 43. MSE Wall Data for Districts 5

MSEW #:	D5-1	D5-2	D5-3	D5-4	D5-5
Location					
1. District	5	5	5	5	5
2. Route	I-86	I-15	I-15	I-15	Gould St - Wall 4
3. Direction (E. W. N, S)					N
4. Mile post (End-1)					
5. GPS-end-1 Latitude	42.912619	43.261631	42.897361	42.875733	42.874597
6. GPS-end-1 Longitude	112.450892	112.308894	112.435506	112.425047	112.459792
7. ProjectWise #					
Dimensions					
8. Length of Wall					394.7 ft
9. Height - minimum					2.7 ft
10. Height - maximum					22 ft
11. Multiple Heights					
12. Wall batter angle					90°
13. Back Slope angle					0°
14. Front Slope angle					0°
15. Berm Height					0
16. Distance to stream					2570 ft
Wall Type & Functionality					
17. MSE Wall Facing					CP: 7-1/4 in. Thick
18. Wall Top Feature					Coping
19. Reinforcement Type					M
20. Use of MSE Wall					Br
21. Traffic Volume					
Historical Data					
22. Year Built					1981
23. Design Life					
24. Engineer of record					Reinforced Earth Co
25. Special Access Needs					
26. Work Zone Requirements					
Structural Data					
27. Wall support					CB
28. Foundation - width					12 in.
29. Foundation - thickness					6 in.
30. Wall Embedment					2.5 to 5 ft
31. Backfill Material					Granular: 0 to 15% - #200
32. Foundation Support					Un
Drainage					
33. Internal Drainage					Un
34. External Drainage					Yes
35. Weep Holes					None
36. Scour Depth					NA
Other					
37. Site Inv. Report Available					No
38. As-built drawings					Yes
39. Design Calculations					No
40. Seismic zone	0.10 to 0.15g	0.15 to 0.20g	0.15 to 0.20g	0.10 to 0.15g	0.10 to 0.15g

Table 43. MSE Wall Data for Districts 5 (continued)

MSEW #:	D5-6	D5-7	D5-8	D5-9	D5-10
Location		Topaz		Ledger Creek	"Siphon"
1. District	5	5	5	5	5
2. Route	Gould St - Wall 5	US-30	US-30	US-30	I-15
3. Direction (E. W. N, S)	S	E		E	
4. Mile post (End-1)		406.69		365.15	
5. GPS-end-1 Latitude	42.873383	42.623844	42.656883	42.647544	42.001147
6. GPS-end-1 Longitude	112.462125	112.120425	111.594842	112.575783	112.198514
7. ProjectWise #					
Dimensions					
8. Length of Wall	147 ft	482 ft		51 ft	
9. Height - minimum	7 ft	4.2 ft		0 ft	
10. Height - maximum	19 ft	5.2 ft		22 ft	
11. Multiple Heights					
12. Wall batter angle	90°	90°		90°	
13. Back Slope angle	0°	0°		0°	
14. Front Slope angle	0°	-35°		0°	
15. Berm Height	0	6 to 42 ft		30 ft	
16. Distance to stream	1160 ft	93 ft		128 ft	
Wall Type & Functionality					
17. MSE Wall Facing	CP: 7-1/4 in. Thick	Fiber Shotcrete		CP	
18. Wall Top Feature	Coping	Ditch/Concrete Barrier		Coping	
19. Reinforcement Type	M	G-WWF		M	
20. Use of MSE Wall	Br	Br		Br	
21. Traffic Volume					
Historical Data					
22. Year Built	1981	2008		1988	2019
23. Design Life					
24. Engineer of record	Reinforced Earth Co	David Statkus			
25. Special Access Needs					
26. Work Zone Requirements		Yes			
Structural Data					
27. Wall support	CB	Foam Block			
28. Foundation - width	12 in.			12 in.	
29. Foundation - thickness	6 in.			6 in.	
30. Wall Embedment	2.5 to 5 ft			4.5 ft	
31. Backfill Material	Granular: 0 to 15% - #200	Granular		Granular	
32. Foundation Support	Un	Un		Un	
Drainage					
33. Internal Drainage	Un	Yes		Un	
34. External Drainage	Yes	Yes: Slope to Drain		None	
35. Weep Holes	None	None		None	
36. Scour Depth	NA	NA		NA	
Other					
37. Site Inv. Report Available	No	No		No	
38. As-built drawings	Yes	Yes		Yes	
39. Design Calculations	No	No		No	
40. Seismic zone	0.10 to 0.15g	0.15 to 0.20g	0.15 to 0.20g	0.15 to 0.20g	0.20 to 0.25g

Table 44. MSE Wall Data for Districts 6

MSEW #:	D6-1	D6-2	D6-3	D6-4	D6-5
Location					
1. District	6	6	6	6	6
2. Route	I-15	I-15	US-20	US-20	US-20
3. Direction (E. W. N, S)	S		N		
4. Mile post (End-1)	189.87				
5. GPS-end-1 Latitude	44.487411	43.489233	43.542903	43.569422	43.626431
6. GPS-end-1 Longitude	112.235362	112.055503	112.004944	111.984608	111.944094
7. ProjectWise #					
Dimensions					
8. Length of Wall			74 ft		
9. Height - minimum					
10. Height - maximum					
11. Multiple Heights					
12. Wall batter angle			90°		
13. Back Slope angle			0°		
14. Front Slope angle					
15. Berm Height					
16. Distance to stream			NA		
Wall Type & Functionality					
17. MSE Wall Facing	CP		CP		
18. Wall Top Feature	Coping		Coping		
19. Reinforcement Type					
20. Use of MSE Wall	Br		Br		
21. Traffic Volume					
Historical Data					
22. Year Built					
23. Design Life					
24. Engineer of record					
25. Special Access Needs					
26. Work Zone Requirements					
Structural Data					
27. Wall support					
28. Foundation - width					
29. Foundation - thickness					
30. Wall Embedment					
31. Backfill Material					
32. Foundation Support			Gr		
Drainage					
33. Internal Drainage					
34. External Drainage					
35. Weep Holes					
36. Scour Depth					
Other					
37. Site Inv. Report Available			No		
38. As-built drawings			No		
39. Design Calculations			No		
40. Seismic zone		0.10 to 0.15g	0.10 to 0.15g	0.15 to 0.20g	0.15 to 0.20g

Table 44. MSE Wall Data for Districts 6 (continued)

MSEW #:	D6-6	D6-7	D6-8	D6-9	D6-10
Location					
1. District	6	6	6	6	6
2. Route	US-20	US-20	US-20	US-20	SH-33
3. Direction (E. W. N, S)	N	N			E
4. Mile post (End-1)	325.58	328.60			99.44
5. GPS-end-1 Latitude	43.724528	43.762075	43.762583	43.875286	43.883586
6. GPS-end-1 Longitude	111.874775	111.844582	111.748983	111.756989	111.748983
7. ProjectWise #					
Dimensions					
8. Length of Wall					65 FT
9. Height - minimum					
10. Height - maximum					
11. Multiple Heights					
12. Wall batter angle					90°
13. Back Slope angle					
14. Front Slope angle					
15. Berm Height					
16. Distance to stream					NA
Wall Type & Functionality					
17. MSE Wall Facing	CP	CP			CP
18. Wall Top Feature	Coping	Coping			Coping
19. Reinforcement Type					
20. Use of MSE Wall	Br	Br			Br
21. Traffic Volume					
Historical Data					
22. Year Built	2016	2016			
23. Design Life					
24. Engineer of record					
25. Special Access Needs					
26. Work Zone Requirements					
Structural Data					
27. Wall support					
28. Foundation - width					
29. Foundation - thickness					
30. Wall Embedment					
31. Backfill Material					
32. Foundation Support					
Drainage					
33. Internal Drainage					
34. External Drainage					
35. Weep Holes					
36. Scour Depth					
Other					
37. Site Inv. Report Available					
38. As-built drawings					
39. Design Calculations					
40. Seismic zone	0.15 to 0.20g	0.15 to 0.20g	0.15 to 0.20g	0.15 to 0.20g	0.15 to 0.20g

Table 44. MSE Wall Data for Districts 6 (continued)

MSEW #:	D6-11				
Location					
1. District	6				
2. Route	SH-32				
3. Direction (E. W. N, S)	N				
4. Mile post (End-1)	7.86				
5. GPS-end-1 Latitude	43.938333				
6. GPS-end-1 Longitude	111.178506				
7. ProjectWise #					
Dimensions					
8. Length of Wall	334 FT				
9. Height - minimum					
10. Height - maximum					
11. Multiple Heights					
12. Wall batter angle	90°				
13. Back Slope angle	0°				
14. Front Slope angle					
15. Berm Height					
16. Distance to stream	114 ft				
Wall Type & Functionality					
17. MSE Wall Facing	CP				
18. Wall Top Feature	Coping				
19. Reinforcement Type					
20. Use of MSE Wall	Br				
21. Traffic Volume					
Historical Data					
22. Year Built					
23. Design Life					
24. Engineer of record					
25. Special Access Needs					
26. Work Zone Requirements					
Structural Data					
27. Wall support					
28. Foundation - width					
29. Foundation - thickness					
30. Wall Embedment					
31. Backfill Material					
32. Foundation Support					
Drainage					
33. Internal Drainage					
34. External Drainage					
35. Weep Holes					
36. Scour Depth					
Other					
37. Site Inv. Report Available					
38. As-built drawings					
39. Design Calculations					
40. Seismic zone	0.20 to 0.25g				

Appendix B
Supplementary Inspection Data – Univ. of Idaho

1. Inspections forms for the Sandpoint Wall, MP 475.75, SB US-95;
2. Inspection forms for the Trestle Creek concrete block wall, MP 41.96, SB SH-200;
3. Inspection forms for the Western Greer Wall, MP 53.00, WB US-12.
4. Photograph of MSE wall located at the eastern end of Kamiah Bridge, MP 66.69, WB US-12.

Table 45. Inspection Summary of Sandpoint Wall – Ohio-DOT Procedure

#	CONDITIONS	Yes, No, N/A
Joints		
1.	Is sand or gravel coming out of joints or are there piles of sand or gravel at the base of the wall?	N/A
2.	Is sand or gravel visible in the horizontal joints?	N/A
3.	Are the joints wide enough to see the sand, gravel or fabric behind the panels when looking perpendicular to the wall face using a flashlight? If yes, record the approximate maximum joint width, in inches.	N/A
4.	If fabric is visible in the joints, is it torn? IMPORTANT - DO NOT POKE OR CUT THE FABRIC.	N/A
5.	Do the joints have a nonuniform size, or are some joints noticeably wider than others? (see Condition Survey)	N/A
6.	Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum offset.	N/A
7.	Is there vegetation growing in the joints? (see Condition Survey) In the Wall Facing?	N/A
~~Wall Facing~~ Wire Gabions		
~~8.~~	~~Are there cracks in more than two facing panels? (see Condition Survey)~~ ~~If yes, record the approximate number of panels that are cracked.~~	
~~9.~~	~~Is the face of the wall bowed or bulged?~~	
8.	Is there corrosion of wire baskets and connections?	No
9.	Is the rockfill in the baskets spilling out?	No
Drainage		
10.	Are there any signs of water flow along the base of the wall?	No
11.	Is there erosion of the embankment at the base of the wall?	No
12.	If there is erosion, is the leveling pad exposed at the base of the wall?	No
13.	Are the catch basins or the catch basin outlets near the wall blocked?	N/A
14.	Is the roadway drainage system above the wall malfunctioning?	No
15.	Does water at the top of the wall collect behind the concrete coping? Top of Wall?	No

Table 45. Inspection Summary of Sandpoint Wall – Ohio-DOT Procedure (continued)

#	CONDITIONS	Yes, No, N/A
Top of the Wall		
16.	Is there settlement at the top of the wall?	No
17.	Are there any open cracks in the concrete coping (not hairline cracks)? If yes, record the approximate maximum crack width. (see Condition Survey)	N/A
18.	Have the construction joints in the concrete coping opened up? (see Survey)	N/A
19.	Is there a gap larger than 1 inch between the approach slab and the approach pavement? If yes, record the approx. max. gap size.	N/A
20.	At abutments, has the joint between the wall coping and the abutment opened up more than two inches?	N/A
21.	Comments: • Wall is in excellent condition • Corrosion is not evident in the gabions	

Table 46. Inspection Summary Sandpoint Wall – Nebraska-DOR Procedure

Nebraska Department of Transportation Procedure						
DEFECTS						
Wall Tilting	Structural Cracking	Facial Deterioration	Bowing of Wall	Panel Staining	Fabric Exposure	Loss of Backfill
9	n/a	9	9	n/a	9	9
DEFECTS						
Erosion at Front of Wall	Joint Spacing	Condition of V-Ditch	Coping Deterioration	Drainage Runoff	Drainage at Front	AVERAGE
9	n/a	n/a	n/a	9	9	**9**
Comments:						

Table 47. Inspection Summary of Sandpoint Wall – NC-DOT procedure

Category Observations			Percent by Rating				Average Rating	Comments
			1	2	3	4		
FACING	1.	Facial Deterioration	100				1.00	Wire Gabions
	2.	Staining	n/a					
	3.	Damage	100				1.00	None
	4.	Cracking	n/a					
	5.	Joint Alignment	100				1.00	
	6.	Joint Spacing	100				1.00	
	7.	Material Loss	100				1.00	None
MOVEMENT	8.	Deflection/Rotation	100				1.00	
	9.	Bulges/Distortion	100				1.00	
	10.	Settlement	100				1.00	
	11.	Heaving	100				1.00	
DRAINAGE	12.	Erosion	100				1.00	
	13.	Scour	100				1.00	No evidence
	14.	Internal/External Drains	100				1.00	
EXTERIOR	15.	Wall Top Attachment	100				1.00	
	16.	Road/Sidewalk/Shoulder	100				1.00	
	17.	Vegetation	100				1.00	

Table 48. Inspection Summary of Trestle Creek Wall – Ohio-DOT Procedure

#	CONDITIONS	Yes, No, N/A
Joints		
1.	Is sand or gravel coming out of joints or are there piles of sand or gravel at the base of the wall?	**No**
2.	Is sand or gravel visible in the horizontal joints?	**No**
3.	Are the joints wide enough to see the sand, gravel or fabric behind the panels when looking perpendicular to the wall face using a flashlight? If yes, record the approximate maximum joint width, in inches.	**No**
4.	If fabric is visible in the joints, is it torn? IMPORTANT - DO NOT POKE OR CUT THE FABRIC.	**No**
5.	Do the joints have a nonuniform size, or are some joints noticeably wider than others? (see Condition Survey)	**No**
6.	Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum offset.	**No**
7.	Is there vegetation growing in the joints? (see Condition Survey) In the Wall Facing?	**No**
Wall Facing ~~Wire Gabions~~		
8.	Are there cracks in more than two facing panels? (see Condition Survey) If yes, record the approximate number of panels that are cracked.	**No**
9.	Is the face of the wall bowed or bulged?	**No**
~~8.~~	~~Is there corrosion of wire baskets and connections?~~	
~~9.~~	~~Is the rockfill in the baskets spilling out?~~	
Drainage		
10.	Are there any signs of water flow along the base of the wall?	**No**
11.	Is there erosion of the embankment at the base of the wall?	**N/A**
12.	If there is erosion, is the leveling pad exposed at the base of the wall?	**No**
13.	Are the catch basins or the catch basin outlets near the wall blocked?	**N/A**
14.	Is the roadway drainage system above the wall malfunctioning?	**Yes**
15.	Does water at the top of the wall collect behind the concrete coping? Top of Wall?	**No**

Table 48. Inspection Summary of Trestle Creek Wall – Ohio-DOT Procedure (continued)

#	CONDITIONS	Yes, No, N/A
Top of the Wall		
16.	Is there settlement at the top of the wall?	**No**
17.	Are there any open cracks in the concrete coping (not hairline cracks)? If yes, record the approximate maximum crack width. (see Condition Survey)	**N/A**
18.	Have the construction joints in the concrete coping opened up? (see Survey)	**N/A**
19.	Is there a gap larger than 1 inch between the approach slab and the approach pavement? If yes, record the approx. max. gap size.	**N/A**
20.	At abutments, has the joint between the wall coping and the abutment opened up more than two inches?	**N/A**
21.	Comments: • **Wall is in excellent condition**	

Table 49. Inspection Summary Trestle Creek Wall – Nebraska-DOT Procedure

Nebraska Department of Transportation Procedure						
DEFECTS						
Wall Tilting	Structural Cracking	Facial Deterioration	Bowing of Wall	Panel Staining	Fabric Exposure	Loss of Backfill
9	9	9	9	9	9	9
DEFECTS						
Erosion at Front of Wall	Joint Spacing	Condition of V-Ditch	Coping Deterioration	Drainage Runoff	Drainage at Front	AVERAGE
9	9	n/a	n/a	9	9	**9**
Comments:						

Table 50. Inspection Summary of Trestle Creek Wall – NC-DOT Procedure

Category Observations			Percent by Rating				Average Rating	Comments
			1	2	3	4		
FACING	1.	Facial Deterioration	100				1.00	Concrete Blocks
	2.	Staining	100				1.00	
	3.	Damage	100				1.00	None
	4.	Cracking	100				1.00	None noted
	5.	Joint Alignment	100				1.00	
	6.	Joint Spacing	100				1.00	
	7.	Material Loss	100				1.00	None
MOVEMENT	8.	Deflection/Rotation	100				1.00	
	9.	Bulges/Distortion	100				1.00	
	10.	Settlement	100				1.00	
	11.	Heaving	100				1.00	
DRAINAGE	12.	Erosion	100				1.00	
	13.	Scour	100				1.00	No evidence
	14.	Internal/External Drains	100				1.00	
EXTERIOR	15.	Wall Top Attachment	100				1.00	
	16.	Road/Sidewalk/Shoulder	100				1.00	
	17.	Vegetation	100				1.00	

Table 51. Inspection Summary of Western Greer Wall – Ohio-DOT Procedure

#	CONDITIONS	Yes, No, N/A
Joints		
1.	Is sand or gravel coming out of joints or are there piles of sand or gravel at the base of the wall?	**N/A**
2.	Is sand or gravel visible in the horizontal joints?	**N/A**
3.	Are the joints wide enough to see the sand, gravel or fabric behind the panels when looking perpendicular to the wall face using a flashlight? If yes, record the approximate maximum joint width, in inches.	**N/A**
4.	If fabric is visible in the joints, is it torn? IMPORTANT - DO NOT POKE OR CUT THE FABRIC.	**N/A**
5.	Do the joints have a nonuniform size, or are some joints noticeably wider than others? (see Condition Survey)	**N/A**
6.	Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum offset.	**N/A**
7.	Is there vegetation growing in the joints? (see Condition Survey) In the Wall Facing?	**N/A**
~~Wall Facing~~ Wire Gabions		
~~8.~~	~~Are there cracks in more than two facing panels? (see Condition Survey)~~ ~~If yes, record the approximate number of panels that are cracked.~~	
~~9.~~	~~Is the face of the wall bowed or bulged?~~	
8.	Is there corrosion of wire baskets and connections?	**Yes**
9.	Is the rockfill in the baskets spilling out?	**No**
Drainage		
10.	Are there any signs of water flow along the base of the wall?	**Yes**
11.	Is there erosion of the embankment at the base of the wall?	**No**
12.	If there is erosion, is the leveling pad exposed at the base of the wall?	**No**
13.	Are the catch basins or the catch basin outlets near the wall blocked?	**No**
14.	Is the roadway drainage system above the wall malfunctioning?	**No**
15.	Does water at the top of the wall collect behind the concrete coping? Top of Wall?	**No**

Table 51. Inspection Summary of Western Greer Wall – Ohio-DOT Procedure (continued)

#	CONDITIONS	Yes, No, N/A
Top of the Wall		
16.	Is there settlement at the top of the wall?	**No**
17.	Are there any open cracks in the concrete coping (not hairline cracks)? If yes, record the approximate maximum crack width. (see Condition Survey)	**N/A**
18.	Have the construction joints in the concrete coping opened up? (see Survey)	**N/A**
19.	Is there a gap larger than 1 inch between the approach slab and the approach pavement? If yes, record the approx. max. gap size.	**N/A**
20.	At abutments, has the joint between the wall coping and the abutment opened up more than two inches?	**N/A**
21.	Comments: • **Wall is in excellent condition** • **Corrosion is not evident in the gabions**	

Table 52. Inspection Summary Western Greer Wall – Nebraska-DOT Procedure

Nebraska Department of Roads Procedure						
DEFECTS						
Wall Tilting	Structural Cracking	Facial Deterioration	Bowing of Wall	Panel Staining	Fabric Exposure	Loss of Backfill
9	n/a	9	9	n/a	9	9
DEFECTS						
Erosion at Front of Wall	Joint Spacing	Condition of V-Ditch	Coping Deterioration	Drainage Runoff	Drainage at Front	AVERAGE
9	n/a	n/a	n/a	9	9	**9**
Comments:						

Table 53. Inspection Summary of Western Greer Wall – NC-DOT Procedure

Category Observations			Percent by Rating				Average Rating	Comments
			1	2	3	4		
FACING	1.	Facial Deterioration	100				1.00	Wire Gabions
	2.	Staining	n/a					
	3.	Damage	100				1.00	None
	4.	Cracking	n/a					
	5.	Joint Alignment	100				1.00	
	6.	Joint Spacing	100				1.00	
	7.	Material Loss	100				1.00	None
MOVEMENT	8.	Deflection/Rotation	100				1.00	
	9.	Bulges/Distortion	100				1.00	
	10.	Settlement	100				1.00	
	11.	Heaving	100				1.00	
DRAINAGE	12.	Erosion	100				1.00	
	13.	Scour	100				1.00	No evidence
	14.	Internal/External Drains	100				1.00	
EXTERIOR	15.	Wall Top Attachment	100				1.00	
	16.	Road/Sidewalk/Shoulder	90	5	5		1.15	Some erosion of steep slope between wall and highway
	17.	Vegetation	100				1.00	

MSE Wall, Kamiah Bridge, US-12

An MSE wall on the north side of the eastern abutment of Kamiah Bridge supports the WB lane of US-12. A boat ramp is located on the north side of the wall, which is 280 feet long and has a maximum height of about 16 feet. Cruciform-shaped concrete panels support the reinforced fill, as shown in the photo in Figure 38. This photograph was found on a website by “chance” and added to the inventory. Unfortunately, as the location of this MSE wall was not known during the visit to Kamiah Bridge, its condition was not surveyed for this project. The photograph reveals some staining and the concrete panels do not appear to show any deterioration. However, its condition can only be confirmed by an actual site inspection.

Figure 38. North MSE Wall at Eastern Abutment of Kamiah Bridge, MP 66.69, WB US-12

Appendix C
Special Inspections Performed by BSU

Introduction

To date, effective inspection of MSE walls is usually conducted by visual observation of conditions outside surface of the MSE wall. Exterior panel/coping measurements which are used to evaluate wall behavior include tilt/bulge, crack width/length, differential settlement, corner spall dimensions, concrete deterioration, shotcrete voids/drummy areas. In addition, measurements are also made on surface erosion width/depth, overlying pavement crack orientation/width and roadway slab/wall separations. Effective nondestructive evaluation methods have yet to be applied in evaluating the quality of the concrete panels supporting the soil backfill between the MSE wall reinforcement. This appendix is dedicated to the application of two non-destructive testing (NDT) methods (Infrared Thermography and Ultrasonic) in the MSE wall assessment process. The work was performed by BSU staff on MSE walls as well as concrete slabs that support soils in front and along the sides of bridge abutments and slopes. Both NDT methods as well as the test results are discussed in the following sections of this appendix.

Thermography

Thermography has been employed for detection of surface defects and to locate possible shallow sub-surface delamination. It also can be used to determine the location of defects in and behind the wall.

This method involves measurement of differential thermal gradients on a concrete surface. Infrared thermography (IRT) is based on processing infrared radiation, which is a form of electromagnetic radiation not visible to human eye. The processed radiation emitted from any object with a temperature above absolute zero are converted into the electronic signals and subsequently into the temperature readings.[42] The emitted electromagnetic radiation is a function of the surface temperature of the specimen. A higher temperature will produce a greater intensity of emission from the surface.

Surface temperature gradient is a major factor in thermography. Different phenomenon in the form of surface and sub-surface anomalies can cause significant temperature gradients on the face of the concrete structures, which can be detected using thermal cameras.

For surface crack assessment, images are collected during the heating and cooling cycles on concrete surfaces, i.e. during sunrise or around sunset. An IR camera can capture temperature gradients on the concrete surface at certain time windows during the heating or cooling cycles. Surface cracks have higher temperatures because the sunlight bounces back and forth on the surfaces inside of the crack (see Figure 39). The deeper and wider the crack, the higher the temperature registered on the surface in the thermal image.

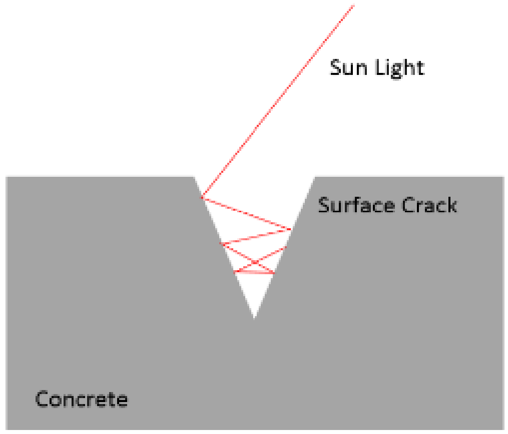


Figure 39. Surface temperature gradient on concrete pavements caused by surface cracks

For sub-surface defect assessment, images are collected in the same fashion as for surface cracks. When exposed to heat, delaminated areas of concrete will interrupt the heat transfer because of lower thermal conductivity compared with the adjacent concrete mass; therefore, spots located above the delamination will have higher temperatures than the adjacent areas of sound concrete (see Figure 40). It also helps to heat the surface using an artificial heating source such as halogen lamps.

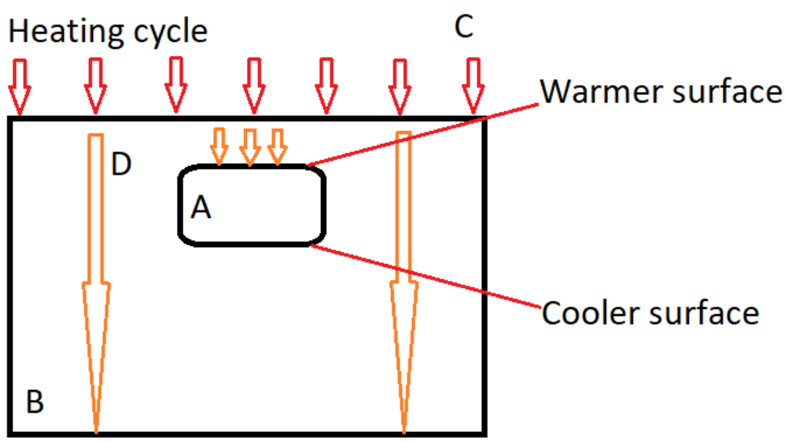


Figure 40. Surface temperature gradient on concrete pavements caused by sub-surface defects

The BSU team has developed an automated thermal imaging system to collect field data and process images in real-time to detect surface and near-surface defects. The IRT system can be used to acquire both thermal and visual images and later are aligned on each other. In order to locate delaminated areas on the target by capturing the temperature gradient on the concrete surface, the raw collected images are processed using a processing algorithm developed at BSU. The surface and near-surface defects can be identified from the processed images. This method may expedite the inspection procedure and possesses the ability to automate the inspection process.[42]

Results of Thermography Studies

In this study, two potential subsurface anomalies have been identified using thermal images on concrete bridge aprons.

In the first case, the thermal and visual images were taken on the surface of concrete slabs in front of a bridge (Site D3-2) in Garden City, Idaho (see Figure 41). A sub-surface anomaly, a possibly a void, will act as an insulator and does not let the heat to transfer to the lower parts of the concrete slab. This is because the anomaly has a lower thermal conductivity compared with an intact concrete section. Therefore, heat accumulates on top of the anomaly and temperature of the surface is elevated compared with the adjacent area of intact concrete. This behavior allows detection of anomalies within 1 inch of the concrete surface using infrared thermography.

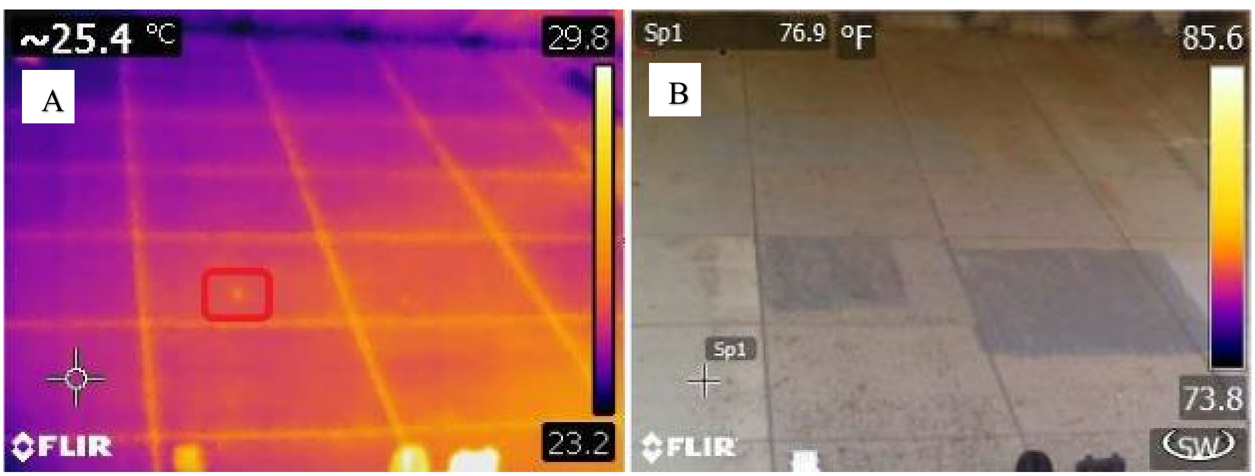


Figure 41. Site name: D3-2, Type of image: A: Thermal image, B: Visual image

In the visual image of Figure 41B, two areas of the slab have been coated. Even though no anomaly is visible on the surface, there is a 2-degree Fahrenheit difference between the area on top of the anomaly shown in the red box in the thermal image (Figure 41A) and the surrounding area. The results indicate the presence of a shallow anomaly. This area was also investigated using an ultrasonic testing device. The ultrasonic test results also indicated the presence of an anomaly. Unfortunately, there was no time, sufficient resources, or permission to core the concrete to verify and determine the exact nature of the suspected anomaly.

The images in Figure 41 were taken during the day. However, it is better practice to take the same images during the sunrise or sunset hours where there is a greater temperature contrast between the surface above the anomaly and the adjacent concrete.[43] Moreover, the surface of the slab will have a greater intensity with respect to the temperature gradient in these certain time windows during the heating (in the morning while the sun is rising) or cooling (in the afternoon while the sun is setting) periods. Within these heating/cooling windows, a greater number of anomalies should be visible in the IR thermal images. Humidity and wind can have considerable negative effects on the temperature contrast in the concrete surface and thus on the sensitivity of the thermal camera measurements.[44]

At the time of our site visit, there was almost no wind and the relative humidity was low, close to 20%. Thus, the conditions were favorable to carry out the thermography investigation.

In the second case, the thermal and visual images of concrete slabs were taken at another site along a side road (D3-1) in Boise (see Figure 42). The thermal image in Figure 42 indicates a potential larger than in the Garden City site.

Figure 42. Site name: D3-1, Type of image: Thermal image, B: Visual image, C: Processed image

In the processed image in Figure 42C, there is a 5-degree Fahrenheit temperature difference between the surfaces above a potential anomaly and the adjacent concrete. Temperature threshold of 106 degrees of Fahrenheit is used to construct the processed image. No visible surface deterioration that could cause a temperature gradient, such as leaching, was detected on the surface of these slabs.

Recommended procedures and practices for use of IR Thermal Imaging

(a) IR thermal camera is recommended for quick screening of surface and near surface defects at large scale.

(b) To ensure sensitivity and reliability, IRT method is recommended to be performed during the heating and cooling periods of the day.

(c) Thermal image segmentation code should be used in further data processing to identify the approximate location of near-surface defects.

Ultrasonic Testing

The second NDT method used in this investigation was ultrasonic imaging evaluation. Because of the speed variance of sound passing in different materials, ultrasonic testing may be useful in evaluating the service condition of MSE walls. Moreover, ultrasonic data can be interpreted by signal processing methods to nondestructively detect subsurface conditions, such as honeycombing or air voids, the thickness of the panel and location of the back of the concrete slabs and walls.

Data Acquired from Ultrasonic Testing

Ultrasonic testing has been employed at two of the study sites to explore the possibility of using such technology for assessment of sub-surface defects along with locating the reinforcement inside the concrete and the measuring wall thickness.

Ultrasonic testing (UT) uses high frequency (greater than 20,000 Hz) sound waves to estimate material properties and potential defects. Moreover, it is used to gather a variety of information on concrete structures such as:

1. Concrete structure profile including variations in the thickness, rebar reinforcement and locations of pipe and tendon ducts.
2. Assessment of structural integrity and localized defects and voids, cavities and loose honeycomb areas in concrete.
3. Provide information on the strength and uniformity of concrete.

A wide variety of defects can be detected and measured using Ultrasonic methods. The equipment can be used to detect anomalies to a depth of around 8 feet depending on concrete quality. The ultrasonic pulse echo (UPE) technology extends ultrasonic pulse velocity (UPV) applications to objects where access is restricted to a single side. Weather conditions and time window have minimum effects on measurement results.

The Pundit Array Transducer, which has 8 channels, was used in this investigation. One channel transmits, and the other seven channels receive the echoes. Each channel transmits in turn, as shown in Figure 43.

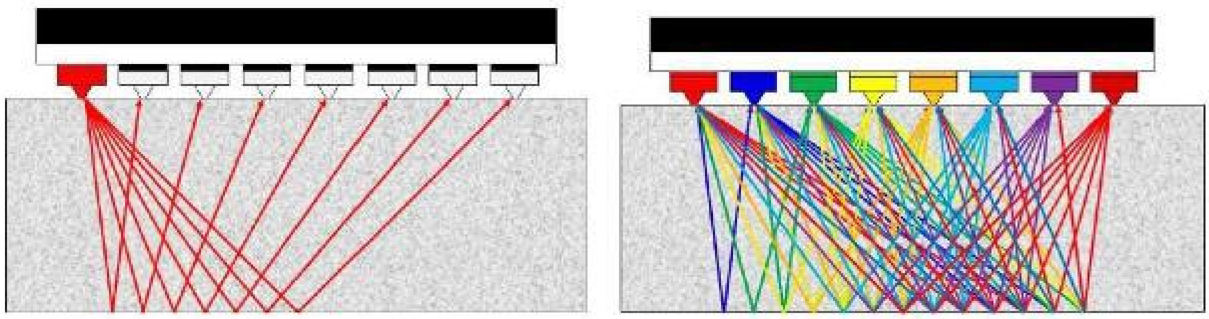


Figure 43. Sequence of sound propagation in Pundit Array Transducer channels

The individual A-Scans which are plotted using the receiving echoes are used to create the B-scan, which is displayed in real time on the output screen. The A-Scan is a data presentation method where signal amplitude is plotted along the y-axis against time on the x-axis. The horizontal distance between any two signals represents the material distance between the two conditions generating the signals. In a linear system, the vertical excursion is proportional to the amplitude of the signal. The B-Scan is a data presentation method applied to pulse echo techniques. It produces a two-dimensional view of a cross-sectional plane through the test object from which the individual A-scans have been collected. The horizontal sweep is proportional to the distance along the test object whereas the vertical sweep is proportional to depth or distance, showing the front and back surfaces of the concrete and any discontinuities in-between. The B-scan (real time) cursor shows depth or distance and horizontal position (see Figure 44). The width of the B-scan corresponds to the width of the aperture, i.e.,
width = (number of channels-1) x 1.2 in.

The readings of the device are in either imperial units or SI units. Therefore, the distances are calculated in meters, feet and/or inches.

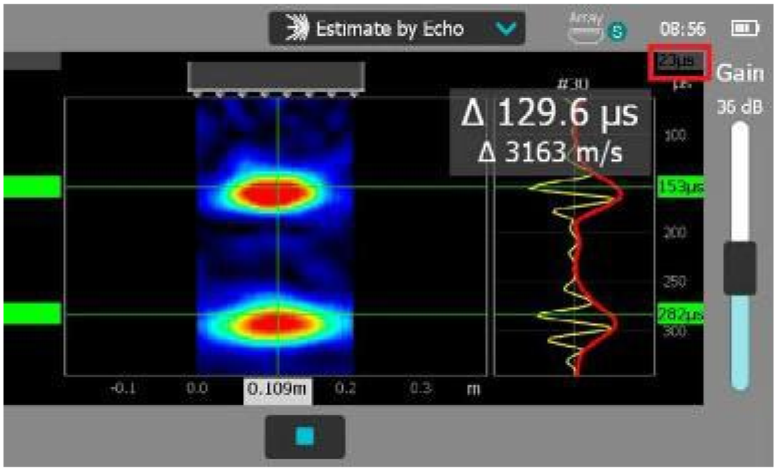


Figure 44. A and B-scans generated in UT data acquisition

The device used to study delamination in the current MSE wall project is the wireless Pundit Live Array Pro tomography scanner. It is connected with an iOS app to an Apple® iPad. The devise comes with Artificial Intelligence (A.I.), user support and 3D imaging capabilities.(45) Figures 45A and 45B show data collection on a concrete bridge apron and a retaining wall.

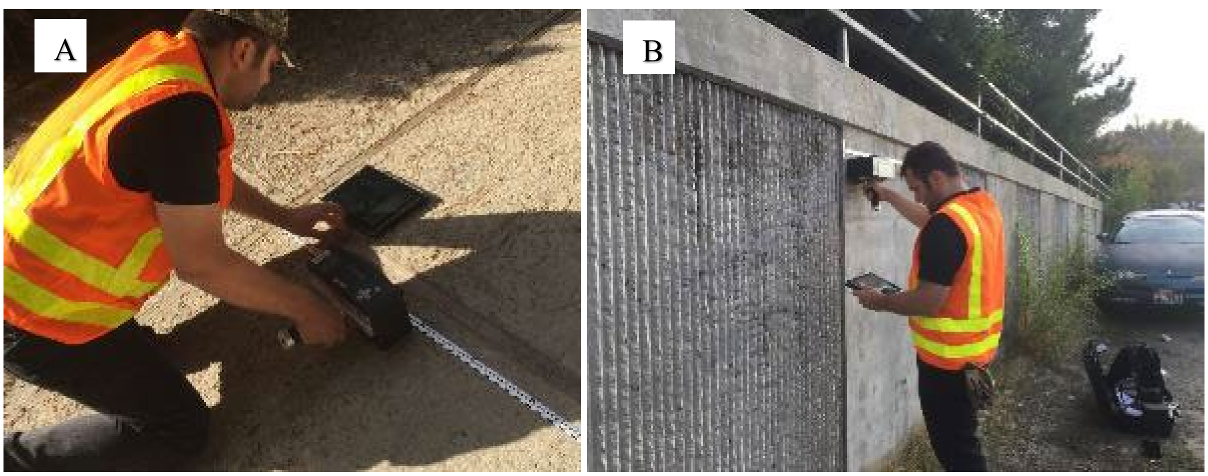


Figure 45. Ultrasound measurements taken at A: Site D3-2, B: Site D3-3

The latest A.I. supported pattern recognition technologies help speed the process of inspection and defect recognition using ultrasonic techniques. The smart positioning system uses a sensitive, fast CMOS imaging sensor and pattern recognition technologies to detect the position of an anomaly in real-time. Therefore, any position or section that is not scanned will be shown as blank and can be scanned later to obtain a complete inspection of the slab or wall. This approach allows accurate stitching of multiple images because of the latest A.I. supported pattern recognition technologies.

Both A-scan and B-scan are used to identify and locate potential delaminations in concrete. The A-scan is used to detect the approximate location of an anomaly and the thickness of the slab with respect to the surface of the concrete. In the B-scan, the corresponding areas in red are indicators of a potential delaminations or voids inside the wall and the inner surface of the slab.

The results of the BSU ultrasonic study are illustrated in Figure 46. The measurements were made at Site D3-2 in an area of the concrete apron where a potential delamination was first identified using infrared thermography. The y-axis in Figure 46 is the distance inside the face of the concrete (0.00 m in the plot) whereas the x-axis is the lateral distance along the slab.

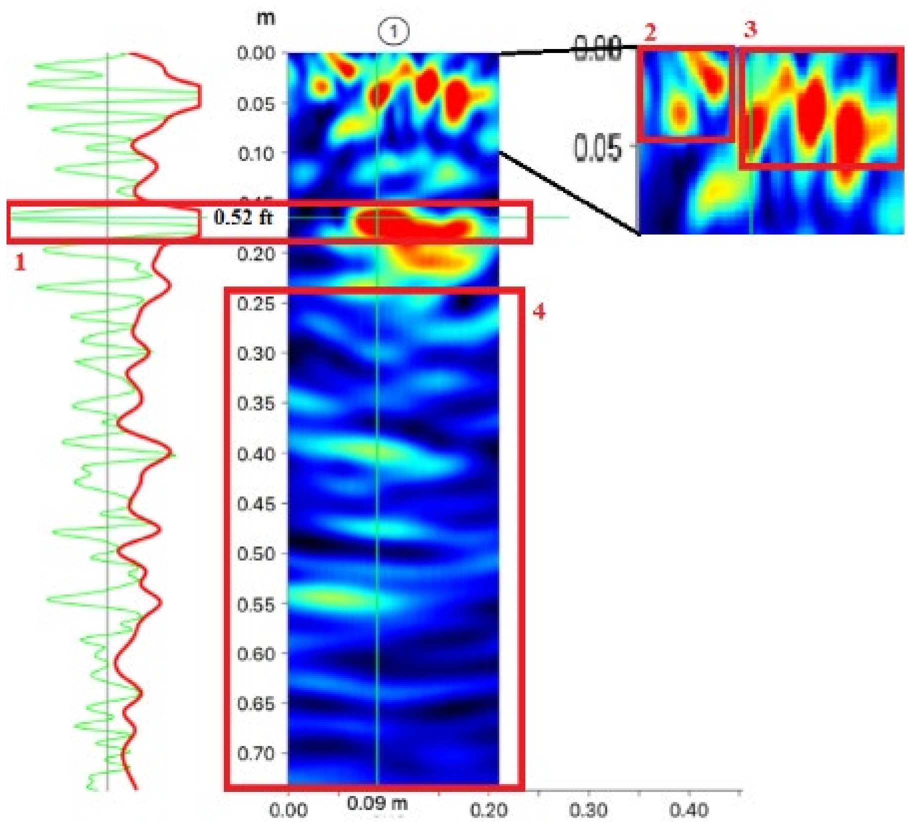


Figure 46. A-scan (left) and B-scan (right) of potential delaminated area in Site D3-2 concrete slab

The first peak in the A-scan plot is an indicator of the inward distance of a potential delamination with respect to the surface of the slab. The anomaly is displayed in the upper red area of the B-scan. Using the ultrasonic scan, the delamination identified first in the thermal image (Figure 41) is estimated to be 0.01 (0.4 inch) to 0.03 meters (1.1 inches) below the concrete surface (see Box 2). It also appears that there are more than one defect present in deeper sections of the wall (see Box 3). The deepest anomaly is located approximately 0.05 meter or around 2 inches beneath the surface of the wall.

The back of the slab is estimated to be 0.16 meters (0.52 ft or 6.3 inches) from the front of the concrete (Box 1). Any readings greater than 0.16 m, which is the approximate thickness of the slab, should be ignored or discarded. Moreover, all the indicators in Box 4 are the echoes of the ultrasonic pulses that were transmitted into the slab. Depending on strength of the ultrasonic wave and the way in which it penetrates the concrete, one or two echoes may be recorded beyond the thickness of the slab. These echoes are the same representations as the thickness of the concrete and have no bearing on the condition of the backfill or reinforcement located behind the interior face of the slab.

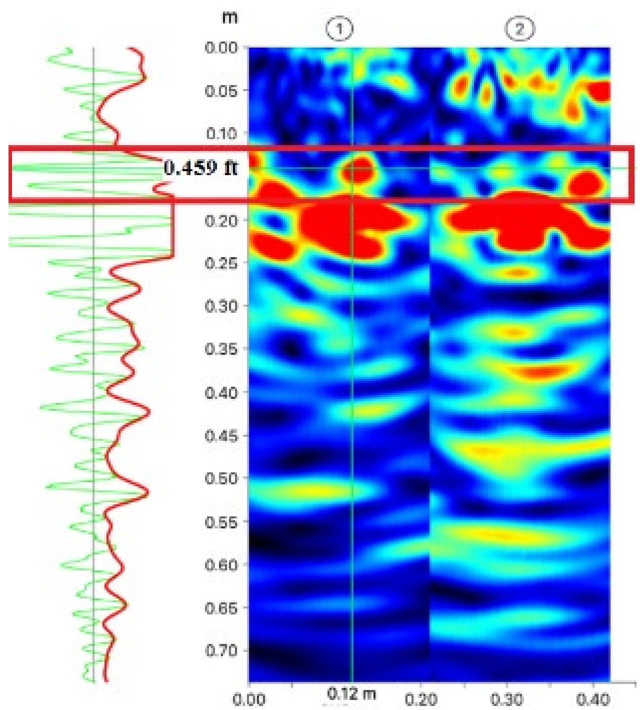


Figure 47. A-scan (left) and B-scan (right) of potential delaminated area in Wall D3-3

Another set of ultrasonic measurements were made along wall D3-3. The results are shown in Figure 47. This plot is a stitched view of the wall from two adjacent readings covering 0.4 meters along the wall alignment. The measurements took less than 10 seconds to complete the readings. Based on the ultrasound readings, the estimated thickness of the retaining wall is 0.14 meter (0.459 ft or 5.5 in.). There is no clear indication of a potential defect in the first set of readings on the wall. However, in the second reading, a potential delamination is visible. The defect is approximately 0.04 meters (1.6 in.)

inside the surface of the wall. The scattered nature of the readings is an index of multiple defects on the same horizon. A schematic drawing of an MSE wall is shown in Figure 48. The ultrasonic survey does not provide any information about the presence of defects or reinforcement in the backfill.

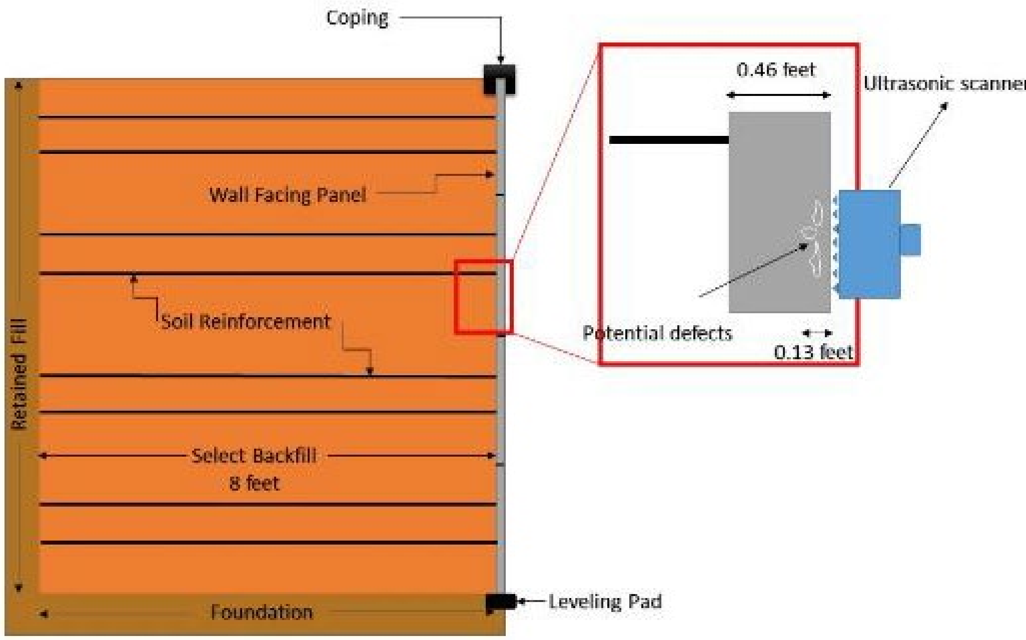


Figure 48. Schematic of MSE wall and results of the Ultrasonic scan

Based on general design criteria of MSE walls [1, 46,47], the typical thickness of an MSE wall panel is 5.5 in. (0.456 feet). This value is very close to the thickness of the wall determined at Site 3D-3 based on the ultrasonic readings (5.5 in. or 0.46 feet). This relationship is an indicator of the sensitivity of the ultrasonic tests in determining the thickness of MSE wall panels. In addition, the ultrasonic tests indicate the presence of defects approximately 1.6 in. (0.13 feet) beneath the outside surface of the wall. Verification of the presence and distance of the defects should be confirmed by either destructive tests (such as coring), other nondestructive tests such as a hammering test and/or large-scale laboratory tests on concrete slabs cast with voids.

Recommended procedures and practice for Ultrasonic Testing

(a) Ultrasonic Testing (UT) is a contact-based, in-depth, defect inspection method for concrete slabs and walls. It is recommended for detecting anomalies in concrete slabs and walls after visual inspection of exterior conditions.

(b) A smooth surface of the target is preferred to ensure the data quality and reduce the extra noise.

(c) Basic knowledge of ultrasound beam formation and propagation in heterogeneous solids is required to interpret the UT data.

(d) All provisions related to safety issues should be considered and safety requirements met when inspecting MSE walls and abutment slabs.

Summary and Conclusions

Visual inspection has been performed on 5 MSE walls in Idaho Transportation Department Districts 3 and 4. Four walls are located in District 3 and one wall in District 4. All the information including visual images of walls and their anomalies have been collected and documented in separate folders. BSU has used inspection procedures based on Nebraska DOT rating system. Using the Nebraska-DOT MSE wall rating system, all 5 MSE walls are in good condition.

Nondestructive testing (NDT) was investigated as a tool to detect and locate defects in concrete slabs and walls. Two different methods were used in this investigation: Infrared thermography (IRT) and ultrasonic testing (UT). One of the strengths of IRT is that it can be used to cover large areas of the wall in a fast and efficient way. In addition, the technique has the potential to explore for delaminations or voids close to the concrete surface. UT is a reliable method to determine the thickness of concrete slabs and walls and to locate potential defects inside the wall. Although not demonstrated in this study, UT may be used to measure the location of the reinforcement and steel rebar in the concrete. All the selected MSE walls and concrete aprons in the two districts have been investigate using thermography. UT was used to inspect two walls (D3-2 and D3-3) in District 3. Further research is recommended to verify the IRT and UT testing methods in detecting delaminations or voids in concrete slabs and panels.

Appendix D
Details of Inspections Performed by ISU

Walls Inspected:

<u>District 5</u>

1. E. Gould Street Overpass, Wall 4
2. E. Gould Street Overpass, Wall 5
3. US-30, Topaz Bridge
4. US-30, Ledger Creek Bridge

<u>District 6</u>

1. US-20, St Leon Exit
2. SH-33 Exit, US-20
3. SH-32, Bitch Creek Bridge

District 5: Gould Street Overpass: Wall 4, Pocatello, Idaho

Table 54. Condition Survey – Gould Street Overpass, Wall 4

E. GOULD STREET OVERPASS	42.874853	EL 4476 FT		9-Jul-18
SOUTH WALL/EAST ABUTMENT WALL 4	112.459225	13:45 TO 15:23		
STATION	CONDITION	HEIGHT ABOVE GROUND	DIMENSION	
			LATERAL	VERTICAL
0+00.0	West End South Wall			
0+21.7	Broken Corner	Below Coping		
0+65.2	Comp Spall	Below Coping	12 in.	
0+70.7	Comp Spall	Below Coping	4 in.	
0+80.0	Broken Corner	82 in.	4.5 in.	2 in.
0+86.7	Comp Spall	Below Coping	11 in.	
0+91.3	Broken Corner	112 in.	2 in.	3 in.
1+01.3	Broken Corner	113 in.	1.5 in.	1 in.
1+10.6	Broken Corner	71 in.	3 in.	4 in.
1+19.6	Spall	80 in.	7 in.	3 in.
1+50.7	Comp Spall	6 in.	2.5 in.	3 in.
1+55.7	Comp Spall	72 in.	10.5 in.	4 in.
1+58.7	Comp Spall	81.5 in.	16 in.	8.5 in.
1+66.1	Comp Spall	81.5 in.	26 in.	6.5 in.
1+66.1	Broken Corner	81.5 in.	Foam in Panel Joint	
1+69.0	Comp Spall	76 in.	17.5 in.	6 in.
2+23.1	Broken Corner	42 in.	6 in.	1 in.
2+27.7	Broken Corner	4 in.	6.5 in.	6 in.
2+53.1	Broken Corner	33 in.	6 in.	7.5 in.
2+53.1	Comp Spall	13 in.	8 in.	3 in.
2+76.8	Comp Spall	14 in.	14 in.	16 in.
2+88.3	Broken Corner	5.5 in.	7 in.	5 in.
3+10.3	Comp Spall	16 in.	14 in.	16 in.
3+18.9	Comp Spall	12.5 in.	17 in.	12.5 in.
3+38	End of Survey			

Table 54. Condition Survey – Gould Street Overpass, Wall 4 (continued)

GOULD STREET OVERPASS WALL 4				
PANEL CRACKS				
STATION	ORIENTATION	HEIGHT	OPEN	WIDTH
1+66.1	Diagonal			HL
3+10.2	Diagonal			HL
MSE BACKFILL LOSS	SOIL TYPE	HEIGHT	OPEN	
STATION	Backfill	12 in.		
2+28.1	Fine Sand	12 in.		
2+33.3	Sand and Gravel	14 in.	7/16 in.	
2+37.9	Sand and Gravel	15 in.	13/16 in.	
MSE BACKFILL LOSS AT ABUTMENT	Soil Type: Fine Sand/Silt	HEIGHT 13 ft	WIDTH 7 to 12 in.	DEPTH 1/2 -1 in.
VEGETATION				
STATION				
3+35.7				

Figure 49. Gould Street Overpass, Wall 4 (Google Earth)

Figure 50. Photo of Gould Street Overpass, Wall 4, taken with sUAV

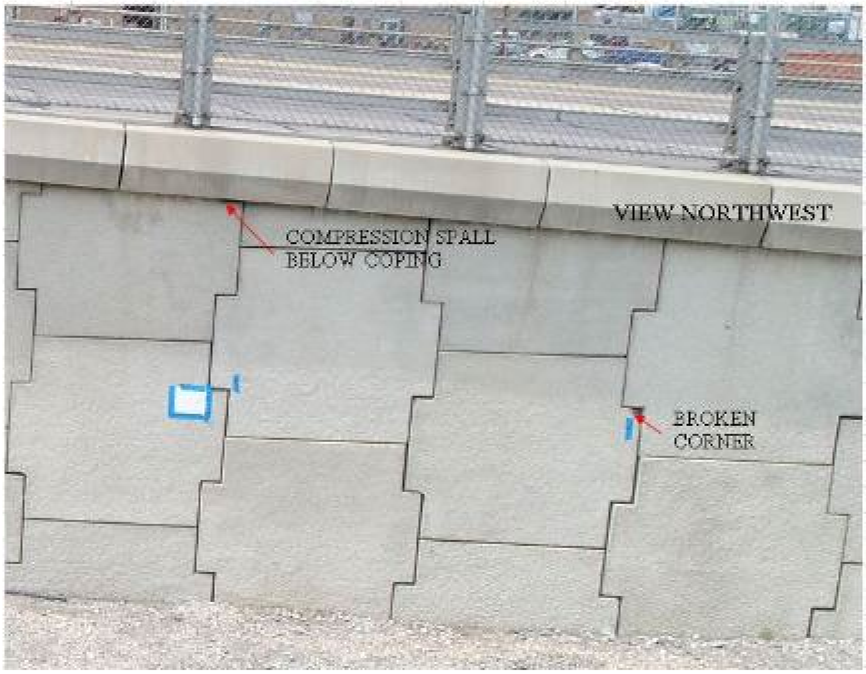


Figure 51. Broken Corner at STA 01+10, Gould Street Overpass, Wall 4

Figure 52. Backfill Loss, Gould Street Overpass, Wall 4

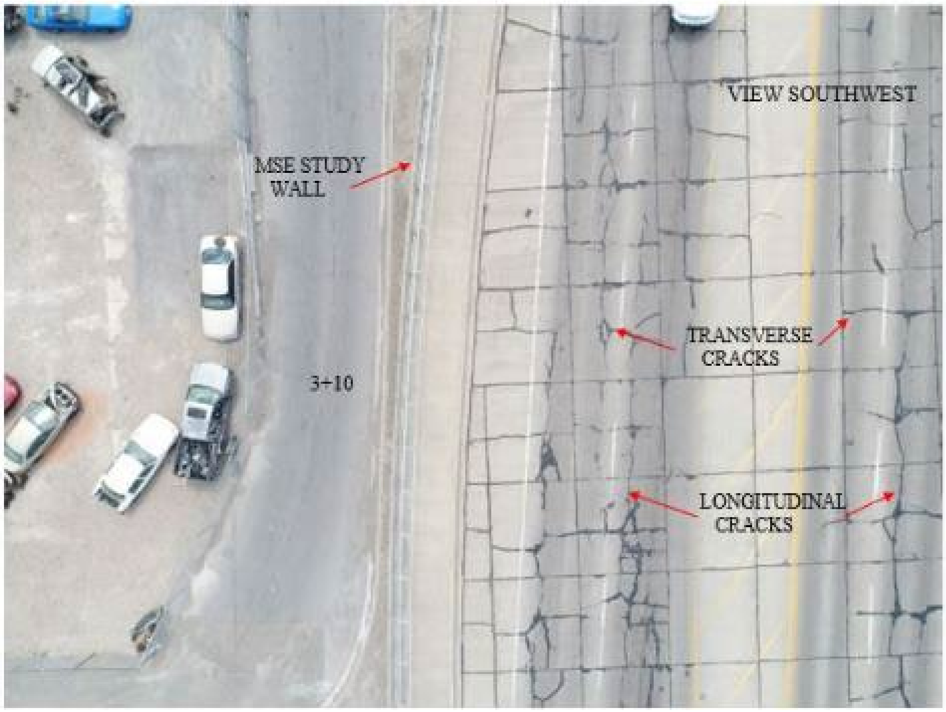


Figure 53. sUAV Photo of Pavement Cracks, Gould Street Overpass, Wall 4

Table 55. Inspection Summary of E. Gould Street Overpass, Wall 4 – Ohio DOT Procedure

#	CONDITIONS	Yes, No, N/A
JOINTS		
1.	Is sand or gravel coming out of joints or are there piles of sand or gravel at the base of the wall?	Yes
2.	Is sand or gravel visible in the horizontal joints?	Yes
3.	Are the joints wide enough to see the sand, gravel or fabric behind the panels when looking perpendicular to the wall face using a flashlight? If yes, record the approximate maximum joint width, in inches.	No
4.	If fabric is visible in the joints, is it torn? IMPORTANT - DO NOT POKE OR CUT THE FABRIC.	N/A
5.	Do the joints have a nonuniform size, or are some joints noticeably wider than others?	No
6.	Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum offset.	No
7.	Is there vegetation growing in the joints? In the Wall Facing?	Yes Sta 3+37.5
WALL FACING		
8.	Are there cracks in more than two facing panels? If yes, record the approximate number of panels that are cracked.	Yes 2
9.	Is the face of the wall bowed or bulged?	No
DRAINAGE		
10.	Are there any signs of water flow along the base of the wall?	No
11.	Is there erosion of the embankment at the base of the wall?	No
12.	If there is erosion, is the leveling pad exposed at the base of the wall?	No
13.	Are the catch basins or the catch basin outlets near the wall blocked?	Partial
14.	Is the roadway drainage system above the wall malfunctioning? (see Survey)	Yes at Abutment
15.	Does water at the top of the wall collect behind the concrete coping? Top of Wall?	No

Table 55. Inspection Summary of E. Gould Street Overpass, Wall 4 – Ohio DOT Procedure (continued)

#	CONDITIONS	Yes, No, N/A
TOP OF THE WALL		
16.	Is there settlement at the top of the wall?	No
17.	Are there any open cracks in the concrete coping (not hairline cracks)? If yes, record the approximate maximum crack width.	No
18.	Have the construction joints in the concrete coping opened up?	No
19.	Is there a gap larger than 1 inch between the approach slab and the approach pavement? If yes, record the approx. max. gap size.	Sealed
20.	At abutments, has the joint between the wall coping and the abutment opened up more than two inches?	No
21.	Comments: - Concerns: see Condition Survey - piping of sand and silt along the face of the bridge abutment - one location - Other Observations/Measurements: - broken corners: 7 MSE Wall panels	

District 5: E. Gould Street Overpass: Wall 5, Pocatello, Idaho

Table 56. Condition Survey – Gould Street Overpass, Wall 5

GOULD STREET OVERPASS	42.873253	EL 4483 FT		10-Jul-19
NORTH WALL/WEST ABUTMENT, WALL 5	112.462264	9:12 TO 10:40 AM		
STATION	CONDITION	HEIGHT ABOVE GROUND	DIMENSION LATERAL	DIMENSION VERTICAL
0+00	East End North Wall			
0+01.3	Broken Corner	108 in.	4 in.	5 in.
0+02.0	Broken Corner	4 in.	6.5 in.	7 in.
0+02.0	Broken Corner	125 in.	6 in.	7.5 in.
0+05.1	Comp Spall	123 in.	17.5 in.	3 in.
0+06.1	Comp Spall	36 in.	3 in.	6 in.
0+06.1	Broken Corner	140 in.	2 in.	2.5 in.
0+06.1	Broken Corner	156 in.	2 in.	2 in.
0+07.2	Comp Spall	94 in.	11 in.	4.5 in.
0+11.1	Broken Corner	94 in.	3 in.	4 in.
0+11.8	Broken Corner	156 in.	4.5 in.	4 in.
0+12.1	Broken Corner	Below Coping		
0+15.1	Broken Corner	Below Coping		
0+26.1	Broken Corner	152 in.	2 in.	2.5 in.
0+45.1	Broken Corner	161 in.	7 in.	4 in.
0+49.5	Comp Spall	161 in.	11 in.	2 in.
0+79.7	Comp Spall	130 in.	13 in.	3 in.
0+96.3	Broken Corner	4 in.	9.5 in.	2 in.
1+38	End of Survey			
PANEL CRACK				
STATION	ORIENTATION	HEIGHT	LENGTH	WIDTH
0+02	DIAGONAL			
SEVERE WALL DAMAGE AT ABUTMENT				
MSE BACKFILL LOSS				
STATION	BACKFILL			
1+01.1	Fine Sand			
1+16.6	Fine Sand			

Figure 54. Gould Street Overpass, Wall 5 (Google Earth)

Figure 55. Photo of Gould Street Overpass, Wall 5, from the Southeast

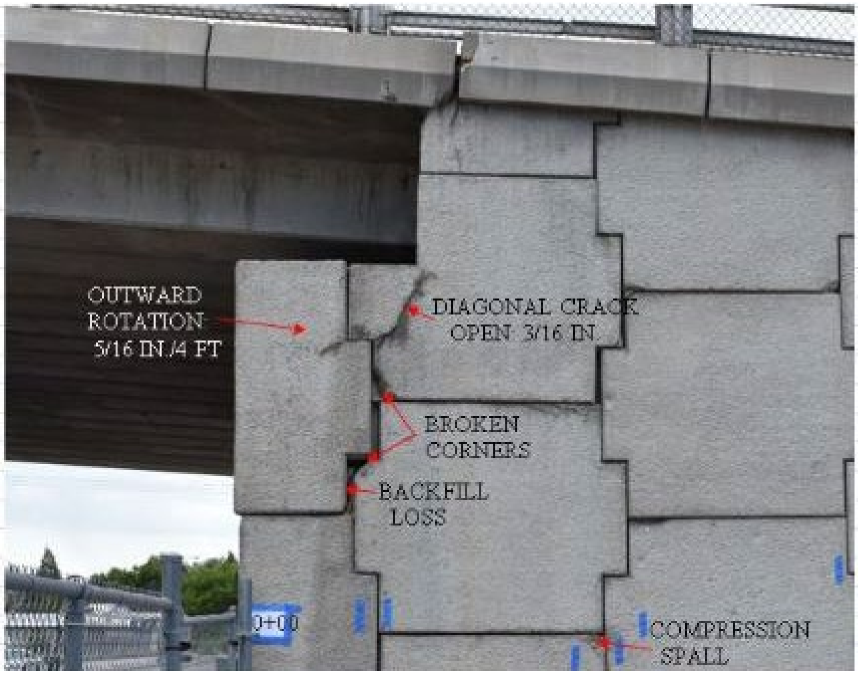


Figure 56. Photo of Gould Street Overpass, Wall 5, taken by sUAV

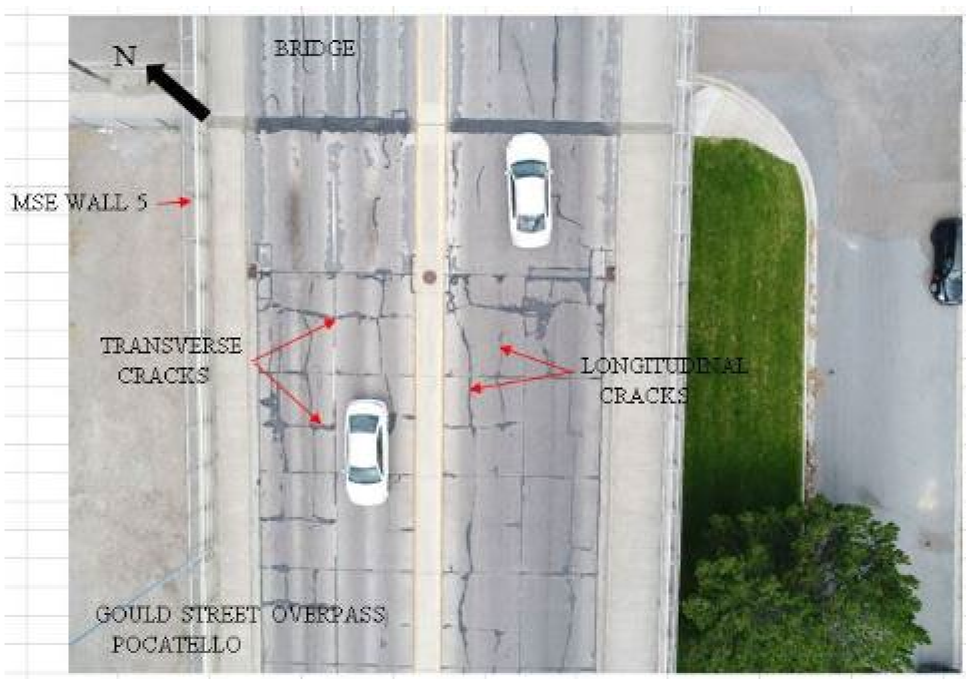


Figure 57. sUAV Photo of Pavement Cracks, Gould Street Overpass, Wall 5

Table 57. Inspection Summary of E. Gould St. Overpass, Wall 5 – Ohio DOT Procedure

#	CONDITIONS	Yes, No, N/A
JOINTS		
1.	Is sand or gravel coming out of joints or are there piles of sand or gravel at the base of the wall?	Yes
2.	Is sand or gravel visible in the horizontal joints?	Yes
3.	Are the joints wide enough to see the sand, gravel or fabric behind the panels when looking perpendicular to the wall face using a flashlight? If yes, record the approximate maximum joint width, in inches.	No
4.	If fabric is visible in the joints, is it torn? IMPORTANT - DO NOT POKE OR CUT THE FABRIC.	N/A
5.	Do the joints have a nonuniform size, or are some joints noticeably wider than others?	Yes at Abutment
6.	Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum offset.	Yes 2-1/4 in.
7.	Is there vegetation growing in the joints? In the Wall Facing?	No
WALL FACING		
8.	Are there cracks in more than two facing panels? If yes, record the approximate number of panels that are cracked.	No
9.	Is the face of the wall bowed or bulged? Rotated?	Yes At Abutment
DRAINAGE		
10.	Are there any signs of water flow along the base of the wall?	No
11.	Is there erosion of the embankment at the base of the wall?	No
12.	If there is erosion, is the leveling pad exposed at the base of the wall?	No
13.	Are the catch basins or the catch basin outlets near the wall blocked? (see Survey)	Partial
14.	Is the roadway drainage system above the wall malfunctioning?	No
15.	Does water at the top of the wall collect behind the concrete coping? Top of Wall?	No

Table 57. Inspection Summary of E. Gould St. Overpass, Wall 5 – Ohio DOT Procedure (continued)

#	CONDITIONS	Yes, No, N/A
TOP OF THE WALL		
16.	Is there settlement at the top of the wall?	Yes
17.	Are there any open cracks in the concrete coping (not hairline cracks)? If yes, record the approximate maximum crack width.	No
18.	Have the construction joints in the concrete coping opened up?	Yes
19.	Is there a gap larger than 1 inch between the approach slab and the approach pavement? If yes, record the approx. max. gap size.	No
20.	At abutments, has the joint between the wall coping and the abutment opened up more than two inches?	Yes
21.	Comments: see Condition Survey - Concerns: - severe damage at abutment - lateral displacement and rigid body rotation - Other Observations/Measurements - numerous broken corners and compression spalls	

District 5: Topaz Bridge, US-30

Table 58. Condition Survey – Topaz Bridge

US-30/TOPAZ BRIDGE	42.623844	EL 4931 FT		12-Jul-19	
SHOTCRETE MSE WALL, SOUTH WALL, WEST ABUTMENT	112.120425	11:10 TO 15:50			
STATION	CONDITION	BASE OF CRACK ABOVE GROUND	LENGTH	WIDTH	
0+00	East End South Wall				
0+15.6	Vertical Crack	10 in.	43 in.	HL to 1/32 in.	
0+40.6	Vertical Crack	3 in.	50 in.	HL	
0+45.9	Vertical Crack	4 in.	49 in.	HL to 1/32 in.	
0+54.1	Vertical Crack	5 in.	48 in.	HL to 1/32 in.	
0+58.8	Vertical Crack	3 in.	50 in.	HL to 1/32 in.	
0+65	Vertical Crack	33 in.	30 in.	HL	
0+70.1	Vertical Crack	11 in.	40 in.	HL to 1/32 in.	
0+72.5	Vertical Crack	18 in.	33 in.	HL to 1/32 in.	Wall Height: 51 in.
0+77.1	Vertical Crack	5 in.	46 in.	HL	
0+86.2	Vertical Crack	1.5 in.	49.5 in.	HL to 1/16 in.	
0+97	Vertical Crack	34 in.	16 in.	HL	
0+99.7	Vertical Crack	18 in.	32 in.	HL to 1/32 in.	
1+03.1	Vertical Crack	24 in.	53.5 in.	HL to 1/32 in.	Wall Height: 53.5 in.
1+08.7	Vertical Crack	0 in.	54.5 in.	HL	
1+10.1	Vertical Crack	8 in.	47 in.	HL to 1/32 in.	
1+40.4	Vertical Crack	12 in.	44.5 in.	HL to 1/32 in.	
1+46	Vertical Crack	0 in.	56 in.	HL to 1/32 in.	
1+52.9	Vertical Crack	26 in.	31.5 in.	HL to 1/32 in.	
1+59.3	Vertical Crack	20 in.	41 in.	HL	
1+60.9	Vertical Crack	36 in.	26.5 in.	HL	
1+63.9	Vertical Crack	0 in.	64 in.	HL to 1/32 in.	
1+65.2	Vertical Crack	18 in.	45.5 in.	HL	
1+83.6	Vertical Crack	33 in.	27.5 in.	HL to 1/32 in.	
1+92.3	Vertical Crack	47 in.	17 in.	HL to 1/32 in.	
1+98.5	Vertical Crack	20 in.	43.5 in.	HL to 1/32 in.	
2+04.4	Vertical Crack	48 in.	16 in.	HL to 1/32 in.	
2+07.1	Vertical Crack	40 in.	22 in.	HL to 1/32 in.	

Table 58. Condition Survey – Topaz Bridge (continued)

STATION	CONDITION	BASE OF CRACK ABOVE GROUND	LENGTH	WIDTH	
2+20.1	Vertical Crack	54 in.	11 in.	HL	
2+31.1	Vertical Crack	42 in.	19.5 in.	HL	
2+33.0	Vertical Crack	49 in.	13 in.	HL	Wall Height: 62 in.
2+37.1	Vertical Crack	53 in.	12 in.	HL to 1/32 in.	
2+37.1	Horizontal Crack	53 in.		HL	
2+45.1	Vertical Crack	55 in.	9 in.	HL	
2+55.1	Vertical Crack	46 in.	16 in.	HL to 1/32 in.	
2+56.0	Vertical Crack	50 in.	13 in.	HL	
2+57.1	Vertical Crack	21 in.	43 in.	HL to 1/32 in.	
2+59.0	Vertical Crack	0 in.	63.5 in.	HL to 1/32 in.	
2+62.1	Vertical Crack	44 in.	18 in.	HL to 1/32 in.	
2+63.1	Vertical Crack	27 in.	35 in.	HL to 1/32 in.	
2+68.1	Vertical Crack	42 in.	21 in.	HL to 1/32 in.	
2+79.6	Vertical Crack	19 in.	38 in.	HL to 1/32 in.	
2+86.0	Vertical Crack	44 in.	15 in.	HL	
2+87.1	Vertical Crack	38 in.	17 in.	HL	
2+89.2	Vertical Crack	43 in.	14 in.	HL to 1/32 in.	
2+92.2	Vertical Crack	41 in.	16 in.	HL to 1/32 in.	
2+94.5	Vertical Crack	41 in.	16.5 in.	HL to 1/32 in.	
2+99.1	Vertical Crack	30 in.	28 in.	HL to 1/32 in.	
3+04.4	Vertical Crack	0 in.	59 in.	HL to 1/32 in.	
3+09.2	Vertical Crack	46 in.	12 in.	HL to 1/32 in.	
3+11.5	Vertical Crack	47 in.	13 in.	HL	
3+16.3	Vertical Crack	35 in.	25 in.	HL	
3+16.3	Horizontal Crack	35 in.		HL	
3+18.9	Vertical Crack	24 in.	36 in.	HL	
3+18.9	Horizontal Crack	24 in.		HL	
3+20.6	Vertical Crack	50 in.	13 in.	HL	
3+29.5	Vertical Crack	46 in.	14.5 in.	HL to 1/32 in.	
3+45.1	Vertical Crack	50 in.	10 in.	HL	
3+53.4	Vertical Crack	18 in.	37.5 in.	HL	
3+56.6	Vertical Crack	47 in.	9 in.	HL	
3+69.2	Vertical Crack	37 in.	19 in.	HL	
3+81.4	Vertical Crack	44 in.	10 in.	HL	
3+85.8	Vertical Crack	47 in.	10 in.	HL	
3+96.0	Vertical Crack	52 in.	7 in.	HL	
4+06.9	Vertical Crack	53 in.	7 in.	HL	

Table 58. Condition Survey – Topaz Bridge (continued)

STATION	CONDITION	BASE OF CRACK ABOVE GROUND	LENGTH	WIDTH
4+16.1	Vertical Crack	50 in.	6 in.	HL
4+26.9	Vertical Crack	48 in.	11 in.	HL
4+32.8	Vertical Crack	43 in.	15 in.	HL
4+38.0	Vertical Crack	46 in.	7 in.	HL
4+40.1	Vertical Crack	49 in.	12 in.	HL
4+43.1	Vertical Crack	50 in.	9 in.	HL
4+45.9	Vertical Crack	48 in.	8.5 in.	HL
4+62.9	Vertical Crack	51 in.	8 in.	HL
4+78.1	END OF SURVEY			

SHOTCRETE VOIDS

	GROUND LEVEL	EAST-WEST	VERTICAL
0+16.1	10 IN.	3.25 in.	3.0 in.
0+34.4	40 IN.	0.5 in.	1.5 in.
	60 IN.	0.6 in.	1.0 in.
3+78.1	51 IN.	4 in.	1.0 in.

EXPOSED REINFORCING STEEL

STATION	HEIGHT ABOVE GROUND
1+74.8	55 in.
2+43.0	60 in.
4+49.1	54 in.

ANIMAL BURROWS

STATION
2+90.1

VERTICAL JOINTS: 6 FT APART

STEEL FIBER DIMENSIONS

1-1/8 IN. LONG

Figure 58. South MSE Wall, Topaz Bridge (Google Earth)

Figure 59. South MSE Wall, West Abutment, Topaz Bridge

Figure 60. sUAV Photo of South MSE Wall, West Abutment, Topaz Bridge, looking North

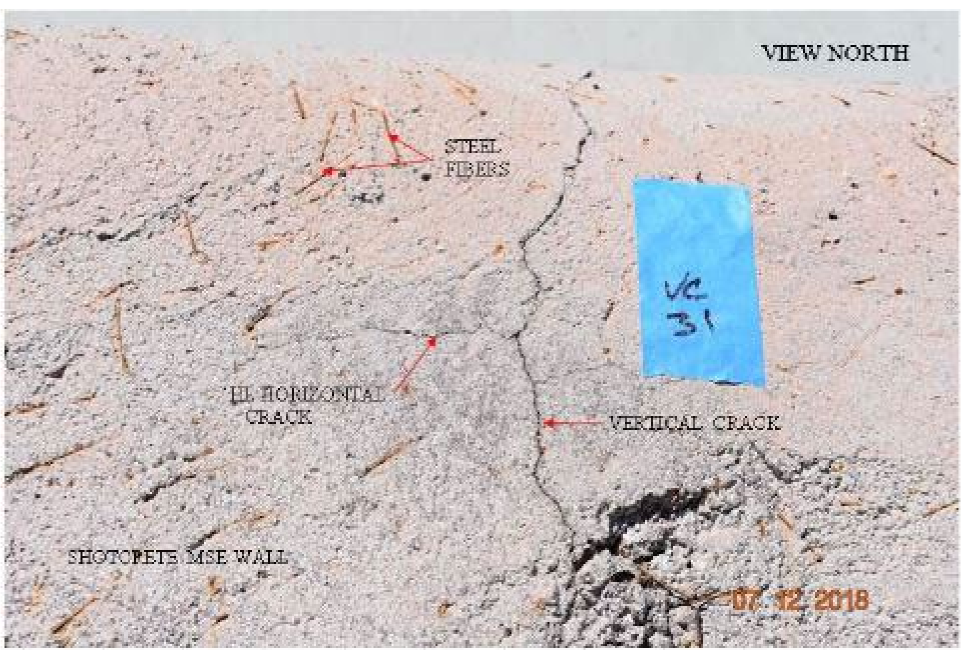


Figure 61. Vert. and Horiz. Cracks in MSE Wall Shotcrete, STA 2 + 37.1, Topaz Bridge

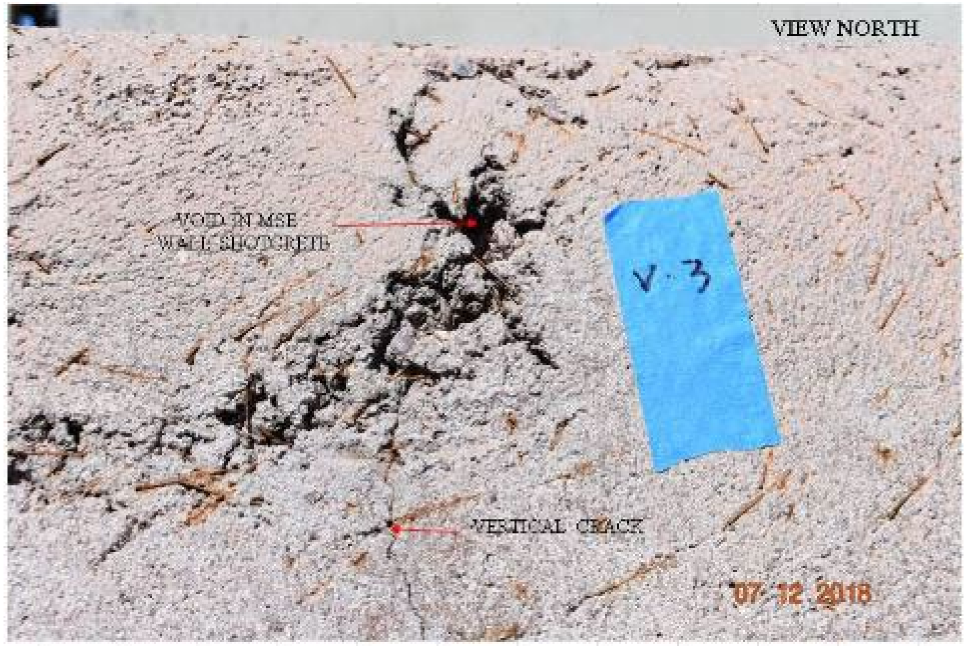


Figure 62. Void and Vert. Crack in MSE Wall Shotcrete, STA 1 + 92, Topaz Bridge

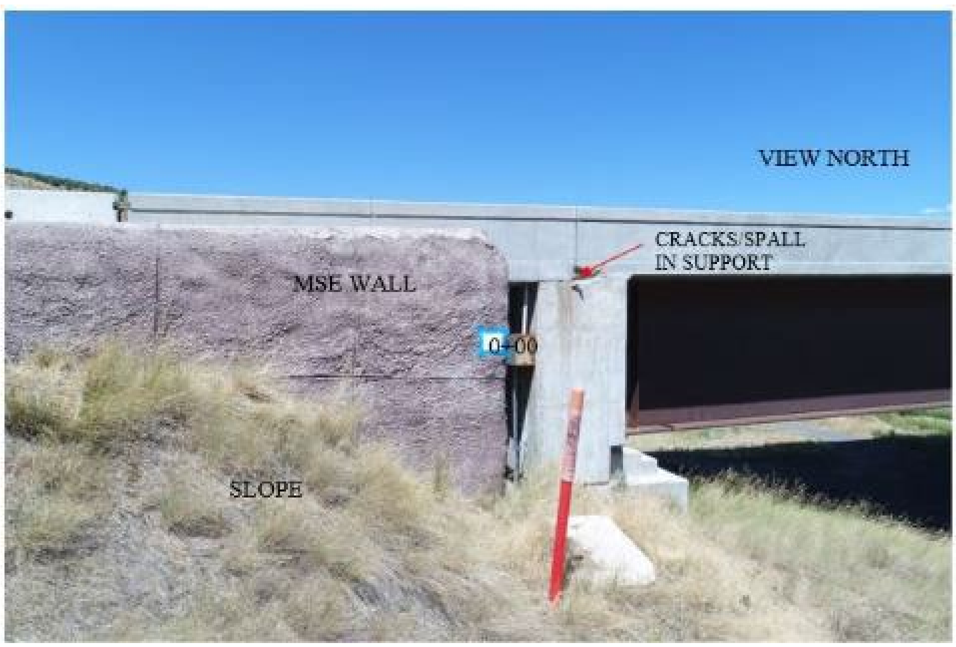


Figure 63. sUAV Photo of East-end of South MSE Wall, Topaz Bridge

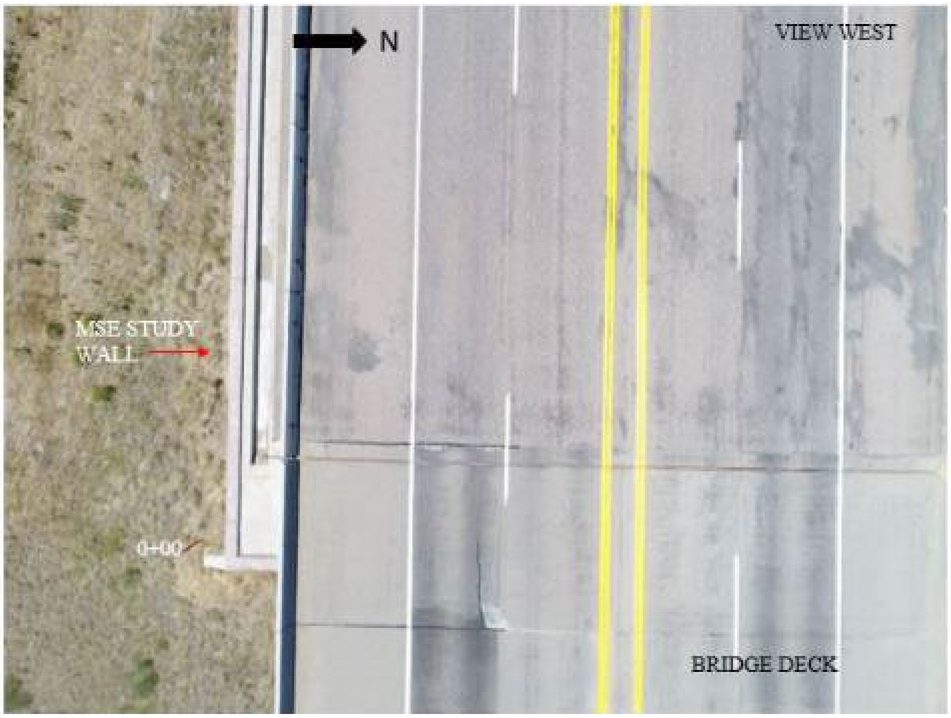


Figure 64. sUAV Photo of Pavement Surface near South MSE Wall, West Abutment, Topaz Bridge

Figure 65. sUAV Photo of Fiber Shotcreted Geofoam Blocks, N. Wall, W. Abutment, Topaz Bridge

Table 59. Inspection Summary of Topaz Bridge – Ohio DOT Procedure

#	CONDITIONS	Yes, No, N/A
JOINTS		
1.	Is sand or gravel coming out of joints or are there piles of sand or gravel at the base of the wall?	No
2.	Is sand or gravel visible in the horizontal joints?	No
3.	Are the joints wide enough to see the sand, gravel or fabric behind the panels when looking perpendicular to the wall face using a flashlight? If yes, record the approximate maximum joint width, in inches.	No
4.	If fabric is visible in the joints, is it torn? IMPORTANT - DO NOT POKE OR CUT THE FABRIC.	NA
5.	Do the joints have a nonuniform size, or are some joints noticeably wider than others? (see Condition Survey)	No
6.	Are the panels offset at the joints either in or out of the wall? (Photo 7) If yes, record the approximate maximum offset.	No
7.	Is there vegetation growing in the joints? In the Wall Facing?	No
WALL FACING		
8.	Are there cracks in more than two facing panels? If yes, record the approximate number of panels that are cracked.	Yes see Survey
9.	Is the face of the wall bowed or bulged?	No
DRAINAGE		
10.	Are there any signs of water flow along the base of the wall?	No
11.	Is there erosion of the embankment at the base of the wall?	No
12.	If there is erosion, is the leveling pad exposed at the base of the wall?	No
13.	Are the catch basins or the catch basin outlets near the wall blocked?	No
14.	Is the roadway drainage system above the wall malfunctioning? (see Survey)	Yes
15.	Does water at the top of the wall collect behind the concrete coping? Top of Wall?	No

Table 59. Inspection Summary of Topaz Bridge – Ohio DOT Procedure (continued)

#	CONDITIONS	Yes, No, N/A
TOP OF THE WALL		
16.	Is there settlement at the top of the wall?	No
17.	Are there any open cracks in the concrete coping (not hairline cracks)? If yes, record the approximate maximum crack width.	N/A
18.	Have the construction joints in the concrete coping opened up?	No
19.	Is there a gap larger than 1 inch between the approach slab and the approach pavement? If yes, record the approx. max. gap size.	No
20.	At abutments, has the joint between the wall coping and the abutment opened up more than two inches?	No
21.	Comments: (see Condition Survey) - animal burrows: Station 2+90 - cracks in shotcrete: HL to 1/32 in. wide - no evidence of slope movement	

District 5: Ledger Creek Bridge, US-30

Table 60. Condition Survey – Ledger Creek Bridge

US-30/LEDGER CREEK BRIDGE, SOUTH WALL, EAST ABUTMENT	42.647544 112.575783	EL 5859 FT 11:18 TO 15:38		10-Jul-18
STATION	CONDITION	HEIGHT ABOVE GROUND	DIMENSION LATERAL	DIMENSION VERTICAL
0+00	East End/South Wall			
0+06	Broken Corner	72 in.	5 in.	8.5 in.
0+24	Broken Corner	48 in.	4 in.	2.5 in.
0+24	Broken Corner	105 in.	2.5 in.	2.5 in.
0+28.5	Broken Corner	Below Coping	8 in.	14 in.
0+35	Broken Corner	108 in.	2.5 in.	2 in.
0+50.8	End Survey			
MSE WALL PANEL CRACKS				
STATION	ORIENTATION	HEIGHT ABOVE GROUND	WIDTH	
0+10	Diagonal	30 in.	HL	
0+15	Polygonal	90 in.	HL	
0+18	Diagonal	62 in.	HL to 1/16 in.	
0+24.5	Diagonal	73 in.	HL to 1/16 in.	
0+32	Diagonal/Horizontal	75 in.	HL to 1/16 in.	
0+38	Polygonal	204 in.	HL to 1/32 in.	
0+43.2	Diagonal	192 in.	HL	
0+46.2	Diagonal/Horizontal	121 in.	HL	
VEGETATION GROWTH				
STATION				
0+41.8				
ABOVE COPING NEAR ABUTMENTS				
PANEL STAINS				
≈ STA 0+25 TO 0+40				
COPING DAMAGE				
Deteriorated Concrete				
Wall Sections Missing				
Reinforcing Steel Exposed				
Horizontal/Vertical Cracks	Open HL to 3 in.			

Figure 66. South Wall, East Abutment, Ledger Creek Bridge (Google Earth)

Figure 67. South Wall, East Abutment, Ledger Creek Bridge, Looking North

Figure 68. Diag. and Vert. Cracks (HL to 1/16 in) and Concrete Deterioration, Ledger Creek Bridge

Figure 69. Polygonal Cracks (HL to 1/32 in) at STA 0+38, S. Wall, E. Abutment, Ledger Creek Bridge

Figure 70. Vegetation Growth, STA 0+41.7, S. Wall, E. Abutment, Ledger Creek Bridge

Figure 71. North Wall, East Abutment, Ledger Creek Bridge

Figure 72. North Wall, West Abutment, Ledger Creek Bridge

Figure 73. sUAV Photo of Pavement Surface above S. Wall, E. Abutment, Ledger Creek Bridge

Table 61. Inspection Summary of Ledger Creek Bridge – Ohio DOT Procedure

#	CONDITIONS	Yes, No, N/A
JOINTS		
1.	Is sand or gravel coming out of joints or are there piles of sand or gravel at the base of the wall?	No
2.	Is sand or gravel visible in the horizontal joints?	No
3.	Are the joints wide enough to see the sand, gravel or fabric behind the panels when looking perpendicular to the wall face using a flashlight? If yes, record the approximate maximum joint width, in inches.	No
4.	If fabric is visible in the joints, is it torn? IMPORTANT - DO NOT POKE OR CUT THE FABRIC.	NA
5.	Do the joints have a nonuniform size, or are some joints noticeably wider than others? (Photo 6)	No
6.	Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum offset.	No
7.	Is there vegetation growing in the joints? (see Condition Survey) In the Wall Facing?	Yes Sta 0+41.8
WALL FACING		
8.	Are there cracks in more than two facing panels? (see Condition Survey) If yes, record the approximate number of panels that are cracked.	Yes 7
9.	Is the face of the wall bowed or bulged?	No
DRAINAGE		
10.	Are there any signs of water flow along the base of the wall?	No
11.	Is there erosion of the embankment at the base of the wall?	No
12.	If there is erosion, is the leveling pad exposed at the base of the wall?	No
13.	Are the catch basins or the catch basin outlets near the wall blocked?	N/A
14.	Is the roadway drainage system above the wall malfunctioning?	No
15.	Does water at the top of the wall collect behind the concrete coping? Top of Wall?	Yes

Table 61. Inspection Summary of Ledger Creek Bridge – Ohio DOT Procedure (continued)

#	CONDITIONS	Yes, No, N/A
TOP OF THE WALL		
16.	Is there settlement at the top of the wall?	No
17.	Are there any open cracks in the concrete coping (not hairline cracks)? If yes, record the approximate maximum crack width. (see Condition Survey)	Yes 3 in.
18.	Have the construction joints in the concrete coping opened up? (see Survey)	Yes
19.	Is there a gap larger than 1 inch between the approach slab and the approach pavement? If yes, record the approx. max. gap size.	No
20.	At abutments, has the joint between the wall coping and the abutment opened up more than two inches?	No
21.	Comments: - Concerns: see Condition Survey - major concrete deterioration in coping - full length of coping - reinforcement exposed - sections of coping missing - concrete cracks and deterioration in MSE wall panel - Station 0+24 see photo - Other Observations/Measurements - cracks open to 1/16 in. in 3 MSE Wall panels - broken corners in 5 MSE Wall panels - some erosion in area between pavement and top of wall	

District 6: US-20, St Leon Exit

Table 62. Condition Survey – US-20, St Leon Exit

US-20/ST LEON	43.542903	EL 4785 FT		13-Jul-18
SOUTH WALL, WEST ABUTMENT	112.004944	9:00 to 10:09		
STATION	CONDITION	HEIGHT ABOVE GROUND	DIMENSION	
			LATERAL	VERTICAL
0+00	West End/South Wall			
0+40.8	Broken Corner	101 in.	3.5 in.	5 in.
0+40.8	Corner Crack	106 in.	REPAIRED	
0+65	END SURVEY			
COPING CRACKS				
STATION	ORIENTATION	WIDTH		
0+08.3	Vertical Crack	HL		
0+21.1	Vertical Crack	HL		
0+34	Vertical Crack	HL		
0+54	Vertical Crack	HL to 1/32 in.		
0+60.4	Vertical Crack	HL to 1/32 in.		
EROSION				
STATION	LOCATION	WIDTH	DEPTH	LENGTH
0+00	West End/South Wall			
	West Abutment	2.6 ft	1.2 ft	3.7 ft
	East End/South Wall			
	East Abutment	1.7 ft	0.5 ft	2.0 ft

Figure 74. South Wall, West Abutment, US-20, St Leon Exit (Google Earth)

Figure 75. South Wall, West Abutment, US-20, St Leon Exit

Figure 76. Close-up Photo of South Wall, West Abutment, US-20, St Leon Exit

Figure 77. Erosion Channel at Edge of South Wall, West Abutment, US-20, St Leon Exit

Figure 78. Erosion Channel at Edge of South Wall, West Abutment, US-20, St Leon Exit

Figure 79. Erosion Channel at Edge of South Wall, West Abutment, US-20, St Leon Exit

Figure 80. South Wall, East Abutment, US-20, St Leon Exit

Figure 81. North Wall, West Abutment, US-20, St Leon Exit

Figure 82. North Wall, West Abutment, US-20, St Leon Exit

Figure 83. sUAV Photo of Area Above South Wall, West Abutment, US-20, St Leon Exit

Table 63. Inspection Summary of US-20, St Leon Exit – Ohio DOT Procedure

#	CONDITIONS	Yes, No, N/A
JOINTS		
1.	Is sand or gravel coming out of joints or are there piles of sand or gravel at the base of the wall?	No
2.	Is sand or gravel visible in the horizontal joints?	No
3.	Are the joints wide enough to see the sand, gravel or fabric behind the panels when looking perpendicular to the wall face using a flashlight? If yes, record the approximate maximum joint width, in inches.	No
4.	If fabric is visible in the joints, is it torn? IMPORTANT - DO NOT POKE OR CUT THE FABRIC.	N/A
5.	Do the joints have a nonuniform size, or are some joints noticeably wider than others?	No
6.	Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum offset.	No
7.	Is there vegetation growing in the joints? In the Wall Facing?	No
WALL FACING		
8.	Are there cracks in more than two facing panels? If yes, record the approximate number of panels that are cracked.	No
9.	Is the face of the wall bowed or bulged? Rotated?	No
DRAINAGE		
10.	Are there any signs of water flow along the base of the wall?	Yes
11.	Is there erosion of the embankment at the base of the wall?	Yes
12.	If there is erosion, is the leveling pad exposed at the base of the wall?	No
13.	Are the catch basins or the catch basin outlets near the wall blocked?	N/A
14.	Is the roadway drainage system above the wall malfunctioning?	Yes
15.	Does water at the top of the wall collect behind the concrete coping? Top of Wall?	Yes

Table 63. Inspection Summary of US-20, St Leon Exit – Ohio DOT Procedure (continued)

#	CONDITIONS	Yes, No, N/A
TOP OF THE WALL		
16.	Is there settlement at the top of the wall?	No
17.	Are there any open cracks in the concrete coping (not hairline cracks)? If yes, record the approximate maximum crack width.	No
18.	Have the construction joints in the concrete coping opened up?	No
19.	Is there a gap larger than 1 inch between the approach slab and the approach pavement? If yes, record the approx. max. gap size.	Yes Local
20.	At abutments, has the joint between the wall coping and the abutment opened up more than two inches?	No
21.	Comments: - Concerns: see Condition Survey - erosion on end at top and in berm along south MSE Wall of west abutment - eroding pavement and undermining outer edge of concrete barrier - erosion on end at top and in berm along south MSE Wall of east abutment	

District 6: SH-33 Exit, US-20

Table 64. Condition Survey – SH-33 Exit, US-20

US-20/SH-33 EXIT	43.883586	EL 4913 FT		13-Jul-18
SOUTH WALL/EAST ABUTMENT	111.748983	11:02 TO 13:30		
STATION	CONDITION	HEIGHT ABOVE GROUND	DIMENSION	
			LATERAL	VERTICAL
0+00	East End of Wall			
0+08.8	Broken Corner	18 in.	2 in.	1 in.
0+13.9	Horizontal Crack	72.3 in.	9 in.	HL
0+41.8	Broken Corner	72.5 in.	9 in.	12 in.
0+41.8	Comp Spall	118 in.	4 in.	14 in.
0+46.9	Broken Corner	120.1 in.	2-3/4 in.	14.5 in.
0+51.5	Comp Spall	72 in.	3.5 in.	9 in.
0+51.5	Comp Spall	84.6 in.	9 in.	37.5 in.
0+51.5	Comp Spall	168 in.	9 in.	18 in.
0+52.0	Broken Corner	55 in.	4 in.	2 in.
0+52.0	Horizontal Crack	58 in.	10 in.	HL to 1/16 in.

PANELS IRON-STAINED ALONG INTERFACES
VERTICAL GAPS BETWEEN PANELS: TIGHT TO 1 IN.
VERTICAL GAPS BETWEEN PANELS LOCALLY
> 7/16 IN. WITHIN 20 FT OF THE ABUTMENT

NO MEASUREABLE SETTLEMENT
COPING CRACKS

STATION	ORIENTATION	WIDTH
0+01.2	Vertical Crack	HL
0+03.3	Vertical Crack	HL to 1/16 in.
0+04.7	Vertical Crack	HL
0+05.7	Vertical Crack	HL to 1/32 in.
0+08.3	Vertical Crack	HL
0+09	Vertical Crack	1/16 to 1/8 in.
0+09.1	Vertical Crack	HL to 1/32 in.
0+12	Vertical Crack	HL
0+13.3	Vertical Crack	HL to 1/8 in.
0+19	Vertical Crack	HL
0+20.1	Vertical Crack	HL

Table 64. Condition Survey – SH-33 Exit, US-20 (continued)

COPING CRACKS

STATION	ORIENTATION	WIDTH
0+24.9	Vertical Crack	HL to 1/16 in.
0+28.3	Vertical Crack	HL
0+30.1	Vertical Crack	HL to 1/16 in.
0+36.6	Vertical Crack	1/16 in.
0+41.5	Vertical Crack	HL to 1/16 in.

COPING: IRON-STAINED

MAJOR OFFSET/ROTATION IN
TWO PANELS NEAR ABUTMENT
OFFSET: 1 TO 3-1/4 IN.
STEEL CHANNEL BRACE

Figure 84. MSE Wall Supporting SH-33 Exit at US-20 (Google Earth)

Figure 85. South MSE Wall, East Abutment of SH-33 Exit at US-20

Figure 86. Close-up View of Displaced South MSE Wall, East Abutment of SH-33 Exit at US-20

Figure 87. Close-up View of Coping Damage at S. MSE Wall, E. Abutment of SH-33 Exit at US-20

Figure 88. South MSE Wall, West Abutment of SH-33 Exit at US-20

Figure 89. Iron Staining and Coping Cracks, N. MSE Wall, E. Abutment of SH-33 Exit at US-20

Figure 90. North MSE Wall, West Abutment of SH-33 Exit at US-20

Figure 91. sUAV Photo of Pavement Surface near S. MSE Wall, E. Abutment of SH-33 Exit at US-20

Table 65. Inspection Summary of SH-33 Exit, US-20 – Ohio DOT Procedure

#	CONDITIONS	Yes, No, N/A
JOINTS		
1.	Is sand or gravel coming out of joints or are there piles of sand or gravel at the base of the wall?	No
2.	Is sand or gravel visible in the horizontal joints?	No
3.	Are the joints wide enough to see the sand, gravel or fabric behind the panels when looking perpendicular to the wall face using a flashlight? If yes, record the approximate maximum joint width, in inches.	No
4.	If fabric is visible in the joints, is it torn? IMPORTANT - DO NOT POKE OR CUT THE FABRIC.	N/A
5.	Do the joints have a nonuniform size, or are some joints noticeably wider than others? (see Condition Survey)	Yes
6.	Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum offset. (see Condition Survey)	Yes 3-1/2 in.
7.	Is there vegetation growing in the joints? In the Wall Facing?	No
WALL FACING		
8.	Are there cracks in more than two facing panels? If yes, record the approximate number of panels that are cracked.	Yes 2
9.	Is the face of the wall bowed or bulged? Rotated?	Yes
DRAINAGE		
10.	Are there any signs of water flow along the base of the wall?	No
11.	Is there erosion of the embankment at the base of the wall?	No
12.	If there is erosion, is the leveling pad exposed at the base of the wall?	No
13.	Are the catch basins or the catch basin outlets near the wall blocked?	N/A
14.	Is the roadway drainage system above the wall malfunctioning?	No
15.	Does water at the top of the wall collect behind the concrete coping? Top of Wall?	No

Table 65. Inspection Summary of SH-33 Exit, US-20 – Ohio DOT Procedure (continued)

#	CONDITIONS	Yes, No, N/A
TOP OF THE WALL		
16.	Is there settlement at the top of the wall?	No
17.	Are there any open cracks in the concrete coping (not hairline cracks)? If yes, record the approximate maximum crack width.	Yes ≈2 in.
18.	Have the construction joints in the concrete coping opened up?	No
19.	Is there a gap larger than 1 inch between the approach slab and the approach pavement? If yes, record the approx. max. gap size.	No
20.	At abutments, has the joint between the wall coping and the abutment opened up more than two inches? (Front of MSE Wall at Abutment)	Yes
21.	Comments: - Concerns: see Condition Survey - major offsets in 2 MSE wall panels near abutment - lateral displacement: 1 to 3-1/4 in. - rigid body rotation - steel channel brace - coping cracked/offset beneath abutment - panels and coping iron-stained - irregular spacing of joints: tight to 1 in.	

District 6: Bitch Creek Bridge, SH-32

Table 66. Condition Survey – Bitch Creel Bridge, SH-32

BITCH CREEK BRIDGE, SH-32, EAST SIDE, SOUTH ABUTMENT	43.938333 111.178506	EL 5903 FT 10:45 TO 14:19		11-Jul-18
STATION	CONDITION	HEIGHT ABOVE GROUND	DIMENSION	
			LATERAL	VERTICAL
0+00	North End Of Wall			
0+05.7	Broken Corner	21 in.	3.5 in.	3 in.
0+06.5	Corner Crack	80 in.		
0+12.0	Corner Crack	72 in.		
0+17.6	Broken Corner	26 in.	2 in.	9 in.
0+24.0	Broken Corner	2 in.	8 in.	3.2 in.
0+42.1	Horizontal Crack	72 in.	12.25 in.	HL to 1/32 in.
0+47.1	Broken Corner	12 in.	4 in.	7 in.
0+72	Horizontal Crack	80 in.	14 in.	HL to 1/16 in.
0+77.1	Horizontal Crack	50 in.	10 in.	HL to 1/32 in.
0+84.1	Broken Corner	33 in.	3.25 in.	4.5 in.
0+84.2	Horizontal Crack	51 in.	22 in.	HL to 1/32 in.
1+08.6	Broken Corner	9 in.	1 in.	7.5 in.
2+28.9	Broken Corner	49.2 in.	2.75 in.	2.25 in.
2+33.0	Broken Corner	55.2 in.	2 in.	2.5 in.
2+52.1	Broken Corner	47 in.	3.5 in.	1 in.
2+77.1	Broken Corner	38 in.	3 in.	10 in.
2+95.5	Broken Corner	65 in.	2.5 in.	2.5 in.
3+13.3	Broken Corner	28.5 in.	1.75 in.	1.5 in.
0+22.4	Animal Burrows	Ground Surface		
1+23.8 TO 127.7	Animal Burrows	Ground Surface		
1+97.6	Slope Erosion	Ground Surface		
	Animal Burrows	Ground Surface		
	Culvert			
0+00	Foam in Gap Between MSE Wall And Abutment			
	Separation Between Wall and Coping Along Major Sections of East Wall			
	Longitudinal Pavement Cracks Along MSE Walls			

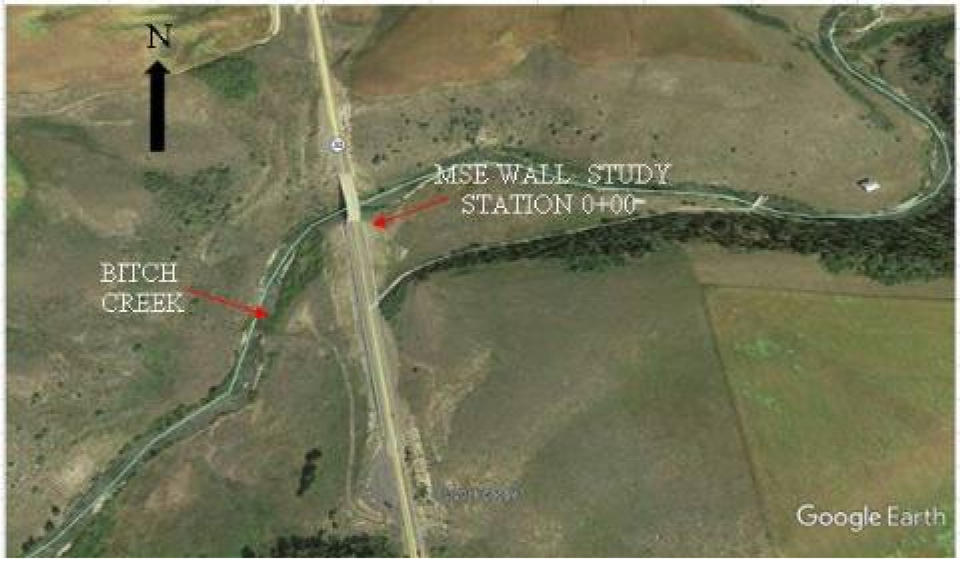


Figure 92. Bitch Creek Bridge, SH-32 (Google Earth)

Figure 93. East MSE Wall, South Abutment, Bitch Creek Bridge, SH-32

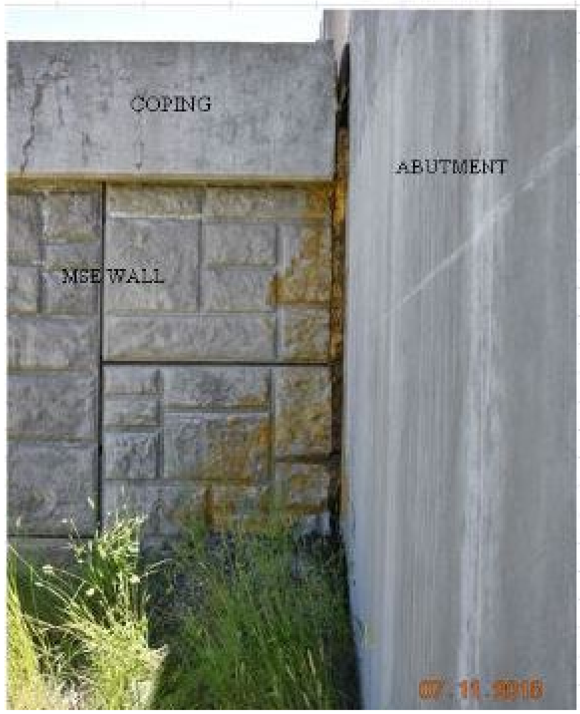


Figure 94. Lateral Displacement Damage at North End of South MSE Wall, Bitch Creek Bridge

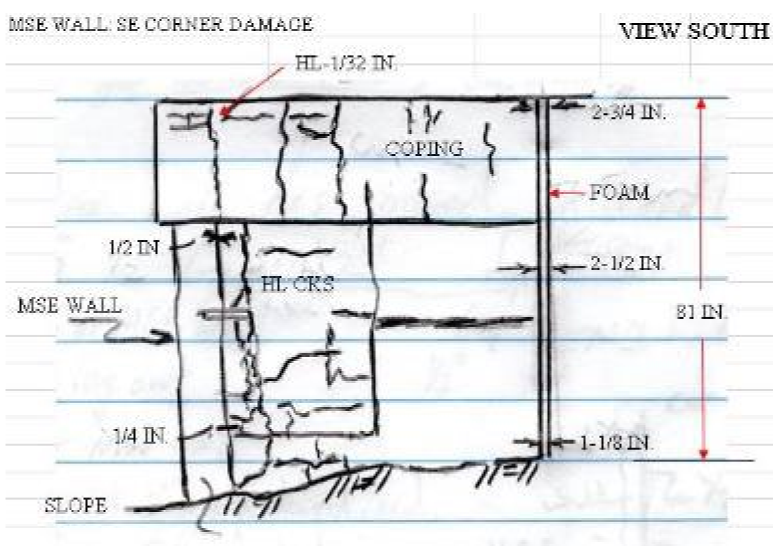


Figure 95. Map of Lateral Displacement Damage at North End of South MSE Wall, Bitch Creek Bridge

Figure 96. Animal Burrows at STA 2+77,1, South MSE Wall, Bitch Creek Bridge

Figure 97. Broken Corner in East MSE Wall, South Abutment, at STA 0+17.1, Bitch Creek Bridge

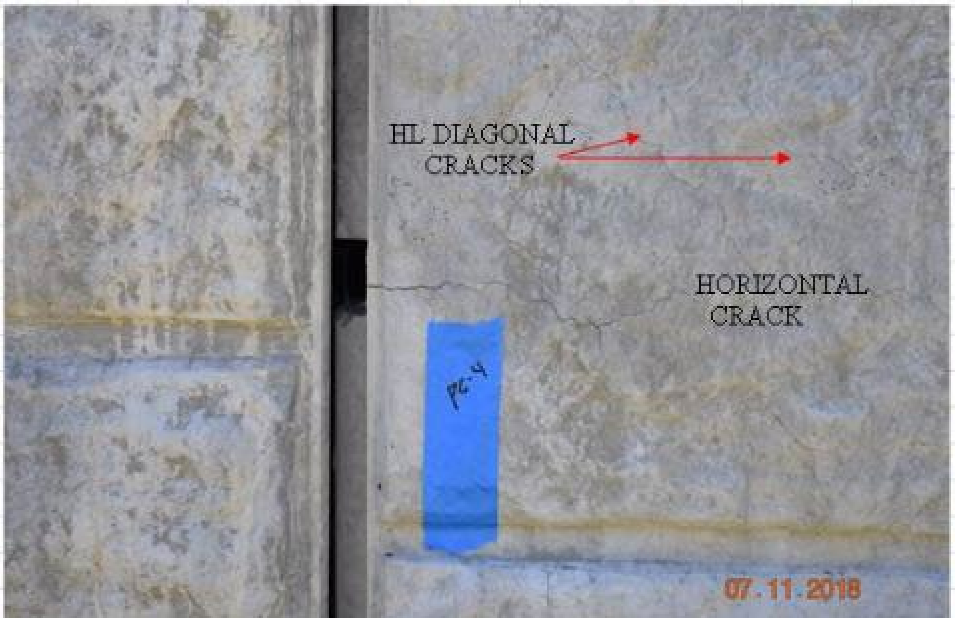


Figure 98. Horiz. and Diag. Cracks in East MSE Wall, South Abutment at STA 0+77.1, Bitch Creek Bridge

Figure 99. Broken Corner in E. MSE Wall, S. Abutment at STA 0+47.1, Bitch Creek Bridge

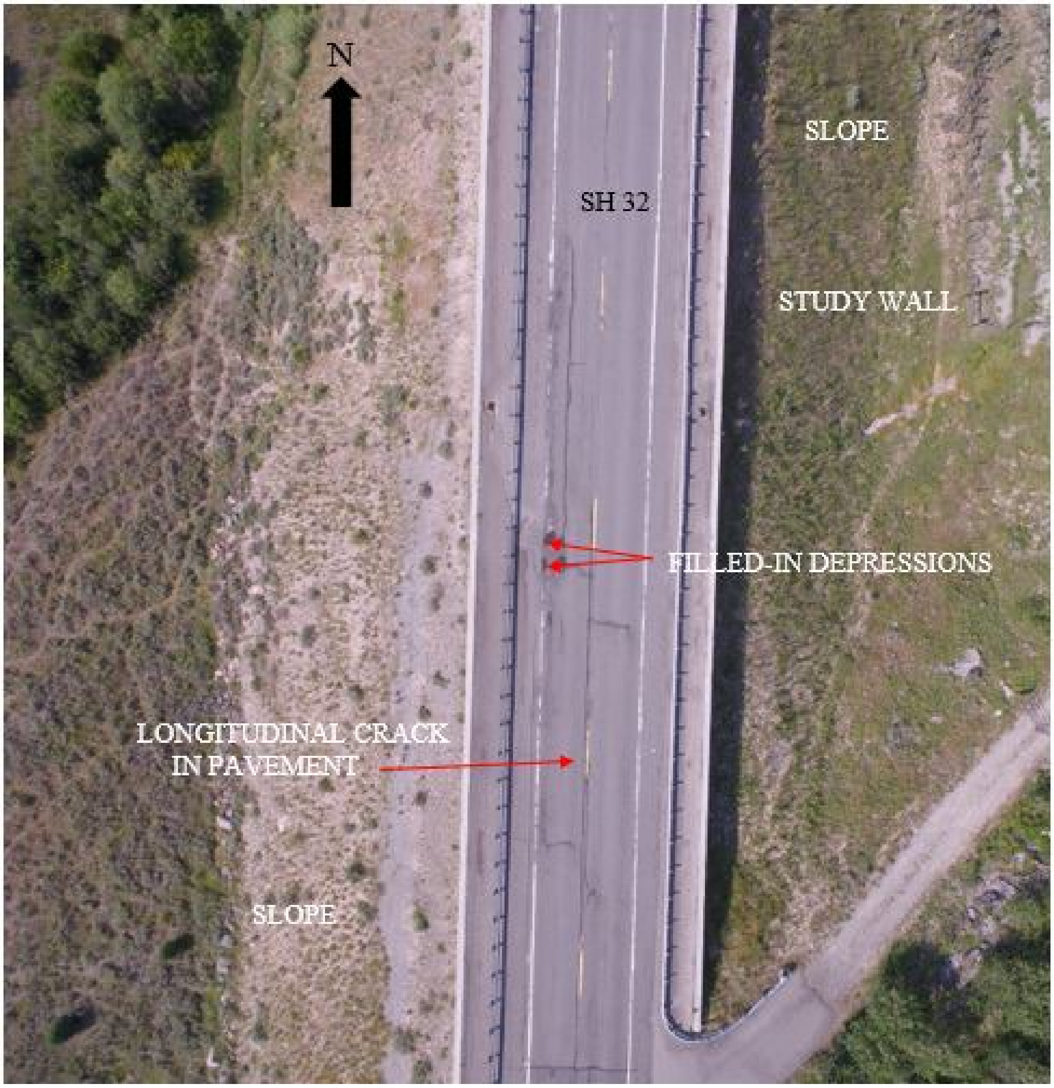


Figure 100. sUAV Photo of Longitudinal Cracks in Pavement from Lateral Slope Movement

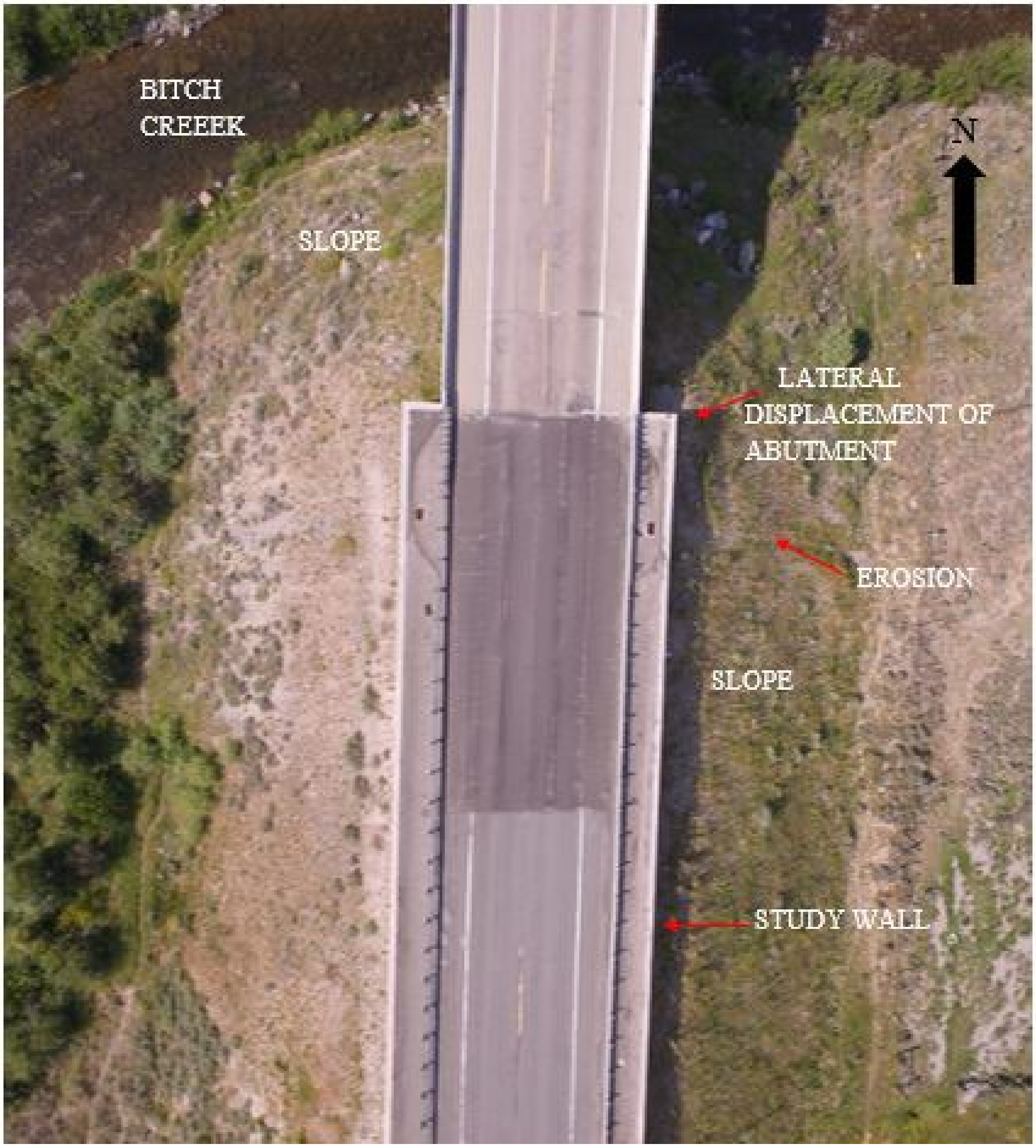


Figure 101. sUAV Photo of Pavement Overlay at South Abutment, Bitch Creek Bridge

Table 67. Inspection Summary of Bitch Creek Bridge – Ohio DOT Procedure

	CONDITIONS	Yes, No, N/A
JOINTS		
1.	Is sand or gravel coming out of joints or are there piles of sand or gravel at the base of the wall?	No
2.	Is sand or gravel visible in the horizontal joints?	No
3.	Are the joints wide enough to see the sand, gravel or fabric behind the panels when looking perpendicular to the wall face using a flashlight? If yes, record the approximate maximum joint width, in inches.	No
4.	If fabric is visible in the joints, is it torn? IMPORTANT - DO NOT POKE OR CUT THE FABRIC.	N/A
5.	Do the joints have a nonuniform size, or are some joints noticeably wider than others? (see Condition Survey)	Yes
6.	Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum offset.	No
7.	Is there vegetation growing in the joints? In the Wall Facing?	No
WALL FACING		
8.	Are there cracks in more than two facing panels? If yes, record the approximate number of panels that are cracked.	Yes 4
9.	Is the face of the wall bowed or bulged? Rotated?	No
DRAINAGE		
10.	Are there any signs of water flow along the base of the wall?	Yes
11.	Is there erosion of the embankment at the base of the wall?	Yes
12.	If there is erosion, is the leveling pad exposed at the base of the wall?	No
13.	Are the catch basins or the catch basin outlets near the wall blocked?	No
14.	Is the roadway drainage system above the wall malfunctioning?	No
15.	Does water at the top of the wall collect behind the concrete coping? Top of Wall?	No

Table 67. Inspection Summary of Bitch Creek Bridge – Ohio DOT Procedure (continued)

#	CONDITIONS	Yes, No, N/A
TOP OF THE WALL		
16.	Is there settlement at the top of the wall?	No
17.	Are there any open cracks in the concrete coping (not hairline cracks)? If yes, record the approximate maximum crack width.	No .
18.	Have the construction joints in the concrete coping opened up?	Yes At Abutment
19.	Is there a gap larger than 1 inch between the approach slab and the approach pavement? If yes, record the approx. max. gap size.	N/A overlay
20.	At abutments, has the joint between the wall coping and the abutment opened up more than two inches? (MSE Wall/Abutment Interface)	Yes
21.	Comments: - Concerns: see Condition Survey - significant lateral displacement/rotation of MSE Wall at abutment interface - lateral displacement: 1-1/8 in. - rigid body rotation: 1-5/8 in./6.8 ft - cracks in MSE wall - major lengths of foam-filled gap between MSE wall and coping - longitudinal cracks and depressions in long sections of pavement above east and west MSE walls - Other Observations/Measurements - tight contacts and spalling between MSE wall panels - slope erosion below catch basin outlets - animal burrows in embankment next to MSE Wall - no evidence of slope movement.	

Appendix E
ArcGIS Implementation

Inputting Data into an ArcGIS Geodatabase

1. To begin, navigate to and double left click on the online ITD ArcGIS Image Server (on your desktop) and double left click on the folders containing the respective ITD Project data. There should be five folders uploaded to the server consisting of the following data categories:

    - A map of the bridges inspected by the user.
    - The attribute fields of the inspection data.
    - Attachments of the excel field inspection forms.
    - Attachments of photos corresponding to observations.
    - Stitched drone images of field sites.

2. Right click on the files that you wish to import into ArcGIS and select download.

3. Once the data have been downloaded, create a folder (press Shift-Control-N simultaneously) that will serve as the primary folder for where the data is stored and call it ITD Project. Then create subfolders inside the main folder with names appropriate for the different data categories (i.e., map_of_bridges, attribute_fields_of_inspection_data, etc.) and store the data in their respective folders. This will make it easy to locate when importing it into ArcGIS. **Note: when naming folders or anything for use in ArcGIS, DO NOT include spaces in the names as this will result in errors (incorrect: ITD Project). Simply keep different words connected or separate them with special symbols such as an underscore (correct: ITD_Project).** See the following screenshot in Figure 102 for an example.

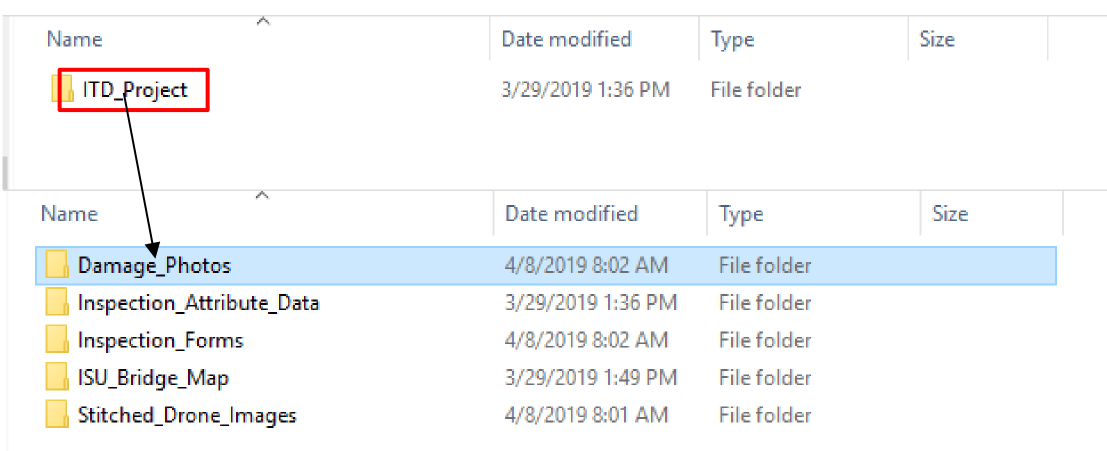


Figure 102. Organizing the Data

4. After downloading the appropriate data, open ArcMap (on your desktop) and when the Getting Started menu appears double left click on Blank Map (see Figure 50). Click the Add Data button that appears as a black plus sign on the upper left-hand side of the screen (see Figure 103). In the menu that appears, click on the Connect to Folder icon that appears as a folder with a plus sign in the upper right-hand corner (Figure 104). Navigate to the ITD_Project folder, select it, and click OK (Figure 105). This creates a connection to the ITD_Project folder for analysis in ArcGIS. Then left click Cancel to close out the menu (Figure 105). After this, left click on the catalog icon on the far right-hand side of the screen, and left click on the little pin to keep the menu displayed (Figure 106). Finally, left click on the plus sign (displayed as a minus sign in the photo below because the folder has already been expanded) next to Folder Connections to see the connected ITD folder that houses all the data (Figure 106).

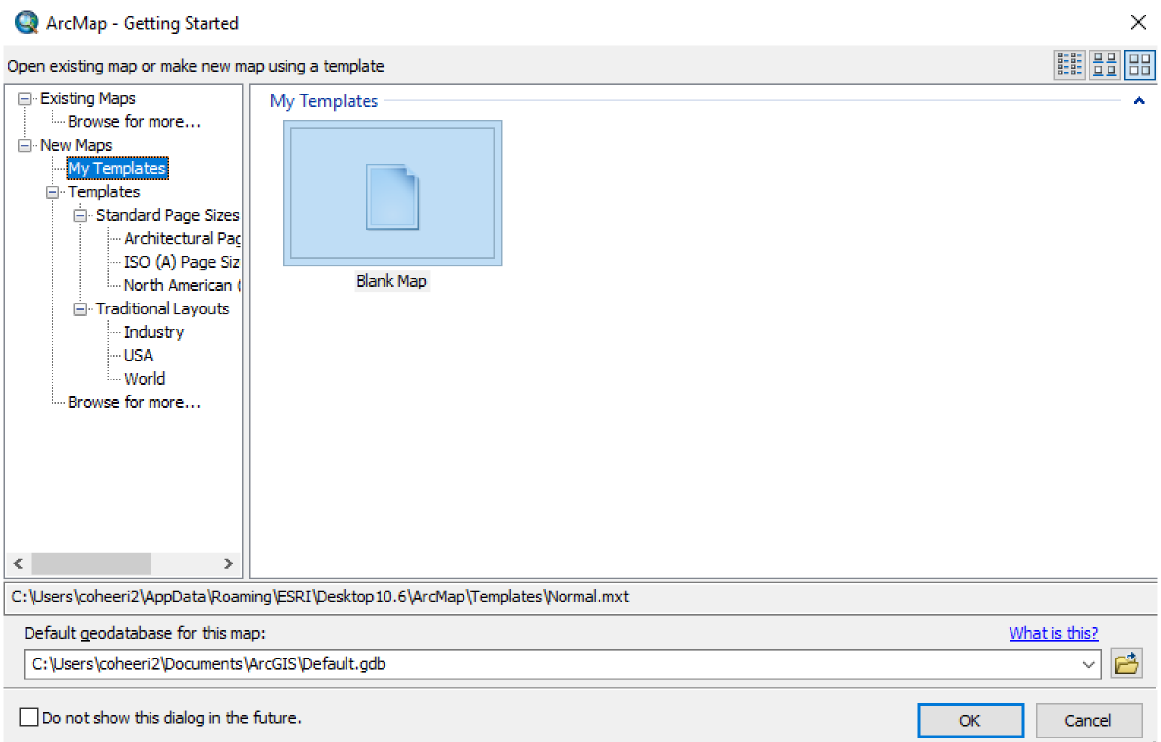


Figure 103. Opening Blank Map

If the intent is to create a new geodatabase, continue on to steps 5 and 6. If additional data is to be placed in an already existing geodatabase, skip to step 7.

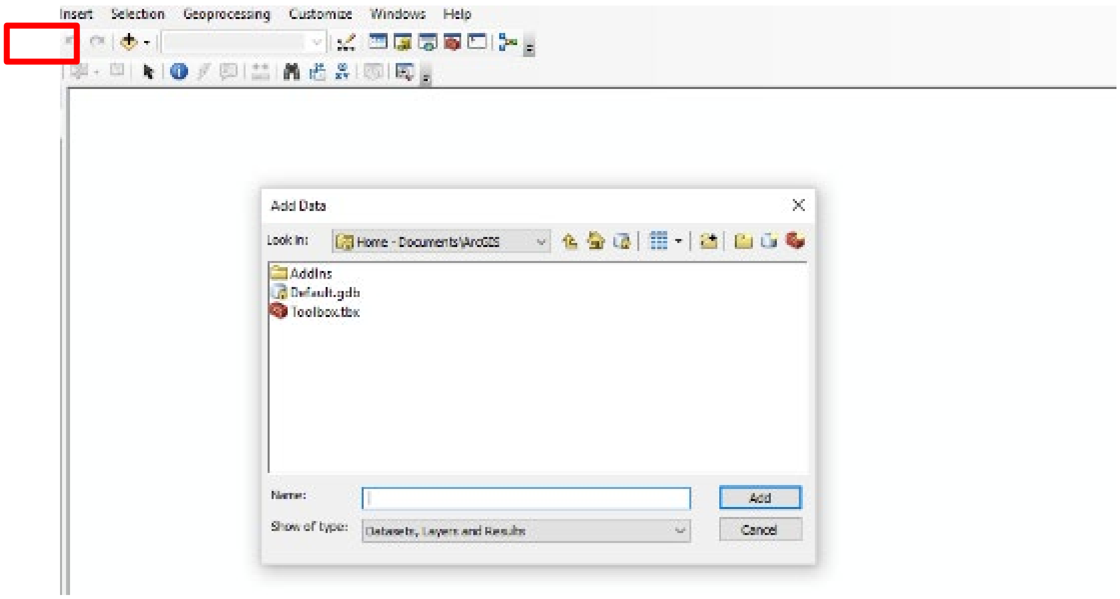


Figure 104. Creating Folder Connection

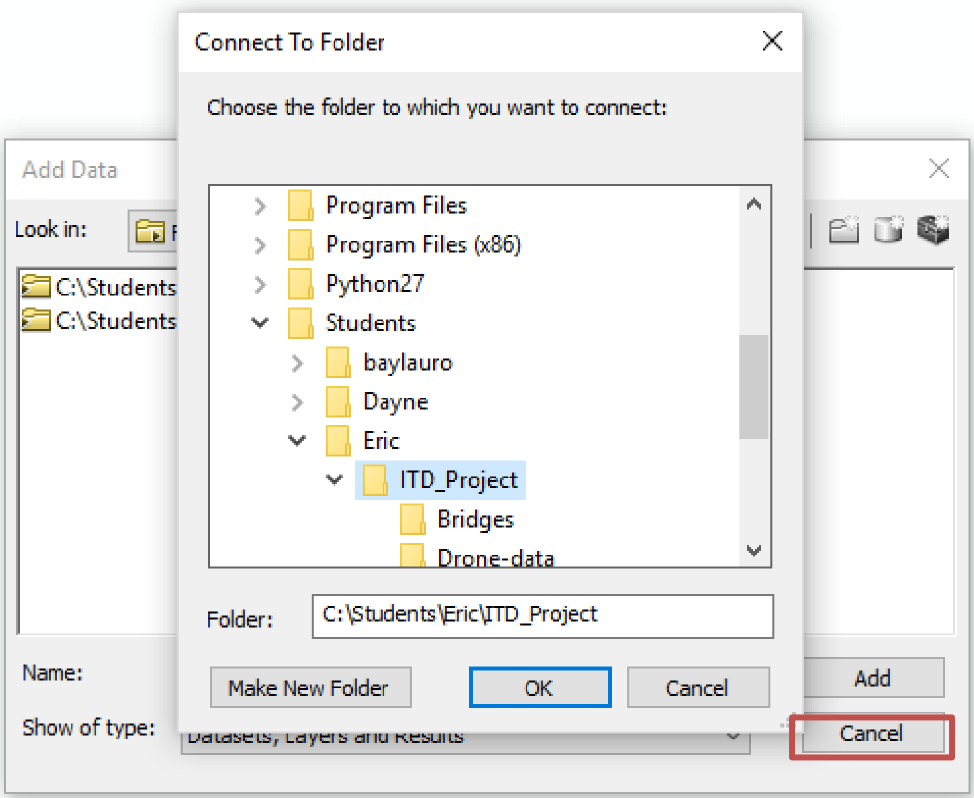


Figure 105. Connecting to Folder

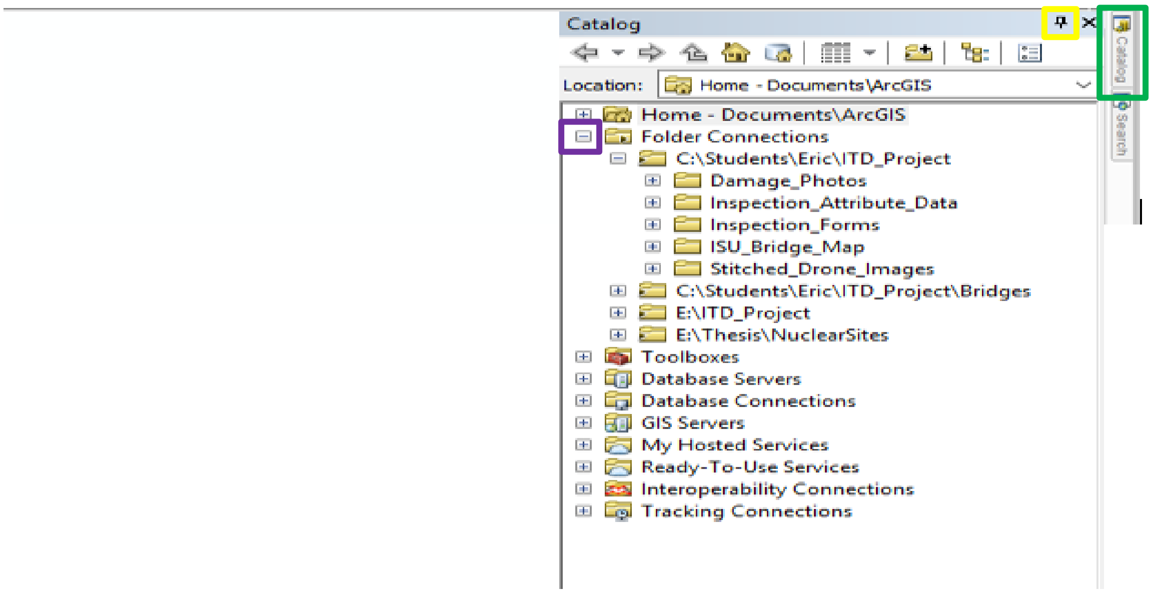


Figure 106. Displaying Folder Connection

5. To best organize the data, it is necessary to create a geodatabase that will house and store the information. Within ArcMap, select the file menu in the upper left-hand corner, then left click on Map Document Properties at the bottom of the menu pane (see red arrow in Figure 107). Select the folder icon that appears to the right of the Default Geodatabase heading (Figure 108). This step brings up the menu in Figure 109. Navigate to and double left click on the ITD folder (see arrows in Figure 109). Then left click on the round cylinder icon that appears in the far upper right-hand corner of the menu (Figure 110). This will create a geodatabase in the main folder where the data will be stored.

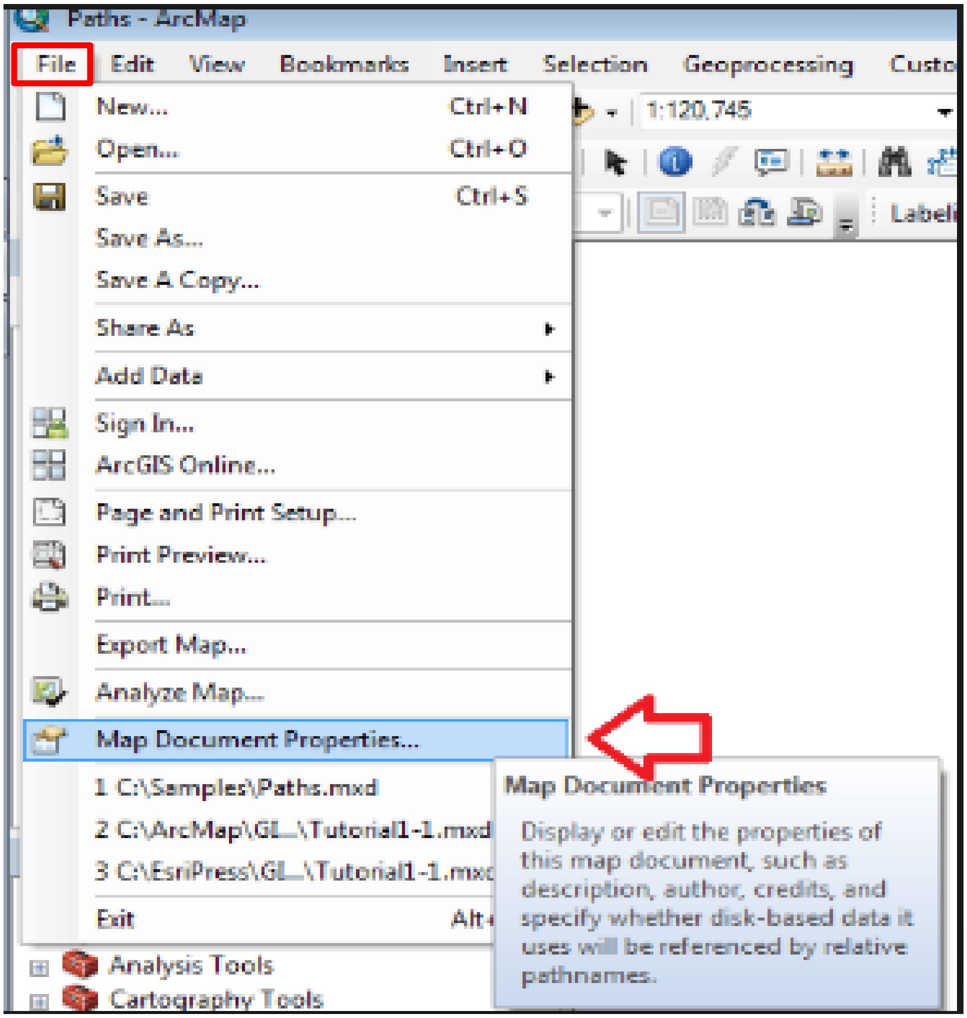


Figure 107. Opening Map Document Properties

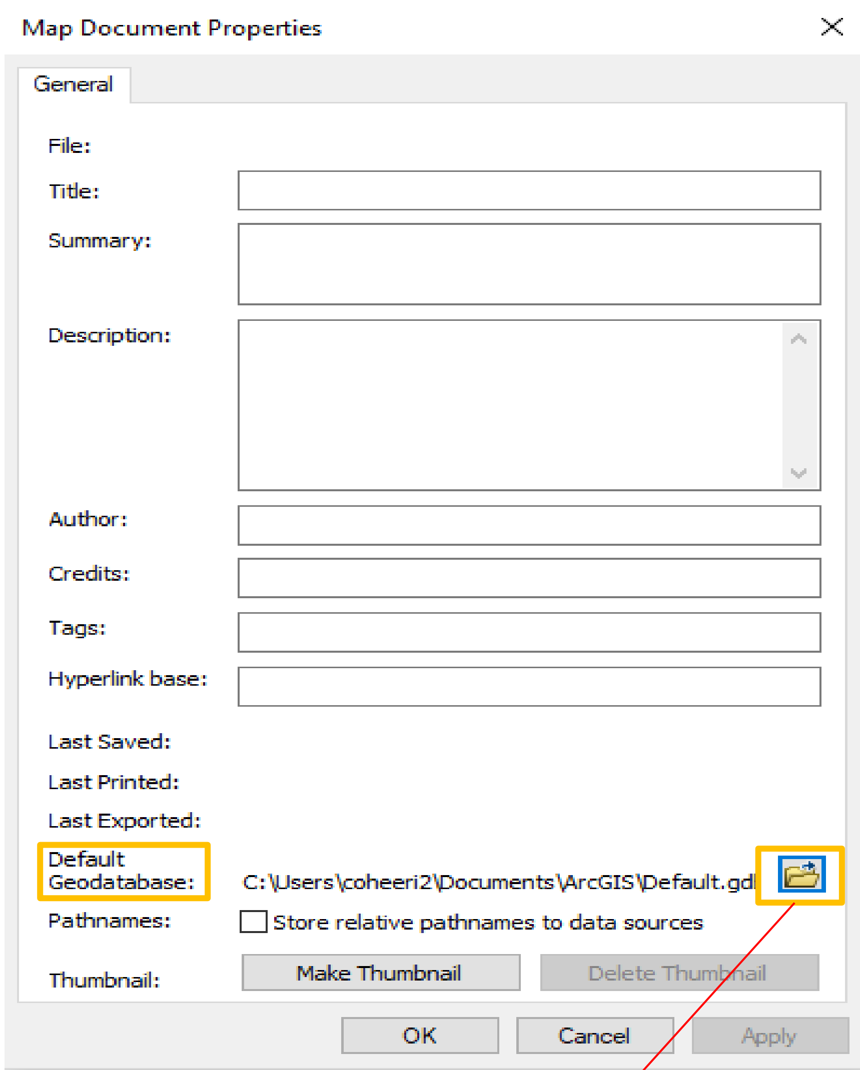


Figure 108. Defining Geodatabase Folder

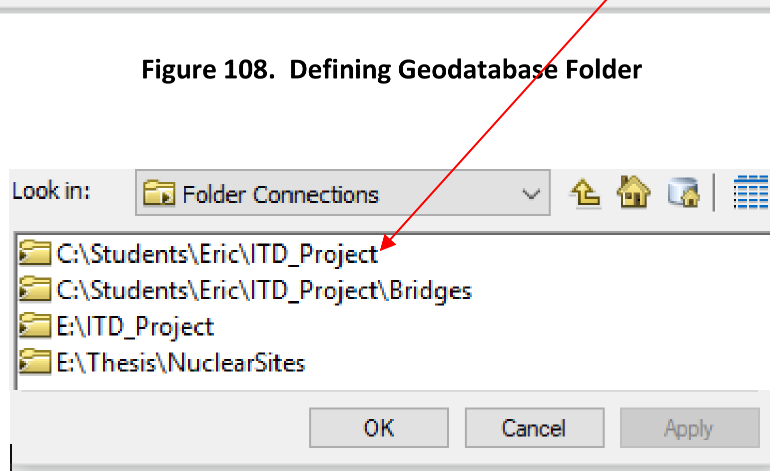


Figure 109. Select ITD Project Folder

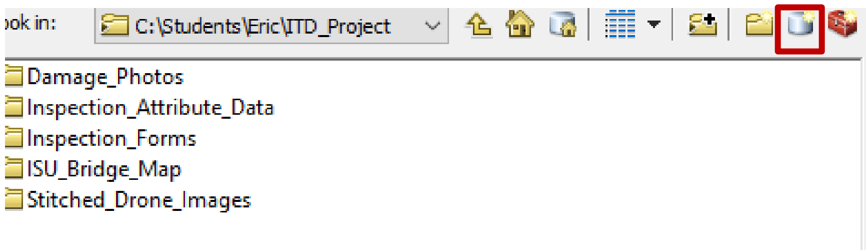


Figure 110. Create Geodatabase

6. STOP. This next step is very important for creating a new geodatabase. Before doing anything else (moving the mouse, clicking on any icons), type a name for the new geodatabase (see Figure 58) and then press enter. This is very easy to mess up if not done just right, and the only way to correct it is to create another geodatabase. Therefore, it is important not to make any movements or clicks with the mouse until the new geodatabase is named in Figure 111. Once complete, left click again on the new geodatabase and then left click on Add (Figure 111). Check the box next to "Store relative pathnames to data sources" to ensure that any data, if uploaded to another machine via a jump drive, will maintain the same links to where the data is stored. Otherwise, the links will be broken. Then left click OK (Figure 112). After clicking OK, the menu will close and the screen will appear as shown in Figure 113.

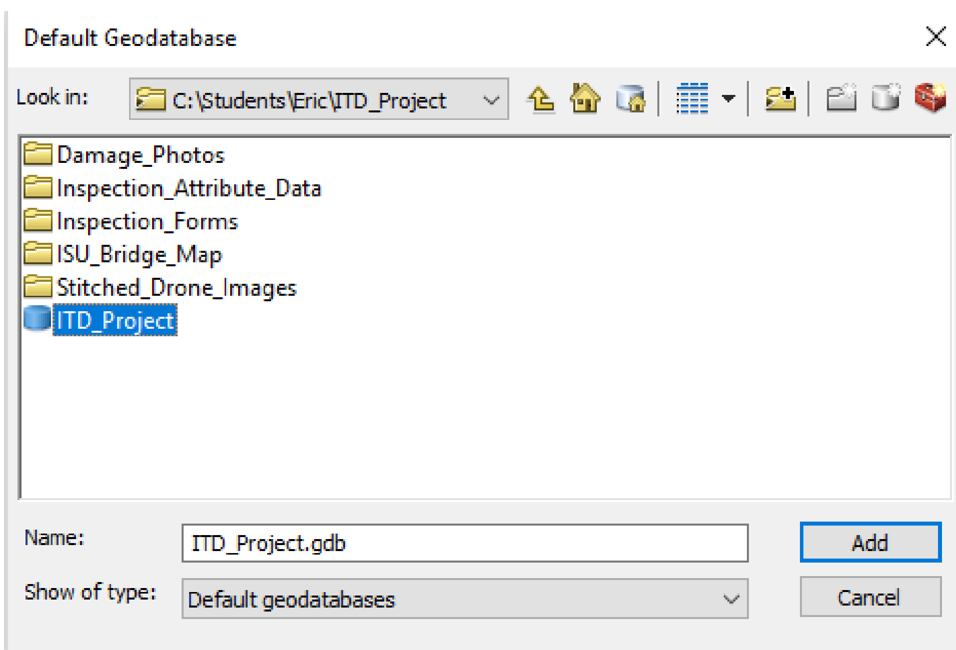


Figure 111. Create a Name for New Geodatabase

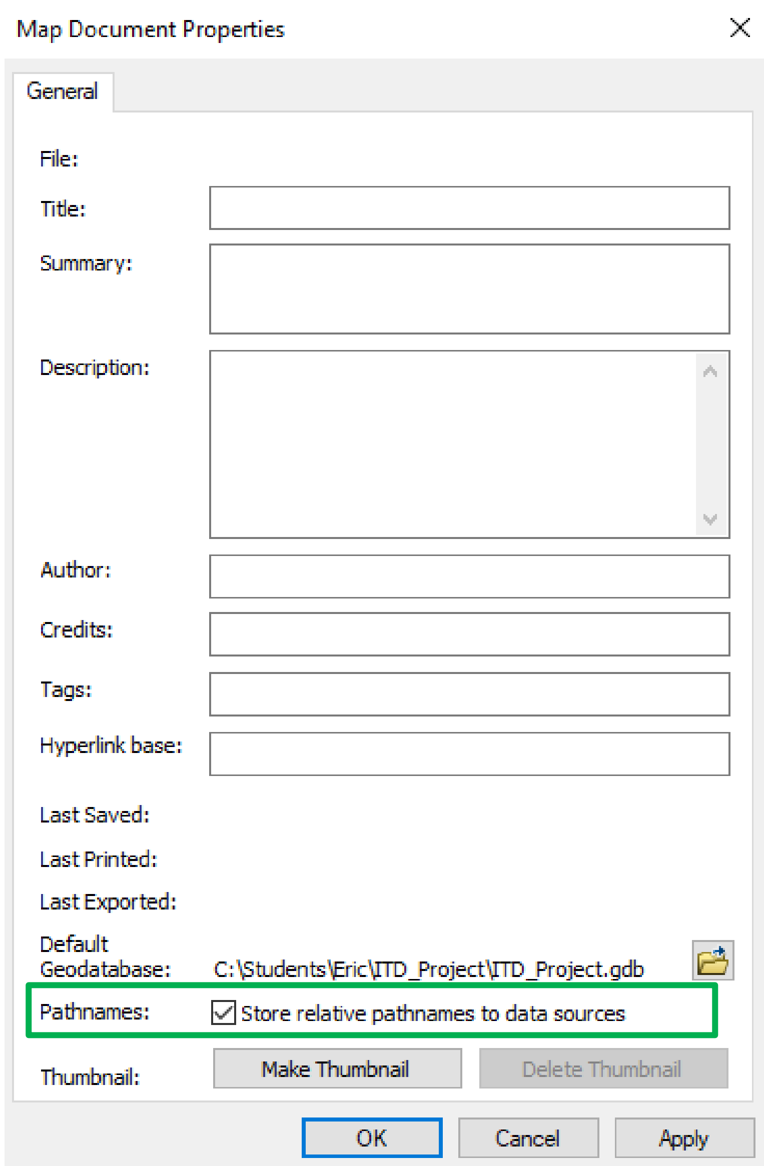


Figure 112. Store Relative Pathnames to Data Sources

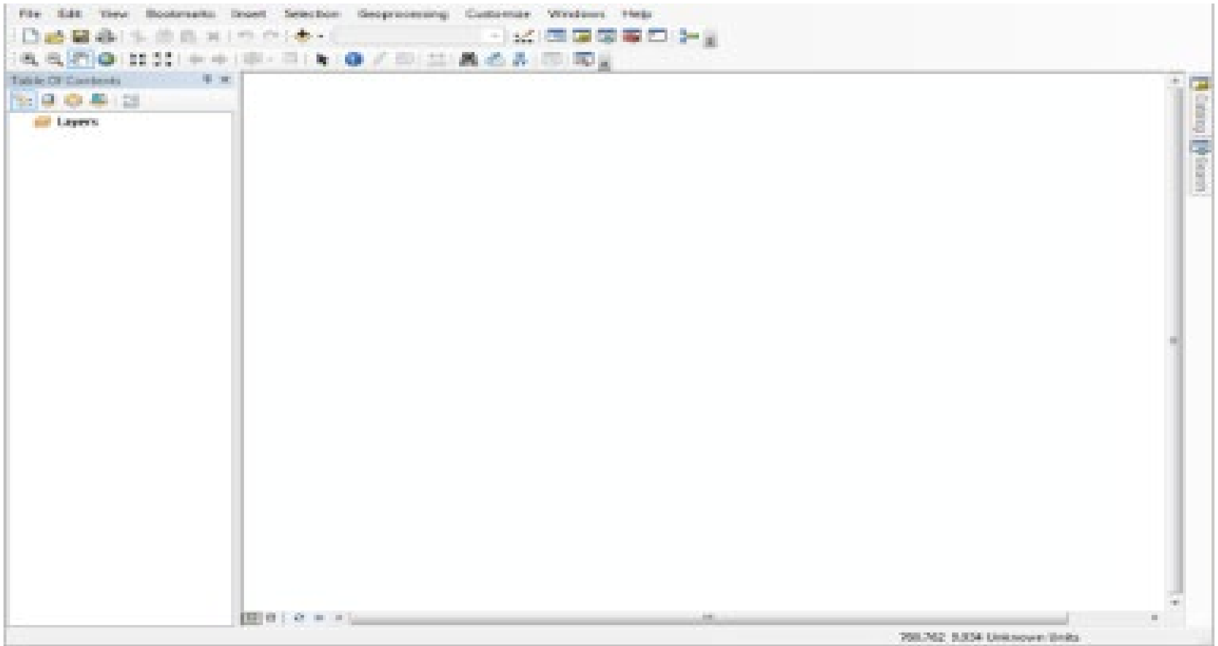


Figure 113. Back to Main Screen

7. Now, to import data files into ArcGIS, left click the Add Data button (see Figure 114), navigate to the ITD Project folder (Figure 115), and double left click the subfolder(s) of the data set you wish to add to open them (in Figure 116, the ISU bridge map is added). Click once on each data file and click Add (Figure 117). This will add each data file as an independent layer in ArcGIS, and each layer will appear on the map (dots representing bridge locations) and in the Table of Contents on the left-hand side of the screen (Figure 118). Repeat this process until you have added all relevant data to the map and Table of Contents.

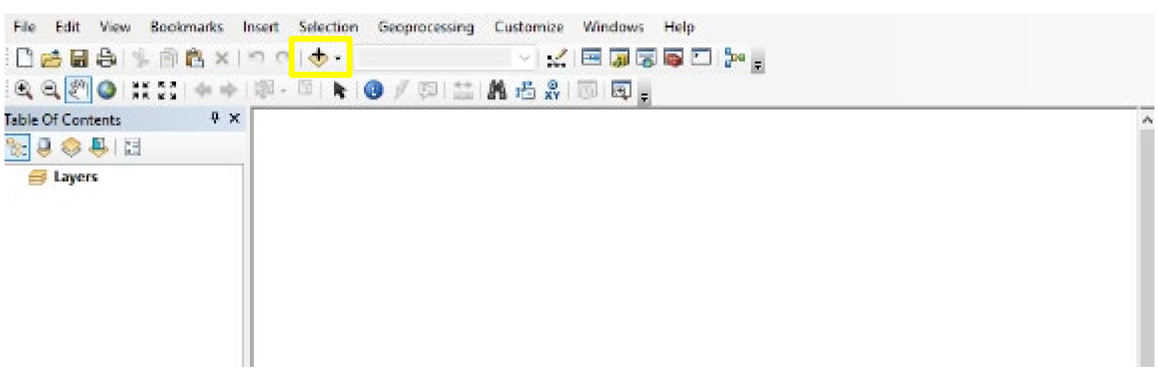


Figure 114. Add ITD Project Data File to ArcGIS

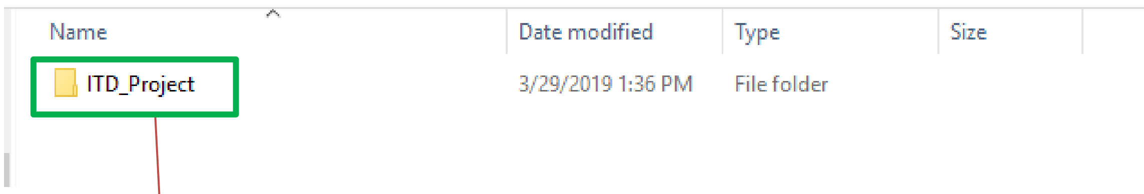


Figure 115. Navigate to ITD Project Folder

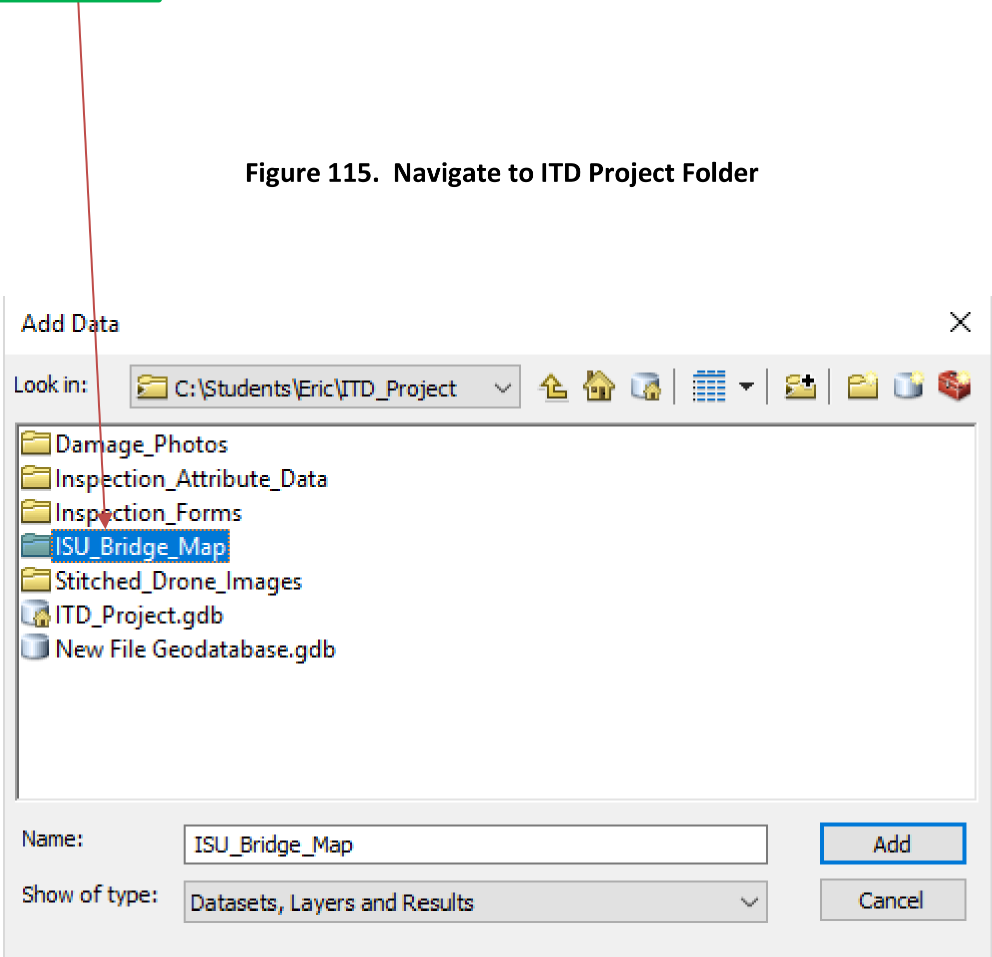


Figure 116. Open Subfolders Containing Relevant Data

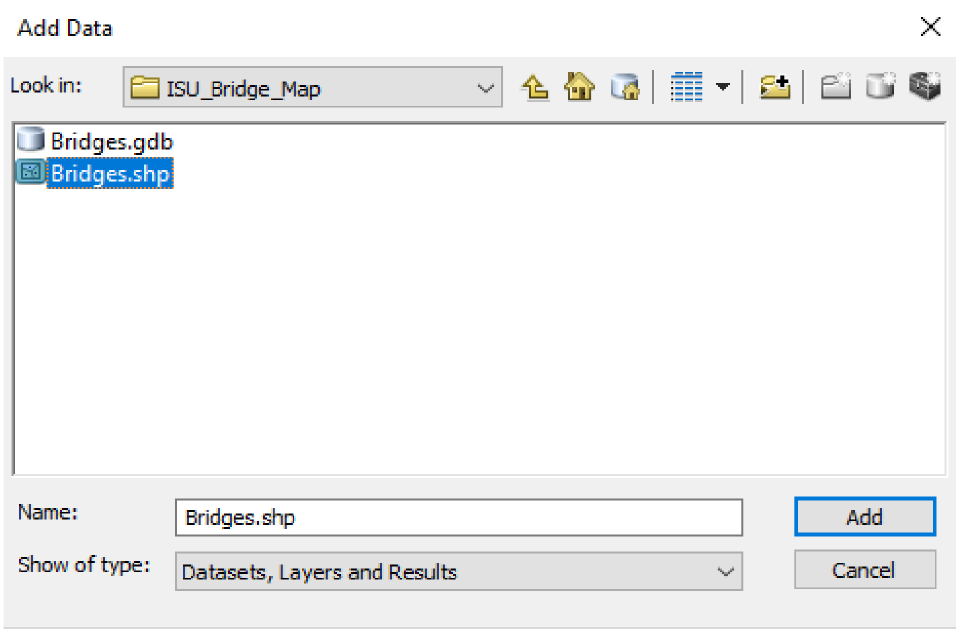


Figure 117. Add Data Layer to Map

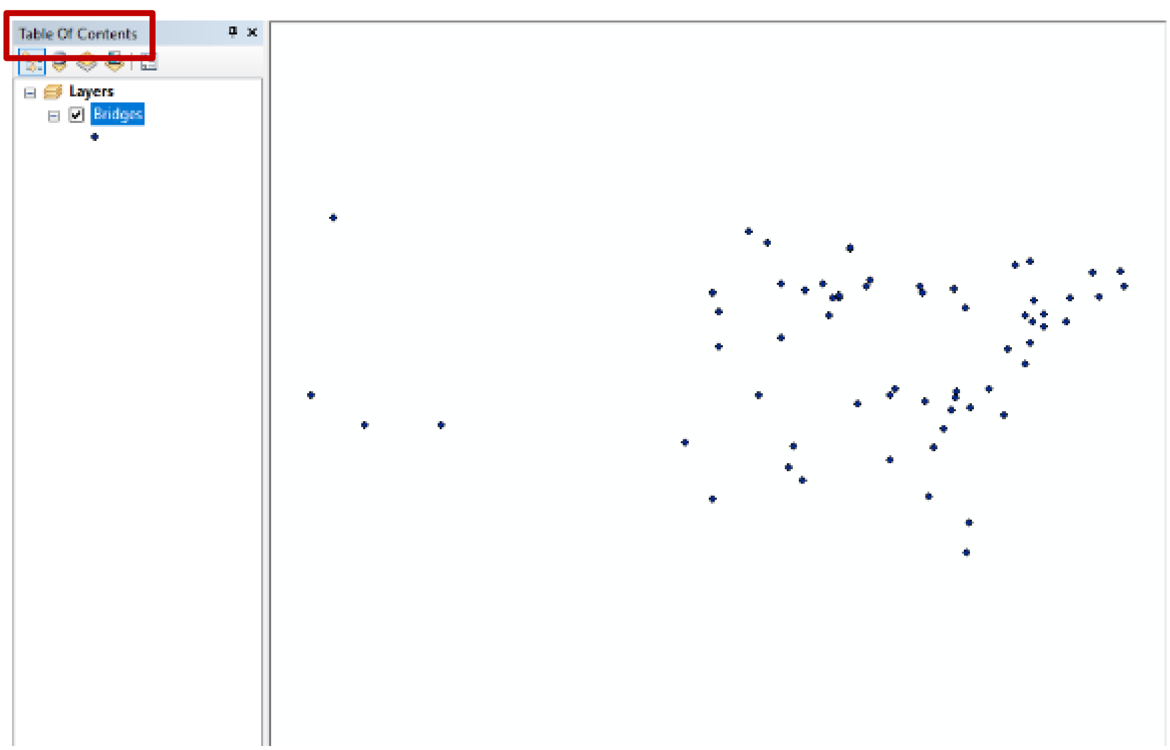


Figure 118. Data Layer in Map and Table of Contents

8. We must next import the data into our geodatabase to properly run analyses on them. This will convert them into feature class datasets. Like we did earlier, expand the ITD_Project folder by clicking the plus sign next to it (Figure 119; if already expanded do not worry about this step), then right click on the geodatabase for the project (Figure 119) and click on Import and then Feature Classes (multiple) (Figure 119). Click on the folder next to Input Features (Figure 120), then select all relevant layers and left click Add (Figure 120). Then left click OK (Figure 121).

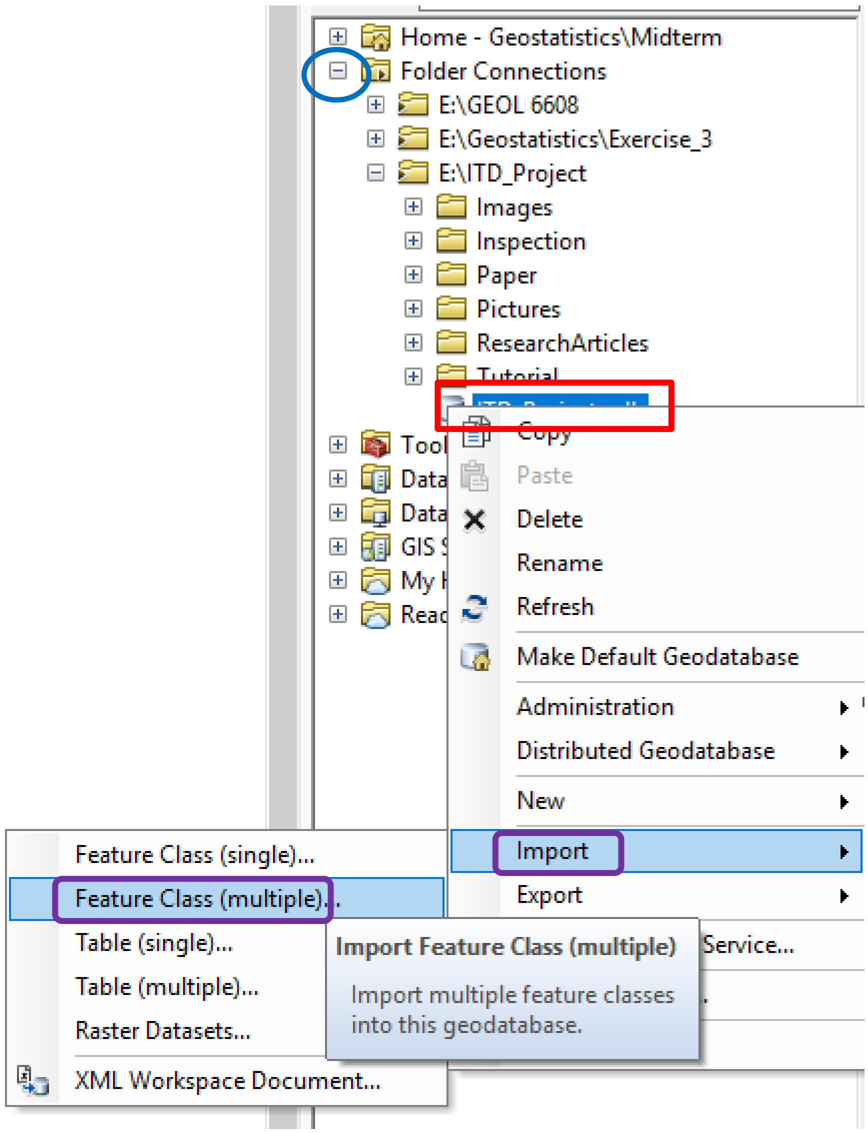


Figure 119. Importing Data into Geodatabase

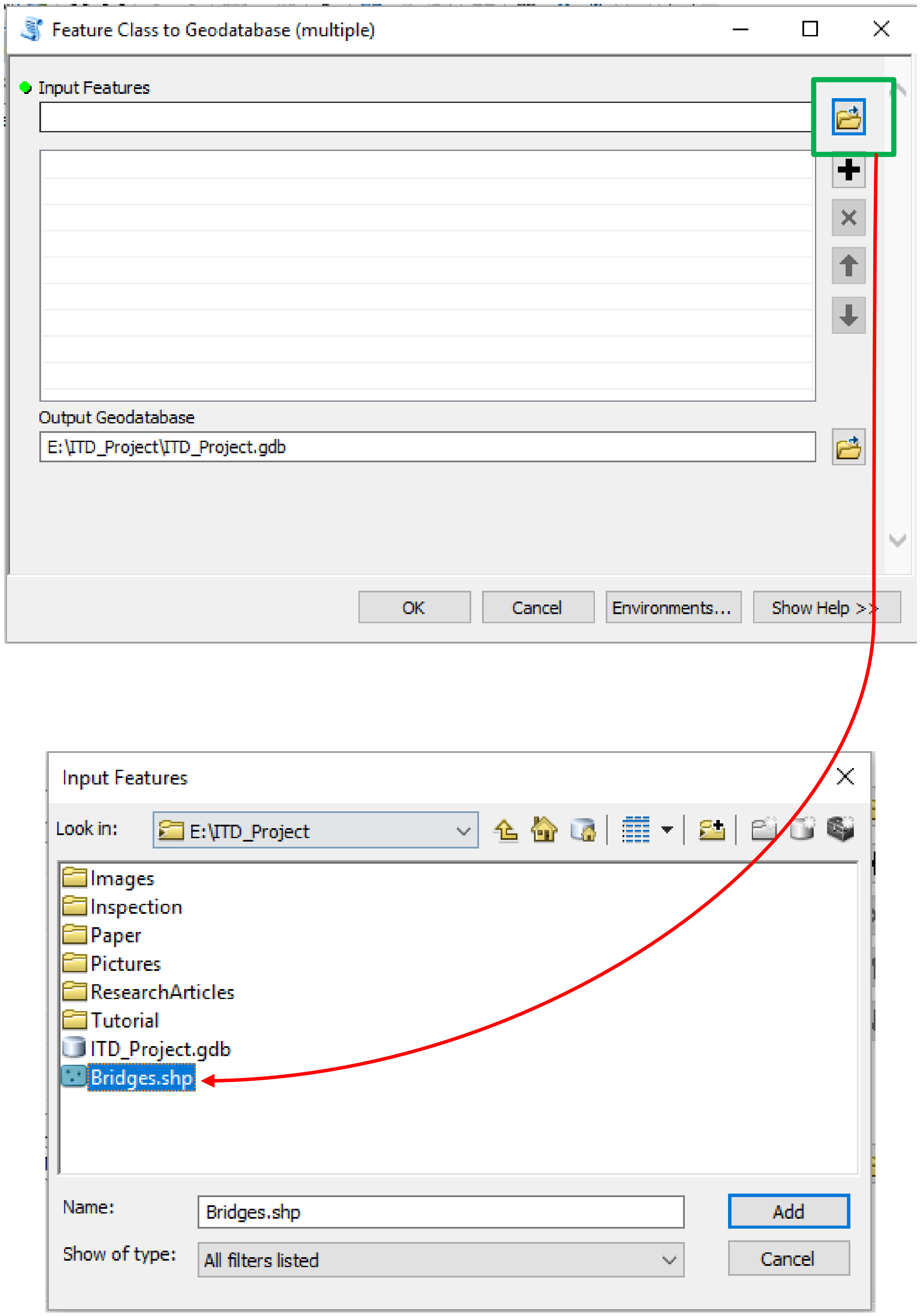


Figure 120. Selecting Input Features

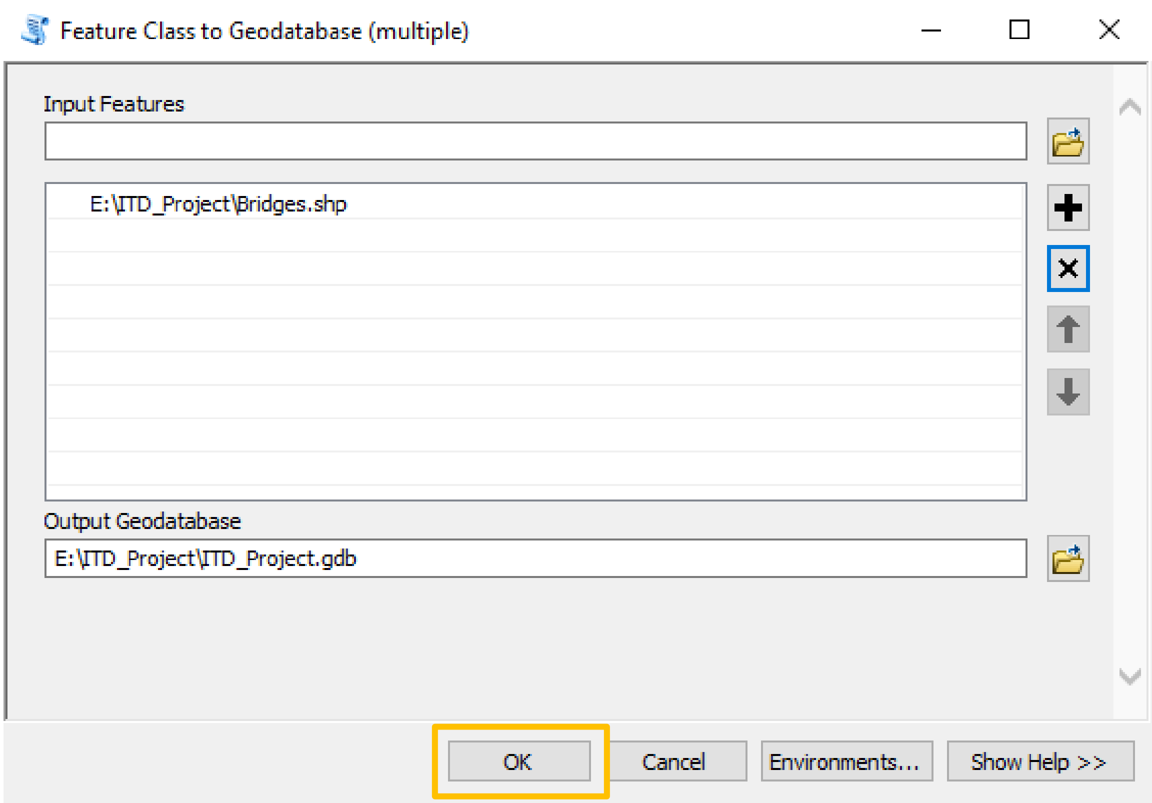


Figure 121. Adding to Geodatabase

9. If done successfully, a little menu with a green checkmark (Figure 122) will pop indicating that the data was properly imported into the project database (if not successful, a red x will pop up instead). Repeat step 8 until all relevant data has been imported into the database.

Figure 122. Final Dialog Box showing Successful Completion of Process

Appendix F
Blank Inspection Forms

1. *Recommended Procedures for MSE Wall Inspections*
2. *MSE Wall Inspections – Condition Survey*
3. *Nebraska Department of Transportation Procedure*
4. *North Carolina Department of* Transportation Procedure

Recommended Procedures for MSE Wall Inspections – Page 1 of 2

WALL INFORMATION

Route		Date	
MSE Wall Location		GPS - Latitude	
Milepost		GPS - Longitude	
ProjectWise #		Direction	

#	CONDITIONS	Yes, No, N/A
Joints		
1.	Is sand or gravel coming out of joints or are there piles of sand or gravel at the base of the wall?	
2.	Are the joints wide enough to see the sand, gravel or fabric behind the panels when looking perpendicular to the wall face using a flashlight? If yes, record the approximate maximum joint width, in inches.	
3.	Do the joints have a nonuniform size, or are some joints noticeably wider than others? (see Condition Survey)	
4.	Are the panels offset at the joints either in or out of the wall? If yes, record the approximate maximum offset.	
5.	Is there vegetation growing in the joints? (see Condition Survey) In the Wall Facing?	
Wall Facing: Concrete Panels, Shotcrete, or Wire Gabions *(choose one only)*		
6.	*Concrete Panels*:	
	Are there cracks in more than two facing panels? (see Condition Survey)	
	If yes, record the approximate number of panels that are cracked.	
	Shotcrete:	
	Are there any cracks or signs of spalling?	
	Are there any signs of voids?	
	Wire Gabions:	
	Is there corrosion of wire baskets and connections?	
	Is the rockfill in the baskets spilling out?	
7.	Is the face of the wall bowed or bulged?	

Recommended Procedures for MSE Wall Inspections – Page 2 of 2

Route ______________________ Wall Location: ____________________________________

#	CONDITIONS	Yes, No, N/A
Drainage		
8.	Is there erosion of the embankment at the base of the wall?	
9.	If there is erosion at the base of the wall?	
10.	Are the catch basins or the catch basin outlets near the wall blocked?	
11.	Is the roadway drainage system above the wall malfunctioning?	
12.	Does water at the top of the wall collect behind the concrete coping? Top of Wall?	
Backfill and Foundations		
13.	Is there settlement of the backfill at the top of the wall?	
14.	Are there any ground cracks below the base of the MSE wall?	
15.	If MSE wall supports a roadway, are there cracks in the pavement above the wall?	
16.	Are there any animal burrows into the foundations of the MSE wall?	
Condition Survey Form		
17.	Was a "Condition Survey Form" completed after observing adverse problems?	

Comments:

MSE WALL INSPECTIONS – Condition Survey

WALL INFORMATION			
Route	____________	Date	____________
MSE Wall Location	____________	GPS - Latitude	____________
Milepost	____________	GPS - Longitude	____________
ProjectWise #	____________	Direction	____________

Report on the following adverse conditions along the wall; take photos for documentation.

1. Excessive Joint widths
2. Joint offsets
3. Panel Cracks
4. Shotcrete Spalls
5. Gabion Corrosion
6. Backfill Loss
7. Verticality of wall
8. Bowing of Wall
9. Erosion near base
10. Drainage
11. Ground Cracks
12. Coping or Guardrail

OBSERVATIONS:

Distance Along Tape	Offset	Notes

Page ____ of _____

MSE WALL INSPECTIONS – Condition Survey

Route: _______________ MSE wall Location: _______________________________________

Distance Along Tape	Offset	Notes

Page ____ of _____

Nebraska Department of Transportation Procedure

WALL INFORMATION			
Route		Date	
MSE Wall Location		GPS - Latitude	
Milepost		GPS - Longitude	
ProjectWise #		Direction	

Nebraska Department of Transportation Procedure						
DEFECTS						
Wall Tilting	Structural Cracking	Facial Deterioration	Bowing of Wall	Panel Staining	Fabric Exposure	Loss of Backfill
DEFECTS						
Erosion at Front of Wall	Joint Spacing	Condition of V-Ditch	Coping Deterioration	Drainage Runoff	Drainage at Front	AVERAGE

Comments:

North Carolina DOT Inspection Procedure

WALL INFORMATION			
Route		Date	
MSE Wall Location		GPS - Latitude	
Milepost		GPS - Longitude	
ProjectWise #		Direction	

NC DOT Inspection Procedure								
Category Observations			Percent by Rating				Average Rating	Comments
			1	2	3	4		
FACING	1.	Facial Deterioration						
	2.	Staining						
	3.	Damage						
	4.	Cracking						
	5.	Joint Alignment						
	6.	Joint Spacing						
	7.	Material Loss						
MOVEMENT	8.	Deflection/Rotation						
	9.	Bulges/Distortion						
	10.	Settlement						
	11.	Heaving						
DRAINAGE	12.	Erosion						
	13.	Scour						
	14.	Internal/External Drains						
EXTERIOR	15.	Wall Top Attachment						
	16.	Road/Sidewalk/Shoulder						
	17.	Vegetation						

Comments: